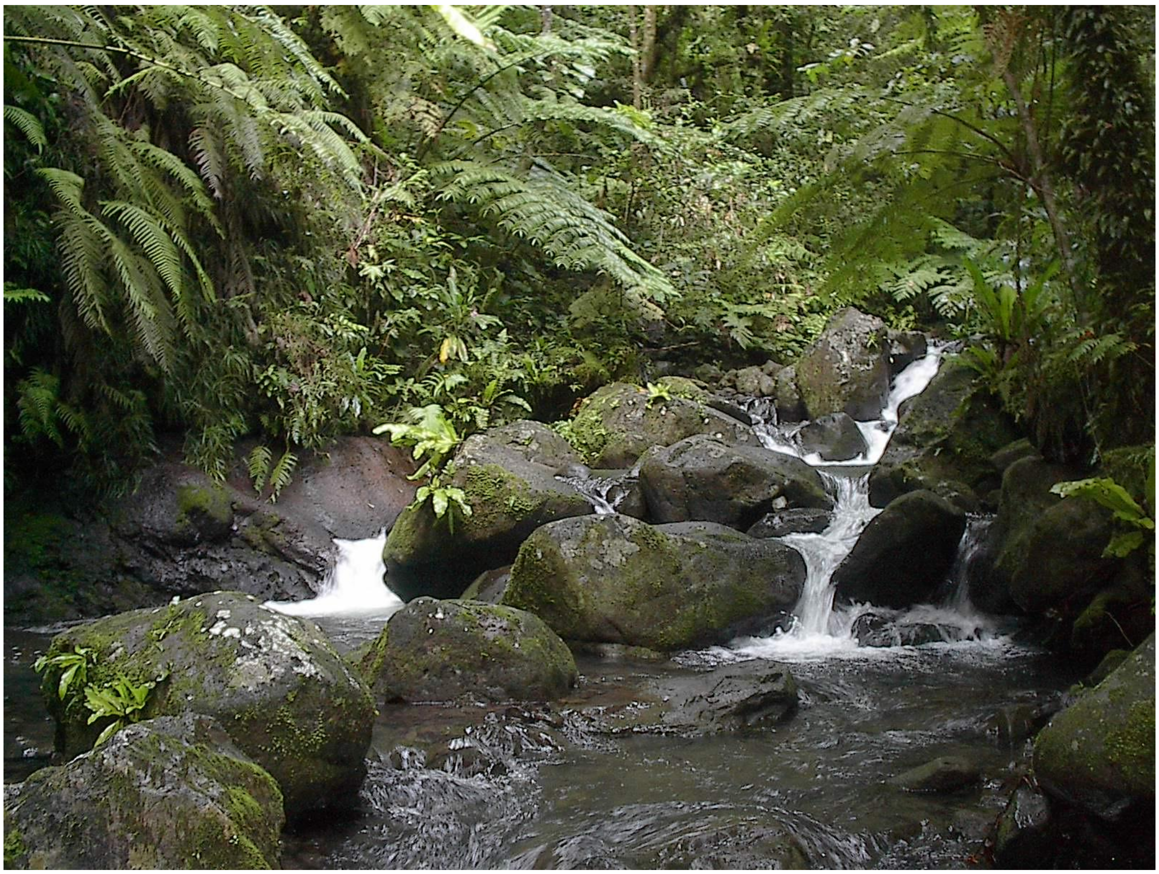
An Evaluation of the American Samoa Stream Monitoring Program: Analysis, Interpretation, and Future Direction



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EXECUTIVE SUMMARY

The American Samoa Stream Monitoring Program (SMP) was initiated in 2003, with the primary objective of institutionalizing within the American Samoa Environmental Protection Agency (ASEPA) a systematic means for collecting, interpreting, and reporting data concerning the condition and status of Territorial streams. The basis of the monitoring program is the American Samoa Watershed Classification, a system whereby designated watersheds are classified along a disturbance gradient. The analyses described in this report are aimed to address one primary research question: What is the relationship between watershed classification and stream condition? In addition to describing the results of statistical analyses exploring the relationship between watershed classification and stream condition, this report will consider a series of four related management questions.

The SMP at its most basic level uses a stratified randomized approach to monitoring streams. The protocol pools all streams located within each watershed class and randomly selects 2 streams from each of the 4 classes for monitoring over an annual period. Data from four years of stream monitoring are here analyzed collectively for the first time. Variables measured include measures of hydrography (temperature, specific conductivity, dissolved oxygen, pH, and turbidity), measures of fecal contamination (*Enterococcus*), and measures of nutrients (ammonium, nitrate/nitrite, total nitrogen, and total phosphorus). There are two types of data that are documented in this report. The first one is the average measure of any parameter sampled during one visit. A second is the level of overall variability within a stream estimated using the Coefficient of Variation (CV). A series of predictions were made concerning how the mean and the CV for each of the study variables would change under increasing pressure from any number of typical (but undefined) anthropogenic disturbances.

Over the four survey years, 30 different streams were sampled, while two streams were sampled twice. Over that time the program did a reasonable job sampling the population of watersheds within each class and collecting data relatively free of place-based bias. With respect to the effect watershed classes on stream variables, these data show several important findings. First, there was significant variability seen in the data at many scales: among stations within a stream, within a stream across time, among streams in a watershed class, and among watershed classes. Second, after summarizing the data, the watershed orderings for most of the variables followed the *a priori* predictions. Third, there was often a statistical difference between the watershed classes. Of the 10 variables examined for effects on mean stream responses, 7 showed a significant watershed class effect. Of the 10 examined for effects on within-stream variability, 7 were significant and 1 was close to significant. Fourth, the least impacted watersheds and the most impacted watersheds were often at opposite ends of the spectrum and were statistically different from each other. Despite the great variability in the data, which was to a certain extent a result of the probabilistic sampling approach, a watershed class signal more often than not emerged from the noise.

After 4 years of stream monitoring on Tutuila, several important management questions have arisen. **Do the stream monitoring results suggest that the current criterion for determining a watershed classification (human population density) is adequate, or does the criterion need to change?** The human population criterion seems to capture the breadth of human impacts, from agriculture to human/animal waste to modification of flow dynamics. Changing this criterion at this time is unwarranted. **Do the stream monitoring results suggest that the current classifications need to be changed (i.e., more or fewer watershed classes)? If so, what might a new classification system look like?** Since the study results rarely demonstrate differences in the classes in the middle of the response gradient, I would recommend reducing the classification framework from 4 classes to 3. **Do the stream monitoring results suggest that the ASEPA continue this effort using the same current probabilistic sampling approach, or is a new stream monitoring plan recommended?** Unless the monitoring objectives have changed or there are noted deficiencies in the results of the SMP, there is little justification at this time to change the monitoring approach. **Do the results of the study provide any information concerning the value of the current surface water standard for total phosphorus (150 µg/L P)?** Nearly half the samples collected exceeded the current surface water standard for total phosphorus (TP); furthermore, over half the streams surveyed exceeded the standard for their average TP concentrations. These data suggest that TP might be present in higher concentrations because of some natural background factor(s), and the standard might be too low. However, since statistical analysis failed to detect a change across the watershed gradient, these data do not suggest what a new standard might be.

ACKNOWLEDGEMENTS

The initial effort to sample streams on Tutuila under the American Samoa Stream Monitoring Program began in 2003. Hope Anderson and Barbara Zennaro continued the sampling program through 2007, and their hard work is graciously recognized. The laboratory staff, including Joe Kim, Ati Tago, Iose Vaouli, and Jansen Masaniai, assisted with the field collections, performed the microbiological analyses, and supported the work in many ways. Many thanks go out to them. Finally, Edna Buchan, Peter Peshut, Elena Vaouli, and Carl Goldstein supported this effort from the beginning and provided necessary leadership. Many thanks to them.

INTRODUCTION

The American Samoa Stream Monitoring Program (SMP) was initiated in 2003, with the primary objective of institutionalizing within the American Samoa Environmental Protection Agency (ASEPA) a systematic means for collecting, interpreting, and reporting data concerning the condition and status of Territorial streams. The majority of American Samoa's perennial streams are on Tutuila, the largest and most populous of the 5 high islands of American Samoa, and the stream monitoring program was basically designed for those streams (although the framework could easily incorporate other islands and streams, if necessary). On Tutuila, there are 163 streams (Burger and Maciolek 1981), most of which are short (average length = 1 km), low order (1^{st} or 2^{nd}) systems draining the steep volcanic slopes of the island. The large number of streams, and their often remote locations, requires a novel approach to assessing the condition of these systems.

The basis of the monitoring program is the American Samoa Watershed Classification, a system whereby designated watersheds (Pederson 2000) are classified along a disturbance gradient. Information regarding the development of this classification framework is described in DiDonato (2004). Using human population density, all 41 delineated watersheds of the 5 volcanic islands (Tutuila, Aunu'u, Ofu, Olosega, and Ta'u) were classified as pristine, minimally disturbed, showing intermediate disturbance, or extensively disturbed. For the purposes of this report, the watershed classes will be referred to as Pristine, Minimal, Intermediate, and Extensive.

The analyses described in this report are aimed to address one primary research question: **What is the relationship between watershed classification and stream condition?** While watershed classification is determined by human population density, stream condition is inferred from a series of indicator variables, comprised of several measures of hydrography (temperature, specific conductivity, dissolved oxygen, pH, and turbidity), an estimation of microbial contamination (via the indicator *Enterococcus*), and four measures of water chemistry (ammonium, nitrite/nitrate, total nitrogen, and total phosphorus). No biological data were used in the first 4 years of the ASEPA SMP. For information on biological aspects of Tutuila streams, see Wade et al. (2008).

In addition to describing the results of statistical analyses exploring the relationship between watershed classification and stream condition, this report will consider a series of related management questions. They are:

1. Do the stream monitoring results suggest that the current criterion for determining a watershed classification (human population density) is adequate, or does the criterion need to change?

2. Do the stream monitoring results suggest that the current classifications need to be changed (i.e., more or fewer watershed classes)? If so, what might a new classification system look like?

3. Do the stream monitoring results suggest that the ASEPA continue this effort using the same current probabilistic sampling approach, or is a new stream monitoring plan recommended?

4. Do the results of the study provide any information concerning the value of the current surface water standard for total phosphorus (150 µg/L P)?

MATERIALS AND METHODS

Stream Selection and Stream Sampling

The streams of Tutuila are too numerous to monitor via census, but the ASEPA is critically interested in understanding the impact of the burgeoning human population on the limited island natural resources, streams included. The SMP then, at its most basic level, uses a stratified randomized approach to monitoring streams. The protocol pools all streams within each watershed class and randomly selects 2 streams from each of the 4 classes for monitoring over an annual period. Each stream is visited once per month, and within each stream, up to 4 sites are visited and sampled for each of the measured parameters. At the conclusion of 1 year, two streams are again randomly selected (with replacement) from each watershed class. These new streams are the new sample frame, and so on. Sampled streams and the annual period when they were sampled are provided in Table 1. The sample year suggests that monitoring occurred over a single calendar year, but that is not the case. Instead, during the first year of monitoring (2003), streams were sampled beginning in March, 2003; sampling concluded in February, 2004. The second year (2004) went from July, 2004, to June, 2005. The third (2005) and fourth years (2006) extended from July, 2005, to June, 2006, and October, 2006 to September, 2007, respectively. Table 2 also lists the streams surveyed over the 4-year period, but this table is organized by watershed name instead of the watershed classification.

The actual sampling date for any stream in a particular month is scheduled in advance, and this, in principle, minimizes the bias that could be introduced into the data by only sampling base flow conditions or, alternatively, storm events. There is no doubt that tropical streams exhibit flashy dynamics, and that tropical rain events probably contribute the majority of the nutrient and sediment loading to nearshore coastal waters. This study design and approach, however, does not attempt to explicitly characterize storm events or quantify their effects on stream water quality. Instead, by establishing a sampling date in advance, and sticking to that schedule (unless it is unsafe to take a field team out because of particularly heavy rains, for example the devastating floods of May, 2003), the sampling effort will tend to characterize over repeated visits the range of variability typical of these streams.

Data collected at every site visit included standard measures of hydrography (temperature, specific conductivity, dissolved oxygen, pH, and turbidity) using a YSI 6600. In addition, 100 mL samples of stream water were collected in sterile bottles and processed for *Enterococcus* using Enterolert® to quantify most probable number (MPN) of this fecal indicator. Water samples were also collected in acid washed polypropylene bottles and frozen prior to analysis for ammonium (NH_4), nitrite+nitrate (NOx), total nitrogen (TN), and total phosphorus (TP) by an outside contract laboratory.

Data Summary

Data from four years of stream monitoring are here analyzed and interpreted. Previously, annual data had been analyzed. This is the first effort to compile and evaluate all data the SMP has collected since 2003.

Prior to analysis, all data were entered into a relational database (Microsoft Access). Not only did this database make possible robust querying of the data, but it also assisted with data quality control (by identifying typographical or formatting mistakes). It also made initial quality assurance checks easy by identifying plausible but nonsensical data (e.g., a pH of 78.1 instead of 7.81).

The experimental unit in all analyses is the individual stream. As previously stated, most streams on Tutuila are short (mean length ca. 1 km), 1^{st} order streams (Burger and Maciolek 1981). Furthermore, at the time this program was developed, ASEPA was uninterested in developing a monitoring program to address finer-scaled ecological data (e.g., a particular segment of stream). Instead this program has the stream as its fundamental unit of interest. What this means, from a practical perspective, is that all analyses of these data work only with a single datum (for each variable) for each stream each time it is visited.

There are two types of data that are documented in this report. The first one is the average measure of any parameter sampled during one visit. If a stream has three sampling stations, the datum that emerges from any visit is the mean value (e.g., mean temperature, mean TN, etc.) for that system. In addition to a measure of central tendency from every stream visit, multiple sampling stations make possible estimating the overall variability within a stream. Stream variability was estimated using the Coefficient of Variation (CV), calculated as the standard deviation of the data normalized to the mean. Intrastream variability is estimated through temporal replication (i.e., monthly sampling).

Expectations

Before analyses were started, a series of predictions were made concerning how the mean and the CV for each of the study variables would change under increasing pressure from any number of typical (but undefined) anthropogenic disturbances. Streams in uninhabited or low-population density watersheds were expected to approximate reference conditions (e.g., Cook 2004); with increasing local human population within a watershed, each stream variable was predicted to exhibit a directional change (Table 3). For example, water temperature should increase with the removal or modification of the stream riparian zone; thus average stream water temperatures were expected to increase from the least disturbed systems to the more disturbed systems. On the other hand, dissolved oxygen (DO) would be expected to decrease in streams impacted by people, particularly as a result of nutrient enrichment and biological oxygen demand. For some variables (e.g., pH or specific conductivity), no specific predictions were made; that is, there are many scenarios that have them going up or down in response to human disturbance. Nutrient concentrations for total nitrogen (TN) and total phosphorus (TP) were expected to increase with increasing human disturbance. For ammonium (NH_4) and nitrite/nitrate (NOx), there were no specific predictions. Those parameters were likely to reflect unique watershed activities (e.g., increased NOx in watershed with significant agricultural activities). Regardless of whether the average for any particular parameter was expected to go up or down in response to human disturbance within the watershed, the overall prediction of this classification framework was for streams from the Pristine and Extensive classes to sit at opposite ends of a gradient; Minimal and Intermediate streams were expected to fall somewhere in between.

Contrary to the stream mean values for specific parameters, the overall level of within stream variability (as estimated by the stream CV) was always expected to increase (Table 3). All stream parameters will change as the stream flows downhill; however, in American Samoa, where the mountainous terrain forces the most extensive watershed modifications to be located near the bottom (close to the sea) of these watershed, the overall intrastream variability will increase more when a stream is heavily impacted towards the bottom of the watershed than when the overall level of disturbance is similar along the length of the stream. For the most part, this study assumes that the level of human disturbance decreases in all watersheds with increasing elevation; the topography of Tutuila is just too steep for much activity in the upper reaches of many streams.

Statistical Model and Data Analysis

The statistical model used to evaluate these stream data was a nested mixed model (Underwood 1997), with 3 main factors. One factor in the model was sample YEAR (i.e., the annual period over which the samples from any particular stream were collected), with 4 levels (2003, 2004, 2005, and 2006). While there is good reason to believe that there will be significant variation across survey years (e.g., a particularly rainy year, or an excessively dry one), the specific effect of YEAR (i.e., significant or nonsignificant) is rather unimportant for the overall interpretation of these data. A second factor was watershed CLASS, also with 4 levels (Pristine, Minimal, Intermediate, and Extensive). This is the primary factor of interest. Both YEAR and CLASS were considered to be fixed factors. The last factor in the model was STREAM, nested within CLASS [written as STREAM(CLASS)]. Because each sampled stream was randomly selected, and because that stream is intended to represent any stream from that watershed class, STREAM(CLASS) is considered a random factor in the model.

Data from the full nested model, a mixture of one random and two fixed factors, was analyzed using SAS (version 9.1), and the key results for evaluating the relationship between the watershed classification and stream condition is the CLASS factor. A specific hypothesis test evaluated that factor, using the MS Error from STREAM(CLASS), to determine if there were significant differences between watershed classes for individual parameters (Underwood 1997). When differences across watershed

CLASS were detected (or were suggested by the probability value), the least square means were compared to evaluate pairwise differences.

RESULTS

The Stream Sample Population

Over the four survey years, 8 streams, 2 from each watershed class, were sampled each year (Table 1). In total, 30 different streams were sampled; two streams (Malota, watershed #3, and Amate, watershed #4) were sampled twice (Table 2). Malota was sampled in 2003 and again in 2006, while Amate was sampled in 2005 and 2006 (Table 1). The 30 target streams were located within 19 of Tutuila's 33 watersheds (Table 2). Of those 19, 14 watersheds are represented in this study by only 1 stream. Watersheds that were sampled more frequently included: Fagalii (#2), 2 streams; Fagamalo (#4), 3 streams; Fagatuitui (#9), 2 streams; Fagaitua (#21), 4 streams; and Nuuuli-Pala (#27), 5 streams. These watersheds were sampled more often because, in most cases, they have a disproportionately large number of streams for their respective classes. With respect to the actual watersheds from which the streams were sampled: Pristine streams were located in 3 watersheds (Maloata, Fagamalo, Fagatuitui); Minimal streams were located in 7 watersheds (Poloa, Fagalii, Aasu, Vatia, Auasi, Alega, Afao-Asili); Intermediate streams were located in 5 different watersheds (Fagasa, Aoa, Amouli, Fagaitua, and Nua-Seetaga); Extensive streams were located in 4 watersheds (Laulii-Aumi, Pago Pago, Nuuuli Pala, and Leone). The proportional composition of each watershed class (calculated as the number of watersheds sampled per class divided by the total number sampled) is fairly close to the overall proportion of each class. This suggests that the sampling program over the four years did a reasonable job sampling the whole population of watersheds within each class; furthermore, because the watersheds were represented proportionally, it suggests that the data collected should be relatively free of bias or specific place-based factors (e.g., the fact that not all the Pristine streams were from Fagatuitui makes it more likely that the data from those streams represent the watershed class, rather than the specific place).

Stream Hydrography and Nutrient Concentrations

Table 4 shows the mean annual values for the 5 stream hydrographic parameters and the 1 bacterial indicator. To reiterate, these numbers are the average of each monthly average stream measurement over the sampling period. One notable observation from these data is the overall level of variability, not only among stream classes but among streams within classes. For example, average monthly DO for Pristine stream ranged from 87.4% to 109.8% for Agasavili and Malota (sampled in 2006), respectively. Stream DO from Intermediate watersheds ranged from 63.5% to 102.7% (Nuu and Amaua streams, both located in Fagaitua watershed). Levels of *Enterococcus* in stream samples were highly variable, as well. Streams from Pristine watersheds demonstrated some of the lowest monthly average *Enterococcus* concentrations (612 MPN in Agasavili), but also showed monthly concentrations that were routinely observed in more impacted watersheds.

Indeed, the lowest measured monthly stream *Enterococcus* concentration over an annual period was seen in Vaitolu stream in Aoa watershed (Intermediate).

With respect to nutrient concentrations, these data show that the typical concentration of NH_4 in Tutuila streams is very low (Table 5). Most streams in the Pristine, Minimal, and even Extensive classes had NH_4 concentrations below 0.01mg/L. However, a few streams stood out for having frequent spikes of NH_4 in the water. Two streams from the Intermediate class (Nuu and Lifalifa streams in Fagaitua) were 10-60X higher than 0.01 mg/L on average. These high concentrations of NH_4 were detected just downstream of a small piggery (a small pen with one big pig in it) on Nuu stream; Lifalifa stream also had a piggery upstream and exhibited runoff during the sampling period. Stream NOx concentrations were also typically low (<0.1 mg/L); however, several streams across the Minimal, Intermediate, and Extensive classes demonstrated higher monthly average concentrations. Alega, Fagalii1, and Massacre streams (all from Minimal watersheds) were higher than 0.1 mg/L, and Massacre had the highest monthly average concentration of any stream in the Minimal class (0.254 mg/L). In the upper portion of the Aasu watershed, there was significant agricultural activity, and this may account for the high NOx levels observed in Massacre stream. Lifalifa stream in Fagaitua (Intermediate) had the highest observed concentration of all streams, but several streams in the Extensive class had concentrations higher than 0.1 mg/L. For total nitrogen (TN), the lowest average monthly concentrations were seen in Matavai and Niutulua streams, both in the Fagamalo watershed (Pristine). Amate stream, also in Fagamalo, had higher average TN concentrations in both years it was sampled, showing again the large amount of stream-to-stream (but within class) variability. TN concentrations were generally higher in Intermediate and Extensive streams; the highest concentrations were in Nuu and Lifalifa streams (Intermediate), and 6 of the 8 Extensive streams had monthly average concentrations above the American Samoa Water Quality Standard (ASWQS, 0.3 mg/L). For total phosphorus (TP), most sampled streams had average concentrations above the ASWQS (0.15 mg/L). The lowest monthly average concentration was 0.07 mg/L in Tialu stream (Fagasa, Intermediate), while the highest was 0.465 mg/L in Amate stream (Fagamalo, Pristine). This was a very surprising result, and highlights again the unique dynamics that may occur in any stream in any class, depending on the specific activities on that stream.

<u>Statistical Results—Monthly Averages</u>

Of the 10 indicator variables measured for this study, 7 showed significant differences in the average monthly values across watershed classes. Table 6 summarizes the results of watershed class comparisons.

Hydrography Temperature, specific conductivity, and dissolved oxygen all showed significant differences across watershed classes, even after accounting for the stream-to-stream variability within classes (Table 6, Figures 1, 2, and 3). Temperature showed a general increase with increasing level of watershed disturbance, with streams from Pristine and Minimal classes showing significantly lower temperatures than those streams from Intermediate and Extensive watersheds. Stream temperatures in Extensive watersheds were slightly lower than those observed in Intermediate streams, although these could not be discriminated statistically. This result generally followed the *a priori* prediction (Table 3). Specific conductivity, a measure of dissolved ions in the water, showed a similar result (Table 6), with specific conductivity generally increasing with increasing levels of human disturbance within a watershed. Streams from Intermediate watersheds had the highest specific conductivities, and they were statistically higher than streams from the other 3 classes. Dissolved oxygen was lowest in the Intermediate streams, while streams from the other classes did not differ from one another. This was perhaps a bit unexpected, as DO levels in highly impacted streams were predicted to be the lowest. However, DO is also highly influenced by overall stream flow rates. The streams with the lowest DO generally were the ones with the lowest flows (either because of human impoundments or because of other natural or anthropogenic dynamics). Neither pH nor turbidity showed statistical differences across classes (Figures 4 and 5).

Enterococcus The concentration (MPN) for the microbiological indicator *Enterococcus* showed significant differences across watershed classes (Table 6, Figure 6). Streams from Pristine watersheds had the lowest average concentrations, followed by streams from Minimal watersheds. Streams from Intermediate and Extensive watersheds had higher concentrations. Streams from Pristine watersheds were significantly different from either Intermediate or Extensive streams (Table 6).

Nutrients Of the 4 nutrients measured, all three of the nitrogen species showed significant differences across watershed classes, and for the most part, all three showed a gradient of increasing concentration with increasing watershed disturbance level (Table 6). For NH_4, Pristine streams had the lowest concentration, while Intermediate streams had the highest (Figure 7). For NOx and TN, though, Pristine watershed streams were lowest, Extensive watershed streams were highest, and the other two classes demonstrated intermediate concentrations along the watershed disturbance gradient (Figures 8 and 9). There was no significant difference among watershed classes for TP (Table 6, Figure 10).

<u>Variability in Hydrography and Nutrient Concentrations</u>

Hydrography For temperature, the CVs for all streams in all classes were less than 10% (Table 7, numbers expressed as a proportion). Similarly, pH demonstrated very little within-stream variability (CV generally less than 0.05, Table 7). Dissolved oxygen CV was generally low for Pristine or Minimal streams (<0.1, with the exception of Fagalii1, where it was 0.2). Variability for DO was higher in the Intermediate and Extensive streams. On the other hand, turbidity showed much greater within-stream variability across all classes. Turbidity was measured with the YSI 6600, and, from my experience, demonstrates a high level of variability from moment to moment in many different aquatic habitats.

Enterococcus Similarly, *Enterococcus* counts can demonstrate a high level of variability within a system (as a stream moves downhill and picks up indicator organisms) and even among duplicate samples collected at the same station (it was not uncommon to have relative percentage differences in field duplicates in the 50% and higher range).

Nutrients Among the measured nutrient parameters, NH_4 typically demonstrated the highest CVs, ranging from 0.67 (measured in Auvaiola stream one time before the number of sampling stations in that stream was reduced from 2 to 1 for safety reasons) to 1.72 (Niutulua stream in Fagamalo, Table 8). This generally resulted from low concentrations in most samples processed for NH_4. Indeed, over 50% of all the samples collected and analyzed for NH_4 were below the detection limit. NOx and TN had lower within-stream variability than NH_4. Even though the overall level of variability was lower in NOx and TN, there appeared to be among class differences in the CVs (Table 8). Intermediate and Extensive streams had CVs for NOx and TN that were generally higher than their counterparts in the Pristine and Minimal classes. The CV for TP was the lowest of all the measured nutrients; values ranged from 0.04 to 0.82.

<u>Statistical Results—Within-stream variability</u>

Of the 10 indicator variables measured for this study, 7 of them showed significant differences in the amount of within-stream variability across watershed classes, while one variable (turbidity) showed nearly significant differences across watershed classes. Only CV of pH and NH_4 did not demonstrate a significant class effect. A summary of these results is provided in Table 9.

Hydrography When evaluated within streams, the overall level of variation, as expressed by the coefficient of variation (CV), increased for temperature, specific conductivity, and dissolved oxygen (Table 9, Figures 11-13). This result indicated that the level of variability increases consistently as streams become more impacted by overall levels of human disturbance in the watershed. For temperature and DO, the level of variability within streams draining Pristine watersheds was in both cases statistically lower than either Intermediate or Extensive streams. There was no difference in the pH CV among the watershed classes (Table 9, Figure 14). For turbidity, the overall p value ($p=0.07$) for the CLASS effect (Table 9) suggested a difference, and the means comparison did indeed find a significant difference between Pristine and Extensive streams (with the other two classes sitting in the middle of that gradient, Figure 15).

Enterococcus The overall level of within-stream variability increased across watershed classes for *Enterococcus* levels (Table 9). In this case, streams in Minimal watersheds were not different from Pristine streams; both, however, were significantly lower than streams draining Extensive watersheds (Figure 16).

Nutrients With respect to CV, there was no statistical effect of watershed class on NH_4 CV (Table 9, Figure 17). However, NOx and TN showed significant differences across watershed classes (Table 9, Figures 18 and 19), and both showed streams from the least impacted watersheds having lower variability than streams from more impacted watersheds. TP also showed a significant difference across watershed class (Figure 20). This contrasts with the result reported earlier, where there were no significant differences in average TP concentrations. This suggests that there is information within measures of stream variability and not only in average concentrations.

GENERAL DISCUSSION

Anyone who has spent time in the tropics understands the flashy dynamics associated with tropical streams. After even a short tropical deluge, a stream can go from clear water to raging muddy torrent in a matter of minutes. Just about every parameter the SMP measures is dramatically altered (usually increased) during those storm flows. There is no doubt that ASEPA has an interest in understanding the impact of those high-flow events (floods), especially with respect to how those conditions may influence the nearshore coral reefs or even the conditions on local bathing beaches (DiDonato and Paselio 2006). However, as required by law, the ASEPA is charged with monitoring and assessing the condition and status of Territorial streams, and this implies characterizing a stream under a variety of flow conditions. This SMP attempts to quantify stream variables under a variety of flow and weather conditions. By not sampling only on good or rainy days, the monitoring program collects data that captures the range of variability observed in these streams. The question becomes, then, can we discern any pattern of stream condition across a gradient (watershed class as determined by human population density) within these flashy systems. In other words, does a watershed signal come out of all the stream noise?

Before addressing this fundamental question, the central assumptions of this program and the monitoring approach should be stated. First, the design assumes that each stream, regardless of the complexity of its network, can be characterized by sampling 2 to 3 stations. Unfortunately, this assumption cannot be directly evaluated with the data collected. If a majority of the streams on the island were complex dendritic networks, then sampling only 2 or 3 stations within those systems would likely miss a significant amount of the system complexity. However, many of the streams in the sample population are relatively simple 1st or 2nd order channels. The approach of the SMP, then, likely does not oversimplify these systems. Second, by using population density, the classification framework assumes that people are spread out equally within a watershed and, consequently, the design assumes that all streams within a given watershed are under similar pressures. This assumption is undoubtedly false. Certainly, the underlying bedrock and other geological aspects of streams within a few square kilometers are similar, but these data show that stream-to-stream variability can be substantial. Three streams from the Fagamalo watershed demonstrate this nicely. Matavai and Niutulua streams, sampled in successive years, were very similar to each other for several measured parameters (e.g., *Enterococcus*, Table 4; TN, TP, Table 5); however, Amate stream, in the same watershed and sampled over the same 2-year period, exhibited concentrations very different from those other streams. This could result from variable human impacts (e.g., more people or pigs on one stream versus another), something for which this stream monitoring program does not account. A third assumption is that streams from different watersheds in the same class behave similarly. This assumption is most certainly false as well. These data show that there is significant within-class variability that this strategy readily identifies; some of that variability can be partitioned but much of it remains unexplained.

Nonetheless, despite a litany of dubious assumptions made in order to simplify evaluating more than 160 highly variable streams with limited manpower, the analysis of these data demonstrates that the design consistently detects (across the watershed disturbance gradient) differences in most water quality measurements, both the average level as well as the quantity of within-stream variability (Tables 6 and 9). Of the hydrographic parameters evaluated, average temperature, specific conductivity, and dissolved oxygen showed the strongest responses across watershed classes (Table 6). Initial predictions concerning temperature were born out, and the prediction for dissolved oxygen was also largely upheld. However, while dissolved oxygen was predicted to decrease in more modified streams due to nutrient enrichment, the results showed that the Intermediate streams had the lowest dissolved oxygen levels compared to streams from the other 3 classes. Based on experience in the field with many of these streams, I surmise that the DO level observed in any Tutuila stream probably reflects more the flow dynamics of that stream. Low-flow streams will tend to result in stagnant ponds, where the DO can dip down to levels that wouldn't be observed in streams with higher flow rates. It is likely that village water systems and other impoundments created by people living along the stream contribute to the highly modified flows in many of these streams.

The microbial indicator *Enterococcus* also changes across the watershed gradient in the predicted manner. *Enterococcus* and fecal coliforms are measured by the ASEPA as indicators of fecal contamination; however, there is some concern about natural populations of these indicators living in the tropical soils and contributing to the numbers observed in these systems. This study cannot draw any conclusions as to the relevance or utility of the *Enterococcus* indicator, only that it does demonstrate predictable differences across watershed classes (for both average and CV). While the sources of these bacteria are legion, the classification framework does successfully partition a significant amount of variation in this naturally-variable parameter.

The nutrient results are somewhat mixed. Average concentrations of nitrogen species demonstrated significant differences across watershed classes; the results for TN matched the initial prediction (there were no predictions for NH_4 or NOx). Furthermore, the number of sampled streams out of compliance for the ASWQS for TN (where compliance is defined as the average concentration of stream TN across the annual period) increased with watershed class (2, 3, 3, and 6 streams out of 8 in the Pristine, Minimal, Intermediate, and Extensive classes, respectively). TP did not show a difference across classes, and the number of sampled streams that had a higher average TP concentration than the ASWQS was 4, 5, 4, and 6 streams in the Pristine, Minimal, Intermediate, and Extensive classes, respectively. From these data, it appears that TN is a more reliable and sensitive indicator of human disturbance in these tropical watersheds. Within-stream variability presented a slightly different picture, with NOx, TN, and TP CVs differing across class and consistent with initial predictions. Interestingly, the average concentration of TP did not change across watershed class but the level of within-stream variability did.

In the cases where significant differences among watershed classes on the average stream measurement existed, the nutrients and *Enterococcus* showed significant differences between the classes at the ends of the watershed gradient. The hydrography parameters were a bit more equivocal, with only temperature showing a significant difference between Pristine and Extensive classes. Specific conductivity and DO successfully discriminated among classes, but in both cases, the Intermediate streams were the only class differing from the other 3 classes. For CVs, all variables showing a significant difference among classes (except TP) found a difference between Pristine and Extensive streams. For TP, the difference instead was between Minimal and Extensive.

MANAGEMENT QUESTIONS

Do the stream monitoring results suggest that the current criterion for determining a watershed classification (human population density) is adequate, or does the criterion need to change?

At the initiation of this program, an effort was made to connect the impacts on tropical resources with some easy-to-measure and relevant criteria. Human population density (culled from the census data and already done by Pederson 2000) was the easiest data to gather, and, more importantly, the only one that did not require a significant amount of GIS legwork to quantify. These analyses demonstrate that human population density has a consistent and predictable effect on the suite of measured stream variables.

The question remains, though, if there are any other criteria that might provide a better means for classifying watersheds. The number of pigs in a watershed has been proposed as another way (and potentially a more direct way) to predict the condition of stream ecosystems (since pigs are kept in sties near stream banks and waste is often conveniently, albeit illegally, washed directly in to the stream). ASEPA conducted a round of surveys and counted all the pigs present in these pig sties. As I would have predicted, the density of pigs and the density of humans within the watersheds are correlated (Pearson's $r=0.48$, $p=0.006$). However, unlike human population density, which demonstrated some breakpoints in the cumulative distribution function (cdf) and justified classifying watersheds based on these breakpoints (DiDonato 2004), the pig cdf does not exhibit any of those breaks (Figure 21). Further, since human and pig densities are correlated, it is not an easy task to use them both simultaneously as criteria for a classification. It might be possible to do such a thing if we make some assumptions about the amount of waste per person and the amount of waste per pig to get some combined animal (people and pigs) effect on these streams. This approach, though, suffers several major shortcomings. First, since pigs are housed on or near streams, their effect on those streams should be spatially explicit. Such an effect will only add more stream-to-stream variability to a dataset that already has plenty. Second, a classification framework that includes pigs explicitly then posits that the major impact on these streams is the addition of fecal waste; these data show that the impacts are likely more general. For instance, the NOx signal in some of these streams probably comes from agricultural activities in the watershed. Some of the highest levels of NOx were observed in Alega, Fagalii1, and Mataalii streams, places where I know there were significant small scale plantations. A pig criterion misses this. Lastly, one of the major impacts on these streams is the modification of the flow regime. We measured flow in the first year of the program, but measurements were not made afterwards. This precludes our ability to make quantitative statements about the effect of flow; however, from my observations, small scale impoundments for agriculture or village water systems is a locally important human impact, one that again is missed by the pig criterion.

It seems, then, that the human density criterion initially employed to classify watersheds is best suited to capture the full range of impacts on these streams. While local stream-to-stream variables (like piggeries) or watershed-level land use data might help us understand or explain more of the variability within these data, they likely will only better characterize the specific nature of a particular impact, but not the overall gradient of impact.

Do the stream monitoring results suggest that the current classifications need to be changed (i.e., more or fewer watershed classes)? If so, what might a new classification system look like?

A new classification system, regardless of the primary criterion, should probably have fewer classes. After 4 years of monitoring and spending lots of money and effort, these data just cannot effectively discriminate 4 watershed classes.

My recommendation would be to revisit the initial data and document that determined and reported the initial classification and see how those data might be used to develop a 3 watershed classification. Initially, the distribution of human population density in Tutuila watersheds had only 2 clear breakpoints. The low cut point seemed to distinguish the unpopulated or sparsely populated watersheds from the rest. There was also another upper cut point that demarcated the highest density watersheds. The majority of the watersheds, however, just sat in a big chunk in the middle. This group, for lack of a better reason, was simply cut in half and became the Minimal and Intermediate classes. This was an arbitrary decision, and the data collected over 4 years generally demonstrate that only the lowest and the highest classes of watersheds can be reliably differentiated. That is not always the case, but it is certainly true more often than not. All this suggests that a new classification system, if adopted, should likely have only 3 classes, basically a low, a high, and an intermediate.

Do the stream monitoring results suggest that the ASEPA continue this effort using the same current probabilistic sampling approach, or is a new stream monitoring plan recommended?

When I first considered this question, I thought it would be very easy to answer, just as soon as I did all my statistical analyses and plotted up the results. Now that I've done a fair bit of that, this question has not become any easier to address.

The first step in thinking about the stream monitoring program and whether it needs to be modified is to ask whether the program is meeting it study objectives. And the program certainly seems to meet its most fundamental objective: to institutionalize within the American Samoa Environmental Protection Agency (ASEPA) a systematic means for collecting, interpreting, and reporting data concerning the condition and status of Territorial streams. It might not be meeting its objective as well as it can be, but the design (e.g., number of watershed classes) can always be tweaked in order to better collect the necessary information on how people impact Territorial streams. A second objective of this SMP was to develop a monitoring program that could assess the condition of streams from a larger perspective, the watershed level, and contribute to a framework that could also be used to assess the conditions of nearshore beaches, coral reefs, reef flats, etc. From my perspective, it seems that the SMP addresses those objectives.

Thus, one answer to the question above is to keep the current probabilistic approach but make some modifications to the sampling protocol to refine the quality and precision of the information gathered. For example, the current monitoring plan has each stream visited once per month for 12 months. As it turns out, since stream is a random factor nested within class [see Methods describing the analytical model], additional measurements within a stream (in this case, 12 visits) does not add much power to discerning the impact of watershed class (Underwood 1997). One way to increase the power to discriminate between classes is to increase the number of streams sampled. One simple recommendation would be to visit 4 streams/class in one annual period, but visit each stream only 6 times (every other month would be one way to capture the variability seen within a year). No extra samples are collected, but the power to distinguish between classes increases. Note that this will occur whether we stick to the 4 or a new 3 watershed class framework. Other things that could be added to the program include some biological sampling (like that of Wade et al. 2008), which would only improve the information we have about these streams.

Do the results of the study provide any information concerning the value of the current surface water standard for total phosphorus (150 µg/L P)?

Based on the TP data collected over the 4 study years, the ASWQS criterion of 0.150 mg/L was exceeded in 19 or the 32 streams (59%) surveyed. With respect to the watershed classes, streams selected from the Pristine, Minimal, Intermediate, and Extensive classes exceeded the threshold standard 4, 5, 4, and 6 of 8 times, respectively. Roughly half the time, even in the most unimpacted watersheds, streams violate the TP standard. That number creeps up a bit in the most impacted watersheds, but not enough to demonstrate that TP concentration in impacted streams are significantly higher.

Even looking at the data at a finer scale (i.e., each water sample collected where TP was quantified), close to 50% of all the samples exceeded the ASWQS, regardless of where in the stream the sample was collected. Specifically, 175 of 343 (51.0%) water samples collected at upstream sites were greater than or equal to 0.150 mg/L, while 163 of 328 (49.7%) water samples collected at downstream sites were greater than or equal to the WQS. Ninety-nine of 243 (40.7%) water samples collected midstream equaled or exceeded the standard.

So what, if anything, can we conclude about the TP standard from these data? Well, first, these data suggest that phosphorus, measured as total phosphorus, is present in relatively consistent concentrations in Tutuila streams. At the upstream stations, where human impacts are expected to be lowest across all watershed classes relative to downstream locations, there doesn’t seem to be much difference across classes (Table 10), with average TP concentrations being similar (from 0.161 to 0.192 mg/L). The median concentration of TP in Intermediate streams (0.100 mg/L) is much lower than in the other 3 classes, which is hard to explain. The ranges, though, are pretty similar across classes, with the exception of a few very high values in Intermediate and Extenstive streams, and the distributions are also similar (Figure 22). This is likely a consequence of the volcanic origin of the island and the weathering processes that drive phosphorus concentrations in aquatic habitats.

These results call in to question whether the current standard for TP is appropriate for the Territory when even the streams considered least impacted routinely exceed the standard. Unfortunately, these data do not offer any real insights into what a new TP standard would look like. Not only is there no significant difference across watershed classes (which, if present, might suggest a new threshold for the standard), but there is very little difference in the distributions of TP concentrations in either the upstream (Figure 22) or downstream (Figure 23) stations. When the downstream stations do not indicate TP concentrations that are related to land use, there’s not much to say about what a new standard might be.

REFERENCES

Burger, I.L. and J. A. Maciolek. 1981. Map inventory of nonmarine aquatic resources of American Samoa with on-site biological annotations. Review draft. US Fish and Wildlife Service, National Fisheries Research Center, Seattle, WA.

Cook, R.P. 2004.Macrofauna of Laufuti Stream, Tau, American Samoa, and the role of physiography in its zonation. Pacific Science 58: 7-21.

DiDonato, G. T. 2004. Developing an initial watershed classification for American Samoa. Report prepared by the American Samoa Environmental Protection Agency, Pago Pago, AS.

DiDonato, G. T. and E. B. Paselio. 2006. Localized beach contamination in American Samoa: results from 2 years of weekly monitoring. Marine Pollution Bulletin 52:466-468.

Pederson, J. 2000. American Samoa watershed protection plan. Report prepared for the American Samoa Environmental Protection Agency and the American Samoa Coastal Zone Management Program. Pedersen Planning Consultants, Saratoga, WY.

Underwood, A.J. 1997. Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge University Press, Cambridge, UK.

Wade, L.M., F. S. Fanolua, A. M. Vargo, K. van Houte-Howes, E. Bardi, and D. L. Vargo 2008 Exploiting Macrofauna Diadromy for Assessing Anthropogenic Impact in American Samoa Streams. Pacific Science 62: 177-190.

FIGURE LEGEND

Figure 1. Stream water temperature (°C) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error.

Figure 2. Stream specific conductivity measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error. The plotted data are the rank-transformed data used in the statistical analysis.

Figure 3. Stream dissolved oxygen (% saturation) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error.

Figure 4. Stream pH measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error.

Figure 5. Stream turbidity (NTU) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error. The plotted data are the log_{10}-transformed data used in the statistical analysis.

Figure 6. Stream *Enterococcus* concentrations (MPN) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error. The plotted data are the log_{10}-transformed data used in the statistical analysis.

Figure 7. Stream ammonium (NH_4) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error. The plotted data are the rank-transformed data used in the statistical analysis.

Figure 8. Stream nitrate+nitrite (NOx) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error. The plotted data are the rank-transformed data used in the statistical analysis.

Figure 9. Stream total nitrogen (TN) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error. The plotted data are the rank-transformed data used in the statistical analysis.

Figure 10. Stream total phosphorus (TP, mg/L) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error. The plotted data are the ln (x+1)-transformed data used in the statistical analysis.

Figure 11. Stream water temperature coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error. The plotted data are the ln-transformed data used in the statistical analysis.

Figure 12. Stream specific conductivity coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are ± 1 standard error. The plotted data are the ln-transformed data used in the statistical analysis.

Figure 13. Stream dissolved oxygen coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are $\pm$ 1 standard error. The plotted data are the ln-transformed data used in the statistical analysis.

Figure 14. Stream pH coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are $\pm$ 1 standard error. The plotted data are the ln-transformed data used in the statistical analysis.

Figure 15. Stream turbidity coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are $\pm$ 1 standard error. The plotted data are the ln-transformed data used in the statistical analysis.

Figure 16. Stream *Enterococcus* coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are $\pm$ 1 standard error.

Figure 17. Stream ammonium (NH_4) coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are $\pm$ 1 standard error.

Figure 18. Stream nitrate+nitrite (NOx) coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are $\pm$ 1 standard error.

Figure 19. Stream total nitrogen (TN) coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are $\pm$ 1 standard error. The plotted data are the ln-transformed data used in the statistical analysis.

Figure 20. Stream total phosphorus (TP) coefficient of variation (CV) measured across 4 sampled watershed classes. Bars are adjusted least square means, and error bars are $\pm$ 1 standard error. The plotted data are the ln-transformed data used in the statistical analysis.

Figure 21. Cumulative distribution functions of human population density and domestic pig density in 33 Tutuila watersheds.

Figure 22. Histograms showing the frequency of total phosphorus (TP) concentrations observed at the upstream station of randomly selected Tutuila streams over the study period.

Figure 23. Histograms showing the frequency of total phosphorus (TP) concentrations observed at the downstream station of randomly selected Tutuila streams over the study period.

Figure 1

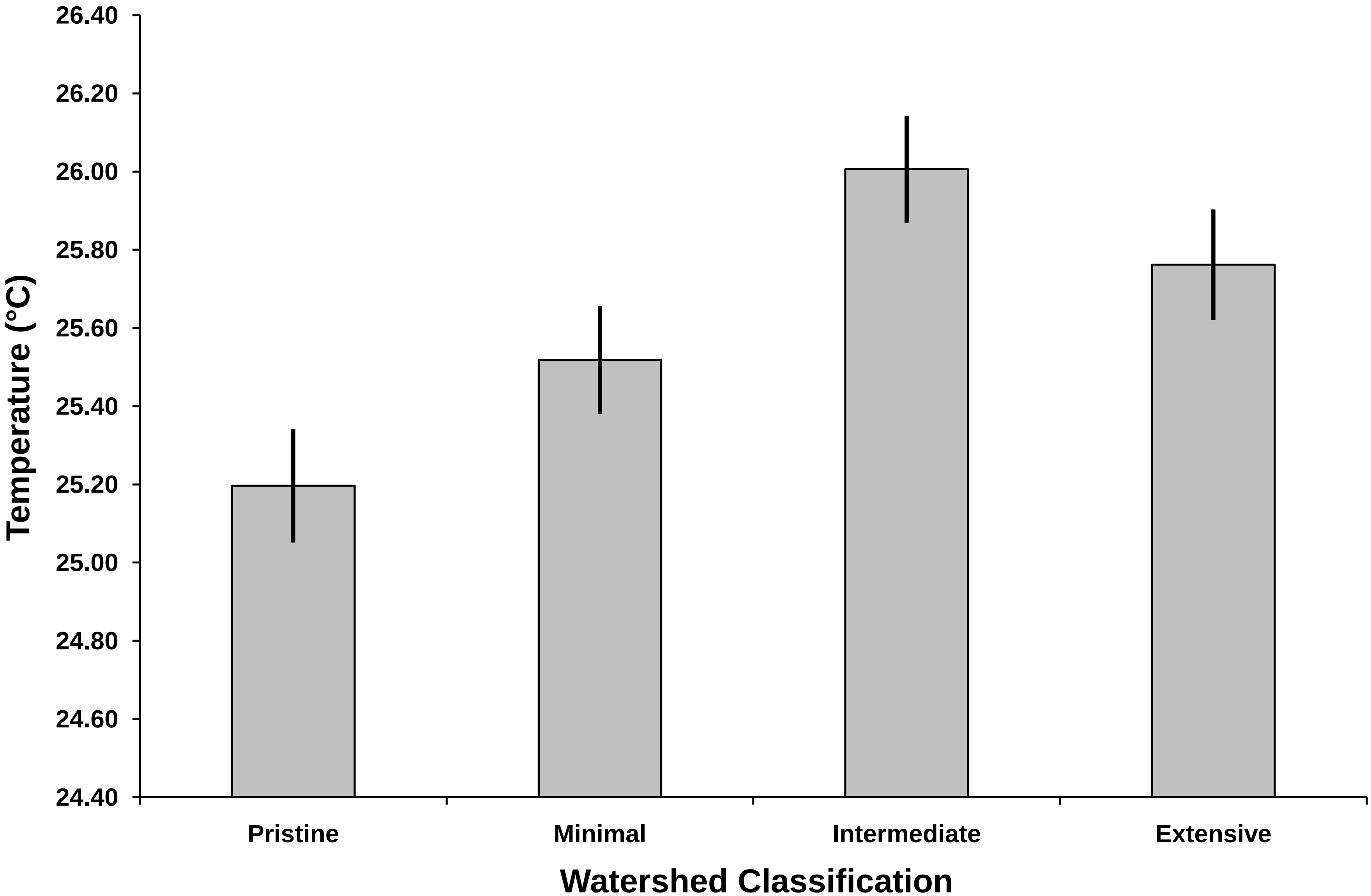
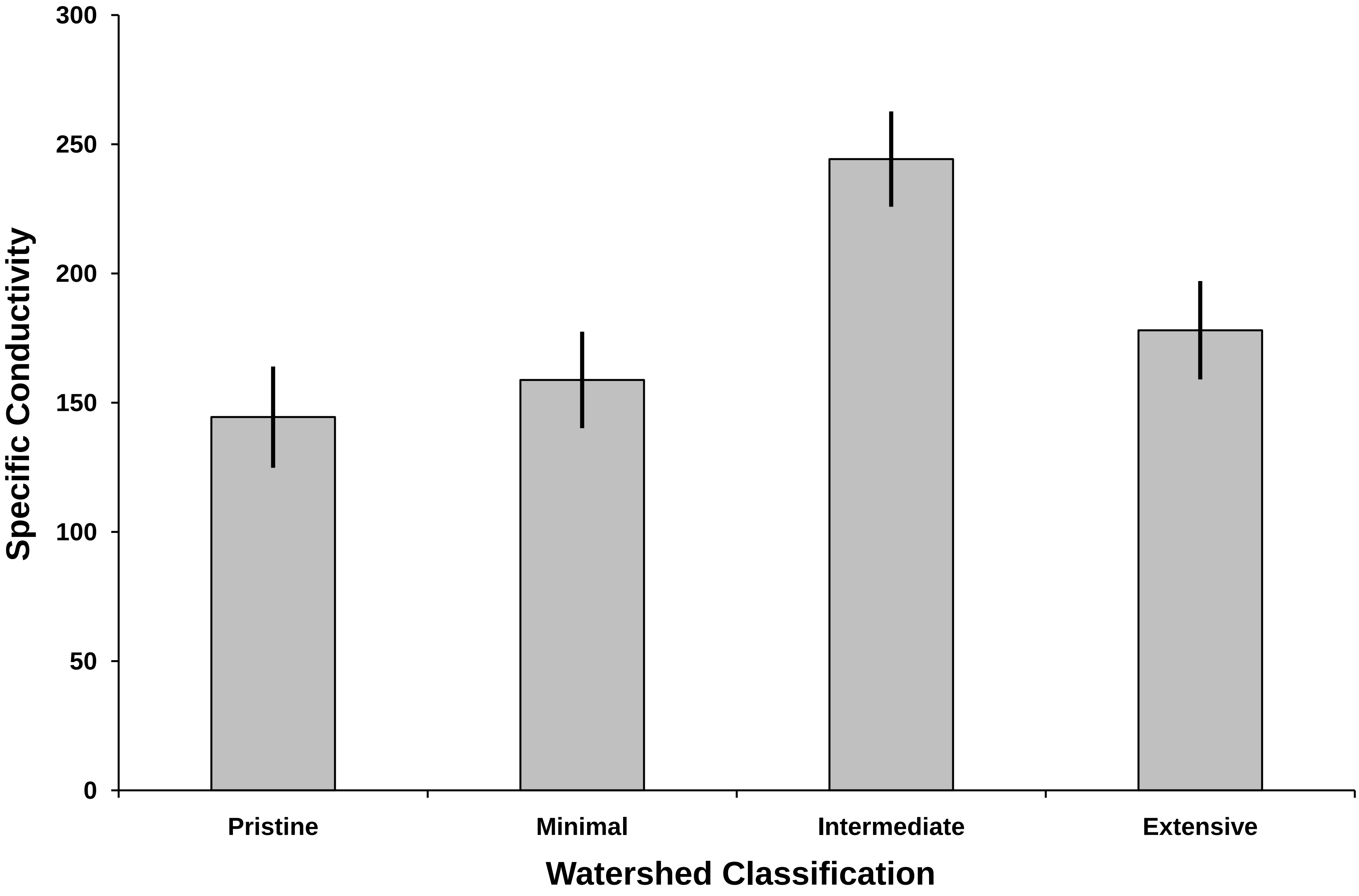

26.40
26.20
26.00
25.80
25.60
25.40
25.20
25.00
24.80
24.60
24.40
Temperature (°C)
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 2


300
250
200
150
100
50
0
Specific Conductivity
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

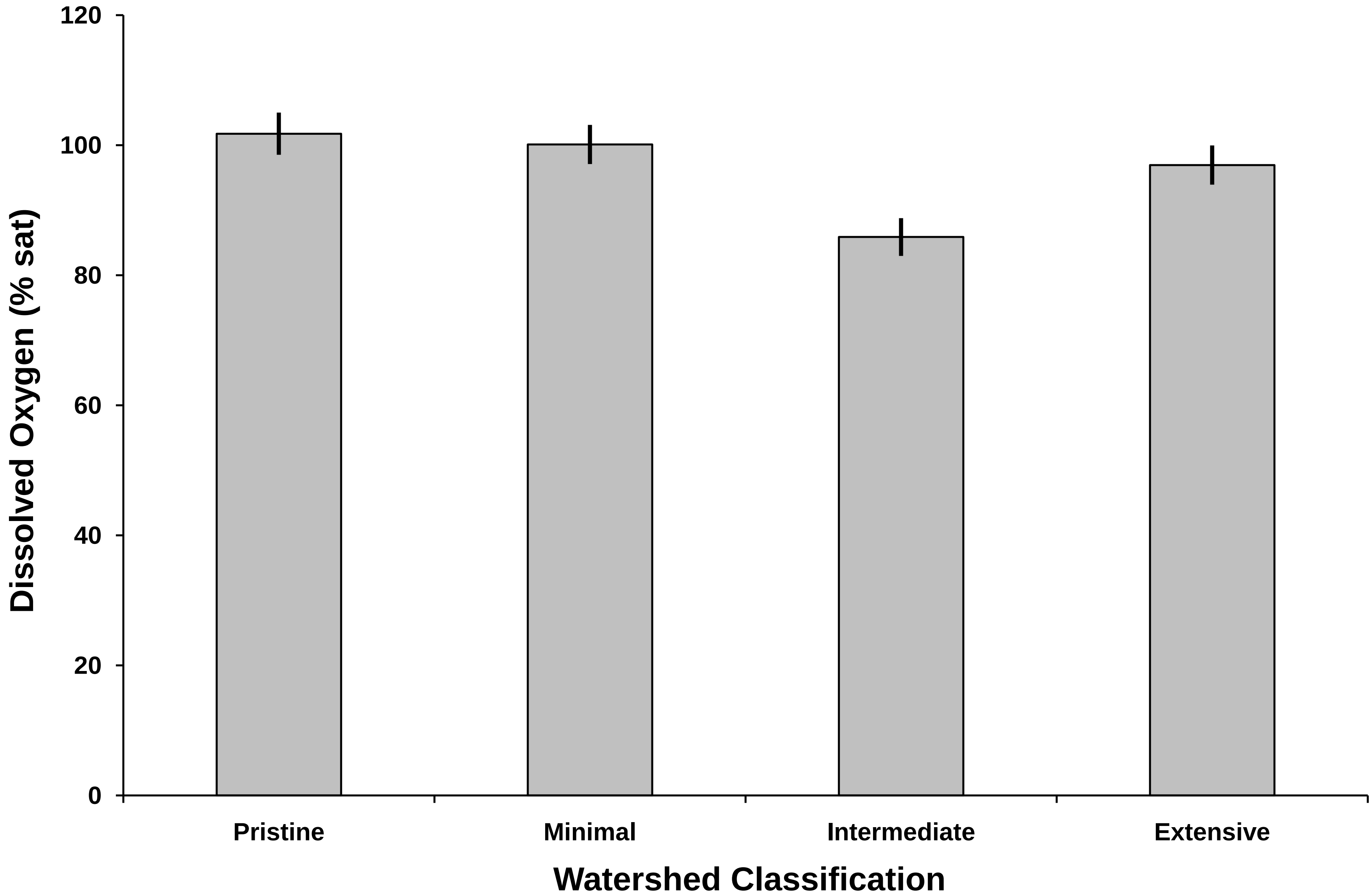
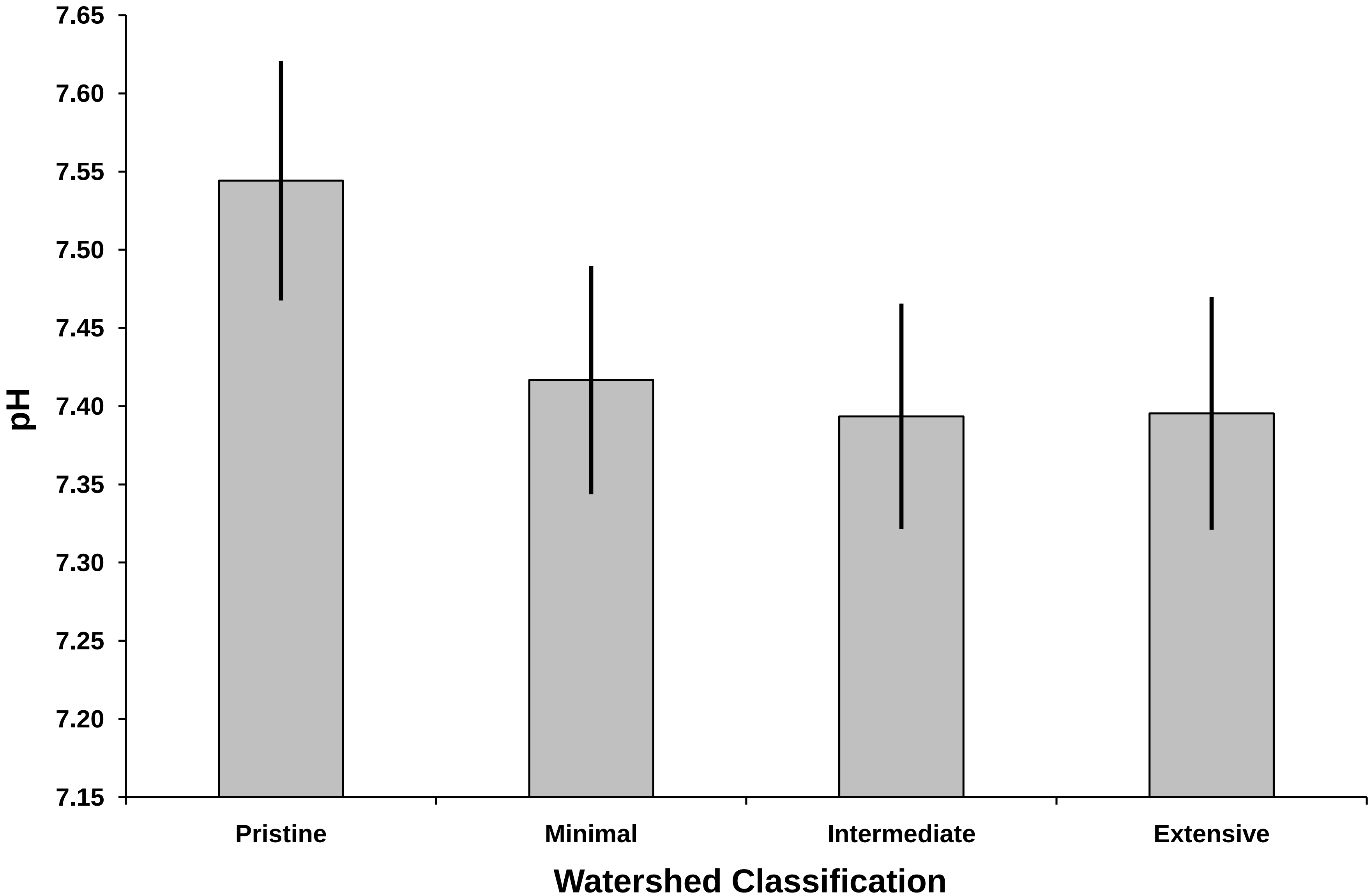

120
100
80
60
40
20
0
Dissolved Oxygen (% sat)
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 4



7.65
7.60
7.55
7.50
7.45
7.40
7.35
7.30
7.25
7.20
7.15
pH
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 5

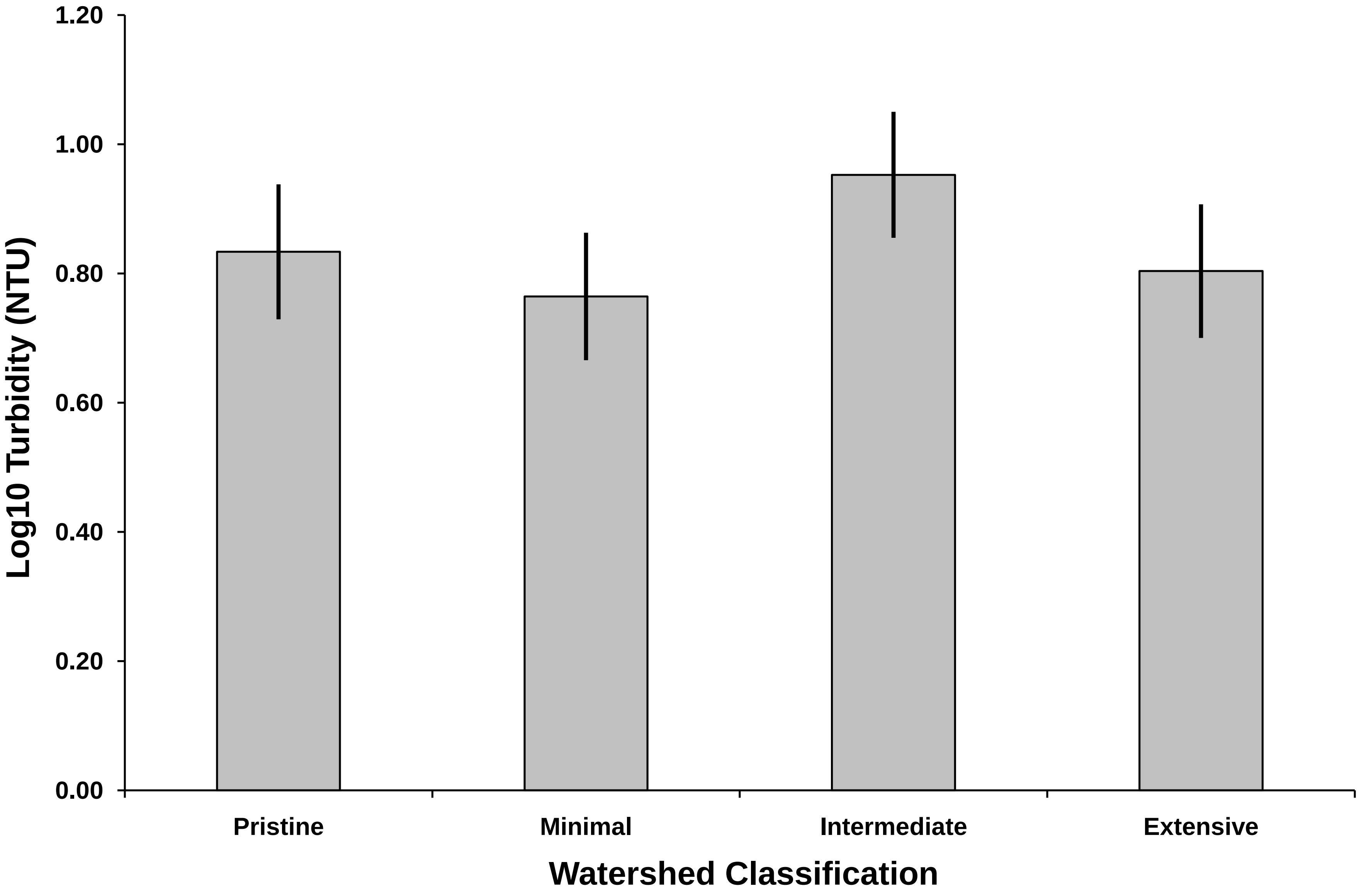

1.20
1.00
0.80
0.60
0.40
0.20
0.00
Log10 Turbidity (NTU)
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 6

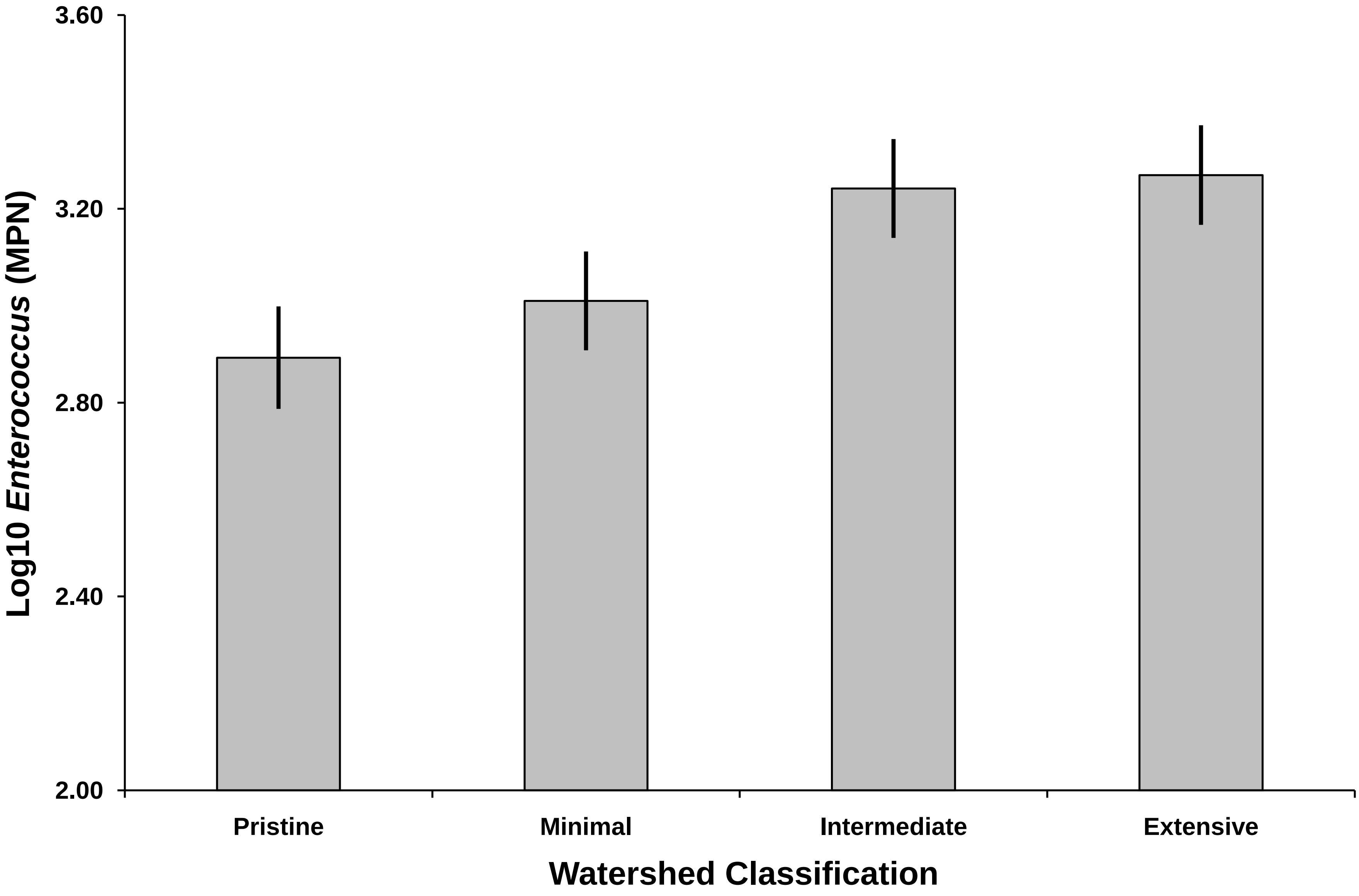

3.60
3.20
2.80
2.40
2.00
Log10 *Enterococcus* (MPN)
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 7

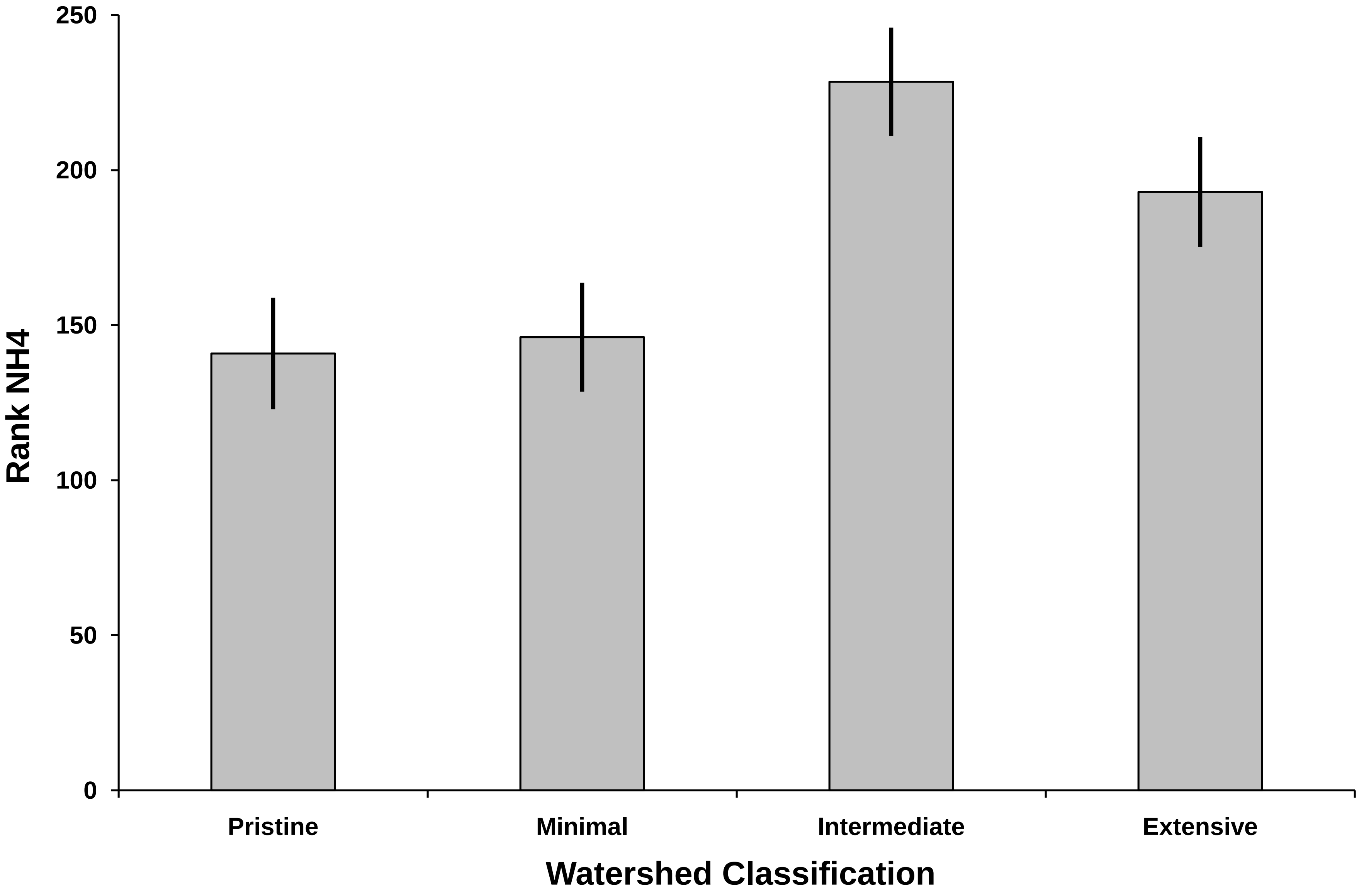
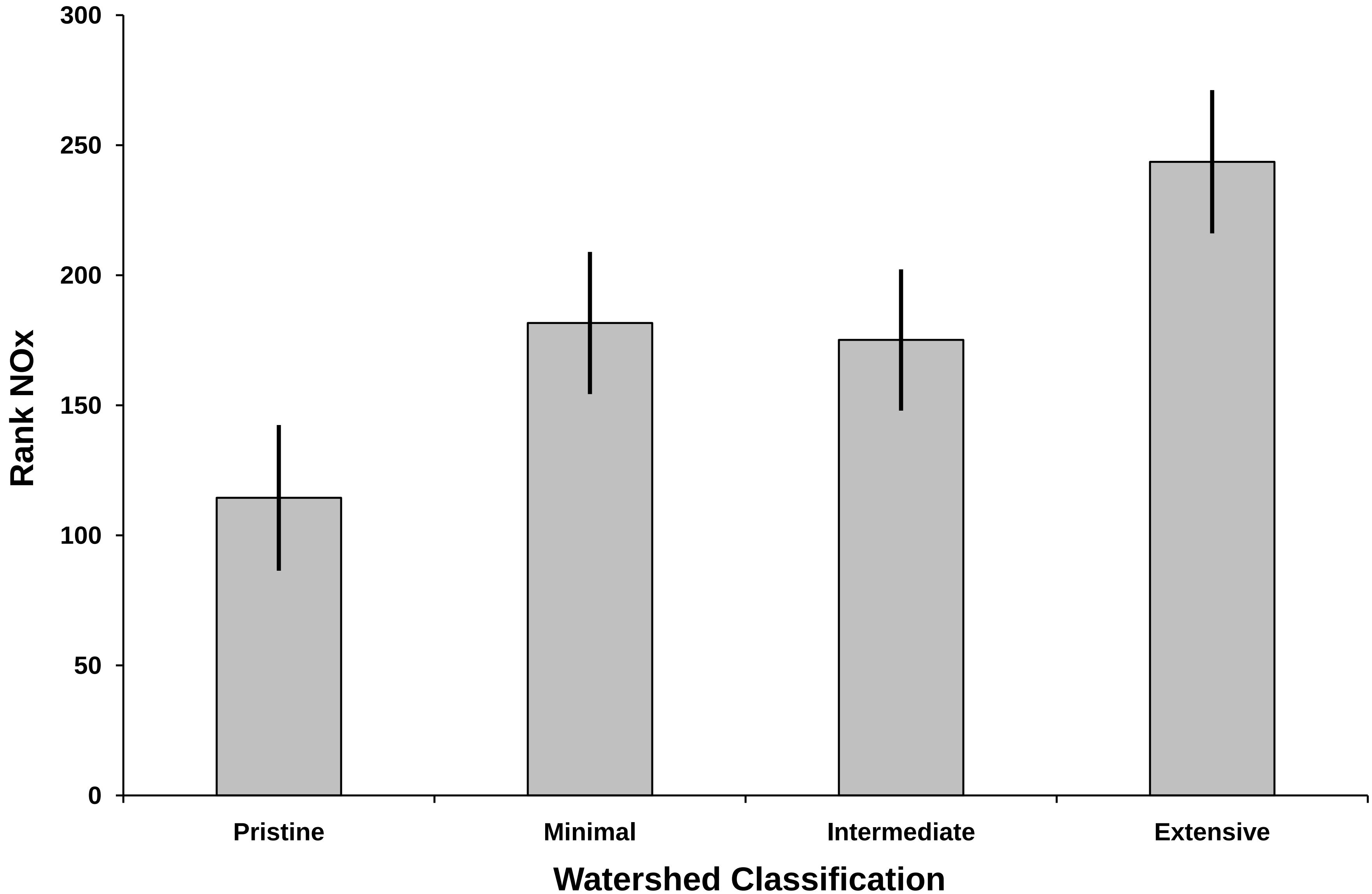

250
200
150
100
50
0
Rank NH4
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 8



300
250
200
150
100
50
0
Rank NOx
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

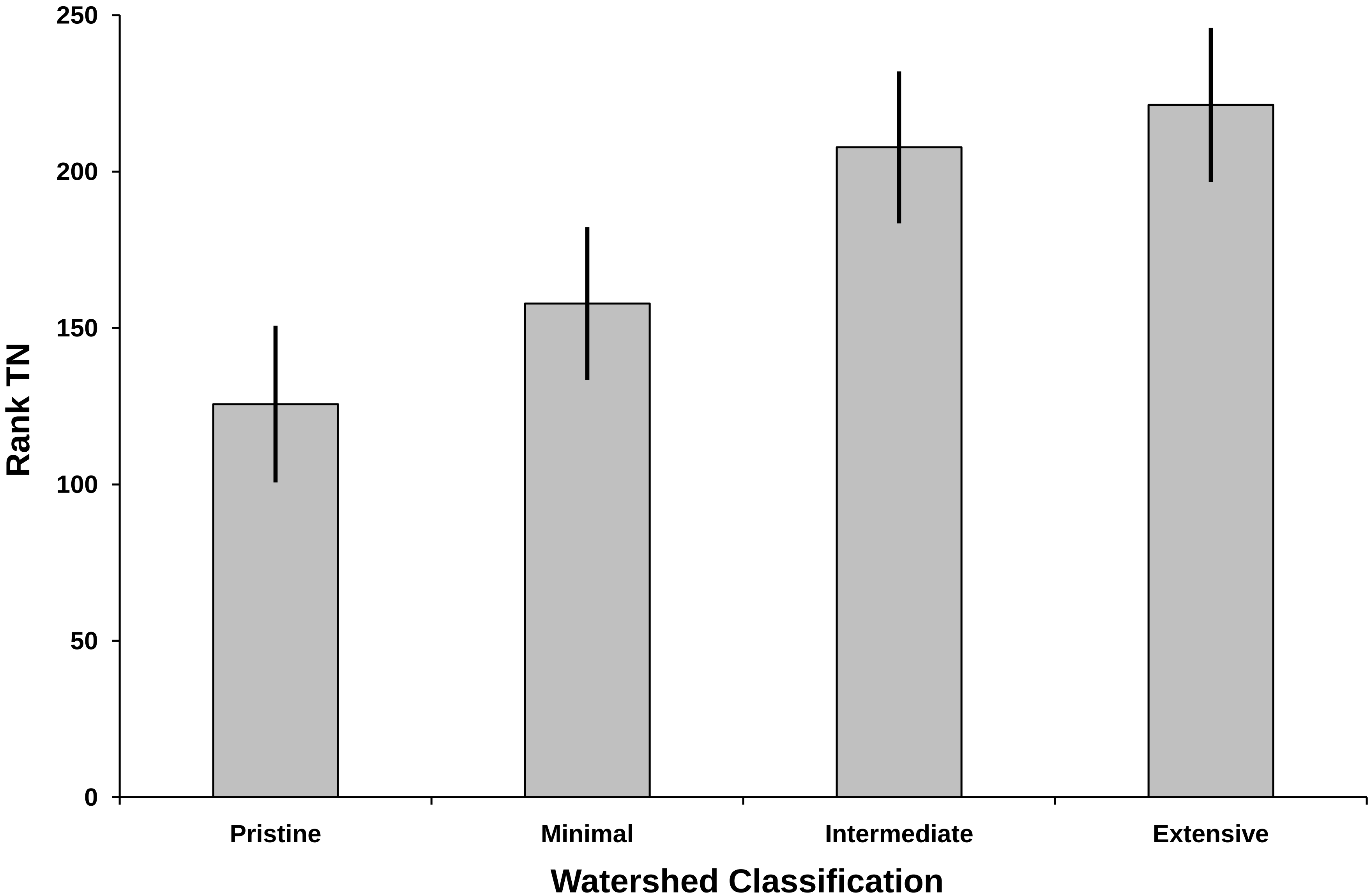

250
200
150
100
50
0
Rank TN
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 10

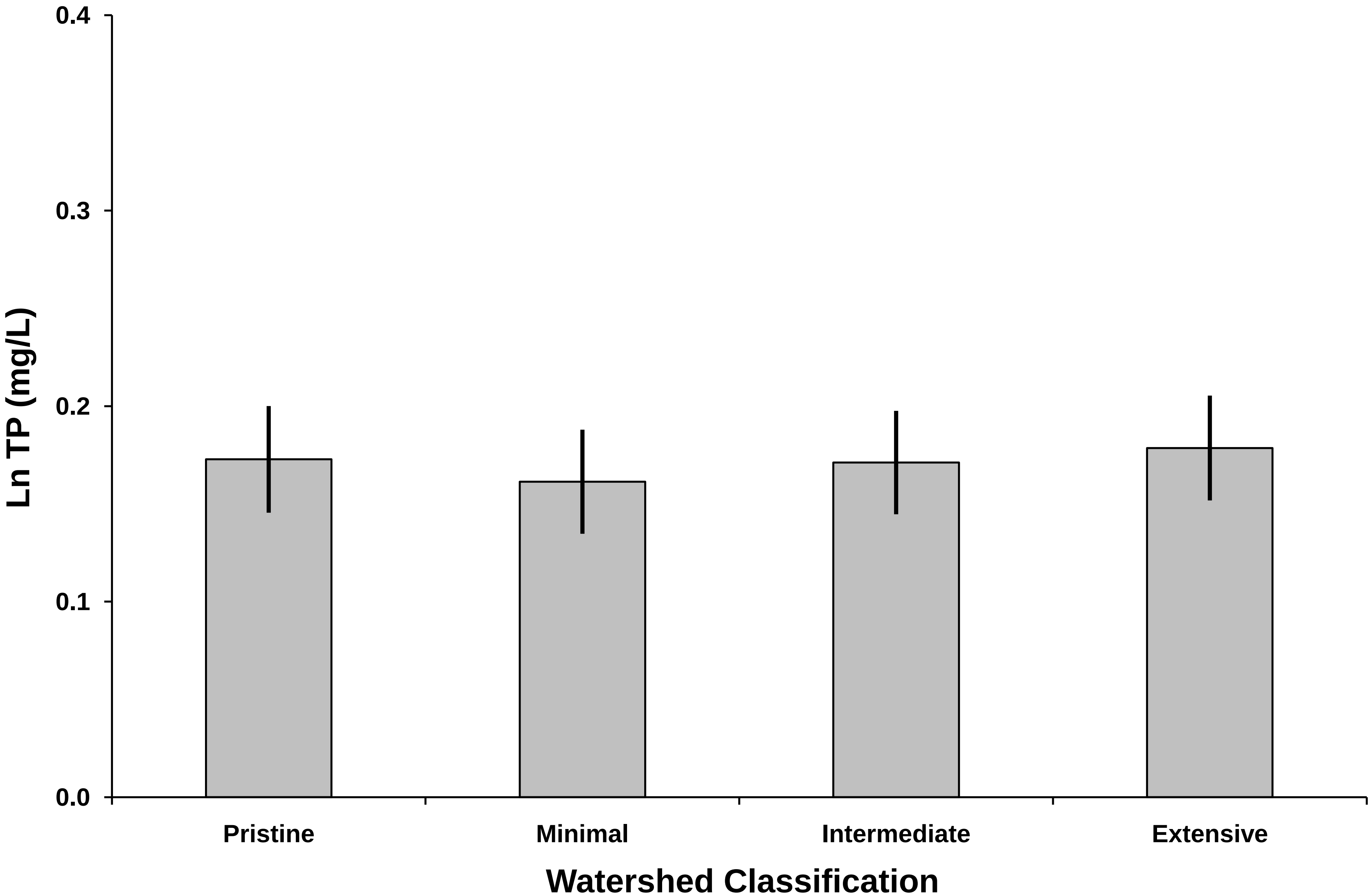

0.4
0.3
0.2
0.1
0.0
Ln TP (mg/L)
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 11

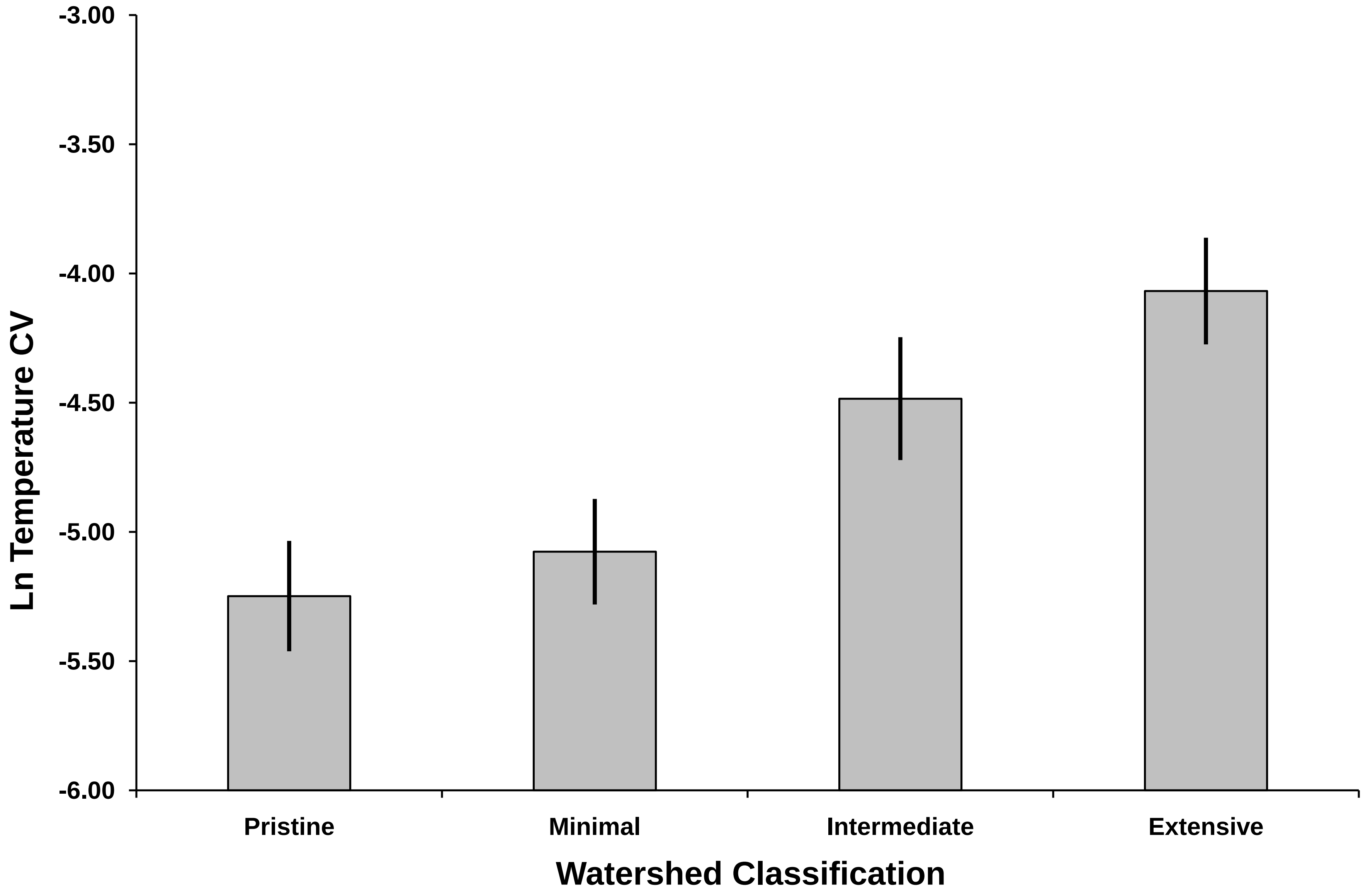
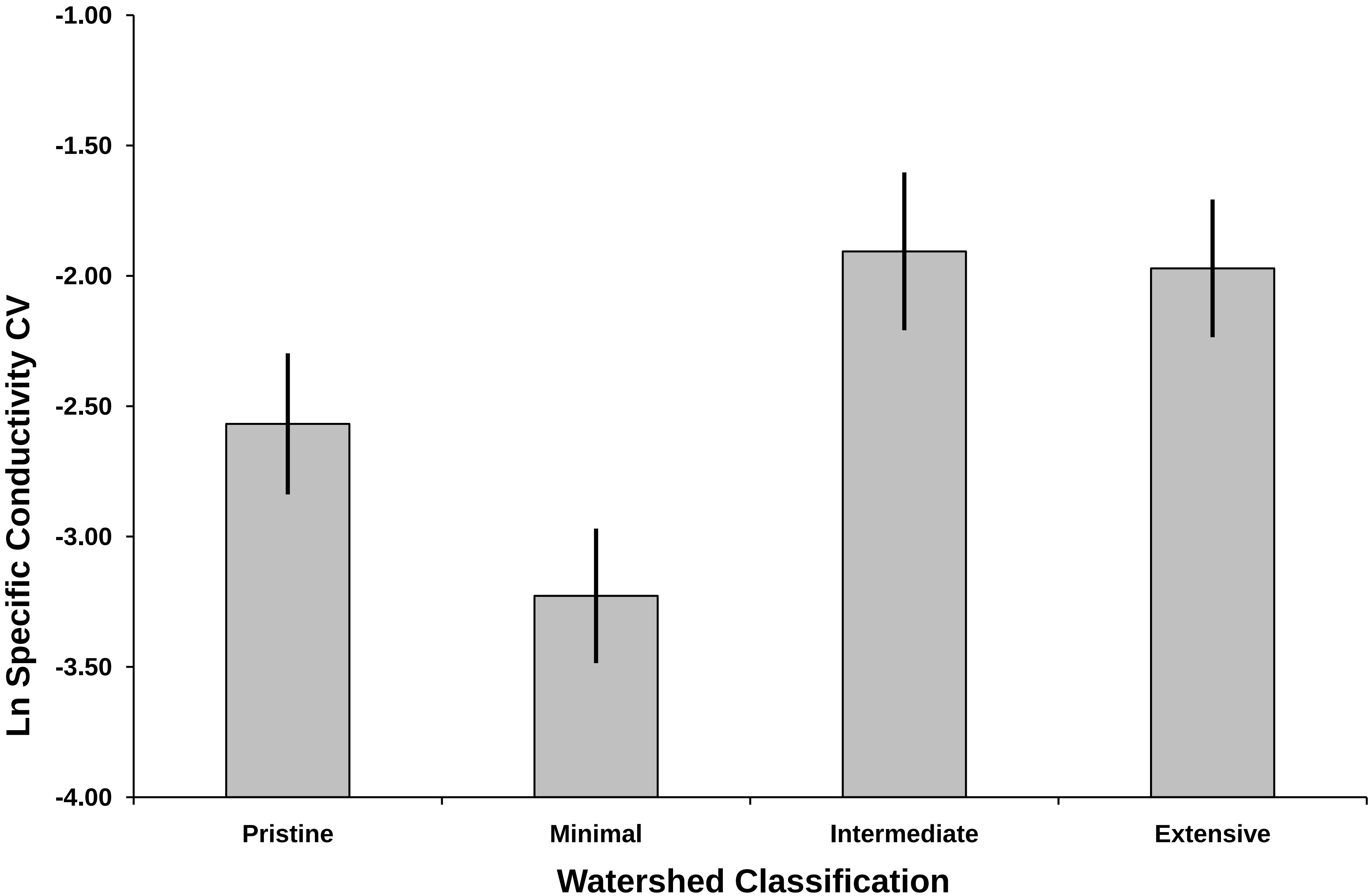

-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
-6.00
Ln Temperature CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 12


-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
Ln Specific Conductivity CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

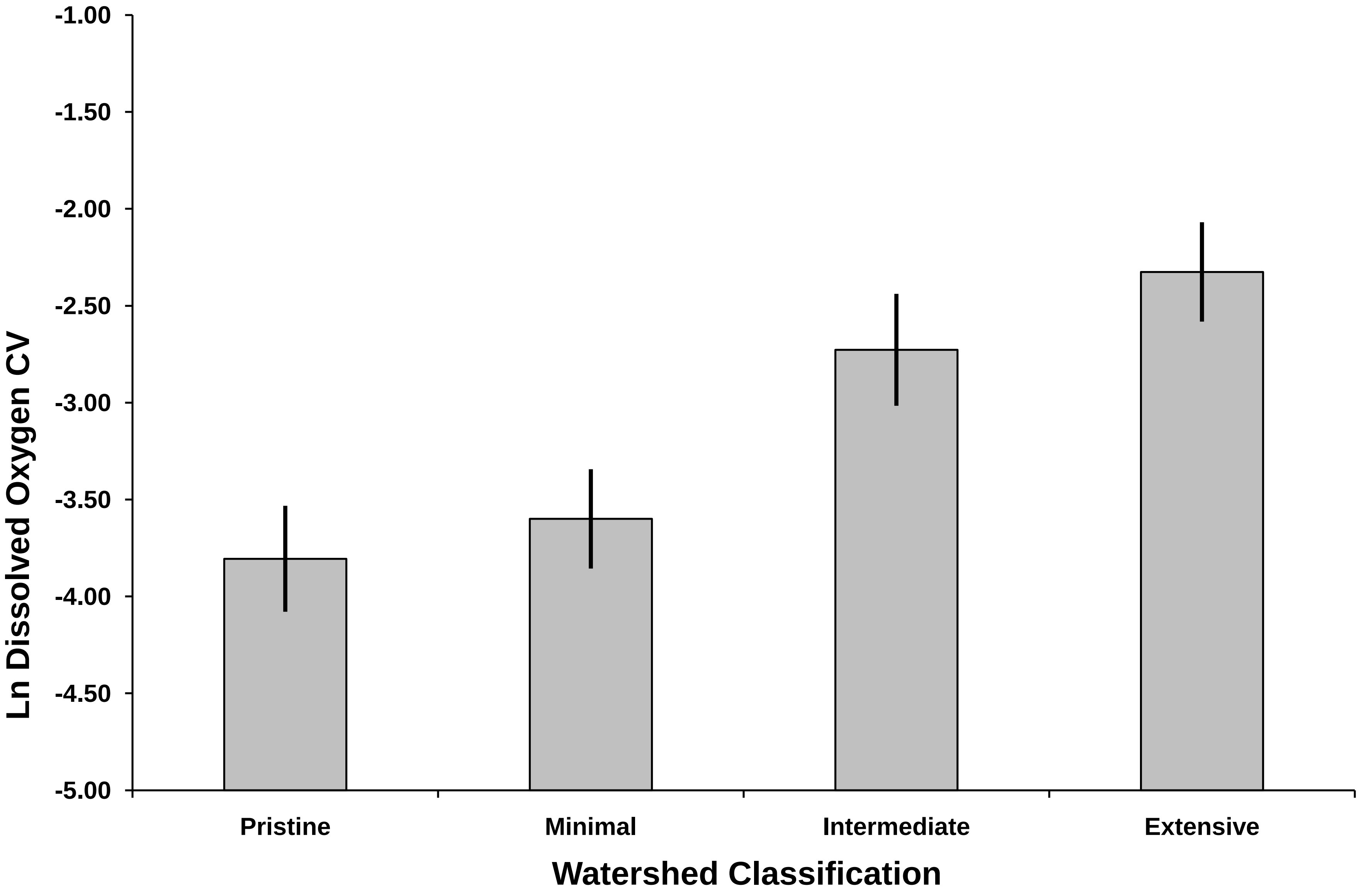
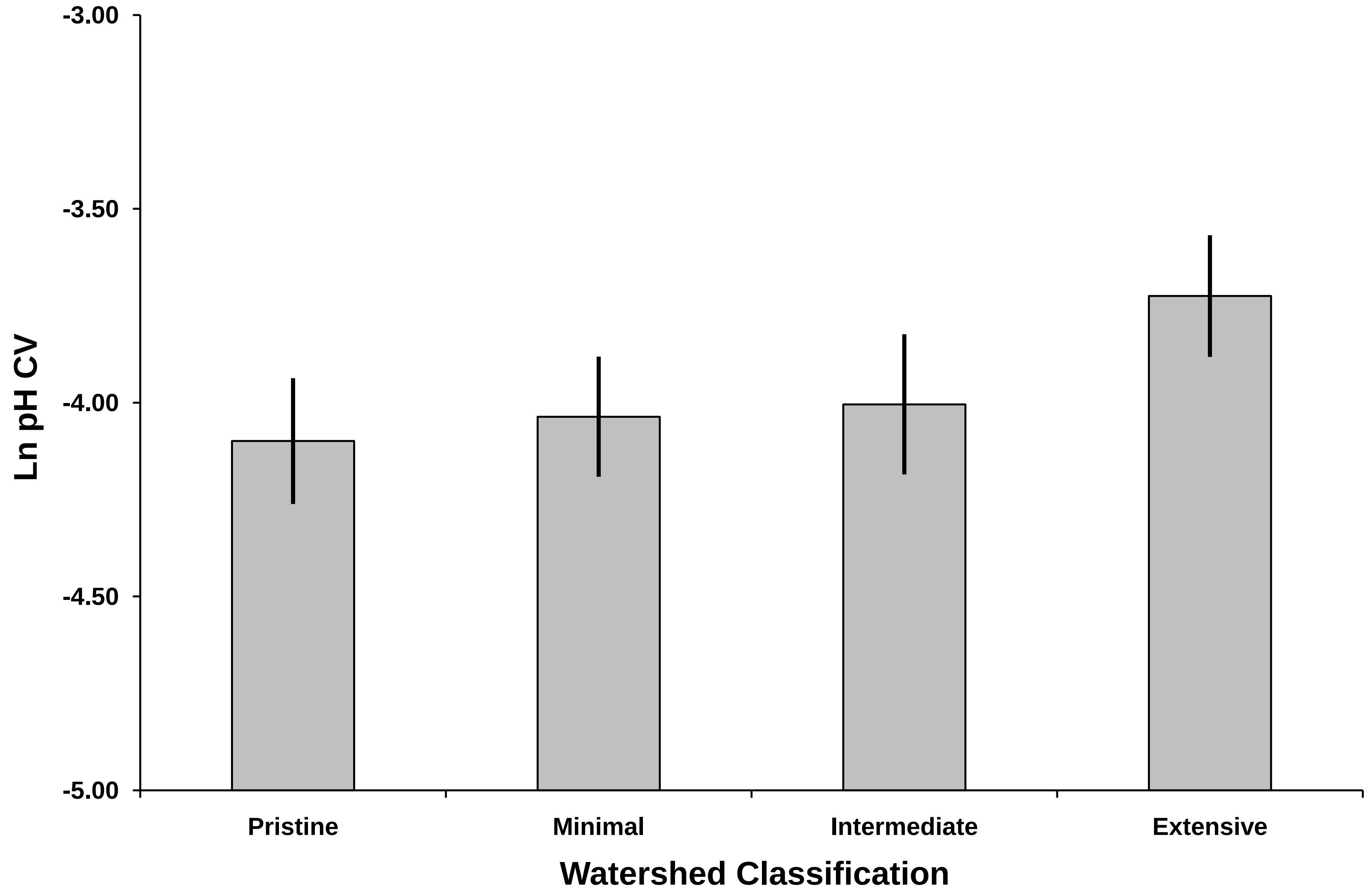
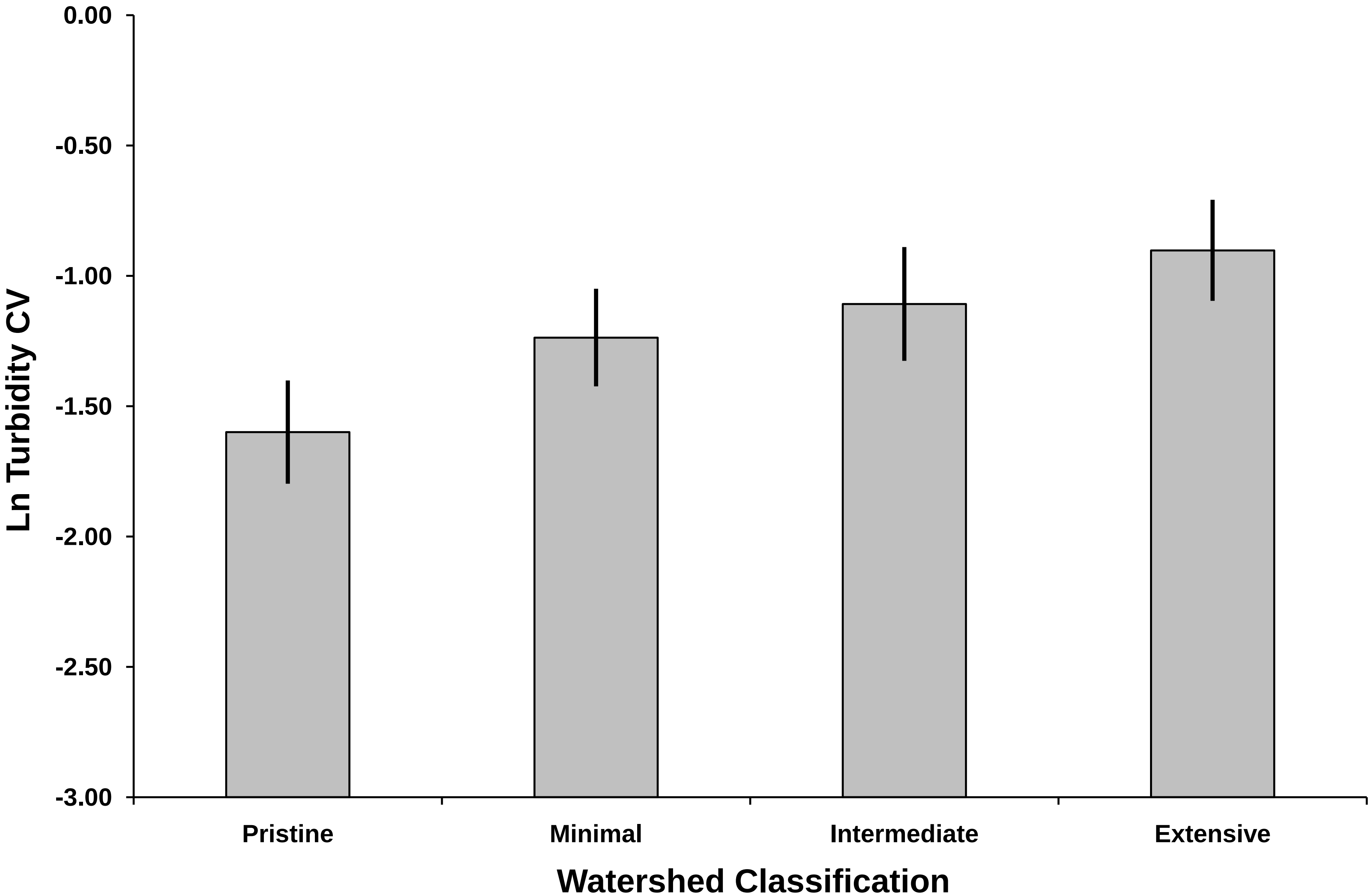

-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
Ln Dissolved Oxygen CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 14



-3.00
-3.50
-4.00
-4.50
-5.00
Ln pH CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 15


0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
Ln Turbidity CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

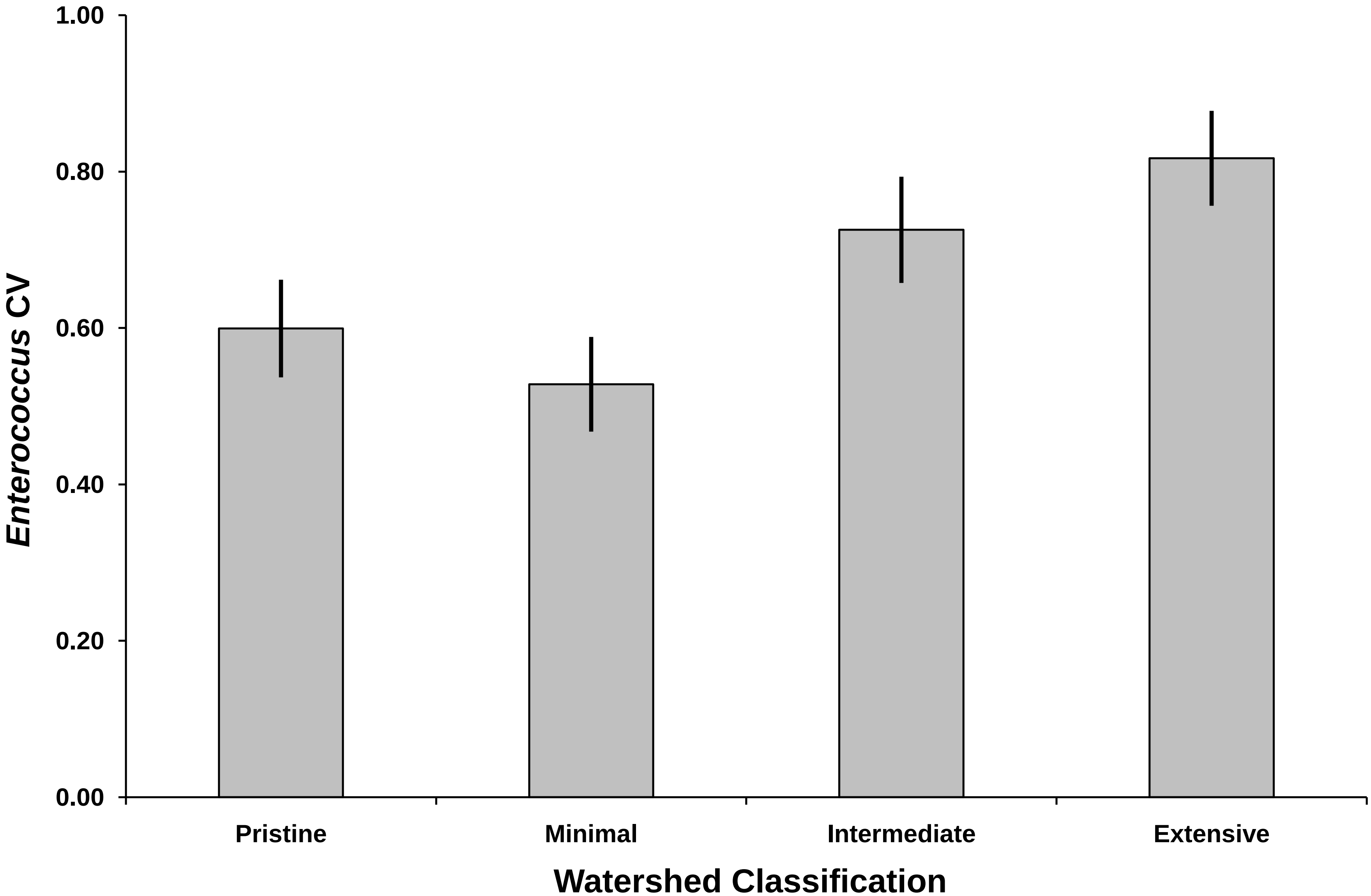
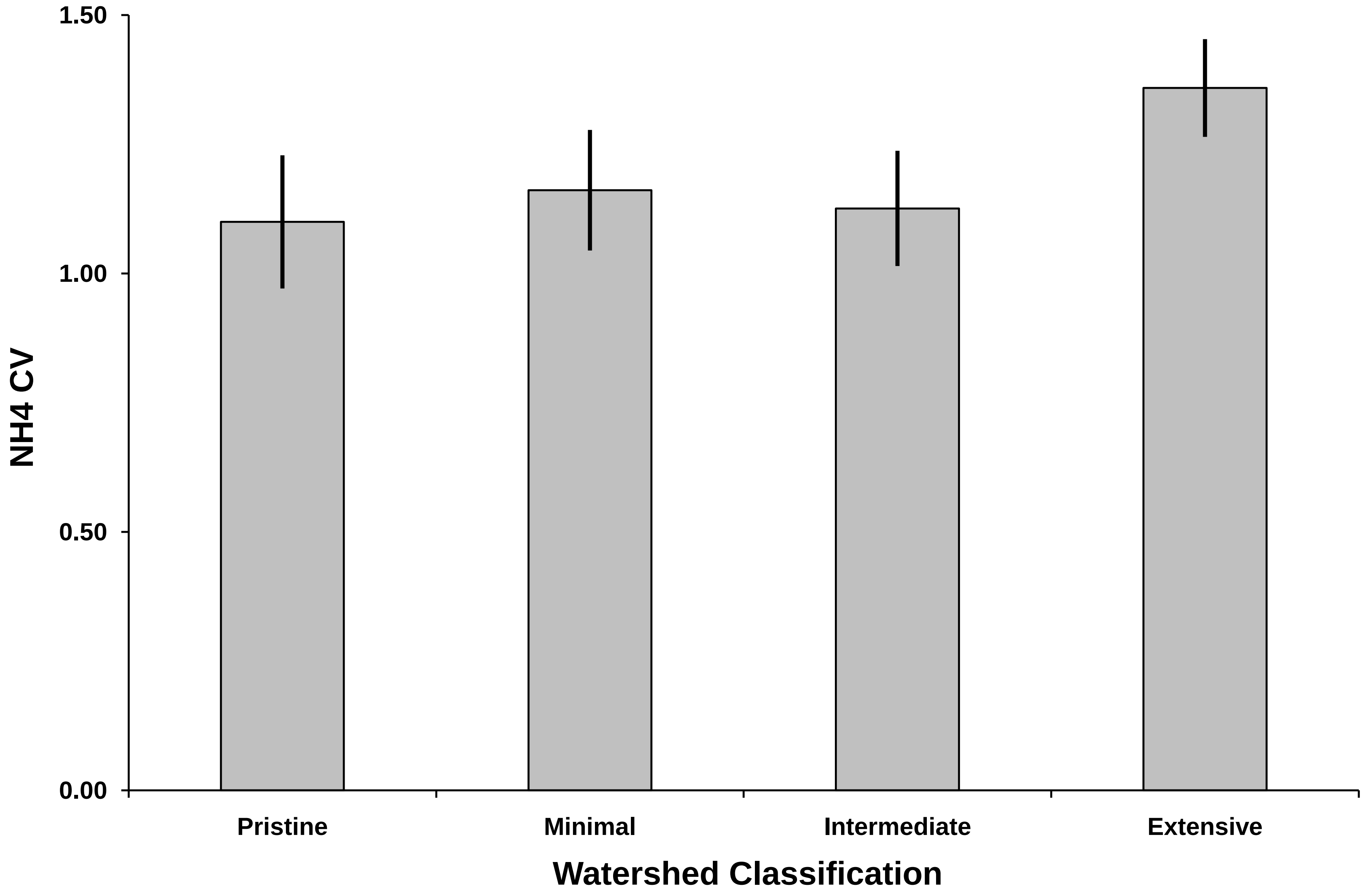

1.00
0.80
0.60
0.40
0.20
0.00
Enterococcus CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 17



1.50
1.00
0.50
0.00
NH4 CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

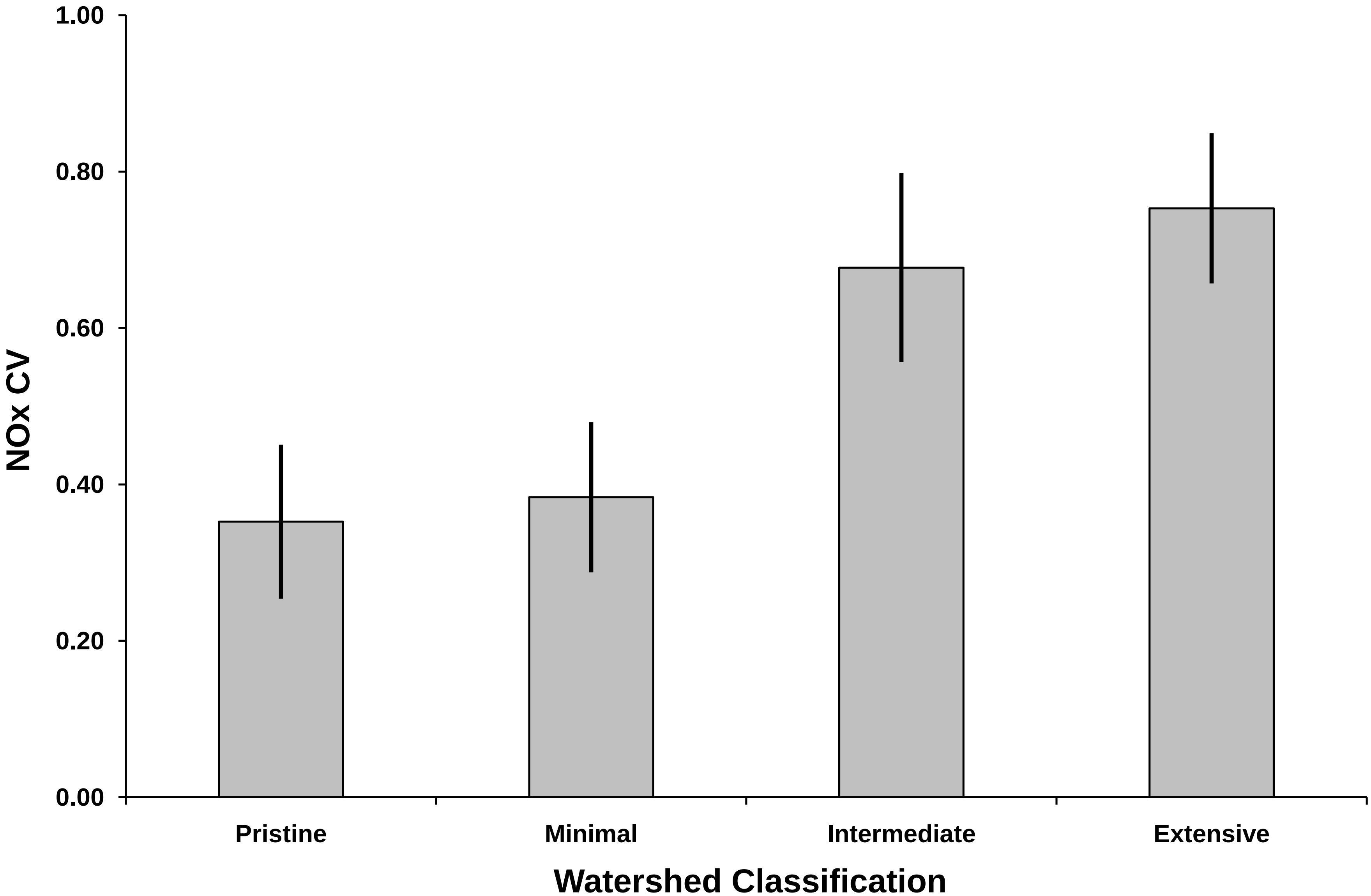
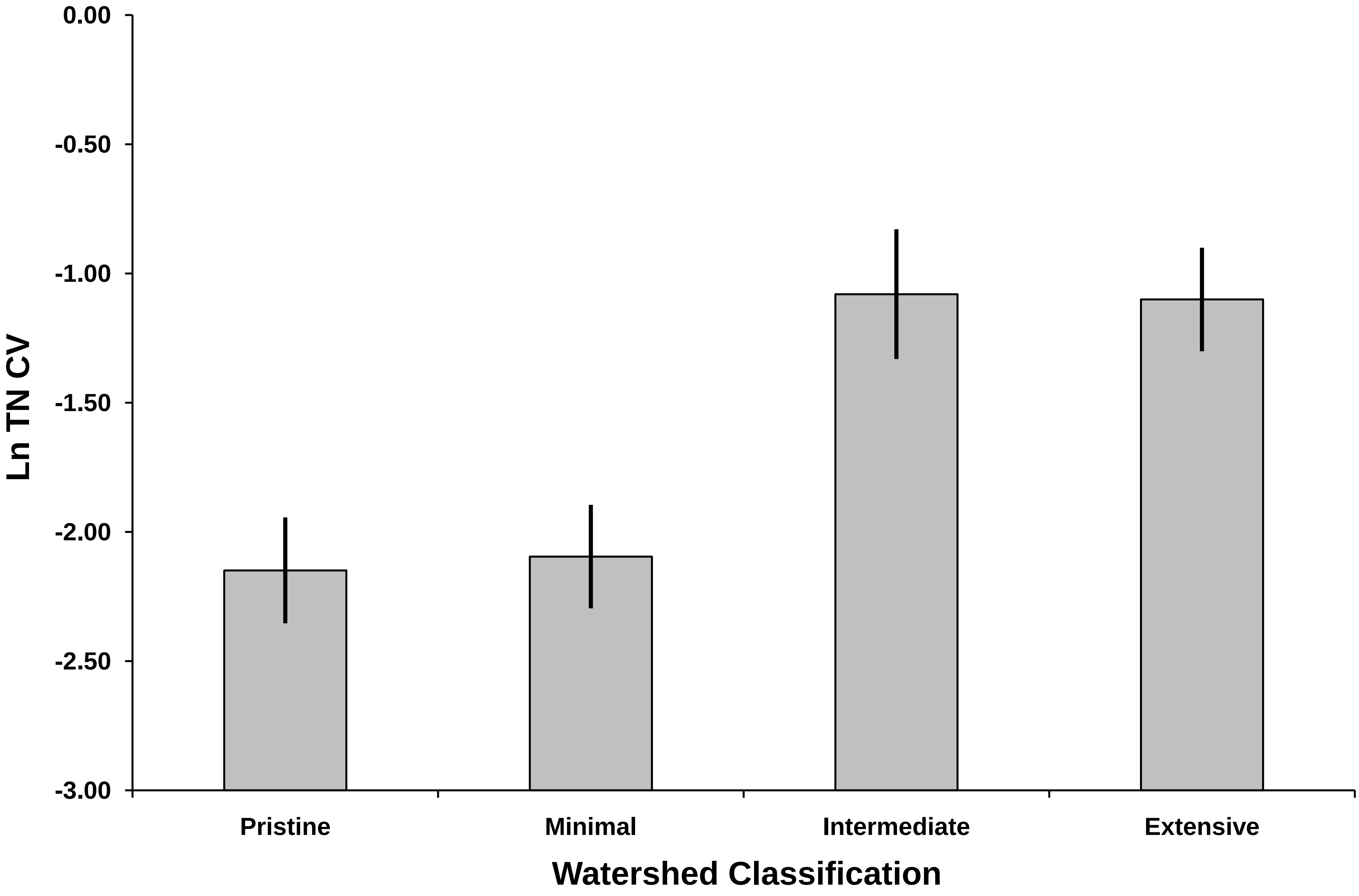
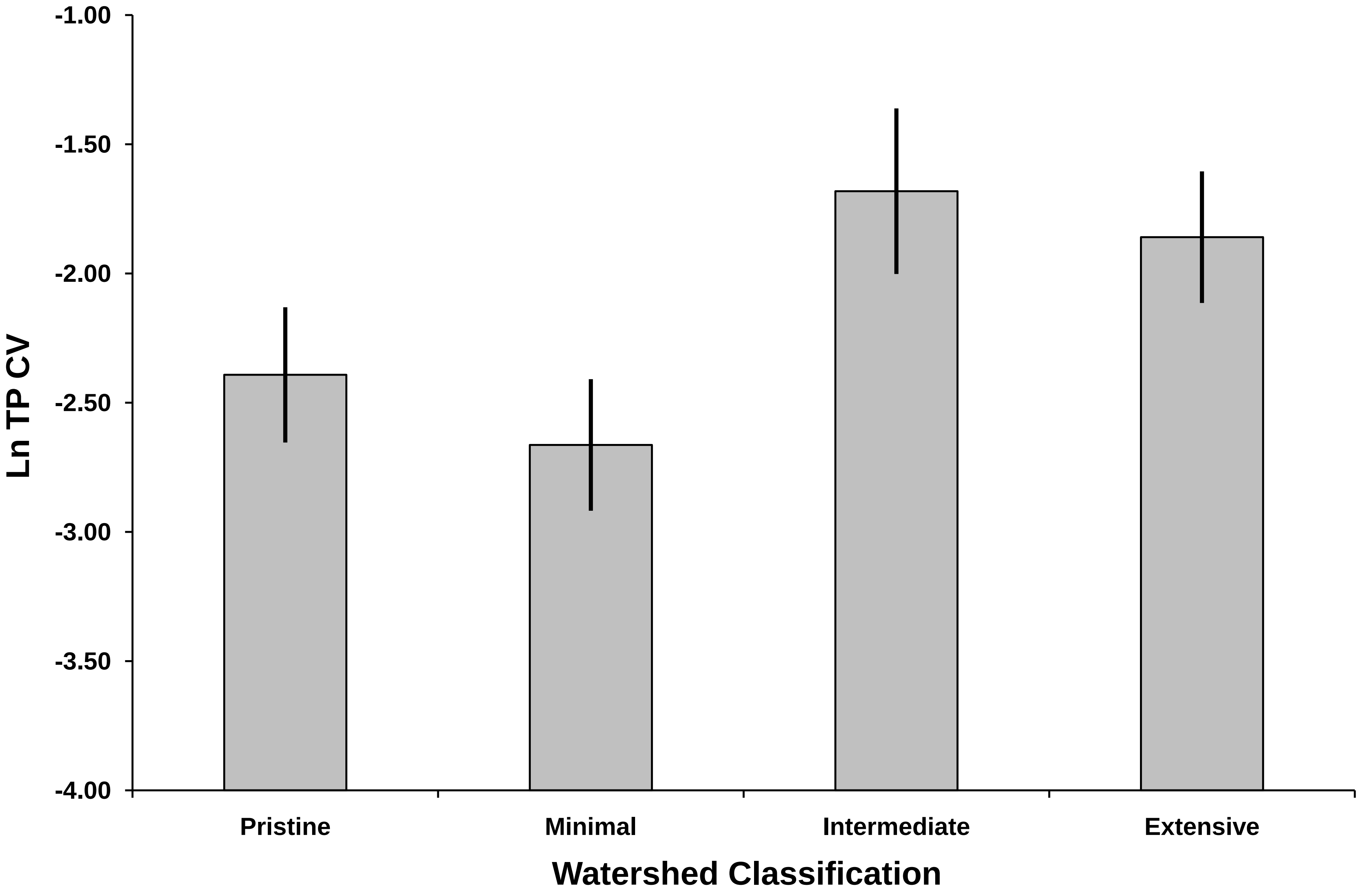

1.00
0.80
0.60
0.40
0.20
0.00
NOx CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 19



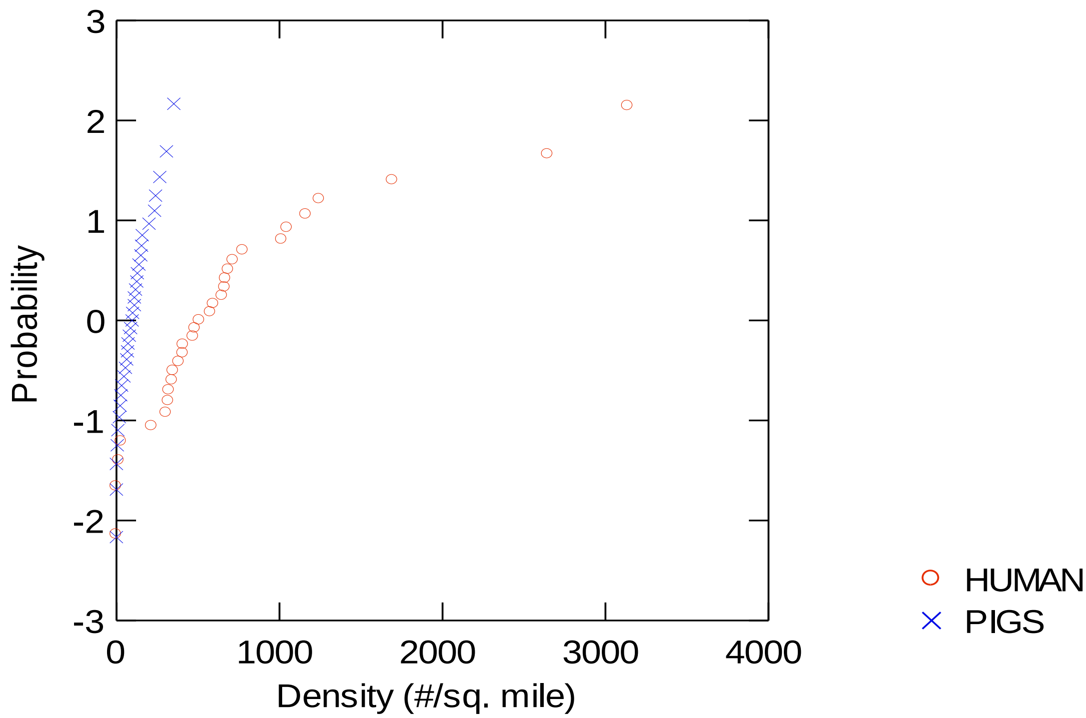
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
Ln TN CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 20



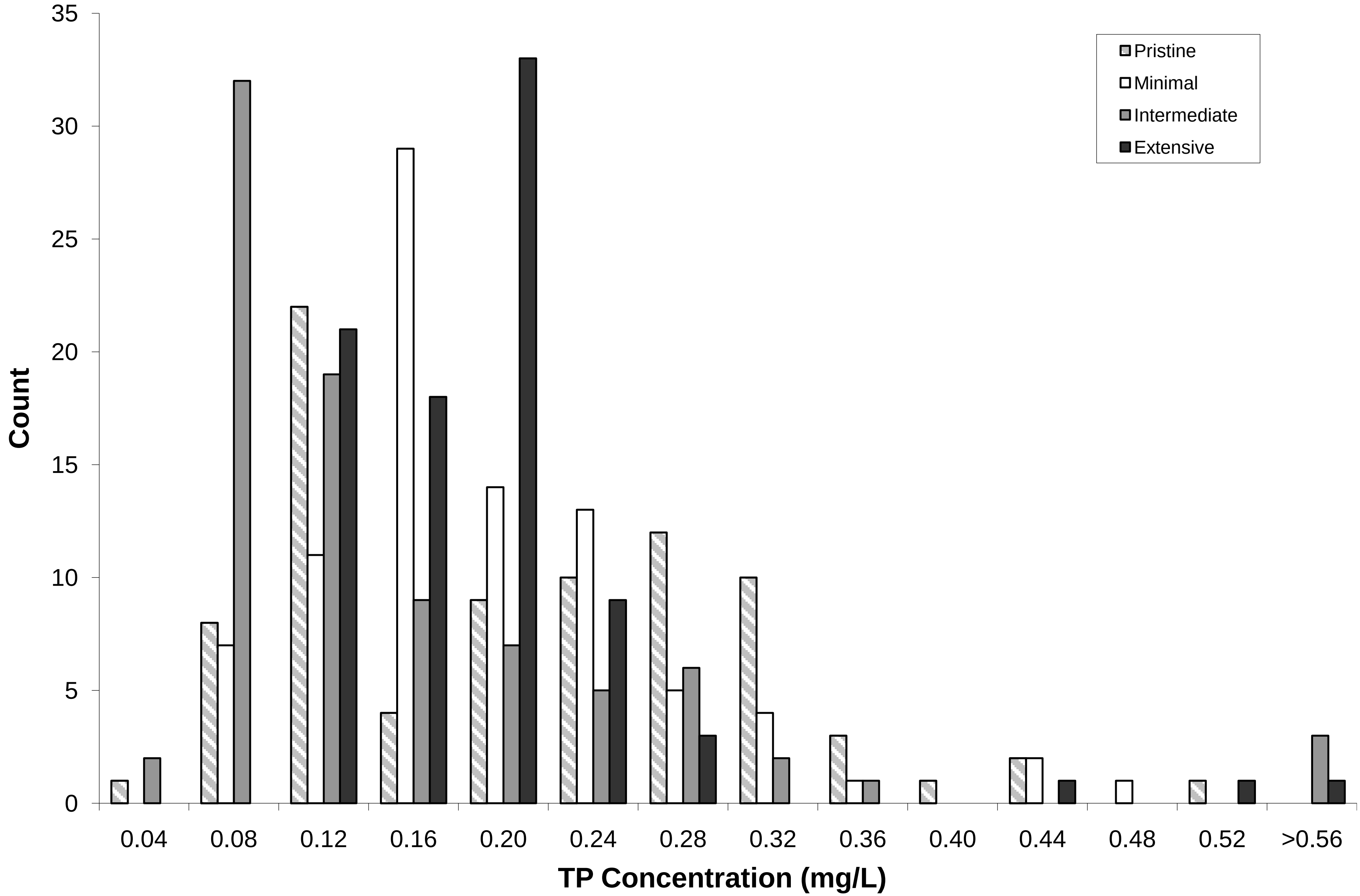
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
Ln TP CV
Pristine
Minimal
Intermediate
Extensive
Watershed Classification

Figure 21



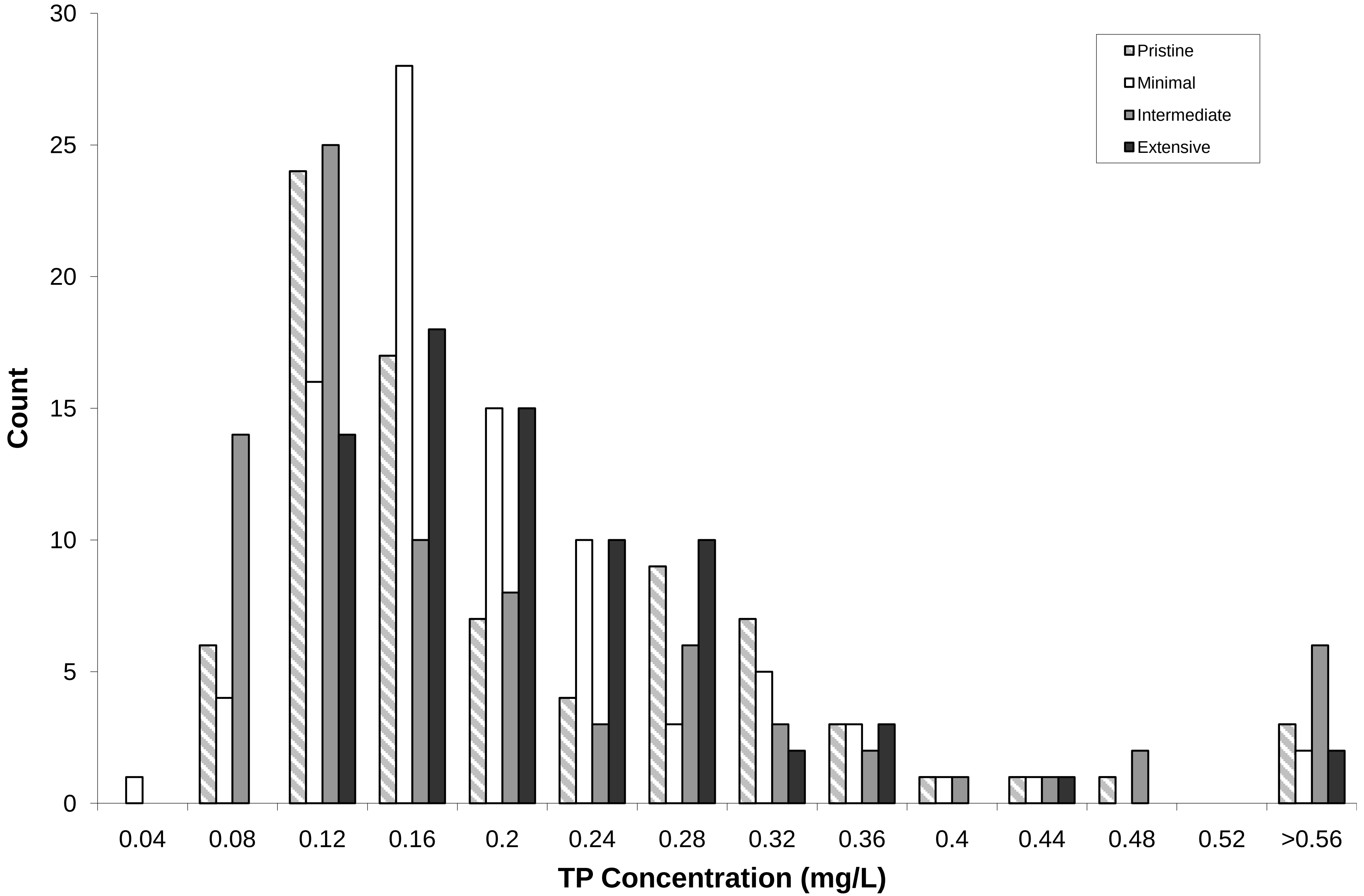
3
2
1
0
-1
-2
-3
Probability
0
1000
2000
3000
4000
Density (#/sq. mile)
HUMAN
PIGS

Figure 22



35
30
25
20
15
10
5
0
Count
Pristine
Minimal
Intermediate
Extensive
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.32
0.36
0.40
0.44
0.48
0.52
>0.56
TP Concentration (mg/L)

Figure 23



30
25
20
15
10
5
0
Count
Pristine
Minimal
Intermediate
Extensive
0.04
0.08
0.12
0.16
0.2
0.24
0.28
0.32
0.36
0.4
0.44
0.48
0.52
>0.56
TP Concentration (mg/L)

Table 1. Watershed classes and the randomly selected streams that were sampled over the initial 4 years of the American Samoa Stream Monitoring Program. Stream names follow Burger and Maciolek (1981). Watershed names and numbers follow Pederson (2000).

Watershed Classification	Year Sampled	Stream Name	Watershed Name (#)
Pristine	2003	Fagatuitui1	Fagatuitui (9)
	2003	Malota	Maloata (3)
	2004	Agasavili	Fagatuitui (9)
	2004	Matavai	Fagamalo (4)
	2005	Amate	Fagamalo (4)
	2005	Niutulua	Fagamalo (4)
	2006	Amate	Fagamalo (4)
	2006	Malota	Maloata (3)
Minimal	2003	Alega	Alega (22)
	2003	Fagaalii1	Fagalii (2)
	2004	Atauloma	Afao-Asili (31)
	2004	Massacre	Aasu (7)
	2005	Fagalii2	Fagalii (2)
	2005	Taugasega	Auasi (19)
	2006	Malivai-tofu	Vatia (10)
	2006	Vaitele	Poloa (1)
Intermediate	2003	Auvaiola	Amouli (20)
	2003	Nuu	Fagaitua (21)
	2004	Vaialae	Nua-Seetaga (32)
	2004	Vaitolu	Aoa (15)
	2005	Lifalifa	Fagaitua (21)
	2005	Tialu	Fagaitua (21)
	2006	Agasili	Fagasa (8)
	2006	Amaua	Fagaitua (21)
Extensive	2003	Mataalii	Nuuuli Pala (27)
	2003	Vailoa	Pago Pago (24)
	2004	Nuuuli	Nuuuli Pala (27)
	2004	Papa	Nuuuli Pala (27)
	2005	Amaile	Nuuuli Pala (27)
	2005	Aumi	Laulii-Aumi (23)
	2006	Leaveave	Nuuuli Pala (27)
	2006	Leone	Leone (30)

Table 2. Watersheds and streams sampled within those watersheds over the 4 year study period. The asterisk indicates streams that were sampled twice.

Watershed Name (#)	Stream Name
Poloa (1)	Vaitele
Fagalii (2)	Fagaalii1
	Fagalii2
Maloata (3)	Malota*
Fagamalo (4)	Amate*
	Matavai
	Niutulua
Aasu (7)	Massacre
Fagasa (8)	Agasili
Fagatuitui (9)	Agasavili
	Fagatuitui1
Vatia (10)	Malivai-tofu
Aoa (15)	Vaitolu
Auasi (19)	Taugasega
Amouli (20)	Auvaiola
Fagaitua (21)	Amaua
	Lifalifa
	Nuu
	Tialu
Alega (22)	Alega
Laulii-Aumi (23)	Aumi
Pago Pago (24)	Vailoa
Nuuuli Pala (27)	Amaile
	Leaveave
	Mataalii
	Nuuuli
	Papa
Leone (30)	Leone
Afao-Asili (31)	Atauloma
Nua-Seetaga (32)	Vaialae

Table 3. Initial predictions concerning the direction of changes expected to occur in streams draining watersheds of increasing disturbance (e.g., higher human population densities).

Indicator Variable	Direction of Predicted Change for Mean Stream Level	Direction of Predicted Change for Overall Stream Variability
Temperature	⇑	⇑
Specific Conductivity	⇔	⇑
Dissolved Oxygen	⇓	⇑
pH	⇔	⇑
Turbidity	⇑	⇑
Enterococcus	⇑	⇑
NH_4	⇔	⇑
NOx	⇔	⇑
TN	⇑	⇑
TP	⇑	⇑

Table 4. Stream hydrographic values and *Enterococcus* levels averaged across all months sampled. Mean (1 S.E.) and number of months data were collected for a particular stream are shown.

Watershed Classification	Year Sampled	Stream Name	Watershed Name (#)	Temp (°C)	Sp Cond (mS/cm)	DO (% sat)	pH	Turb (NTU)	Entero (MPN)
Pristine	2003	Fagatuitui1	Fagatuitui (9)	25.1 (0.3)	0.15 (0.01)	95.8 (1.1)	7.84 (0.07)	2.7 (1.0)	3739.2 (1752.6)
				7	7	5	7	7	8
	2003	Malota	Maloata (3)	25.0 (0.2)	0.07 (0.00)	106.0 (1.7)	7.39 (0.10)	43.0 (25.6)	1933.4 (1219.3)
				11	11	10	11	11	12
	2004	Agasavili	Fagatuitui (9)	25.8 (0.3)	0.16 (0.02)	87.4 (3.6)	7.79 (0.17)	3.6 (1.2)	611.9 (155.8)
				9	9	6	9	8	9
	2004	Matavai	Fagamalo (4)	25.3 (0.2)	0.11 (0.01)	102.0 (3.0)	7.70 (0.15)	2.6 (0.7)	825.3 (266.3)
				11	11	7	11	11	10
	2005	Amate	Fagamalo (4)	25.0 (0.1)	0.32 (0.14)	102.4 (2.5)	7.17 (0.12)	24.0 (8.6)	1639.0 (548.5)
				12	12	11	12	12	12
	2005	Niutulua	Fagamalo (4)	25.3 (0.1)	0.33 (0.13)	105.2 (2.9)	7.48 (0.11)	5.9 (1.9)	827.1 (229.4)
				12	12	11	12	12	12
	2006	Amate	Fagamalo (4)	25.1 (0.2)	0.08 (0.01)	105.5 (4.1)	7.59 (0.08)	104.1 (59.9)	6344.9 (2392.3)
				12	12	12	12	12	12
	2006	Malota	Maloata (3)	25.0 (0.2)	0.51 (0.44)	109.8 (2.2)	7.40 (0.09)	25.9 (14.5)	2104.4 (936.0)
				12	12	12	12	12	12
Minimal	2003	Alega	Alega (22)	25.3 (0.3)	0.12 (0.00)	102.7 (1.6)	7.45 (0.05)	4.6 (2.1)	1261.8 (351.2)
				12	12	12	12	12	12
	2003	Fagaalii1	Fagalii (2)	25.5 (0.2)	0.08 (0.00)	82.8 (5.0)	6.96 (0.09)	31.6 (13.4)	3697.8 (1267.1)
				11	11	10	11	11	12
	2004	Atauloma	Afao-Asili (31)	26.2 (0.2)	0.12 (0.01)	101.6 (1.9)	7.64 (0.16)	5.2 (3.0)	1814.0 (1250.4)
				10	10	6	10	10	10
	2004	Massacre	Aasu (7)	25.6 (0.2)	0.13 (0.01)	99.9 (2.2)	7.73 (0.13)	2.5 (0.9)	2951.7 (993.8)
				11	11	8	11	11	10
	2005	Fagalii2	Fagalii (2)	25.2 (0.1)	0.30 (0.13)	105.8 (2.8)	7.46 (0.10)	6.8 (2.5)	982.7 (300.2)
				12	12	11	12	12	12
	2005	Taugasega	Auasi (19)	25.6 (0.2)	0.38 (0.08)	103.7 (2.2)	7.46 (0.09)	9.6 (2.5)	2878.4 (1983.3)
				12	12	12	12	12	12
	2006	Malivai-tofu	Vatia (10)	25.5 (0.1)	0.12 (0.03)	101.2 (2.7)	7.18 (0.09)	2.7 (0.6)	1263.8 (440.7)
				12	12	12	12	12	12
	2006	Vaitele	Poloa (1)	25.2 (0.1)	0.10 (0.01)	103.3 (4.1)	7.45 (0.06)	32.2 (14.8)	4152.1 (2086.7)
				12	12	11	12	12	12
Intermediate	2003	Auvaiola	Amouli (20)	25.4 (0.3)	0.19 (0.01)	82.6 (6.0)	7.55 (0.13)	37.4 (11.5)	5926.4 (1548.7)

				12	12	12	12	12	12
	2003	Nuu	Fagaitua (21)	26.7 (0.3)	0.31 (0.05)	63.5 (8.0)	7.20 (0.08)	34.4 (8.9)	11786.3 (2292.6)
				12	12	12	12	12	12
	2004	Vaialae	Nua-Seetaga (32)	25.6 (0.3)	0.18 (0.03)	102.2 (3.1)	7.88 (0.13)	4.9 (1.5)	2479.1 (1024.7)
				11	11	7	11	11	10
	2004	Vaitolu	Aoa (15)	26.1 (0.3)	0.32 (0.04)	72.0 (4.7)	7.90 (0.11)	3.2 (1.3)	483.8 (87.5)
				11	11	8	11	11	10
	2005	Lifalifa	Fagaitua (21)	26.5 (0.2)	0.43 (0.09)	87.0 (4.3)	7.21 (0.18)	41.8 (11.8)	6047.2 (1880.1)
				12	12	12	12	12	12
	2005	Tialu	Fagaitua (21)	25.8 (0.2)	0.35 (0.08)	89.0 (4.2)	7.14 (0.10)	6.6 (2.4)	2166.2 (656.6)
				12	12	12	12	12	12
	2006	Agasili	Fagasa (8)	25.8 (0.1)	0.08 (0.00)	88.1 (3.9)	6.80 (0.09)	4.1 (1.2)	4072.9 (1992.0)
				12	12	12	12	12	12
	2006	Amaua	Fagaitua (21)	26.1 (0.2)	0.16 (0.03)	102.7 (2.7)	7.47 (0.11)	10.3 (3.2)	1188.8 (469.4)
				12	12	12	12	12	12
Extensive	2003	Mataalii	Nuuuli Pala (27)	26.2 (0.2)	0.12 (0.01)	102.0 (1.5)	7.09 (0.07)	6.9 (4.0)	1860.6 (454.5)
				10	10	9	10	10	12
	2003	Vailoa	Pago Pago (24)	26.8 (0.2)	0.15 (0.01)	99.3 (2.8)	7.14 (0.07)	7.8 (1.3)	3033.5 (427.9)
				11	11	10	11	11	12
	2004	Nuuuli	Nuuuli Pala (27)	25.8 (0.3)	0.18 (0.03)	84.2 (5.7)	7.65 (0.17)	10.1 (3.6)	2544.7 (503.6)
				11	11	8	11	10	10
	2004	Papa	Nuuuli Pala (27)	25.9 (0.4)	0.14 (0.02)	96.3 (8.1)	7.82 (0.18)	3.2 (1.3)	4081.2 (1043.0)
				9	9	7	9	7	9
	2005	Amaile	Nuuuli Pala (27)	24.9 (0.2)	0.51 (0.27)	101.1 (6.5)	7.18 (0.12)	7.4 (3.6)	2617.1 (1353.7)
				12	12	11	12	12	12
	2005	Aumi	Laulii-Aumi (23)	25.4 (0.2)	0.33 (0.09)	89.9 (5.5)	7.36 (0.10)	9.3 (3.5)	2247.1 (620.5)
				12	12	12	12	12	12
	2006	Leaveave	Nuuuli Pala (27)	25.6 (0.3)	0.12 (0.02)	95.9 (8.5)	7.36 (0.05)	11.9 (5.5)	4921.4 (1658.6)
				12	12	12	12	12	12
	2006	Leone	Leone (30)	25.4 (0.2)	0.07 (0.01)	106.7 (5.7)	7.56 (0.06)	32.0 (16.2)	3995.4 (1719.5)
				12	12	11	12	12	12

Table 5. Stream nutrient concentrations averaged across all months sampled. Mean (1 S.E.) and number of months data were collected for a particular stream are shown.

Watershed Classification	Year Sampled	Stream Name	Watershed Name (#)	NH4 (mg/L)	NOx (mg/L)	TN (mg/L)	TP (mg/L)
Pristine	2003	Fagatuitui1	Fagatuitui (9)	0.004 (0.003) 8	0.066 (0.012) 8	0.283 (0.103) 8	0.110 (0.021) 8
	2003	Malota	Maloata (3)	0.002 (0.002) 10	0.013 (0.001) 10	0.238 (0.154) 10	0.143 (0.053) 10
	2004	Agasavili	Fagatuitui (9)	0.010 (0.004) 9	0.044 (0.010) 9	0.233 (0.035) 9	0.086 (0.009) 9
	2004	Matavai	Fagamalo (4)	0.010 (0.007) 11	0.031 (0.006) 11	0.138 (0.015) 11	0.192 (0.008) 11
	2005	Amate	Fagamalo (4)	0.001 (0.001) 12	0.050 (0.005) 12	0.337 (0.079) 12	0.307 (0.025) 12
	2005	Niutulua	Fagamalo (4)	0.002 (0.001) 12	0.016 (0.002) 12	0.154 (0.018) 12	0.181 (0.007) 12
	2006	Amate	Fagamalo (4)	0.007 (0.004) 12	0.044 (0.006) 12	0.768 (0.361) 12	0.465 (0.160) 12
	2006	Malota	Maloata (3)	0.002 (0.001) 12	0.022 (0.002) 12	0.208 (0.073) 12	0.131 (0.016) 12
Minimal	2003	Alega	Alega (22)	0.000 (0.000) 10	0.154 (0.008) 10	0.252 (0.017) 10	0.217 (0.009) 10
	2003	Fagaalii1	Fagalii (2)	0.003 (0.001) 10	0.216 (0.024) 10	0.467 (0.084) 10	0.228 (0.036) 10
	2004	Atauloma	Afao-Asili (31)	0.002 (0.001) 10	0.024 (0.003) 10	0.143 (0.041) 10	0.083 (0.010) 10
	2004	Massacre	Aasu (7)	0.005 (0.002) 11	0.254 (0.026) 11	0.426 (0.033) 11	0.172 (0.006) 11
	2005	Fagalii2	Fagalii (2)	0.001 (0.000) 12	0.023 (0.003) 12	0.124 (0.012) 12	0.153 (0.006) 12
	2005	Taugasega	Auasi (19)	0.009 (0.006) 12	0.042 (0.014) 12	0.348 (0.131) 12	0.312 (0.011) 12
	2006	Malivai-tofu	Vatia (10)	0.004 (0.002) 12	0.013 (0.001) 12	0.134 (0.009) 12	0.120 (0.004) 12
	2006	Vaitele	Poloa (1)	0.002 (0.001) 12	0.083 (0.006) 12	0.269 (0.064) 12	0.139 (0.021) 12
Intermediate	2003	Auvaiola	Amouli (20)	0.016 (0.007)	0.065 (0.012)	0.418 (0.054)	0.247 (0.018)

				10	10	10	10
	2003	Nuu	Fagaitua (21)	0.687 (0.275)	0.095 (0.034)	1.650 (0.400)	0.390 (0.104)
				10	10	10	10
	2004	Vaialae	Nua-Seetaga (32)	0.089 (0.054)	0.051 (0.013)	0.283 (0.088)	0.105 (0.019)
				11	11	11	11
	2004	Vaitolu	Aoa (15)	0.014 (0.005)	0.044 (0.007)	0.219 (0.018)	0.084 (0.007)
				11	11	11	11
	2005	Lifalifa	Fagaitua (21)	0.147 (0.054)	0.914 (0.143)	2.090 (0.229)	0.452 (0.106)
				12	12	12	12
	2005	Tialu	Fagaitua (21)	0.009 (0.003)	0.022 (0.005)	0.188 (0.017)	0.070 (0.006)
				12	12	12	12
	2006	Agasili	Fagasa (8)	0.004 (0.002)	0.149 (0.015)	0.285 (0.046)	0.098 (0.009)
				12	12	12	12
	2006	Amaua	Fagaitua (21)	0.002 (0.001)	0.040 (0.012)	0.178 (0.017)	0.167 (0.008)
				12	12	12	12
Extensive	2003	Mataalii	Nuuuli Pala (27)	0.002 (0.002)	0.300 (0.055)	0.438 (0.073)	0.161 (0.013)
				10	10	10	10
	2003	Vailoa	Pago Pago (24)	0.016 (0.005)	0.286 (0.020)	0.521 (0.049)	0.231 (0.008)
				10	10	10	10
	2004	Nuuuli	Nuuuli Pala (27)	0.063 (0.055)	0.079 (0.019)	0.353 (0.048)	0.195 (0.028)
				11	11	11	11
	2004	Papa	Nuuuli Pala (27)	0.012 (0.007)	0.121 (0.033)	0.254 (0.035)	0.131 (0.006)
				9	9	9	9
	2005	Amaile	Nuuuli Pala (27)	0.002 (0.001)	0.103 (0.008)	0.240 (0.020)	0.238 (0.054)
				12	12	12	12
	2005	Aumi	Laulii-Aumi (23)	0.028 (0.010)	0.065 (0.014)	0.406 (0.116)	0.318 (0.037)
				12	12	12	12
	2006	Leaveave	Nuuuli Pala (27)	0.003 (0.001)	0.132 (0.015)	0.326 (0.043)	0.176 (0.012)
				12	12	12	12
	2006	Leone	Leone (30)	0.006 (0.003)	0.098 (0.012)	0.358 (0.079)	0.147 (0.023)
				12	12	12	12

Table 6. Effects of watershed class on indicator averages. Least square means are ordered from lowest to highest, and different superscripts indicate significant pairwise differences between watershed class Pristine=P, Minimal=M, Intermediate=I, Extensive=E, ns=not significant.

	Transformation	Class Effect	Least Square Means
Temperature	None	$p<0.01$	P^{a} $M^{a,b}$ $E^{b,c}$ I^{c}
Specific Conductivity	Rank	$p<0.001$	P^{a} M^{a} E^{a} I^{b}
Dissolved Oxygen	None	$p<0.01$	I^{a} E^{b} M^{b} P^{b}
pH	None	ns	I^{a} E^{a} M^{a} P^{a}
Turbidity	Log10	ns	M^{a} E^{a} P^{a} I^{a}
Enterococcus	Log10	$p<0.05$	P^{a} $M^{a,b}$ I^{b} E^{b}
NH_4	Rank	$p<0.01$	P^{a} $M^{a,b}$ $E^{b,c}$ I^{c}
NOx	Rank	$p<0.05$	P^{a} $I^{a,b}$ $M^{a,b}$ E^{b}
TN	Rank	$p<0.05$	P^{a} $M^{a,b}$ I^{b} E^{b}
TP	Ln	ns	M^{a} I^{a} P^{a} E^{a}

Table 7. Measure of stream hydrographic variability (coefficient of variation, CV) averaged across all months sampled. Mean (1 S.E.) and number of months data were collected for a particular stream are shown.

Watershed Classification	Year Sampled	Stream Name	Watershed Name (#)	Temp CV	DO CV	pH CV	Turb CV	Entero CV
Pristine	2003	Fagatuitui1	Fagatuitui (9)	0.009 (0.001) 7	0.052 (0.008) 5	0.013 (0.003) 7	0.752 (0.152) 7	0.905 (0.134) 8
	2003	Malota	Maloata (3)	0.007 (0.002) 11	0.027 (0.006) 10	0.031 (0.004) 11	0.301 (0.086) 11	0.753 (0.120) 12
	2004	Agasavili	Fagatuitui (9)	0.009 (0.004) 9	0.077 (0.019) 6	0.040 (0.010) 9	0.557 (0.134) 8	0.523 (0.148) 9
	2004	Matavai	Fagamalo (4)	0.012 (0.002) 11	0.009 (0.003) 7	0.026 (0.006) 11	0.463 (0.127) 11	0.608 (0.113) 10
	2005	Amate	Fagamalo (4)	0.003 (0.001) 12	0.057 (0.009) 11	0.023 (0.007) 12	0.091 (0.027) 12	0.299 (0.090) 12
	2005	Niutulua	Fagamalo (4)	0.006 (0.001) 12	0.016 (0.006) 11	0.026 (0.016) 12	0.330 (0.071) 12	0.606 (0.102) 12
	2006	Amate	Fagamalo (4)	0.007 (0.001) 12	0.027 (0.009) 12	0.040 (0.008) 12	0.090 (0.021) 12	0.464 (0.134) 12
	2006	Malota	Maloata (3)	0.010 (0.002) 12	0.042 (0.013) 12	0.020 (0.010) 12	0.209 (0.051) 12	0.636 (0.140) 12
Minimal	2003	Alega	Alega (22)	0.005 (0.001) 12	0.022 (0.007) 12	0.010 (0.004) 12	0.329 (0.056) 12	0.375 (0.063) 12
	2003	Fagaalii1	Fagalii (2)	0.006 (0.002) 10	0.202 (0.060) 9	0.037 (0.005) 10	0.185 (0.041) 10	0.732 (0.117) 11
	2004	Atauloma	Afao-Asili (31)	0.017 (0.004) 10	0.024 (0.007) 6	0.014 (0.002) 10	0.253 (0.045) 10	0.460 (0.075) 10
	2004	Massacre	Aasu (7)	0.010 (0.002) 11	0.028 (0.009) 8	0.018 (0.003) 11	0.519 (0.067) 11	0.514 (0.066) 10
	2005	Fagalii2	Fagalii (2)	0.012 (0.001) 12	0.030 (0.006) 11	0.031 (0.016) 12	0.498 (0.145) 12	0.393 (0.062) 12
	2005	Taugasega	Auasi (19)	0.003 (0.001) 12	0.047 (0.007) 12	0.030 (0.006) 12	0.499 (0.126) 12	0.547 (0.128) 12
	2006	Malivai-tofu	Vatia (10)	0.012 (0.003) 12	0.049 (0.011) 12	0.028 (0.004) 12	0.634 (0.104) 12	0.403 (0.060) 12
	2006	Vaitele	Poloa (1)	0.010 (0.003) 12	0.096 (0.080) 11	0.036 (0.012) 12	0.211 (0.042) 12	0.799 (0.095) 12
Intermediate	2003	Auvaiola	Amouli (20)	0.023 (0.010)	0.075 (0.039)	0.014 (0.003)	0.395 (0.184)	0.719 (0.212)

				3	3	3	3	4
	2003	Nuu	Fagaitua (21)	0.019 (0.005)	0.376 (0.073)	0.029 (0.005)	0.649 (0.108)	0.751 (0.155)
				10	10	10	10	10
	2004	Vaialae	Nua-Seetaga (32)	0.013 (0.003)	0.069 (0.028)	0.022 (0.005)	0.263 (0.055)	0.993 (0.157)
				11	7	11	11	10
	2004	Vaitolu	Aoa (15)	0.029 (0.003)	0.273 (0.043)	0.040 (0.007)	0.490 (0.089)	0.809 (0.120)
				10	7	10	10	10
	2005	Lifalifa	Fagaitua (21)	0.024 (0.005)	0.174 (0.112)	0.021 (0.006)	0.712 (0.170)	0.551 (0.140)
				10	10	10	10	11
	2005	Tialu	Fagaitua (21)	0.012 (0.003)	0.061 (0.025)	0.015 (0.002)	0.574 (0.086)	1.010 (0.104)
				12	12	12	12	12
	2006	Agasili	Fagasa (8)	0.005 (0.001)	0.076 (0.028)	0.051 (0.011)	0.319 (0.096)	0.387 (0.098)
				12	12	12	12	12
	2006	Amaua	Fagaitua (21)	0.008 (0.001)	0.040 (0.017)	0.018 (0.005)	0.394 (0.094)	0.585 (0.112)
				12	12	12	12	12
Extensive	2003	Mataalii	Nuuuli Pala (27)	0.038 (0.007)	0.116 (0.024)	0.035 (0.008)	0.995 (0.147)	0.964 (0.101)
				10	9	10	10	12
	2003	Vailoa	Pago Pago (24)	0.040 (0.009)	0.137 (0.019)	0.025 (0.005)	0.367 (0.069)	0.796 (0.102)
				11	10	11	11	12
	2004	Nuuuli	Nuuuli Pala (27)	0.027 (0.007)	0.216 (0.070)	0.030 (0.004)	0.918 (0.137)	1.061 (0.128)
				11	8	11	10	10
	2004	Papa	Nuuuli Pala (27)	0.026 (0.005)	0.085 (0.016)	0.022 (0.004)	0.593 (0.105)	0.905 (0.170)
				9	7	9	7	9
	2005	Amaile	Nuuuli Pala (27)	0.012 (0.002)	0.073 (0.016)	0.030 (0.006)	0.363 (0.096)	0.727 (0.138)
				12	11	12	12	12
	2005	Aumi	Laulii-Aumi (23)	0.005 (0.001)	0.275 (0.096)	0.029 (0.005)	0.643 (0.150)	0.793 (0.114)
				12	12	12	12	12
	2006	Leaveave	Nuuuli Pala (27)	0.029 (0.004)	0.075 (0.009)	0.020 (0.002)	0.397 (0.080)	0.770 (0.110)
				12	11	12	12	12
	2006	Leone	Leone (30)	0.021 (0.003)	0.150 (0.045)	0.040 (0.008)	0.311 (0.071)	0.520 (0.069)
				12	11	12	12	12

Table 8. Measure of stream nutrient variability (coefficient of variation, CV) averaged across all months sampled. Mean (1 S.E.) and number of months data were collected for a particular stream are shown.

Watershed Classification	Year Sampled	Stream Name	Watershed Name (#)	NH_4 CV	NOx CV	TN CV	TP CV
Pristine	2003	Fagatuitui1	Fagatuitui (9)	1.19 (0.36) 3	0.32 (0.04) 8	0.20 (0.09) 8	0.20 (0.07) 8
	2003	Malota	Maloata (3)	0.69 1	0.25 (0.05) 10	0.12 (0.03) 10	0.10 (0.01) 10
	2004	Agasavili	Fagatuitui (9)	0.84 (0.19) 7	0.69 (0.20) 8	0.28 (0.06) 9	0.27 (0.06) 9
	2004	Matavai	Fagamalo (4)	1.22 (0.18) 5	0.49 (0.07) 11	0.13 (0.04) 11	0.08 (0.03) 11
	2005	Amate	Fagamalo (4)	1.33 (0.09) 3	0.12 (0.03) 12	0.17 (0.09) 12	0.04 (0.01) 12
	2005	Niutulua	Fagamalo (4)	1.72 (0.02) 7	0.62 (0.10) 12	0.38 (0.10) 12	0.44 (0.03) 12
	2006	Amate2	Fagamalo (4)	0.88 (0.23) 7	0.17 (0.07) 12	0.22 (0.06) 12	0.07 (0.01) 12
	2006	Malota2	Maloata (3)	0.93 (0.28) 7	0.15 (0.05) 12	0.18 (0.05) 12	0.07 (0.02) 12
Minimal	2003	Alega	Alega (22)	1.41 1	0.07 (0.01) 10	0.05 (0.01) 10	0.03 (0.00) 10
	2003	Fagaalii1	Fagalii (2)	0.93 (0.30) 5	0.14 (0.06) 9	0.10 (0.04) 9	0.08 (0.03) 9
	2004	Atauloma	Afao-Asili (31)	1.24 (0.22) 6	0.51 (0.07) 10	0.18 (0.03) 10	0.16 (0.02) 10
	2004	Massacre	Aasu (7)	1.29 (0.13) 11	0.26 (0.04) 11	0.25 (0.03) 11	0.12 (0.01) 11
	2005	Fagalii2	Fagalii (2)	1.61 (0.12) 7	0.59 (0.08) 12	0.20 (0.03) 12	0.08 (0.01) 12
	2005	Taugasega	Auasi (19)	1.17 (0.11) 9	0.73 (0.09) 12	0.33 (0.09) 12	0.24 (0.08) 12
	2006	Malivai-tofu	Vatia (10)	0.90 (0.20) 7	0.45 (0.06) 12	0.25 (0.03) 12	0.11 (0.05) 12
	2006	Vaitele	Poloa (1)	0.72 (0.30) 7	0.31 (0.04) 12	0.18 (0.03) 12	0.06 (0.01) 12
Intermediate	2003	Auvaiola	Amouli (20)	0.67	0.67 (0.04)	0.26 (0.10)	0.02 (0.00)

				1	2	2	2
	2003	Nuu	Fagaitua (21)	1.35 (0.04)	0.75 (0.21)	0.77 (0.13)	0.82 (0.09)
				7	8	8	8
	2004	Vaialae	Nua-Seetaga (32)	1.60 (0.06)	0.24 (0.08)	0.43 (0.13)	0.26 (0.09)
				11	11	11	11
	2004	Vaitolu	Aoa (15)	1.32 (0.11)	0.97 (0.13)	0.52 (0.07)	0.41 (0.07)
				11	11	11	11
	2005	Lifalifa	Fagaitua (21)	0.84 (0.11)	1.04 (0.06)	0.75 (0.13)	0.69 (0.11)
				11	11	11	11
	2005	Tialu	Fagaitua (21)	1.34 (0.10)	0.94 (0.10)	0.45 (0.06)	0.39 (0.04)
				10	11	12	12
	2006	Agasili	Fagasa (8)	1.09 (0.20)	0.28 (0.06)	0.24 (0.03)	0.17 (0.04)
				7	11	11	11
	2006	Amaua	Fagaitua (21)	0.80 (0.32)	0.53 (0.13)	0.26 (0.06)	0.07 (0.02)
				6	12	12	12
Extensive	2003	Mataalii	Nuuuli Pala (27)	1.57 (0.16)	1.33 (0.08)	0.99 (0.12)	0.24 (0.08)
				2	10	10	10
	2003	Vailoa	Pago Pago (24)	1.54 (0.16)	0.54 (0.08)	0.48 (0.08)	0.22 (0.03)
				9	10	10	10
	2004	Nuuuli	Nuuuli Pala (27)	1.26 (0.15)	1.14 (0.10)	0.56 (0.09)	0.31 (0.08)
				10	11	11	11
	2004	Papa	Nuuuli Pala (27)	1.43 (0.17)	0.65 (0.08)	0.33 (0.05)	0.15 (0.04)
				8	9	9	9
	2005	Amaile	Nuuuli Pala (27)	1.60 (0.09)	0.28 (0.03)	0.23 (0.03)	0.21 (0.11)
				9	12	12	12
	2005	Aumi	Laulii-Aumi (23)	1.07 (0.12)	0.91 (0.10)	0.52 (0.11)	0.34 (0.07)
				9	12	12	12
	2006	Leaveave	Nuuuli Pala (27)	1.20 (0.23)	0.58 (0.05)	0.32 (0.06)	0.20 (0.03)
				7	12	12	12
	2006	Leone	Leone (30)	1.22 (0.19)	0.60 (0.12)	0.27 (0.06)	0.17 (0.06)
				9	12	12	12

Table 9. Effects of watershed class on indicator coefficients of variation (CV). Least square means are ordered from lowest to highest, and different superscripts indicate significant pairwise differences between watershed class Pristine=P, Minimal=M, Intermediate=I, Extensive=E, ns=not significant.

	Transformation	Class Effect	Least Square Means
Temp CV	Ln	$p<0.01$	P^{a} $M^{a,b}$ $I^{b,c}$ E^{c}
Specific Conductivity CV	Ln	$p<0.01$	M^{a} $P^{a,b}$ E^{b} I^{b}
Dissolved Oxygen CV	Ln	$p<0.01$	P^{a} M^{a} I^{b} E^{b}
pH CV	Ln	ns	P^{a} M^{a} I^{a} E^{a}
Turbidity CV	Ln	$p=0.070$	P^{a} $M^{a,b}$ $I^{a,b}$ E^{b}
Enterococcus CV	none	$p<0.05$	M^{a} $P^{a,b}$ $I^{b,c}$ E^{c}
NH4 CV	none	ns	P^{a} I^{a} M^{a} E^{a}
NOx CV	none	$p<0.05$	P^{a} $M^{a,b}$ $I^{b,c}$ E^{c}
TN CV	Ln	$p<0.05$	P^{a} M^{a} E^{b} I^{b}
TP CV	Ln	$p<0.05$	M^{a} $P^{a,b}$ E^{b} I^{b}

Table 10. Average, median, and ranges (min, max) of TP concentration for all samples collected at upstream stations during the 4 year survey.

Watershed Classification	Average TP (mg/L)	Median TP (mg/L)	Range
Extensive	0.178	0.168	0.084, 1.01
Intermediate	0.161	0.100	0.034, 1.41
Minimal	0.172	0.151	0.042, 0.449
Pristine	0.192	0.184	0.034, 0.488