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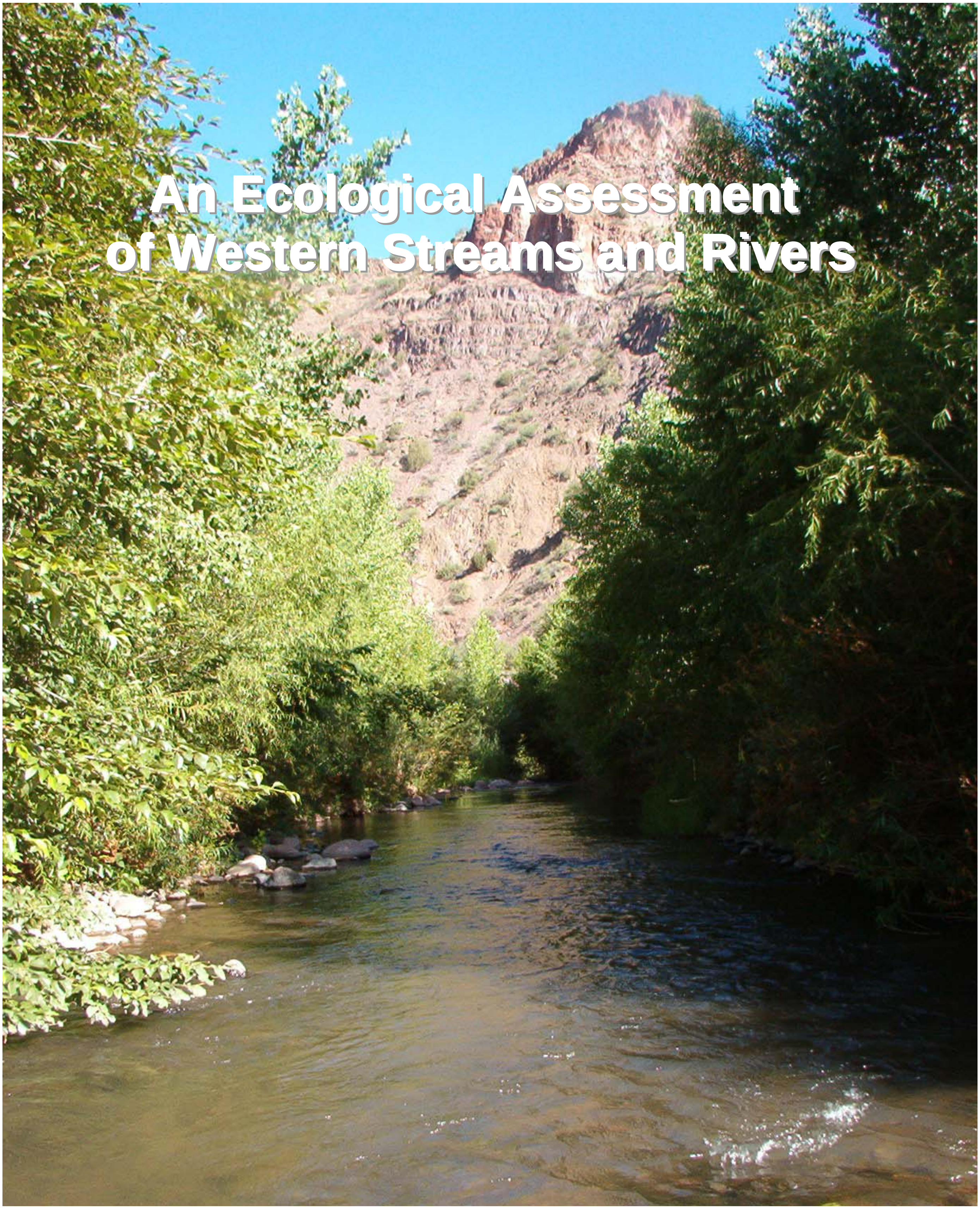
An Ecological Assessment of Western Streams and Rivers



Environmental Monitoring and Assessment Program

Figure 1. Geographic range of EMAP West study. EMAP West included all perennial streams and rivers, exclusive of the "Great Rivers" (lower sections of the Columbia, Snake, Missouri, and Colorado Rivers) in a twelve state area.

An Ecological Assessment of Western Streams and Rivers

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Executive Summary

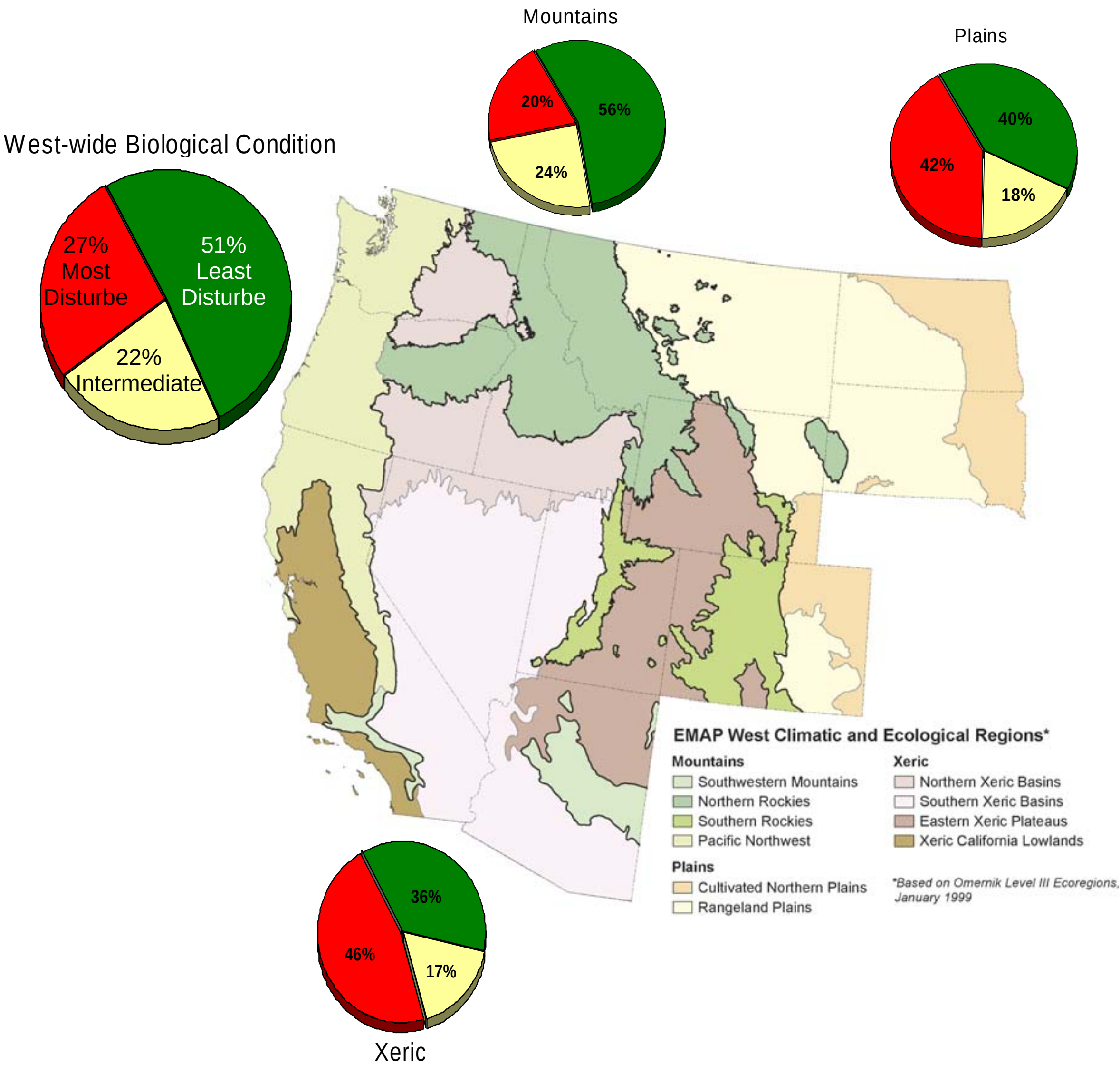
In the 30 years since the passage of the Clean Water Act, Congress, the American Public and other interested parties have been asking the U.S. Environmental Protection Agency to describe the condition of the waters in the U.S. They want to know if there is a problem, how big the problem is if there is one, and whether the problem is widespread or occurs in hotspots. Additionally, they have been asking to understand the types of human activities that are affecting streams and rivers, and which are likely to be the most important. These are seemingly simple questions, and yet they have not been answered in a reliable way in the past. This report presents the results of a unique collaboration between the U.S. Environmental Protection Agency and twelve western States, designed to answer these questions for the rivers and streams of the West.

Covering 42% of the land area, and 28% of the stream and river length in the lower 48 states, EMAP West is the largest monitoring and assessment effort designed to answer the questions being asked of EPA that has been conducted to date. The States and EPA collected biological, chemical and physical data at over 1340 perennial stream and river locations to assess the ecological condition of western waters and the most important factors affecting those conditions. Results provide clear pictures of the biological quality of flowing waters across the West, within each of three climatic zones, and in ten ecological regions. In partnership with the States and EPA Regions 8, 9, and 10, the EMAP program sent four-person teams to collect samples at sampling sites chosen by an innovative statistical design that insures representative results.

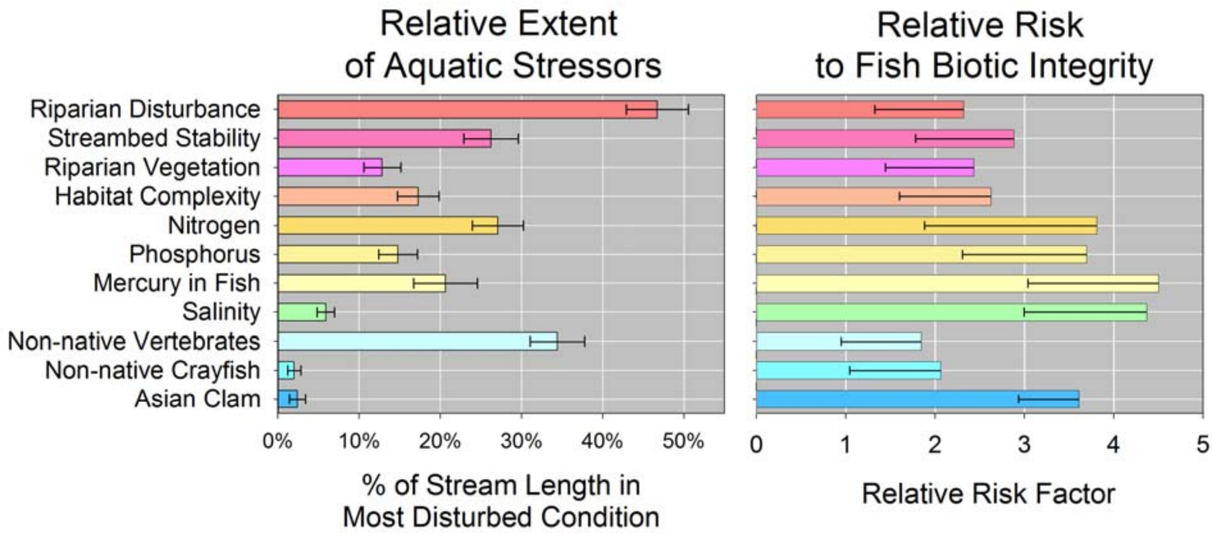
This information fills an important gap in meeting requirements of the Clean Water Act. The purpose of the assessment is fourfold:

- Report on the ecological condition of all perennial flowing streams and rivers with the exception of those considered “Great Rivers,” (the lower Columbia, Snake, Missouri and Colorado Rivers).
- Describe the ecological condition of western streams and rivers with direct measures of plants, fish, and other aquatic life. Assessments of stream quality have historically relied solely on chemical analysis or sometimes on the status of game fish.
- Identify and rank the relative importance of chemical, physical and biological disturbances affecting stream and river condition.
- Encourage states to include these design and measurement tools as a portion of their State monitoring programs, so that future condition assessments will be ecologically and statistically comparable both regionally and nationally.

The results of these surveys show that only 51% of the stream and river length in the West could be considered in least-disturbed condition. Of the three climatic areas of the West, the mountains appear to be in the best shape with 56% of the length of flowing waters in least-disturbed condition. The plains and xeric regions present the most concerns with close to 50% of the length of streams and rivers in the most-disturbed conditions (42% and 46%, respectively).



The results also reveal what is most likely responsible for diminishing biological quality in flowing waters across the West. Disturbance of shoreline (or riparian) habitat was the most widespread stressor observed across the West, and in each of the three major regions. Excess mercury in fish was widespread across the xeric and plains areas but not the mountains. Non-native vertebrates, primarily fish, were very common across the entire West. Evaluation of the stressors most likely responsible for poor condition in the West is best understood by looking at both the extent of each stressor (i.e., how widespread it is) and the relative risk posed to aquatic biota when a specific stressor is present. High nitrogen concentrations are found in just over one-quarter of western streams, and fish assemblages are almost four times as likely to be in poor condition when nitrogen exceeds a critical threshold as when nitrogen is below these critical values. Excess salinity also poses a high relative risk to fish when it occurs, but is present in only 5% of the stream resource. From a management point of view, the highest priority stressors to address are those that are both common, and that pose high risk to biota.



We trust that this report will be useful for land managers, decision makers and citizens throughout the region. Readers who wish to know more about the technical background are directed to the scientific journals where the methodologies and supporting information already have been published and to the appendices of this report.

Finally, we firmly believe that knowledge of the current quality of our flowing waters that this report describes is among the first steps in deciding rational management plans and priorities. We believe that the results of this assessment, and others like it in the future, will let the public know, as the USA Today put it: "*whether to celebrate environmental successes, tackle new threats or end efforts that throw money down a drain*".

Foreword

This report presents an ecological assessment of non-tidal streams and rivers across twelve states of the western U.S. (Figure 1). It is based on the results of a unique and experimental monitoring program implemented through the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP) during the years 2000-2004. We present these results in a way that we hope both environmental resource managers and the general public find useful, with two major objectives in mind: (1) to document, in as clear and unbiased a manner as possible, the overall condition of the vast network of streams and rivers of the western U.S.; and (2) to demonstrate the utility and flexibility of an EMAP-like approach to environmental monitoring and assessment at this regional scale.

Our approach in collecting the data for this assessment has two key characteristics. First, it focuses as much as possible on direct measures of biological indicators, and on the chemical and physical properties of streams and rivers that are most likely to have effects on biological communities. Second, it uses an innovative statistical design that insures that the results are representative of the region, and allows us to extend this statistical certainty in the results to subregions of the West (e.g., to major ecological regions) where desired.

The assessment is divided into two major categories. We first document the ecological condition of streams and rivers in the West, through the use of direct measures of their resident biological assemblages: aquatic vertebrates (e.g., fish and amphibians); and benthic macroinvertebrates (e.g., larval insects, snails, mussels, worms and crustaceans). We then assess the relative importance of potential stressors on those assemblages, based on direct measures of their chemical, biological and physical habitat. We present the results in this way in order to inform readers about where the major aquatic ecological issues occur in the region, what the most important threats to the aquatic ecological condition are, and how much risk these stressors pose to aquatic ecosystems.

This report is written for the public, for environmental managers, and for decision-makers. Much of the technical background for the report has already been published in the scientific literature, and we refer sparingly throughout the report to these publications (denoted by superscript numbers in the text). The key publications that support the elements of this assessment are listed in Appendix A at the back of the report. Readers who wish to learn more about the design, specific indicators, or other elements of the assessment are encouraged to consult this list and read the technical papers upon which this assessment is based.

Purpose

This Ecological Assessment of Western Streams and Rivers has four purposes:

- Report on the ecological condition of all perennial flowing waters smaller than the "Great Rivers" of the western U.S.;
- Focus on direct measures of biological assemblages in assessing ecological condition;
- Identify and rank the relative importance of potential stressors affecting stream and river condition, using supplemental measures of chemical, physical and biological habitat;
- Influence how States design their monitoring programs, and how they assess and report on the condition of streams and rivers.

The U.S. EPA Environmental Monitoring and Assessment Program (EMAP) assembled crews in the years 2000 through 2004 to collect over 1500 samples on 1340 perennial streams throughout the western U.S. This project, known as EMAP West, included both wadeable streams and non-wadeable rivers, and sampled sites that were either randomly chosen to be representative of the entire population of flowing waters in the West, or hand picked to represent the best possible condition ("reference sites"). This ambitious project was carried out in partnership with twelve western states (Arizona, California, Colorado, Idaho, Montana, Nevada, North Dakota, Oregon, South Dakota, Utah, Washington and Wyoming), the U.S. Geological Survey (USGS), multiple universities, and Environmental Protection Agency (EPA) Regions 8, 9 and 10. All of the crews were trained to use identical sampling methods to facilitate comparisons across the region, and all of the data were subject to strict quality assurance procedures (see Appendix B).

Introduction

Most historic assessments of stream quality have focused on describing the chemical quality of streams and, occasionally, on sport fisheries impacts. As we have made progress in controlling chemical problems, it has become obvious that the primary ecological concern is actually the condition of the plant and animal communities that inhabit these streams and rivers.

In this assessment we have tried to address this concern not by ignoring physical and chemical measurements, but by shifting the focus to direct measurements of the biota (e.g., fish and other vertebrates, and stream invertebrates) themselves. In this assessment, ecological condition is defined by biological indicators. The biological organisms in a stream integrate the many physical and chemical stressors and forces, including other biota (invasive and/or non-native species), that are acting in, and on, the stream ecosystem. Stream and river condition can be determined by assessing appropriate biological indicators (see *Indicators of Ecological Condition*, below), or combinations of these indicators called indices. Information on the ecological condition of streams and rivers is supplemented by measurements of other stream characteristics, especially those physical, chemical, or other biological factors that might

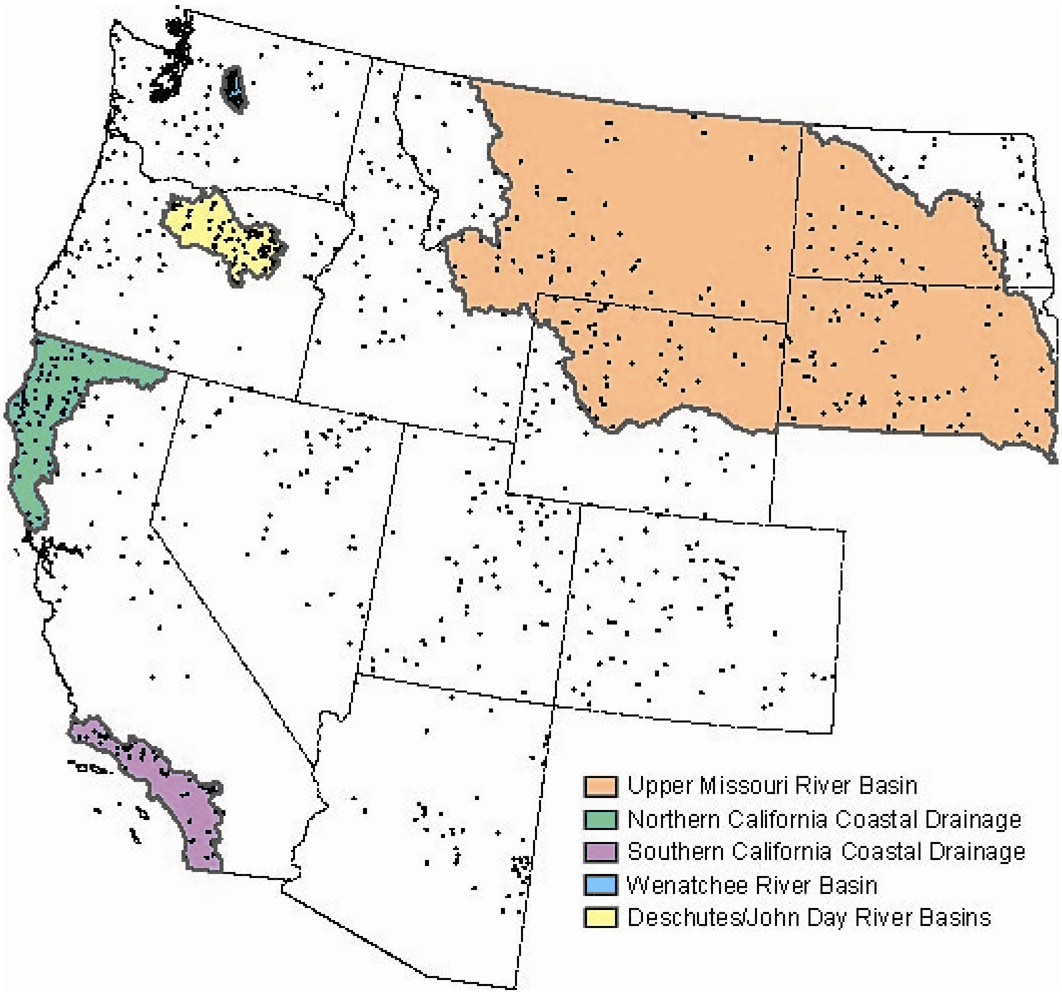


Figure 2. EMAP West study area with five special interest areas highlighted. Also shown is location of 965 probability sites sampled and used for reporting on ecological condition.

influence or affect stream condition. These stream characteristics allow us to assess the factors that might have a negative effect on the ecological condition of streams (i.e., stressors).

EMAP West

EMAP West was a five-year effort to collect stream and river data across the twelve-state area represented by the portions of EPA Regions 8, 9 and 10, located in the conterminous United States (Figure 1). The methods employed were consistent across the region, and across stream sizes. They were developed to allow one four-person crew to collect the maximum amount of data on vertebrate, macroinvertebrate and algal assemblages, physical and chemical habitat, invasive riparian plant species, and major toxic contaminants in fish tissue, in a one day visit to each site[1, 2]. The sites were chosen according to a probability design, where each site has a known probability of being selected for sampling, and collectively the sites are statistically representative of the population of flowing waters in the region. EMAP's probability design uses the same philosophy as a Gallup Poll (or other opinion polls), and brings the statistical rigor of sample surveys to the science of environmental assessment. Within the EMAP West region, several special interest areas were identified for additional site selection (Figure 2). The higher density probability design in these areas will allow us to make future, stand-alone, assessments of each area (the Upper Missouri River Basin, the Wenatchee Basin of Washington, the John Day and Deschutes River Basins in Oregon, the Northern California coast, and the Southern California coast), as well as each of the 12 western states. In this Assessment we present results at three different levels of geographic resolution—West-wide, in three major climatic regions (Mountains, Xeric and Plains) and in 10 ecological regions of the West (see *Reporting Units for EMAP West*, below). These results make up the bulk of this Assessment. Interested readers are urged to consult the references in Appendix A for additional information on probability designs[3-5]. The specific details of the EMAP West design, as well as detailed information on data, indicators and analyses used in this report, can be found in the EMAP West Statistical Summary[6].

The EMAP West Region

The region covered by EMAP West comprises almost 42% of the land area of the conterminous United States. It is roughly half federal land (primarily managed by the U.S. Forest Service and Bureau of Land Management) and half private, with 7% under tribal jurisdiction. It is a topographically and climatically varied region, including the western Great Plains, the Rocky Mountains and the Continental Divide, the rainforests of the Olympic Peninsula, the rugged peaks of the Sierra Nevada, and the intensely arid climates of the Sonoran and Mohave Deserts. Within this diverse geographic region are the headwaters (and main stems) of the Missouri, the Arkansas, the Rio Grande, the Snake, and the Colorado Rivers. Rapid population growth has been, and continues to be, a consistent theme in the West, as do competing uses for the water. The EMAP West region includes some of the most rapidly growing metropolitan areas of the country: Denver and the front range of the Rockies, Salt Lake City and the Wasatch Front, Phoenix, Las Vegas, the San Diego to Los Angeles corridor, Portland and Seattle. In spite of this history of rapid growth, water has always been a scarce and precious resource in the West. The rivers of the West have been valued for their scenic beauty (e.g., the Grand Canyon of the Colorado River), their biological resources (e.g., salmon of the Pacific Northwest), and their capacity to generate vast quantities of electrical power and irrigation water.

Reporting Units for EMAP West

We report here at three levels of geographic resolution:

(1) the Executive Summary and the main body of the report present results for all of the EMAP West region (referred to as “West-wide”);

(2) the main body of the report focuses on three major climatic regions (Mountains, Plains and Xeric), in addition to the West-wide results; and

(3) results for ten aggregated ecological regions (or ecoregions, areas that have similar soils, vegetation, climate, and physical geography) are presented briefly in Appendix C.

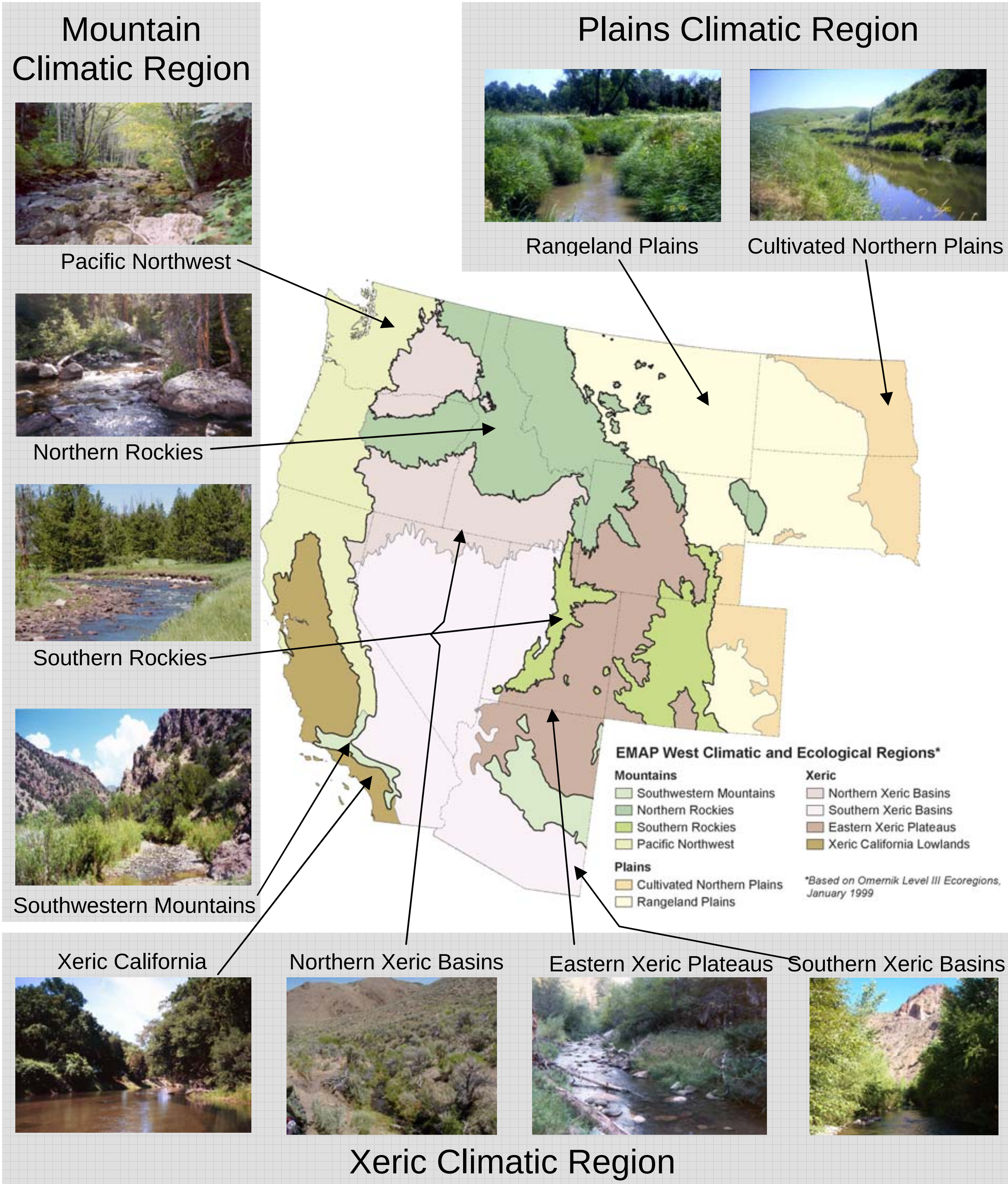


Figure 3. Location of three climatic regions (Mountains, Plains and Xeric) and ten aggregated ecological regions used as reporting units in this assessment. Photographs are of typical probability sites sampled as part of EMAP West in each ecological region.

Both the climatic regions and ecoregions we report on here are aggregations of Omernik ecoregions[7]. As a result of their similar characteristics, one expects the water resources within a particular climatic or ecological region to have similar characteristics, similar stresses and similar responses to those stresses. An ecoregion perspective highlights the differences, for example, between mountain areas with the steep slopes, shallow soils, and cooler climate, and valley areas that are relatively flat, have deep soils, and warmer temperatures; ecoregions permit us to have different expectations for flowing waters in these very different areas. Typically, management practices within an ecoregion are applicable to many flowing waters with similar problems, because the characteristics of the streams in the ecoregion are similar. The climatic and ecological regions used for EMAP West are illustrated in Figure 3, with photographs of probability sites sampled for this assessment. Interested readers are directed toward the references in Appendix A for further information on Omernik ecoregions and their characteristics.

What is an Ecological Assessment?

When we speak of assessing the ecological condition of streams and rivers of the western United States, we are focused on evaluating two critical components of aquatic ecosystems: the condition of their biota, and the relative importance of human-caused stressors.

The ecological condition of streams and rivers is represented by the condition of their biotic communities—the living components of aquatic ecosystems that integrate the many forms of human disturbance and stream modifications that we are interested in assessing. Often these components are assessed in terms of their biotic integrity, one of the main characteristics of aquatic systems that the Clean Water Act aims to protect. Biotic Integrity is defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region"[8, 9].

Stressors, or the pressures that human beings exert on aquatic systems through their use of the surrounding environment, are the chemical, physical and biological components of the ecosystem that have the potential to degrade biotic integrity. Some obvious chemical stressors are toxic compounds, excess nutrients (nitrogen and phosphorus) or acidity from acidic deposition or mining. Most physical stressors are created when we modify the physical habitat of a stream network—excess sedimentation, bank erosion, loss of streamside trees and vegetation can all degrade biotic integrity, and may result from human activities in watersheds. Biological stressors are characteristics of the biota themselves that can influence biotic integrity; examples are non-native or invasive species (either in the streams and rivers themselves, or in the riparian areas adjacent to them). One of the key components of an ecological assessment is a measure of how important (e.g., how common) each of these stressors is in a region, and how severely they affect biotic integrity.

Indicators of Ecological Condition

We estimate the ecological condition of streams and rivers by analyzing the composition and relative abundance of key biotic assemblages—in the case of EMAP West, we focus on aquatic vertebrates (fish and amphibians) and macroinvertebrates (larval insects, crustaceans, worms and mollusks). The Clean Water Act explicitly aims "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters". Our assessment of ecological condition is focused on biological integrity, because of the inherent capacity of biological organisms and assemblages to integrate the chemical and physical stressors that affect them over time. Our measures of biotic integrity include two examples of a widely used indicator of condition called the Index of Biotic Integrity, or IBI. The IBI is a multi-metric index—the total score is the sum of scores for a variety of individual measures, or metrics, that make up the key characteristics of biotic integrity (e.g., taxonomic richness, habitat and trophic composition, sensitivity to human disturbance, and other aspects of the biota that reflect "naturalness"). Originally developed for fish in Midwestern streams, the IBI has been modified numerous times for other regions, taxonomic groups, and ecosystems[10, 11]. Some of the details of IBI development for this assessment are given in the following paragraphs. In addition to assessing ecological condition on the basis of biotic integrity, we employ another commonly used measure to report on the health of macroinvertebrate assemblages—the Observed/Expected, or O/E, index. O/E is a measure of how many kinds of macroinvertebrates are expected to occur at a site, but are not actually found at that site. Our O/E index is also described below.

Aquatic Vertebrate IBI

The IBI we use to assess aquatic vertebrates includes metrics chosen to represent these key characteristics of biological integrity: taxonomic richness (number of species); taxonomic composition (e.g., is the assemblage dominated by trout or minnows); habitat use (e.g., bottom-dwelling vs. water-column species); life history (e.g., are migrating species present); reproductive strategies (e.g., are there species present that require clean gravels to spawn); pollution tolerance; feeding groups (e.g., fish-eating vs. insect-eating); and the presence of non-native species. For each of the three climatic regions of the West (Figure 3), we chose one metric from each of these classes of characteristics, and scored them against regional expectations of what value was possible for each stream (based on reference conditions—see *"Setting Expectations"* below). The resulting IBI combines all of the metrics in each region into an index whose values range from 0 to 100, with 100 denoting the best possible condition. The process we used to develop the IBI for aquatic vertebrates in EMAP West is described in some detail in the EMAP West Statistical Summary[6].

Macroinvertebrate IBI

The characteristics of the macroinvertebrate assemblages used to measure biotic integrity were: taxonomic richness (number of taxa); taxonomic composition (e.g., is the assemblage dominated by non-insects); taxonomic diversity; feeding groups (e.g., are there shredders, scrapers or predators present); habits (e.g., are there burrowing, clinging or climbing taxa present); and pollution tolerance. Different specific metrics were chosen in each of these categories, in each of the three climatic regions of the West (Figure 3). Each metric was scored against our expectations of what value was possible for each stream (based on reference conditions—see *"Setting Expectations"* below), and then combined to create an overall IBI, whose values range from 0 to 100. A detailed discussion of the process we used to develop a macroinvertebrate IBI can be found in the EMAP West Statistical Summary[6].

Macroinvertebrate O/E

In addition to biotic integrity, the loss of key taxa can be used as a measure of ecological condition[12-15]. For EMAP West, we developed an O/E index, described in detail in the EMAP West Statistical Summary[6], that is simply the number of macroinvertebrate taxa observed at a site divided by the number of taxa expected to occur (based on the reference site approach described in *Setting Expectations*, below). The values range from 0 (none of the expected taxa present) to slightly greater than 1 (more taxa than expected present). This index is a direct measure of how many taxa are missing at a site—a value of 0.5 indicates that half of the macroinvertebrate taxa we expected to find at a site were missing.

Aquatic Indicators of Stress

As human beings utilize the landscape, their actions can produce effects that are stressful to aquatic ecosystems. These aquatic stresses can be chemical, physical, or in some cases, biological. In this assessment we have selected a short list of stressors from each of these categories. These are not intended to be all-inclusive, and in fact some stressors that are likely to be important are not included here because we have no current way to assess them at the site scale (e.g., water withdrawals for irrigation). We hope that future assessments of stream and river condition in the West will include a more comprehensive list of stressors from each of these categories.

The use of land for cattle grazing can supply both nutrients and excess sediments to streams in the West, but is not itself considered a stressor

We emphasize that the highlighted stressor indicators are direct measures of stress in the stream or adjacent riparian areas. They are not landuse or land cover alterations such as row crops, mining or grazing. While any form of human landuse can be a source of one or more stressors to streams, we choose to focus on the stressors themselves, rather than on their sources.

Chemical Stressors

We report here on four indicators of chemical stress:

- ***Total phosphorus concentration***—phosphorus is a nutrient, and is usually considered to be the most likely nutrient limiting algal growth in freshwaters throughout the U.S. It is a common ingredient in fertilizers, and high concentrations may be associated with agricultural and urban landuse.
- ***Total nitrogen concentration***—nitrogen is another nutrient, and is particularly important as contributor to coastal and estuarine algal blooms. Sources include fertilizers, wastewater, animal wastes, and atmospheric deposition.

Excessive nutrients, like phosphorus and nitrogen, can lead to algal blooms, and other biotic effects

- ***Salinity—***excessive salinity occurs in areas with high evaporative losses of water, and can be exacerbated by repeated use of water for irrigation, or by water withdrawals (by slowing transit time of flowing waters). Both electrical conductivity and total dissolved solids (TDS) can be used as measures of salinity; for EMAP West, we have chosen to use conductivity.
- ***Mercury in Fish Tissue***—Sources of mercury in the environment include some types of mining (especially gold mining), coal combustion, the burning of industrial and residential waste, herbicides, fungicides, and pulp, paper and textile effluents. Because it is a fairly common contaminant in coal and solid waste, airborne mercury is very widespread, and is a common contaminant in rain and snow across most of the U.S. Once it reaches lakes and streams, mercury can be converted to toxic methylmercury by bacteria, and begin to accumulate in algae, invertebrates and vertebrates. Higher trophic levels (e.g., piscivorous [fish-eating] fish) and long-lived species tend to accumulate higher concentrations of methylmercury. For EMAP West, we sampled large piscivorous fish, large non-piscivorous fish and small fish, and measured whole-body mercury concentrations in each group. If mercury concentrations exceeded the levels established for the protection of wildlife (see Appendix D) in any of the three fish groups sampled at a site, that site was considered to be stressed by mercury.

Physical Habitat Stressors

Although there are many aspects of stream and river habitats that can become stressful to aquatic organisms when altered or modified, we focus here on four specific aspects of physical habitat:

- ***Streambed stability***—streams and rivers adjust their channel shape and streambed particle size in response to the supply of water and sediments from their drainage areas. One measure of this interplay between sediment supply and transport is relative bed stability (RBS). The measure of RBS that we use in this assessment is a ratio comparing the particle size of observed sediments to the size sediment each stream can move or scour during its flood stage, based on the size, slope and other physical characteristics of the stream channel[16]. The RBS ratio differs naturally among regions, depending upon landscape characteristics that include geology, topography, hydrology, natural vegetation, and natural disturbance history. Values of the RBS Index can be either substantially lower (finer, more unstable streambeds) or higher (coarser, more stable streambeds) than those expected based on the range found in least-disturbed reference sites—both high and low values are considered to be

Low Relative Bed Stability (RBS) is characterized by the accumulation of larger than expected quantities of very fine silt and sediment in streams.

indicators of ecological stress. Excess fine sediments can destabilize streambeds when the supply of sediments from the landscape exceeds the ability of the stream to move them downstream. This imbalance results from numerous human uses of the landscape, including agriculture, road building, construction and grazing. Lower than expected streambed stability may result either from high inputs of fine sediments (from erosion) or increases in flood magnitude or frequency (hydrologic alteration). When low RBS results from fine sediment inputs, stressful ecological conditions can develop because fine sediments begin filling in the habitat spaces between stream cobbles and boulders. The instability (low RBS) resulting from hydrologic alteration can be a precursor to channel incision and arroyo formation. Perhaps less well recognized, streams that have higher than expected streambed stability can also be considered stressed—very high bed stability is typified by hard, armored streambeds, such as those often found below dams where fine sediment flows are interrupted, or within channels where banks are highly altered (e.g., paved or lined with rip-rap).

- ***Habitat complexity***—the most diverse fish and macroinvertebrate assemblages are found in streams and rivers that have complex forms of habitat: large wood, boulders, undercut banks, tree roots, etc. Human use of streams and riparian areas often results in the simplification of this habitat, with potential effects on biotic integrity. For this assessment, we use a measure that sums the amount of in-stream habitat consisting of undercut banks, boulders, large pieces of wood, brush, and cover from overhanging vegetation within a meter of the water surface[16], all of which are quantified by EMAP field crews.

- ***Riparian Vegetation***—the presence of a complex, multi-layered vegetation corridor along streams and rivers is a measure of how well the stream network is buffered against sources of stress in the watershed. Intact riparian areas can help reduce nutrient and sediment runoff from the surrounding landscape, prevent bank erosion, provide shade to reduce water temperature, and provide leaf litter and large wood that serve as food and habitat for stream organisms. The presence of canopy trees in the riparian corridor indicates longevity; the presence of smaller woody vegetation typically indicates that riparian vegetation is reproducing, and suggests the potential for future sustainability of the riparian corridor. For this assessment we use a measure of riparian vegetation complexity that sums the amount of woody cover provided by three layers of riparian vegetation: the ground layer, woody shrubs, and canopy trees[16].

Healthy and intact riparian corridors provide important services to streams--preventing or reducing the impact of landuse in the watershed

- ***Riparian Disturbance***—the vulnerability of the stream network to potentially detrimental human activities increases with the proximity of those activities to the streams themselves. For this assessment, we use a direct measure of riparian human disturbance that tallies eleven specific forms of human activities and disturbances (e.g., roads, landfills, pipes, buildings, mining, channel revetment, cattle, row crop agriculture, silviculture) along the stream reach, and weights them according to how close to the stream channel they are observed[16]. The index generally varies from 0 (no observed disturbance) to 6 (4 types of disturbance observed in the stream, throughout the reach; or 6 types observed on the banks, throughout the reach).

Biological Stressors

Although most of the factors that we can clearly identify as stressors to streams and rivers are either chemical or physical, there are aspects of the biological assemblages themselves that we might consider stresses. Biological assemblages can be stressed by the presence of non-native species, which can either prey on, or compete with, native species. When non-native species become established in either vertebrate or invertebrate assemblages, their presence conflicts with the definition of biotic integrity that the Clean Water Act is designed to protect ("having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region"). In many cases, non-native species have been intentionally introduced. Brown trout and brook trout, for example, are common inhabitants of streams in higher elevation areas of the Mountain and Xeric climatic regions, where they have been stocked as game fish. To the extent that non-native game fish and amphibians compete with, and potentially exclude, native fish, however, they might be considered a threat to biotic integrity.

The bullfrog (*Rana catesbeiana)* is a widespread non-native vertebrate species in the Western U.S.

- ***Non-native Vertebrate Species***—Whether to consider non-native vertebrates (fish and amphibians) as stressors may be as much a societal issue as a scientific one. As an illustration of this, consider that the most commonly occurring non-native vertebrate species in Western streams are brown trout, brook trout, rainbow trout, common carp, smallmouth bass, green sunfish and largemouth bass (in order of the number of stream kilometers where they are found, but considered non-native). With the exception of common carp, these species are all game fish, introduced intentionally by state fish and game agencies in order to encourage sport fishing. A real dilemma develops when we consider that the presence of game fish, despite their being intentionally introduced, conflicts with the definition of biotic integrity that the Clean Water Act is designed to protect. We report here on the presence of non-native fish and amphibians as an indicator of potential stress, primarily to provide information about how widespread they are in the West. Additional information on other kinds of vertebrate species considered to be non-native in parts or all of the West can be found in the EMAP West Statistical Summary[6].

- ***Non-native Crayfish Species***—Although EMAP West sampling was not designed to sample crayfish effectively, both native and non-native crayfish species were found in the macroinvertebrate (i.e., sampled by kick-net) and aquatic vertebrate (i.e., sampled by electro-fishing) samples. By comparing the species list found with records on non-native distribution, we determined the presence of three non-native crayfish species in the EMAP West database: *Orconectes virilis* (a Canadian and northern U.S. species that has moved into the Southwest), *Pacifastacus leniusculus leniusculus* (native to the Northwest, but now moving into the Southwest), and *Procambarus clarkii* (a Southeastern and Mexican species that has colonized much of the West). In this Assessment, we report on the presence or absence of non-native crayfish (any of the above-listed species), rather than their abundance, because we cannot guarantee that they were sampled quantitatively. Details of crayfish data collection and interpretation can be found in the EMAP West Statistical Summary[6].

The Louisiana (or red swamp) crayfish (*Procambarus clarkii*) is an invasive species from the Southeastern U.S. and Mexico, now found in all of the West with the exception of the Plains

- ***Asian Clam***—The Asian clam (*Corbicula fluminea*) is primarily an economic concern because it fouls water intake pipes. It may also have ecological effects, but the demonstration of these has been elusive. It is known to compete with native clam species, and may also compete with other filter-feeding benthic invertebrates. *Corbicula* is considered to an invasive species and if present at all, it has the capacity to be very abundant. EMAP West macroinvertebrate samples frequently contain Asian clam, but we are not confident that they are sampled quantitatively. For this reason, we report on their presence or absence in this Assessment.

Setting Expectations

In order to assess current ecological condition, we need to be able to compare what we measure today to some estimate of what we would expect our measurements to look like in a less-disturbed world. Setting reasonable expectations for each of our indicators is one of the greatest challenges to making an assessment of ecological condition. Should we take a historical perspective, and try to compare our current conditions to estimates of pre-Columbian conditions, or to pre-industrial conditions, or to conditions at some other point in history? Or should we accept that some level of anthropogenic disturbance is a given, and simply use the best of today's conditions as the yardstick against which everything else is assessed?

These questions, and their answers, all relate to the concept of reference condition[17, 18]; what do we use as a reference, or yardstick, to assess today's condition? Because of the difficulty of estimating historical conditions for many of our indicators, EMAP West uses "Least-Disturbed Condition" as our reference. Least Disturbed Condition is found in conjunction with the best available physical, chemical and biological habitat conditions given today's state of the landscape. It is described by evaluating data collected at sites selected according to a set of explicit criteria defining what is "best" (or least disturbed by human activities). These criteria vary from region to region, and were developed iteratively with the goal of identifying the least amount of ambient human disturbance in each climatic region of the West. If done correctly, reference criteria describe the sites whose condition is "the best of what's left" in the West.

To develop biological indicators for EMAP West, we use the chemical and physical data we collected at each site (e.g., nutrients, chloride, turbidity, excess fine sediments, riparian condition, etc.) to determine whether any given site is in Least Disturbed Condition for its ecoregion. Note that we deliberately do not use data on landuse in the watersheds for this purpose—sites in agricultural areas (for example) may well be considered Least Disturbed, provided that they exhibit chemical and physical conditions that are among the best for the region. Nor do we use data on the biological assemblages themselves, since these are the primary components of the stream and river ecosystems for which we need estimates of Least Disturbed Condition, and to use them would constitute circular reasoning. For each of the stressor indicators, a similar process (identifying Least Disturbed sites according to specific criteria, but excluding the specific stressors themselves from the criteria identifying the sites) was used. Interested readers can find more detailed information about how we determined Least Disturbed Condition in the EMAP West Statistical Summary[6] and in Appendix D.

We then use a reference site approach[18, 19] to set expectations—the Least Disturbed sites in each region are sampled using identical methods to the sites we are trying to assess. The range of conditions found in these "reference sites" describes a distribution of values, and extremes of this distribution are used as thresholds to distinguish sites in relatively good condition from those that are clearly not. One common approach is to examine the range of values (e.g., for a particular IBI) in all of the reference sites in a region, and to use the 5th percentile of this distribution to separate the most disturbed sites from moderately disturbed sites; similarly, the 25th percentile of the reference distribution can be used to distinguish between moderately disturbed sites and those in Least Disturbed Condition[20, 21]. Details on how we set thresholds for this Assessment can be found in Appendix D at the back of this report.

Extent of Resource

The sampling frame used to select the sites for sampling in EMAP West is based on the perennial stream network contained in EPA's River Reach file (known as RF3). RF3 is a digitized version of 1:100,000 scale USGS topographic maps, showing both perennial and non-perennial streams. The total length of the RF3 stream network in the EMAP West region that is labeled perennial is 628,625 km. A significant proportion of this total (207,770 km, or 33%; Figure 4) was found through site evaluation and sampling to be either non-perennial, or non-target in some other way (e.g., wetlands, reservoirs, irrigation canals). This is an important finding for the States of the West, who are required to report on the condition of all perennial streams under their jurisdiction; west-wide, the total perennial stream resource is overestimated by one-third in RF3. The level of overestimation varies greatly from one climatic region to another—more than half (55%) of the RF3 stream length in the Xeric region was non-target, as was 33% in the Plains, and 24% in the Mountains.

The remaining "target stream length" (420,855 km) represents the portion of the sampling frame that meets our criteria for inclusion in this Assessment (i.e., perennial streams and rivers). Part of the target stream length (73,967 km, or 18%) was not

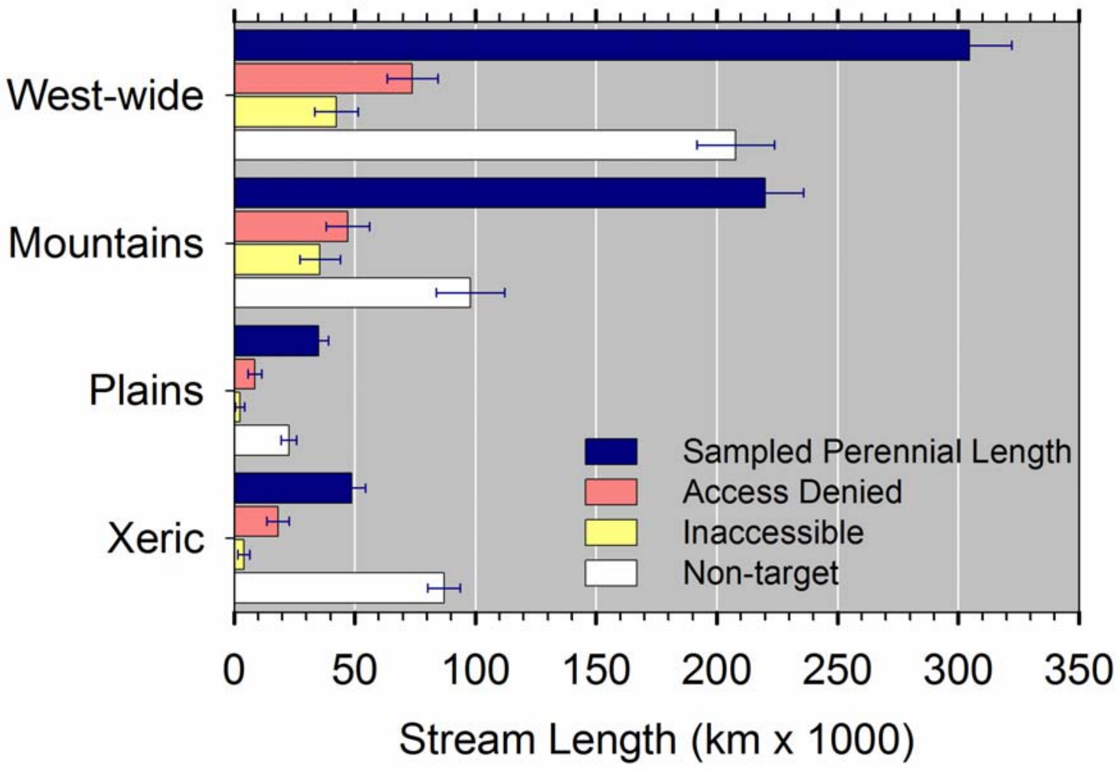


Figure 4. Stream length estimates (with 95% confidence intervals) for key categories of streams in EMAP West, including target sampled (all accessible perennial streams and rivers), and non-target (non-perennial streams, or non-streams).

accessible to sampling because crews were denied access by landowners (Figure 4). Again, this proportion varied from one climatic region to another (16% in the Mountains; 18% in the Plains; 26% in the Xeric). An additional portion of the target stream length (42,344 km, or 11%) was physically inaccessible due to physical barriers or other unsafe local conditions (Figure 4). The unsampled portion of the stream resource in the West cannot be assessed for condition—no inferences should be made that apply the results of this Assessment to the unsampled portion of the stream population. The remainder of the sampling frame constitutes the assessed length of stream for this Assessment--304,544 km, representing 48% of the original frame length, and 72% of the target stream length (Figure 4).

Ecological Condition

Results for the indicators of ecological condition (aquatic vertebrate IBI, macroinvertebrate IBI and macroinvertebrate O/E Index) are shown for all of the EMAP West region, and for the three climatic regions, in Figure 5. Additional results at the ten ecoregion level are shown in Appendix C. The same format is used to display the results for chemical (Figure 6), physical (Figure 7) and biological habitat (Figure 8) indicators. In all of these figures the order of the climatic regions (Plains, Xeric and Mountains) follows the results for the vertebrate IBI, with the first region (Plains) having the highest percentage of stream length in most-disturbed condition for this indicator. Readers with an interest in any given climatic region should be able to scan across pages to compare and contrast the ecological and stressor condition for that region.

West-wide, results suggest that roughly half of the stream length is in least disturbed condition, while approximately one-quarter is in most disturbed condition, but results vary according to which assemblage and which index is being assessed. More important, results vary greatly by region.

Aquatic Vertebrate Biotic Integrity

In the case of aquatic vertebrates, 18% of the stream length in the West would be considered to be in most-disturbed condition, while 44% was in least-disturbed condition. Approximately 9% of the stream length west-wide consisted of small streams where no fish or amphibians were collected—these streams are considered to be ‘unassessed’ because we cannot assume that their lack of aquatic vertebrates was due to anything other than natural causes (i.e., small size).

One of the biggest issues for assessing vertebrate (particularly fish) data in the West is the large numbers of streams where the presence of threatened and/or endangered fish species limits the amount of sampling that can be conducted. West-wide, 12% of stream length could not be sampled because crews were denied sampling permits by the agencies responsible for protecting threatened and endangered fish species. One could interpret the sum of stream lengths in most-disturbed condition (18%) and where permits were denied (12%) as a measure of the total stream length in the West where aquatic vertebrate assemblages have significant problems (i.e., 30%).

On a regional basis, the Plains climatic region clearly has the largest proportion of streams in most disturbed condition with respect to aquatic vertebrates (50%), but the smallest proportion where threatened and endangered species issues precluded sampling (0%). The Xeric region has 35% of stream length in most-disturbed condition, and an additional 13% where sampling permits were denied, for a total of 48% with aquatic vertebrate problems. The Mountain region has the lowest proportion in most-disturbed condition of any climatic region (9%), and was very similar to the Xeric in its amount of threatened and endangered species issues (14% of stream length in the Mountains). The very large total length of streams in the Mountains creates a situation where west-wide results largely reflect the condition of Mountain streams.

Macroinvertebrate Biotic Integrity

West-wide, 27% of stream length is considered to be in most-disturbed condition with respect to macroinvertebrate biotic integrity. At most of the scales used in this assessment, there is a slightly larger proportion of stream length in most-disturbed condition for macroinvertebrates than for aquatic vertebrates. This generalization may be influenced by the amount of stream length that is unassessed for vertebrates—if streams with threatened and endangered fish species (and therefore unassessed) are included in the proportion of stream length with aquatic vertebrate assemblages in most disturbed condition, then lack of vertebrate biotic integrity would appear as the more common problem.

The Xeric climatic region has the largest proportion of streams in most-disturbed condition for macroinvertebrates (46%), followed by the Plains (42%) and Mountains (20%). The regions in Figure 5 are ordered from 'worst' to 'best' according to the aquatic vertebrate results. If the order had been determined by the macroinvertebrate results, the ranking of the regions would have been Xeric>Plains>Mountains.

Macroinvertebrate O/E

Roughly 17% of stream length west-wide has 50% or fewer of the reference taxa we expect to see in the macroinvertebrate assemblages. As was the case for the macroinvertebrate IBI, the climatic region with the largest proportion of high-taxa-loss streams was the Xeric (33%), followed by the Plains (23%) and the Mountains (13%). At all of the scales used in this Assessment (west-wide, the three climatic regions, and the ten ecoregions (see Appendix C)), the O/E results follow closely the macroinvertebrate IBI, suggesting that taxa loss, as measured by our O/E index, is a good indicator of biotic integrity[15].

Stressor Condition

The summary results for indicators of chemical, physical and biological habitat are shown in Figures 6 through 8. These figures are formatted identically to Figure 5, so that west-wide and regional results can be compared across all indicators. The order of the regions is also the same, with the climatic regions listed from worst to best according to the aquatic vertebrate IBI results in Figure 5.

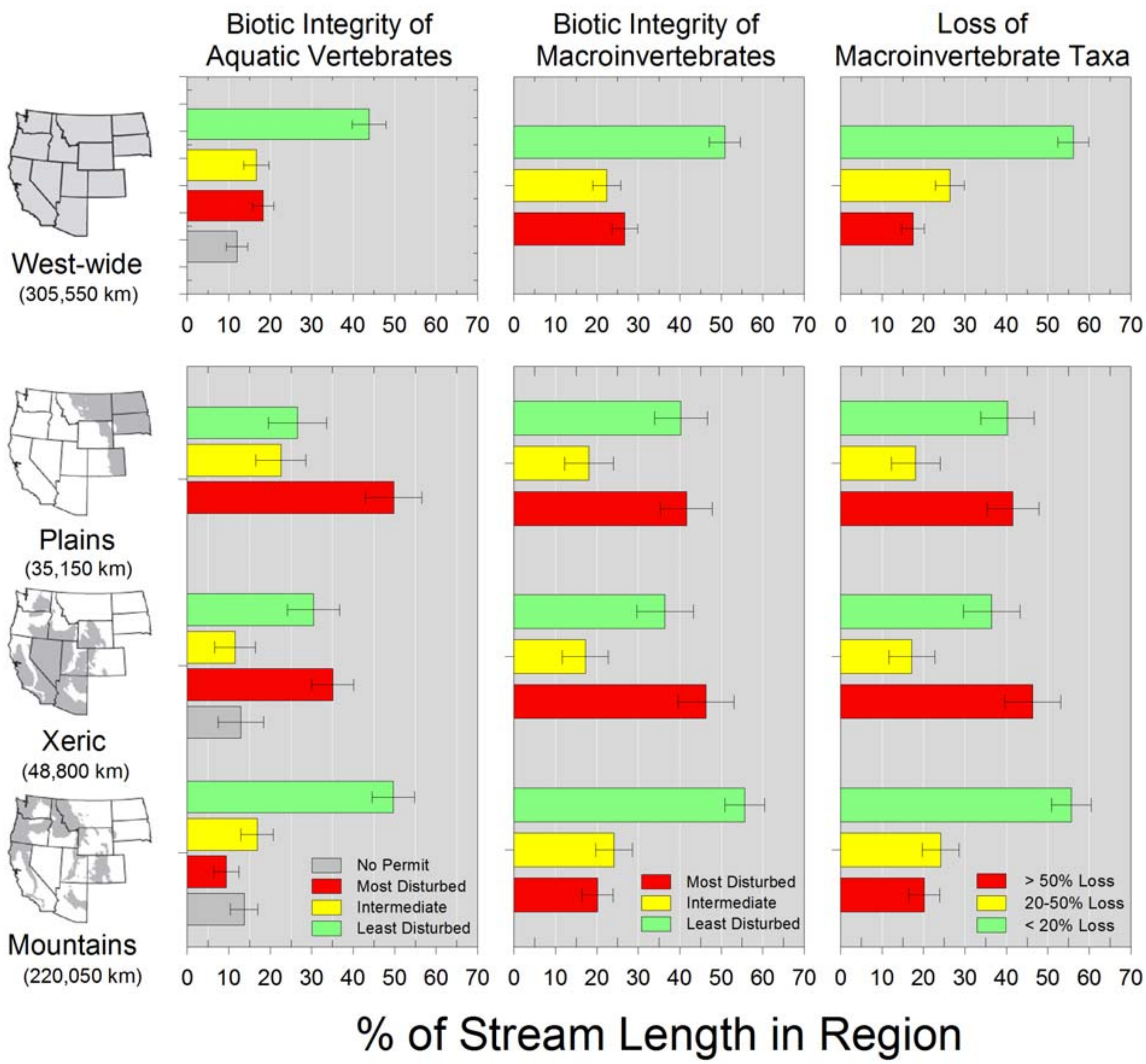


Figure 5. Summary of results for ecological condition indicators for all of the West, and for three climatic regions. Bars (with 95% confidence intervals) show the percentage of stream length in each region with index scores in each condition class. Numbers in parentheses are the total sampled perennial stream length in each region. Regional results are sorted according to the aquatic vertebrate results, with regions at top having the highest proportion of stream length in most disturbed condition. For aquatic vertebrates, a small percentage of stream length in each region could not be assessed due to small stream size: West-wide=9%; Plains=1%; Xeric=10%; Mountains=10%.

Chemical Stressors

Phosphorus: Approximately 15% of stream length west-wide was in most-disturbed condition for phosphorus (see Appendix D for regional thresholds for all indicators), and roughly 48% would be considered to be in least-disturbed condition for this nutrient (Figure 6). Of the climatic regions, the Plains had the highest proportion of streams

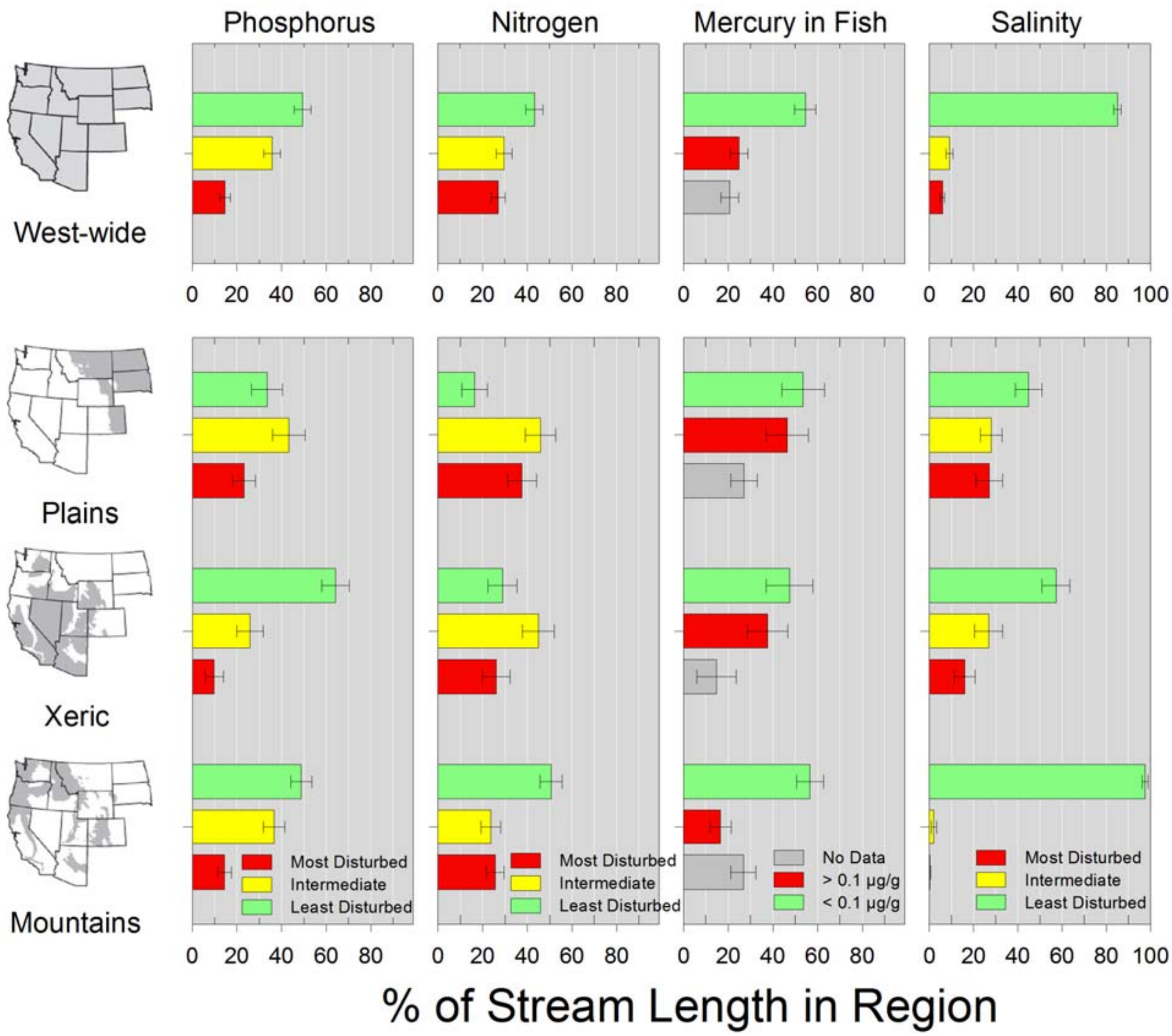


Figure 6. Summary of results for chemical indicators of stress for all of West and in three climatic regions. Details of figure are as in Figure 5. Both acidity and selenium were found in most disturbed condition in less than 1% of stream length west-wide (not shown)

exceeding the phosphorus threshold (23%), followed by the Mountains (15%) and Xeric (10%) regions.

Nitrogen: West-wide, nitrogen thresholds were exceeded in 15% of stream length, and 44% of streams were considered to be in least-disturbed condition with respect to nitrogen (Figure 6). The regional and ecoregional results do not follow exactly the pattern for phosphorus (Figure 6, Appendix C); the Plains had the highest proportion of stream length in poor condition for nitrogen (38%), and the Xeric and Mountain climatic regions had identical proportions (26%). In general, most regions exhibited higher proportions of stream length in poor condition for nitrogen than for phosphorus.

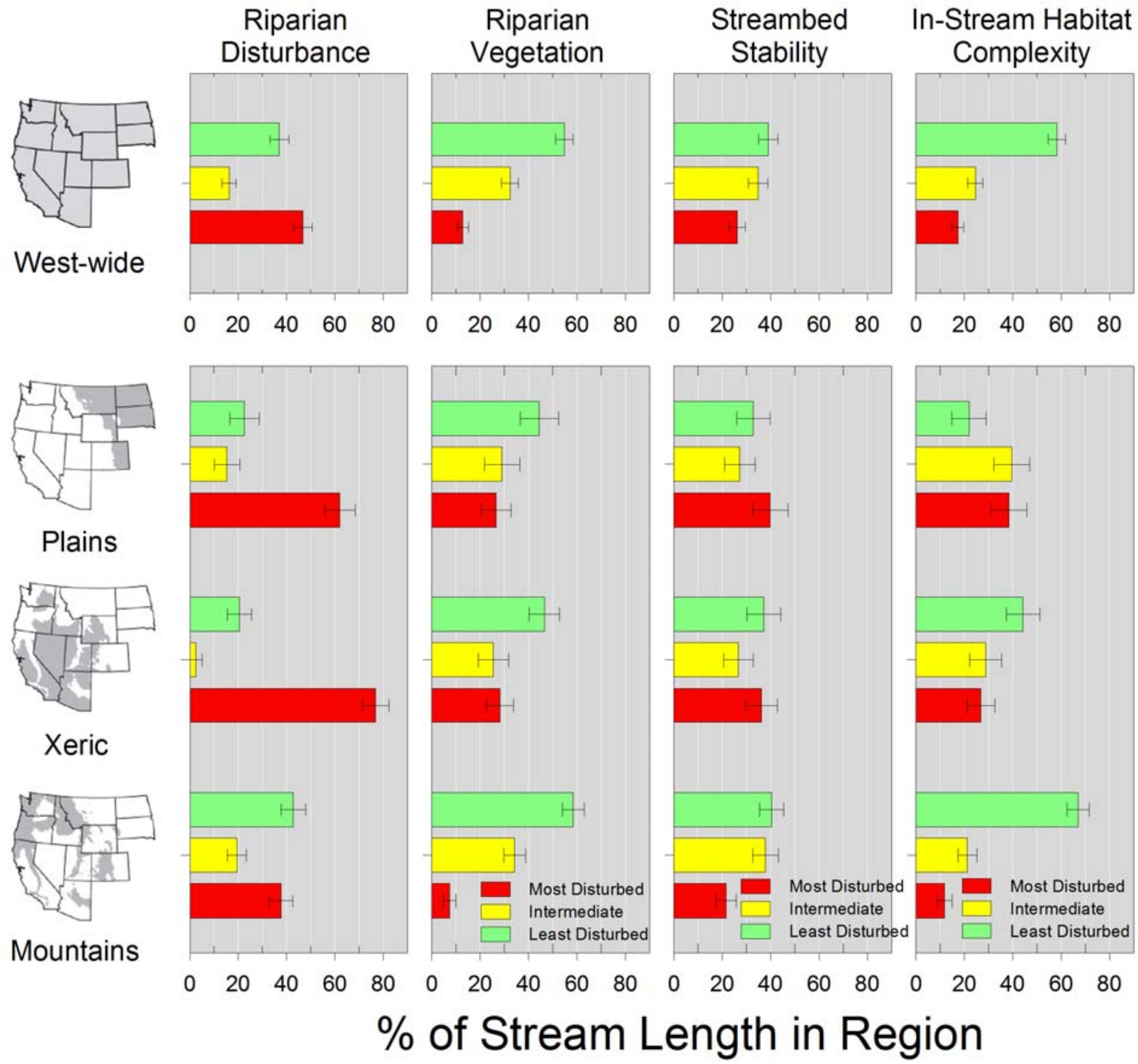


Figure 7. Summary of results for physical habitat indicators for all of West and in three climatic regions. Details of figure are as in Figure 5.

Mercury in Fish Tissue: West-wide 25% of stream length (Figure 6) had one or more classes of fish (large piscivores, large non-piscivores or small forage fish) that exceeded the level determined to be protective of wildlife (0.1 micrograms of mercury per gram of fish tissue (µg/g)), but another 21% could not be assessed due to the difficulty of sampling fish in some subregions (sampling permit restrictions). Because mercury accumulation in fish tissue is strongly affected by trophic level and size, many of the results that exceed the 0.1 µg/g criterion were for large, piscivorous fish. Mercury concentrations exceeding the wildlife criterion were most common in the Plains climatic region (46% of stream length), followed by the Xeric (38%) and Mountain (17%) regions.

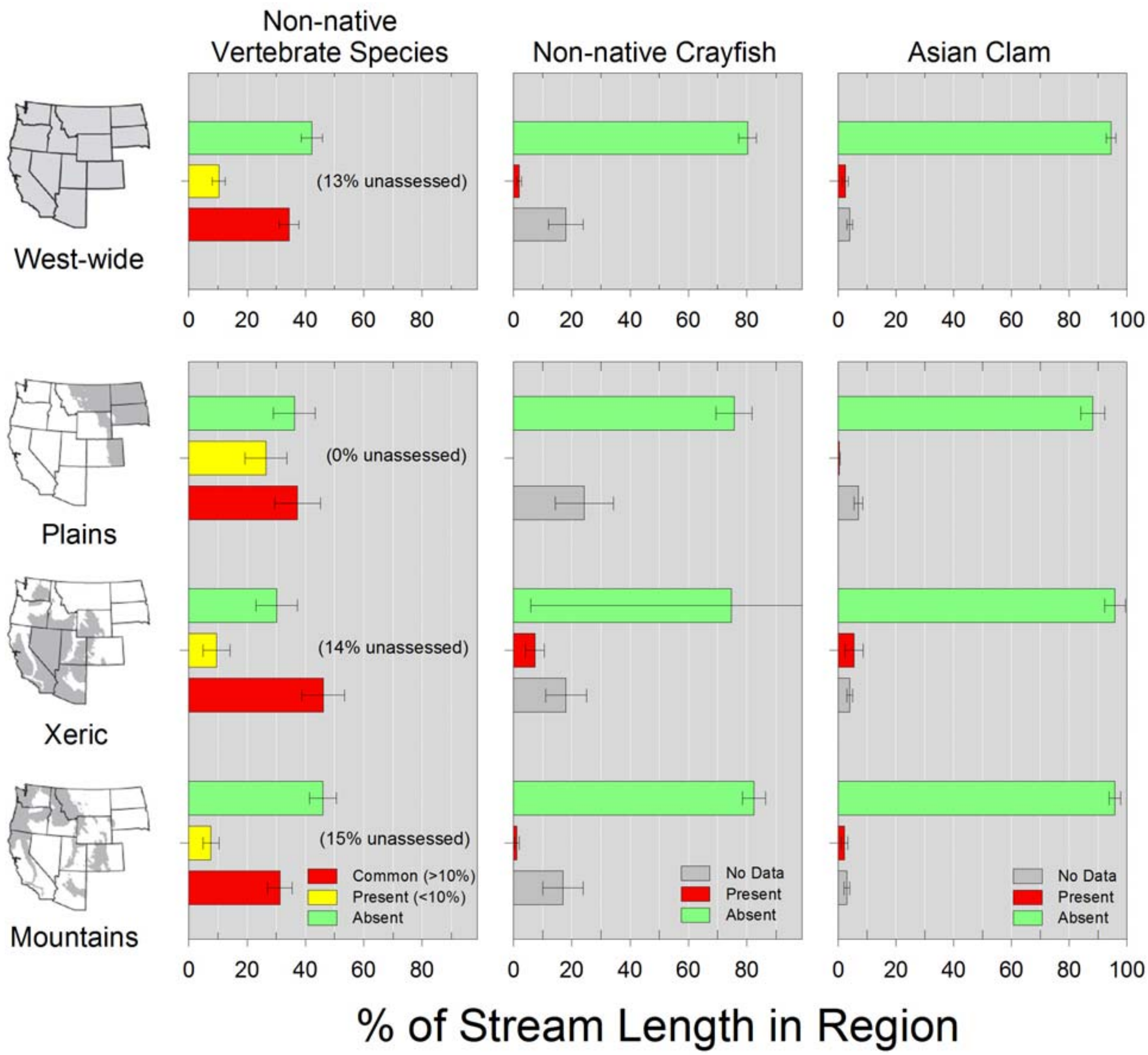


Figure 8. Summary of results for biological stressor indictors for all of West and in three climatic regions. Details of figure are as in Figure 5.

Salinity: Roughly 6% of stream length west-wide had salinity levels considered to be in the most disturbed range, while nearly 85% were considered to be in least-disturbed condition (Figure 6). As was the case for many of the stressors presented in the Assessment, the Plains climatic region had the highest proportion of stream length in poor condition with respect to salinity (27%), followed by the Xeric region (16%). In the Mountains, salinity was in the most disturbed range in less than 1% of stream length.

Other chemical stressors: While we focus in this assessment on the chemical indicators described above, many additional chemical variables were measured in EMAP West, and two potential chemical stressors deserve mention:

- Acidity (either from acidic deposition or mining) can be a concern in many parts of the U.S. None of the EMAP probability sites was acidic (defined as having an Acid Neutralizing Capacity [ANC] less than 0 microequivalents per liter), and less than 1%

of stream length in the West would be considered likely to be acidic during high runoff periods such as spring snowmelt (ANC < 50 microequivalents per liter).

- Selenium is a toxic ion that can accumulate in wildlife. Based on the proposed EPA chronic criterion for selenium in water (5 parts per billion), less than 1% of stream length (and in each of the climatic regions) exhibits toxic levels of selenium.

Physical Habitat Stressors

Riparian Disturbance: Levels of riparian disturbance exceeded the regional thresholds in 47% of stream length west-wide (Figure 7). In the climatic regions, the highest proportion of stream length with high riparian disturbance was the Xeric (77%), followed by the Plains (62%) and the Mountains (38%). One of the most striking findings of this Assessment is the widespread distribution of riparian disturbance, especially in the Xeric region, where more than three-quarters of stream length has significantly more riparian disturbance than is found in reference sites. The same is true of nearly two-thirds of the stream length in the Plains.

Riparian Vegetation: West-wide 13% of stream length had severely simplified riparian vegetation (Figure 7). The Xeric (28%) and Plains (27%) climatic regions had roughly equal proportions of stream length with riparian vegetation in most-disturbed condition. Only a small proportion of streams (7%) in the Mountain climatic region had riparian vegetation in most-disturbed condition. It is worth noting that these estimates are considerably smaller than those for riparian disturbance, suggesting that land managers have done a relatively good job of preserving riparian vegetation, even along streams where disturbance from roads, agriculture, grazing, etc., is widespread.

Streambed Stability: Across the West, roughly 26% of stream length exhibited problems with sedimentation, with the highest proportion of streams exceeding the thresholds in the Plains (40%) and Xeric (36%) climatic regions (Figure 7). While streams with either very low or very high streambed stability can be considered to be in the most-disturbed category, the vast majority of the stream length with streambed stability problems exhibit low stability, indicating that their substrates are dominated by finer sediments than expected.

In-Stream Habitat Complexity: Degraded habitat complexity was found in 17% of stream length west-wide (Figure 7). In the climatic regions, the highest proportions of habitat complexity in most-disturbed condition were found in the Plains (38%) and Xeric (27%) regions. Simplification of in-stream habitat was found in only 12% of stream length in the Mountains.

Other physical habitat stressors: We focus in this assessment on the physical habitat indicators that are well understood and can be easily assessed. Additional indicators will be possible in future EMAP West assessments, but have not been sufficiently developed at this time. Two obvious examples about which EMAP scientists are often asked are stream incision (i.e., arroyo formation) and hydrologic alteration (water withdrawals, altered flow regimes, and agricultural return-flow). In both of these cases, the greatest difficulty in interpreting possible indicators of stress results from the need to separate natural variability from anthropogenic effects. As these indicators, and their geographic variability, become better understood, we will be better able to include them in future assessments.

Biological Stressors

Non-native Vertebrate Species: Non-native fish and/or amphibians were common (i.e., they represented more than 10% of individuals collected at a site) in roughly 34% of stream and river length west-wide (Figure 8). Differences among the climatic regions were not large in the case of this indicator, with the Xeric (46%), Plains (37%) and Mountains (31%) climatic regions all showing widespread presence of non-native vertebrate species. Much larger differences were found between ecological regions (see Appendix C).

Non-native Crayfish: One or more species of non-native crayfish were present in 2% of stream length west-wide. They were completely absent from the Plains climatic region. All of the areas with significant stream length where non-native crayfish were found are in the Southwestern states (see detailed results in Appendix C). This probably reflects the fact that two of the three species are considered native to the northern portion of the EMAP West region, and the third species primarily invades warm water habitats.

Asian Clam: the Asian clam was found in just over 2% of the stream length west-wide. Like non-native crayfish, they are primarily found in the Xeric and southwestern areas of the EMAP West region.

Other biological stressors: Although they do not lend themselves to the reporting format of the rest of EMAP West data, crews also collected data on the presence or absence of 12 invasive plants in the riparian areas adjacent to each stream reach (Common Burdock, Giant Reed, Cheatgrass, Musk Thistle, Canada Thistle, Teasel, Russian-olive, Leafy Spurge, English Ivy, Reed Canary Grass, Himalayan Blackberry and Salt Cedar). The list of target species varied from state to state, as described in the Statistical Summary[6]; on average field crews were looking for 8 of these species within a particular state. This list of 12 species is only a subset of the full set of plants invading western riparian areas; as a result, the data are of great use in evaluating these particular species in the region, but cannot be used to asses the status of riparian plant invasions throughout the region. West-wide, 34% of stream length had one or more invasive riparian plant species present.

Ranking of Stressors

An important prerequisite to making wise policy and management decisions is an understanding of the relative magnitude or importance of potential stressors. There are multiple ways that we might choose to define "relative importance" with stressors. One aspect to consider is how common each stressor is—i.e., what is the extent, in kilometers of stream, of each stressor and how does it compare to the other stressors? We might also want to consider the severity of each stressor—i.e., how much effect does each stressor have on biotic integrity, and is its effect greater or smaller than the effect of the other stressors? Because each view provides important input to policy decisions, we present separate rankings of the relative extent and the relative severity

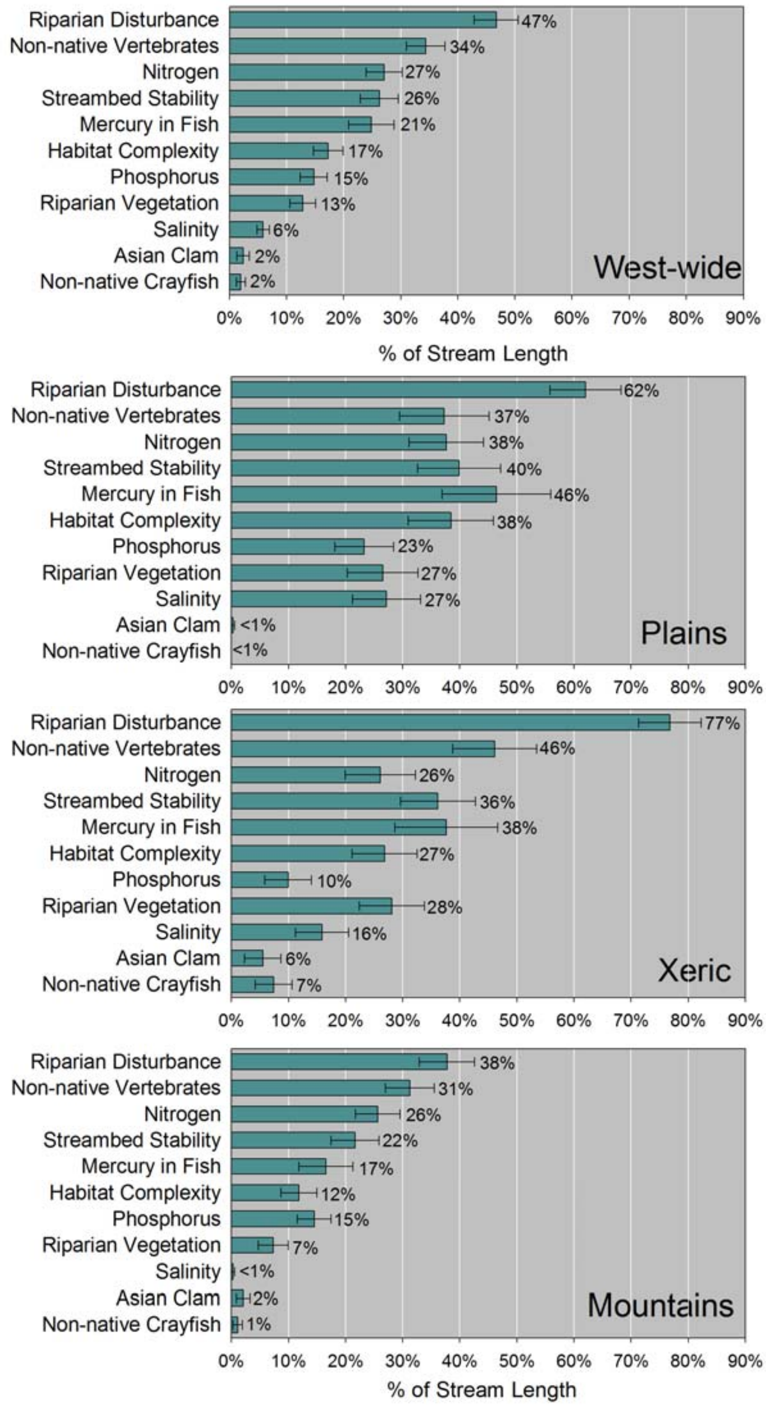


Figure 9. Relative extent of stressors (proportion of stream length with stressor in most disturbed condition) west-wide, and each climatic region. The order of stressors (from highest to lowest percent in most-disturbed condition) is set by the west-wide results and is consistent in each panel.

of stressors to flowing waters in the West. Ideally, we'd like to combine these two factors (extent and effect) into a single measure of relative importance. We currently have no methodology for combining the two rankings, and so present both with a discussion of their implications.

Relative Extent

Figure 9 shows the EMAP West stressors ranked according to the proportion of stream and river length for each that is in most-disturbed condition. Results are presented for all of the West (top panel) and for each climatic region, with the stressors ordered (in all panels) according to their relative extent west-wide.

Riparian disturbance is the most pervasive stressor west-wide, and in each of the climatic regions. Across all of the West, fully 47% of the stream length shows significant signs of riparian disturbance. In the Xeric region, this proportion climbs to 77%, while in the Plains, 62% of stream length is considered to be in most disturbed condition with respect to riparian disturbance. Even in the Mountains, where levels of disturbance are in general lower than the other climatic regions, riparian disturbance is found in 38% of the stream length.

The least common stressors are the two non-native macroinvertebrate groups (non-native crayfish and Asian clam), where only 2% of stream length west-wide is affected. Only in the Xeric region does either of these indicators suggest a relatively widespread problem: 7% of stream length in the Xeric region had non-native crayfish taxa present.

Between these two extremes (riparian disturbance vs. non-native macroinvertebrates), the different types of stressors (chemical, physical and biological) rank without any particular pattern. The top three stressors west-wide are representatives of the physical (riparian disturbance), biological (non-native vertebrates) and chemical (nitrogen) classes of stressor. We cannot conclude from this analysis that, for example, physical habitat is more commonly found in most disturbed condition than either chemical or biological habitat.

Three stressors occur consistently near the top of the rankings in every panel of Figure 9: riparian disturbance, streambed instability and mercury in fish tissue are among the five most common stressors west-wide and in each climatic region. Elevated mercury concentrations in fish are thought to be the result of atmospheric deposition; because elevated rates of mercury deposition are widespread, one might expect mercury contamination of fish tissue to be elevated in all regions of the West, which it is. Riparian disturbance and streambed instability, on the other hand, result from local disturbance. In fact, disturbance of riparian areas is a likely contributor to erosion and excess fine sediments in streams, resulting in a close association between the two indicators.

Relative Risk

In order to address the question of severity of stressor effects, we borrow the concept of “relative risk” from medical epidemiology, because of the familiarity of the language it uses. We have all heard, for example, that we run a greater risk of developing heart disease if we have high cholesterol levels. Often such results are presented in terms of a relative risk ratio—e.g., the risk of developing heart disease is four times higher for a person with total cholesterol level of 300 mg than for a person with total cholesterol of 150 mg.

In Figure 10 we present relative risk values for the biological and stressor data on streams in the West. The relative risk values we present can be interpreted in exactly the same way as the cholesterol example—how much more likely is a stream to have poor biotic integrity if a stressor is present (or found in high concentrations) than if it is absent (or found in low concentrations). In technical terms, the relative risk ratio represents the proportional increase in the likelihood of finding a biological indicator in the most-disturbed class when the stressor's condition in the same stream is also in the most-disturbed class (see Appendix E for details of relative risk calculation). Because different biological assemblages and different aspects of those assemblages (e.g., biotic integrity vs. taxa loss) are expected to be affected by different stressors, relative risk is calculated separately for each of the ecological condition indicators presented in this Assessment. A relative risk value of 1.0 indicates that there is no association between the stressor and the biological indicator, while values very much greater than one suggest greater relative risk. We also calculate confidence intervals (shown as brackets in Figure 10) for each ratio, in order to focus the discussion only on the most significant relative risks. When the confidence intervals for any given ratio fall below a value of one, we do not consider the relative risk to be statistically significant.

The significant relative risks in Figure 10 give us an idea both of how severe each stressor's effect on the biota is, and which stressors we might want to focus on when a given assemblage is in poor ecological condition. For the entire West, several stressors stand out as having impacts of concern for the biotic integrity of both aquatic vertebrates and macroinvertebrates. Excess nitrogen, excess phosphorus and excess salinity all have relative risks greater than three for both assemblages. In the case of aquatic vertebrates, mercury also shows an elevated risk ratio. The geographic differences in relative risk are interesting. In general, Plains regions are dominated by high relative risks for excess nitrogen and phosphorus. The Xeric and Mountain regions appear to have a broader range of stressors that present high relative risks to the biota.

In an assessment of relative risk based on cross-sectional survey data (as opposed to data from a controlled experiment) it is impossible to separate completely the effects of individual stressors that often occur together. For example, streams with high nitrogen concentrations often exhibit high phosphorus as well; streams with high riparian disturbance often have sediments far in excess of expectations. In the case of EMAP West, the presence of the Asian clam is associated with poor biotic integrity for both vertebrates and macroinvertebrates, and with high macroinvertebrate taxa loss. While it might be tempting to conclude that the presence of this non-native mollusk is affecting the community structure of streams, it is equally likely that the kinds of streams where Asian clam has become established are places where biotic integrity is typically low due to the presence of many other stressors. The analysis presented in Figure 10 treats the stressors as if they occur in isolation, even though we know they do not. We do not currently have an analytical technique to separate the effects of correlated stressors, other than to point out in the discussion where co-occurrence of stressors should be considered in the interpretation of the assessment.

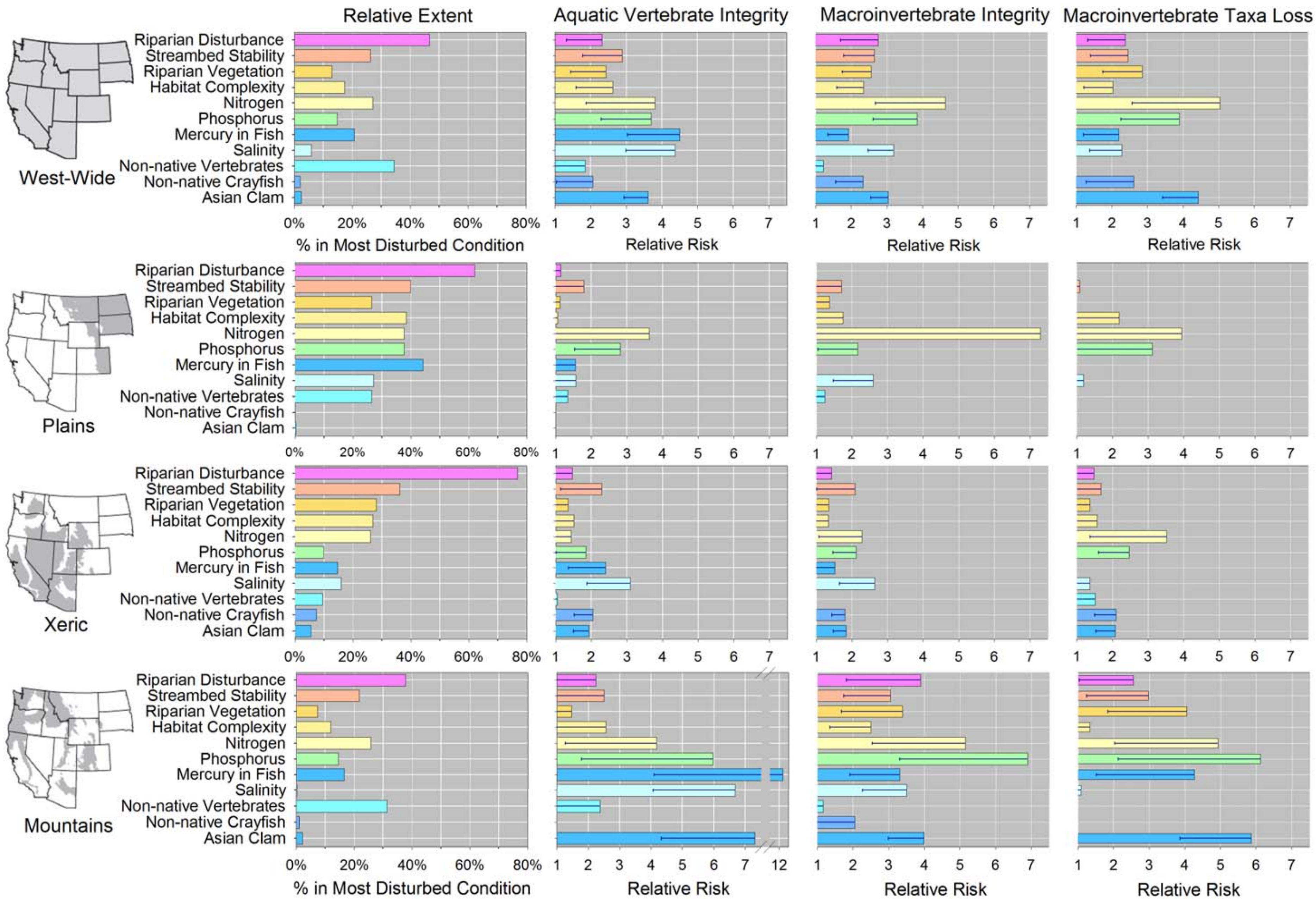


Figure 10. Relative extent and relative risk of stressors west-wide and in three climatic regions. Stressors are grouped into general classes (physical, chemical and biological habitat). Scales for all relative risk panels are identical, with the exception of the Aquatic Vertebrate IBI in the Mountains, where one extremely high ratio necessitates a different scale. Relative risk ratios below 1.0 are not shown. 95% lower confidence bounds are shown to indicate significance of ratios—intervals that encompass 1.0 are not considered significant.

Combining Extent and Relative Risk

The most comprehensive assessment of the effect of stressors on ecological condition comes from combining the relative extent and relative risk results (Figure 10)—stressors that pose the greatest risk to individual biotic indicators will be those that are both common (i.e., they rank high in terms of extent in Figure 9) and whose effects are potentially severe (i.e., exhibit high relative risk ratios in Figure 10). The analogies in human health persist. To make the greatest overall improvement in human health, one would focus on factors that are high both in terms of their relative risk (e.g., obesity) and their occurrence (e.g., obesity occurs at the 50% level in every state). In the case of EMAP West, we have tried to facilitate this combined evaluation of stressor importance by including side-by-side comparisons of relative extent and relative risk in Figure 10.

A quick examination of the west-wide results suggests some common patterns among the biological indicators. In the case of aquatic vertebrates, the four highest relative risks are for chemical stressors (mercury, salinity, nitrogen and phosphorus, in order of their relative risk ratios). Of these, only nitrogen and mercury occur in more than 20% of stream length, making them possible targets for management decisions. Riparian disturbance is the most common stressor, and has a comparatively moderate relative risk ratio for aquatic vertebrates (2.5); the combination of widespread occurrence and significant, though moderate, relative risk may also make it a target for restoration efforts aimed at fish.

For both macroinvertebrate indices, nitrogen and phosphorus exhibit high relative risks, but nitrogen is nearly twice as common, suggesting that management decisions aimed at reducing nitrogen runoff to streams could have broad positive impact on macroinvertebrate biotic integrity, and prevent further taxa loss. High salinity, where it occurs, is strongly associated with poor biotic integrity (relative risk > 3), but its rarity (ca. 6% of stream length west-wide) suggests that focusing on reducing salinity might only make sense in local situations. As in the case for aquatic vertebrates, riparian disturbance exhibits a moderate relative risk (2.5 to 3) for macroinvertebrates, but is so widespread that it might be a reasonable target for widespread restoration efforts.

At the scale of the EMAP West climatic regions, small sample sizes make it more difficult to draw clear conclusions. Nitrogen is the stressor that exhibits the highest relative risk in the Plains for all biological indicators, but it is not statistically significant for any of them. Salinity shows a significant relative risk value for biotic integrity of macroinvertebrates in the Plains and Xeric regions, as well as for fish in the Xeric region—it occurs in more than 25% of stream length in the Plains, suggesting that is the area most likely to benefit from salinity control efforts. High salinity is less common in the Xeric (16% of stream length), but because it might pose a risk to both fish and macroinvertebrates, land managers may choose to focus control efforts in the Xeric region as well as the Plains.

In the Mountains, many of the stressors exhibit significant relative risks. For fish, mercury, Asian clam presence, salinity and phosphorus all have ratios over 5. Of these, mercury is the most common. For macroinvertebrate biotic integrity, phosphorus, nitrogen, Asian clam and riparian disturbance all exhibit relative risk values near 4 or above. Of these, riparian disturbance is the most obvious target for restoration efforts—it is the most common stressor in the Mountains, occurring in 38% of stream length.

Conclusions

The Western U.S. is an enormous and diverse landscape. Not surprisingly, the ecological condition of its streams and rivers varies widely geographically. The vast majority (i.e., more than 70%) of stream and river length in the West is located in the mountainous areas, where the condition of the biology is relatively good. The three measures of biological condition we use in this report range from 17% to 26% (of stream length) in most-disturbed condition for the mountainous areas of the West. The poorest overall condition is probably found in the Plains, where aquatic vertebrates exhibit most-disturbed biotic integrity in ca. 45% of stream length; the macroinvertebrate indices suggest 24% to 42% of the Plains stream resource is in most-disturbed condition. The Plains, however, is the region with the fewest streams (in terms of length—12% of the west-wide total). In the Xeric region, biological conditions are intermediate between the Mountains and the Plains, with 35-45% of stream length in most-disturbed condition for the biological indicators. Xeric streams represent about 16% of the total stream length in the West. One surprising conclusion to be drawn from all of this is that, while the Plains have the highest proportion of their stream length with poor biotic integrity, there are more kilometers of streams in the Mountains with poor biotic integrity than anywhere else in the West, because stream the resource is so much more extensive there.

Of the potential stressors we examine in this report, disturbance of riparian areas is by far the most wide-spread. Just under half (47%) of stream length west-wide has riparian disturbance in the most-disturbed category, but this proportion ranges from 38% in the Mountains to more than three-quarters of stream length (77%) in the Xeric region. Readers may be surprised to learn that mercury in fish tissue is also a widespread stressor. Using a mercury criterion intended to protect fish-eating wildlife (e.g., river otters), we find that 21% of stream length west-wide exceeds the criterion, but that this proportion is as high as 46% in the Plains and 38% in the Xeric region. Nutrients are also common stressors in the West, with nitrogen concentrations found in the most-disturbed category in 27% of stream length west-wide, but in 38% of the Plains stream length.

Appendix A: References

EMAP Stream and River Sampling Methods

1. Peck, D. V., Averill, D. K., Herlihy, A. T., Hughes, R. M., Kaufmann, P. R., Klemm, D. J., Lazorchak, J. M., McCormick, F. H., Peterson, S. A., Cappaert, M. R., Magee, T. & Monaco, P. A. (2005). Environmental Monitoring and Assessment Program - Surface Waters Western Pilot Study: Field Operations Manual for Non-Wadeable Rivers and Streams. EPA Report EPA 600/R-05/xxx, U.S. Environmental Protection Agency, Washington, DC.
2. Peck, D. V., Herlihy, A. T., Hill, B. H., Hughes, R. M., Kaufmann, P. R., Klemm, D. J., Lazorchak, J. M., McCormick, F. H., Peterson, S. A., Ringold, P. L., Magee, T. & Cappaert, M. R. (2005). Environmental Monitoring and Assessment Program - Surface Waters Western Pilot Study: Field Operations Manual for Wadeable Streams. EPA Report EPA 600/R-05/xxx, U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

Probability Designs

3. Olsen, A. R., Sedransk, J., Edwards, D., Gotway, C. A., Liggett, W., Rathbun, S., Reckhow, K. H. & Young, L. J. (1999). Statistical issues for monitoring ecological and natural resources in the United States. *Environmental Monitoring and Assessment* **54,** 1-45.
4. Stevens Jr., D. L. (1997). Variable density grid-based sampling designs for continuous spatial populations. *Environmetrics* **8,** 167-195.
5. Stevens Jr., D. L. & Urqhart, N. S. (2000). Response designs and support regions in sampling continuous domains. *Environmetrics* **11,** 11-41.

EMAP West

6. Stoddard, J. L., Peck, D. V., Olsen, A. R., Larsen, D. P., Van Sickle, J., Hawkins, C. P., Hughes, R. M., Whittier, T. R., Lomnicky, G., Herlihy, A. T., Kaufmann, P. R., Peterson, S. A., Ringold, P. L., Paulsen, S. G. & Blair, R. (2005). Environmental Monitoring and Assessment Program (EMAP): Western Streams and Rivers Statistical Summary. EPA Report EPA 600/R-05/xxx, U.S. Environmental Protection Agency, Washington, DC.

Ecological Regions

7. Omernik, J. M. (1987). Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* **77,** 118-125.

Indices of Biotic Integrity

8. Karr, J. R. & Dudley, D. R. (1981). Ecological perspective on water quality goals. *Environmental Management* **5,** 55-68.
9. Frey, D. G. (1977). The integrity of water - an historical approach. In *The Integrity of Water*. (Ballentine, S. K. & Guarala, L. J., Eds), pp. 127-140. U.S. Environmental Protection Agency, Washington DC.

10. Barbour, M. T., Stribling, J. B. & Karr, J. R. (1995). Multimetric approach for establishing biocriteria and measuring biological condition. In *Biological assessment and criteria: tools for water resource planning and decision making*. (Davis, W. S. & Simon, T. P., Eds), pp. Chapter 6, pg. 63-77. Lewis, Boca Raton, FL.

11. Karr, J. R. (1981). Assessment of biotic integrity using fish communities. *Fisheries* **6,** 21-27.

Observed/Expected Models

12. Van Sickle, J., Hawkins, C. P., Larsen, D. P. & Herlihy, A. T. (2005). A null model for the expected macroinvertebrate assembalge in streams. *Journal of the North American Benthological Society* **24,** 178-191.

13. Wright, J. F. (2000). An introduction to RIVPACS. In *Assessing the Biological Quality of Fresh Waters*. (Wright, J. F., Sutcliffe, D. W. & Furse, M. T., Eds), pp. 1-24. Freshwater Biological Association, Ambleside, UK.

14. Hawkins, C. P., Norris, R. H., Hogue, J. N. & Feminella, J. W. (2000). Development and evaluation of predictive models for measuring the biological integrity of streams. *Ecological Applications* **10,** 1456-1477.

15. Hawkins, C. P. (In Press (2005)). Quantifying biological integrity with predictive models: comparisons with three other assessment methods. *Ecological Applications*.

Physical Habitat

16. Kaufmann, P. R., Levine, P., Robison, E. G., Seeliger, C. & Peck, D. (1999). Quantifying Physical Habitat in Wadeable Streams. EPA Report EPA/600/3-88/021a, U.S. EPA, Washington, D.C.

Reference Condition

17. Stoddard, J. L., Larsen, D. P., Hawkins, C. P., Johnson, R. K. & Norris, R. H. (In Press (2005)). Setting expectations for the ecological condition of running waters: the concept of reference condition. *Ecological Applications*.

18. Bailey, R. C., Norris, R. H. & Reynoldson, T. B. (2004). *Bioassessment of Freshwater Ecosystems: Using the Reference Condition Approach*. Kluwer Academic Publishers, New York.

19. Hughes, R. M. (1995). Defining acceptable biological status by comparing with reference conditions. In *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making for Rivers and Streams*. (Davis, W. & Simon, T., Eds), pp. Chapter 4, pg. 31-47. Lewis, Boca Raton, FL.

Other EMAP Assessments

20. Stoddard, J. L., Herlihy, A. T., Hill, B. H., Hughes, R. M., Kaufmann, P. R., Klemm, D. J., Lazorchak, J. M., McCormick, F. H., Peck, D. V., Paulsen, S. G., Olsen, A. R., Larsen, D. P., Van Sickle, J. & Whittier, T. R. (In Press). Mid-Atlantic Integrated Assessment (MAIA)--State of the Flowing Waters Report. EPA Report EPA 600/R-05/xxx, U.S. Environmental Protection Agency, Washington, DC.

21. U.S. Environmental Protection Agency (2000). Mid-Atlantic Highlands Streams Assessment. p. 64. EPA Report EPA/903/R-00/015, U.S. Environmental Protection Agency, Region 3, Philadelphia, PA.

Biological Condition Gradient/Quality of Reference Sites

22. Lattin, P. D. (In Preparation). A process for characterizing watershed level disturbance using orthophotos.

23. Davies, S. P. & Jackson, S. K. (In press). The Biological Condition Gradient: A conceptual model for interpreting detrimental change in aquatic ecosystems. *Ecological Applications*.

Toxic contaminant criteria

24. Lazorchak, J. M., McCormick, F. H., Henry, T. R. & Herlihy, A. T. (2003). Contamination of fish in streams of the Mid-Atlantic Region: an approach to regional indicator selection and wildlife assessment. *Environmental Toxicology and Chemistry* **22,** 545-553.

Relative Risk

25. Van Sickle, J., Stoddard, J. L., Paulsen, S. G. & Olsen, A. R. (In Press). Using relative risk to compare the effects of aquatic stressors at a regional scale. *Environmental Management*.

Appendix B: Quality Assurance

EMAP West included extensive quality assurance (QA), designed to ensure that the data were of the highest quality. Interested readers are referred to the EMAP West Statistical Summary[6] for details of EMAP's QA program and its results. Some key elements of the QA program include:

- Field protocols and training—both wadeable and non-wadeable sites were sampled according to extensively documented and tested field methods[1, 2]. Over the course of the study, more than 200 state, federal and contract crew members were trained in these methods directly by the EMAP scientists that developed them. Training included annual refresher courses for returning crew members.
- Laboratory QA and inter-laboratory comparisons—the laboratories for analyzing water chemistry, fish tissue contaminants and macroinvertebrate samples developed and followed extensive internal QA procedures. In addition, all labs participated in inter-laboratory comparisons (e.g., by analyzing audit samples).
- Vouchering and archiving of aquatic vertebrates—wherever possible, identification of vertebrate species was done in the field, with vouchering of specimens from each taxon found. Taxonomic identification of preserved fish and amphibians was conducted by the Smithsonian Institute's National Museum of Natural History, specimens were also archived by this organization.
- Automated entry of field data—EMAP utilized standard field forms for data collection in the field, with centralized data entry via scanning and automated generation of electronic data files. This system has extensive internal QA and consistency checks.
- Internal consistency checks for physical habitat, chemistry and biological data—all data generated as part of this project underwent internal consistency checks to verify the validity of the data.

Appendix C: Ecoregional Results

In the main body of this report, we present results for all of the EMAP West region, and for each of three climatic regions. In this appendix, we present results for the ten ecological regions shown in Figure 3. These results are presented in exactly the same formats as previously, with indicators of ecological condition (Figure 11), and chemical, physical and biological habitat indicators (Figures 13, 14 and 15) shown on sequential pages to allow the reader to compare indicators for any ecoregion of interest. In the interest of space, we present only limited interpretation of these ecoregional results, but encourage the reader to study the figures and draw his or her own conclusions.

Among the conclusions to be drawn from the ecoregional results:

- The Cultivated Plains has the highest proportion of length in most-disturbed condition for aquatic vertebrates (63%), followed by the Southwestern Mountains (56%) and Eastern Xeric Plateaus (50%). The smallest proportions of streams in most-disturbed condition (with respect to aquatic vertebrates) were found in the Pacific Northwest (7%) and Northern Rockies (9%) (Figure 11).
- The Xeric Northern Basins had the highest proportion of stream length where fish could not be sampled due to permit restrictions (31%); most of these restrictions were due to the presence of endangered bull trout. If combined with the proportion in most-disturbed condition for biotic integrity, the Xeric Northern Basins would have 47% of stream length with aquatic vertebrate problems.
- As was the case for climatic regions, macroinvertebrate IBI results do not mirror the vertebrate results at the finer ecoregional level (Figure 11). The Xeric California Lowlands (53%) and Xeric Southern Basin and Range (53%) have the highest proportions in most-disturbed condition for macroinvertebrates. The Xeric California Lowlands, in particular, shows a stark contrast between vertebrate and macroinvertebrate results, perhaps reflecting the presence of different stressors to which these two assemblages react. At the less disturbed end of the scale, the mountainous ecoregions (e.g., Northern Rockies [17%] and Pacific Northwest [22%]) have the smallest proportions of stream length in poor condition, but the highest total lengths of streams and rivers (100,900 km and 84,200 km, respectively).
- The rank order of ecoregions (highest to lowest percentage in most-disturbed condition) for the macroinvertebrate O/E index is very similar to that of the macroinvertebrate IBI (Figure 11). The highest proportion of stream length with more than 50% taxa loss is found in the Xeric California Lowlands (53%), followed by the Xeric Southern Basin and Range (43%). The lowest percentages are in the Southern Rockies (11%) and Northern Rockies (12%).
- The Cultivated Plains has 54% of its stream length in most-disturbed condition with respect to phosphorus (Figure 12), followed by the Southwestern Mountains (45%) and Southern Rockies (24%). The smallest proportions of streams with high phosphorus concentrations were found in the Xeric Eastern Plateau (6%) and Pacific Northwest (11%).

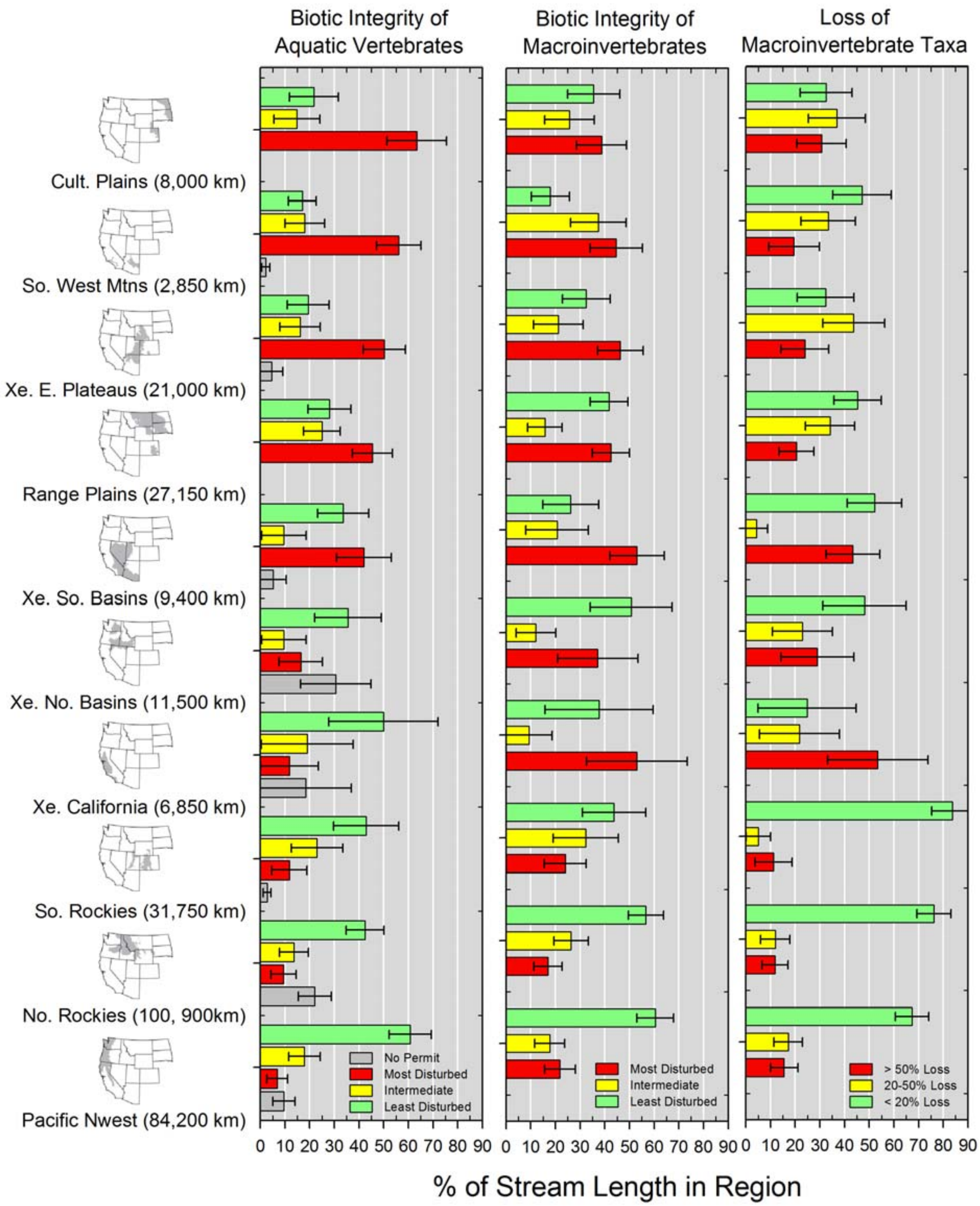


Figure 11. Summary of results for ecological condition indicators for 10 ecological regions. Bars (with 95% confidence intervals) show the percentage of stream length in each region with index scores in each condition class. Numbers in parentheses are the total sampled perennial stream length in each region. Regional results are sorted according to the aquatic vertebrate results, with regions at top having the highest proportion of stream length in most disturbed condition. In each region a small percentage of stream length could not be assessed for aquatic vertebrate due to insufficient sampling or small stream size. These percentages ranged from 0% in the Cultivated Plains to nearly 20% in the Southern Rockies.

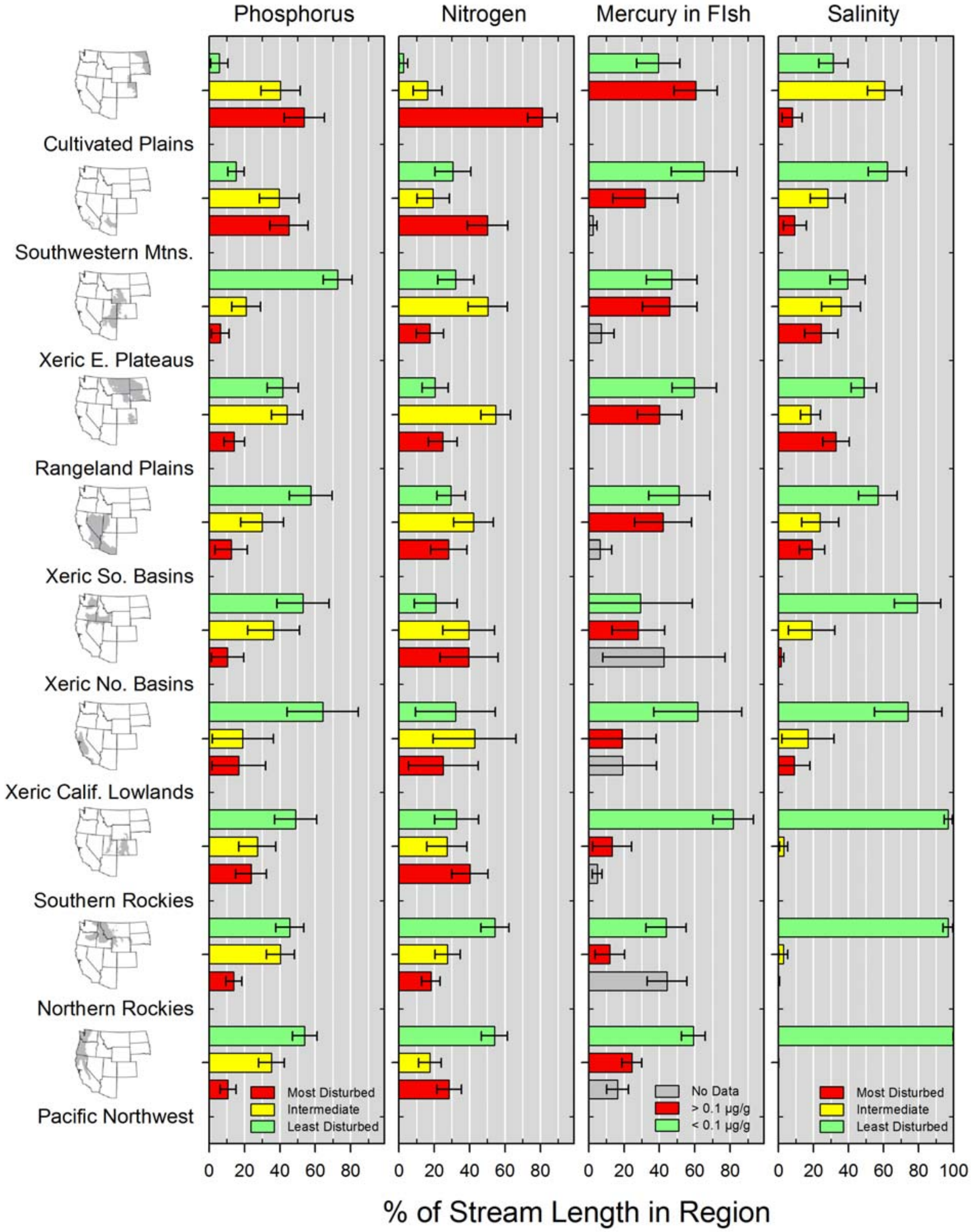


Figure 12. Summary of results for chemical indicators of stress for 10 ecological regions. Symbols and details of figure area as in Figure 11.

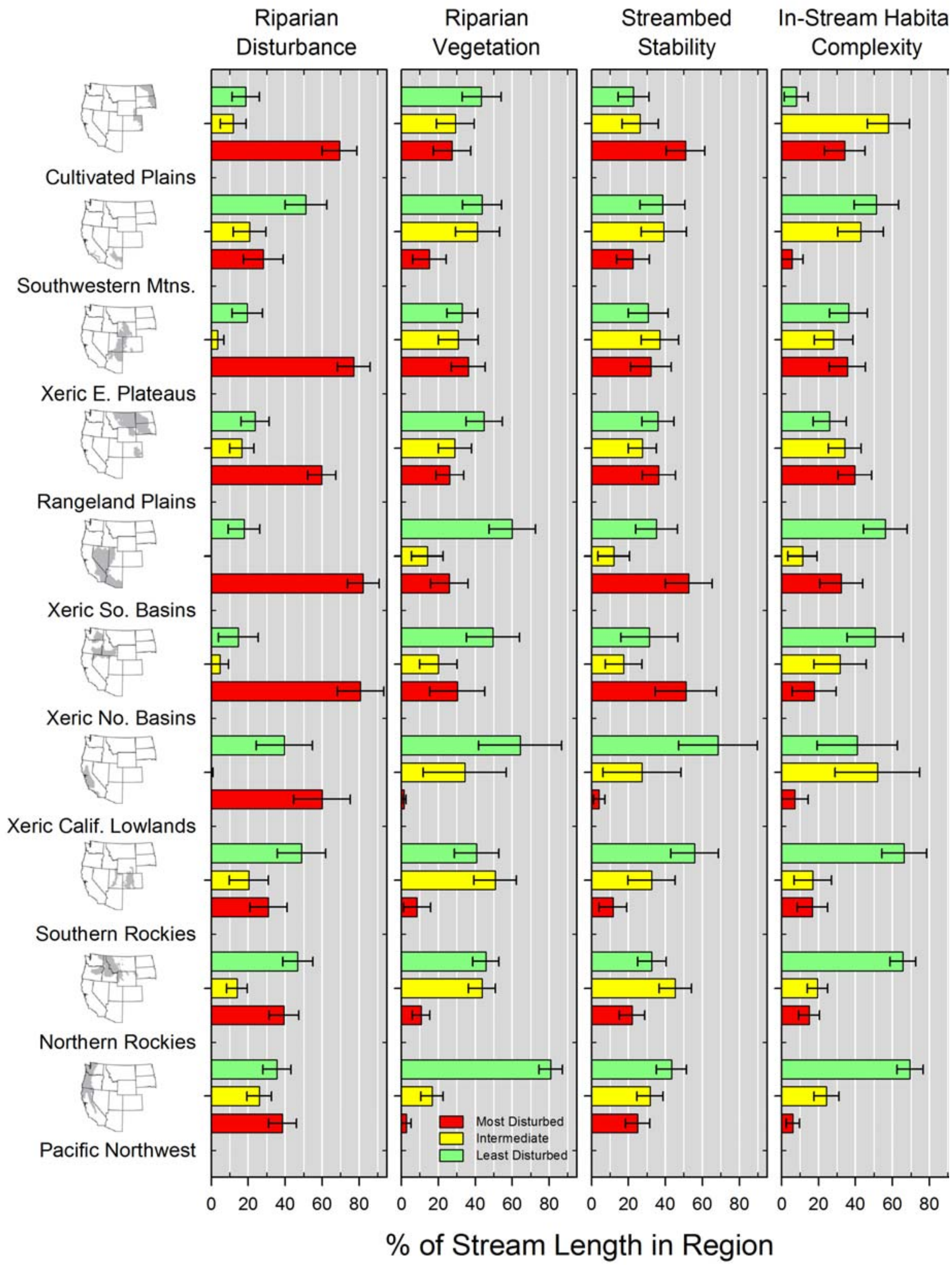


Figure 13. Summary of results for physical habitat indicators for 10 ecological regions. Symbols and details of figure are as in Figure 11.

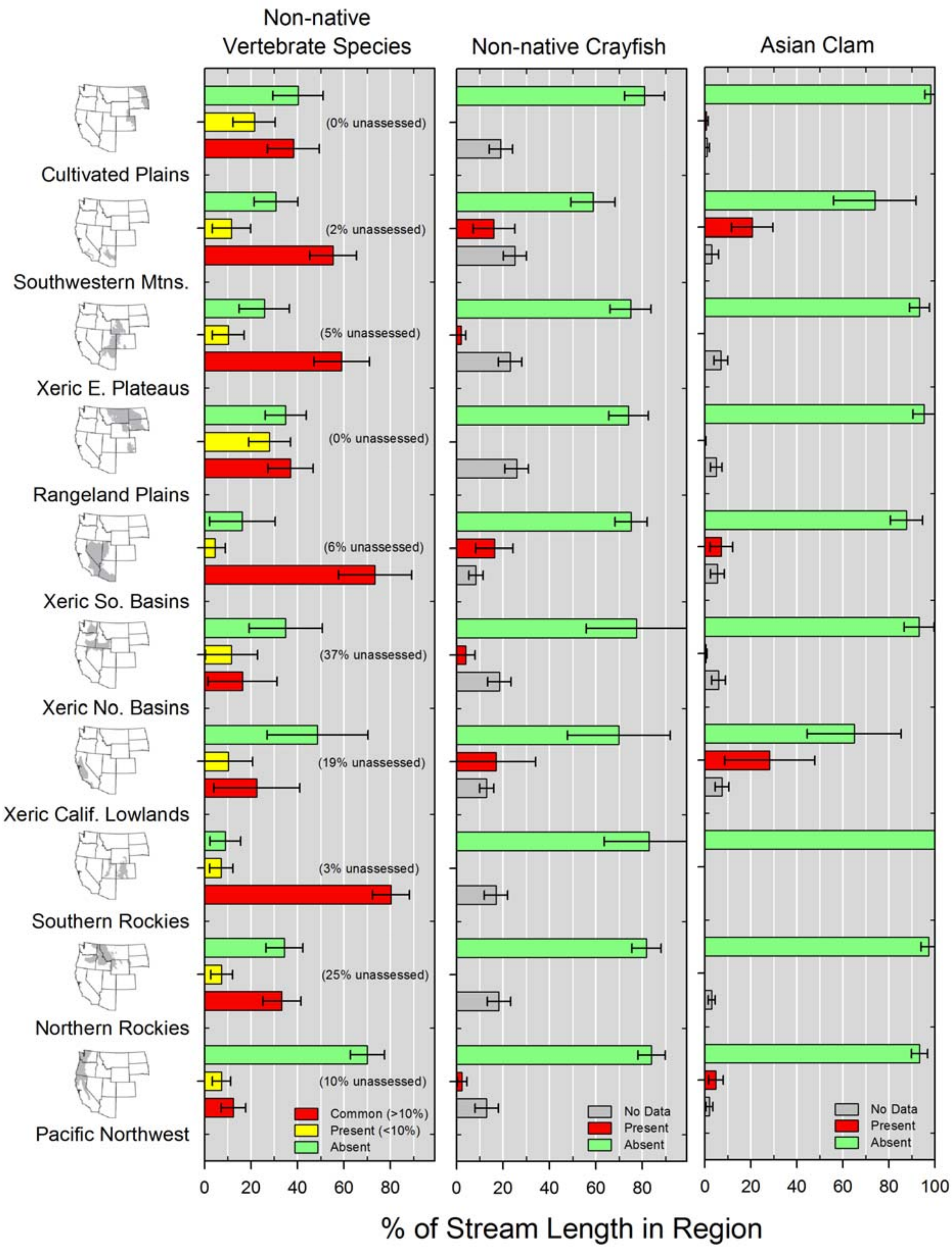


Figure 14. Summary of results for biological indicators of stress for 10 ecological regions. Symbols and details of figure are as in Figure 11.

- The Cultivated Plains (81%) and Southwestern Mountains (50%) ecoregions also had high proportions in most-disturbed condition for nitrogen (Figure 12), while the regions with the smallest percentages were the Northern Rockies (18%) and Xeric Eastern Plateaus (18%).
- The Rangeland Plains (33%), Xeric Eastern Plateaus (25%) and Xeric Southern Basin and Range (19%) had the highest proportions of stream length with high salinity (Figure 12). In the Northern and Southern Rockies and the Pacific Northwest, salinity problems were virtually non-existent, with <1% of stream length exceeding the regional criteria.
- Riparian disturbance was most common in the Northern and Southern Xeric Basin and Range ecoregions (81% and 82% in most disturbed condition, respectively, Figure 13), followed by the Xeric Eastern Plateaus (77%) and Cultivated Plains (70%). The lowest proportions of stream length with high amounts of riparian disturbance were in the Southwestern Mountains (28%) and Southern Rockies (31%).
- The ecoregion with the highest proportion of stream length with Riparian Vegetation in most-disturbed condition (Figure 13) was the Xeric Eastern Plateaus (36%), followed by the Xeric Northern Basin and Range (30%), the Cultivated Plains (27%) and Rangeland Plains (26%). The lowest percentages of streams with low structural complexity in riparian areas occurred in the Xeric California Lowlands (1%) and Pacific Northwest (3%).
- Three ecoregions had more than 50% of stream length in most disturbed condition for streambed stability (Figure 13): the Xeric Southern Basin and Range (53%), Xeric Northern Basin and Range (51%), and the Cultivated Plains (51%). Problems with sediments were least common in the Xeric California Lowlands (4%) and Southern Rockies (12%).
- The Rangeland Plains was the ecoregion with the highest proportion of in-stream habitat complexity in most-disturbed condition (40%), followed by the Eastern Xeric Plateaus (36%) and Cultivated Plains (34%) ecoregions (Figure 13). The fewest streams with severely simplified habitat were found in the Pacific Northwest (6% in most-disturbed condition) and Southwestern Mountains (6%).
- Non-native fish and/or amphibians were common (more than 10% of individuals collected) in 80% of the stream length in the Southern Rockies ecoregion (Figure 14). The Xeric Southern Basin and Range (73%), Xeric Eastern Plateaus (59%) and Southwestern Mountains (55%) all had abundant non-native vertebrates in more than half their stream length. The Pacific Northwest had the smallest proportion of stream length with high non-native abundance (13%). The Xeric Northern Basin and Range appears to have a relatively low proportion of streams with non-natives making up more than 10% of the assemblage (16%), but the high proportion of unassessed streams in this ecoregion (37%) make this number unreliable.

- All of the areas with significant stream length where non-native crayfish were found (Figure 14) are in the Southwestern states: the Xeric California Lowlands (17%), Xeric Southern Basins (16%) and Southwestern Mountains (16%).
- Asian clams, like non-native crayfish, were primarily found in the Xeric and Southwestern areas of the EMAP West region (Figure 14). 28% of the stream length in the Xeric California Lowlands was populated with Asian clam, along with 21% of the Southwestern Mountains and 7% of the Xeric Southern Basin ecoregion.
- Among the invasive riparian plants included in EMAP West surveys (but not shown in Figures 13-15), Cheatgrass and English Ivy were on the list of target species in all states. West-wide, Cheatgrass was found on 11% of the stream length; its presence varied from less than 0.1% in the Pacific Northwest ecoregion to 42% in the Xeric Northern Basin ecoregion. West-wide English Ivy was found on less than 0.5% of the stream length, but its presence ranged from 0% of stream length in at least six of the ten ecoregions, to 7.7% of stream length in the Xeric California Lowlands.

The relative extent of stressors in the 10 ecological regions is illustrated shown in Figure 15, with the order of stressors set by the west-wide results shown in Figure 9, and listed consistently in each panel of Figure 15. Among the most striking results:

- Riparian disturbance was the most commonly occurring stressor in seven of the ten ecological regions.
- The Northern and Southern Xeric Basin and Range regions were typified by high rates of habitat disturbance (riparian disturbance, streambed stability and habitat complexity).
- Non-native vertebrates were the first or second most common stressor in six of ten ecoregions, three of which are mountain ecoregions.

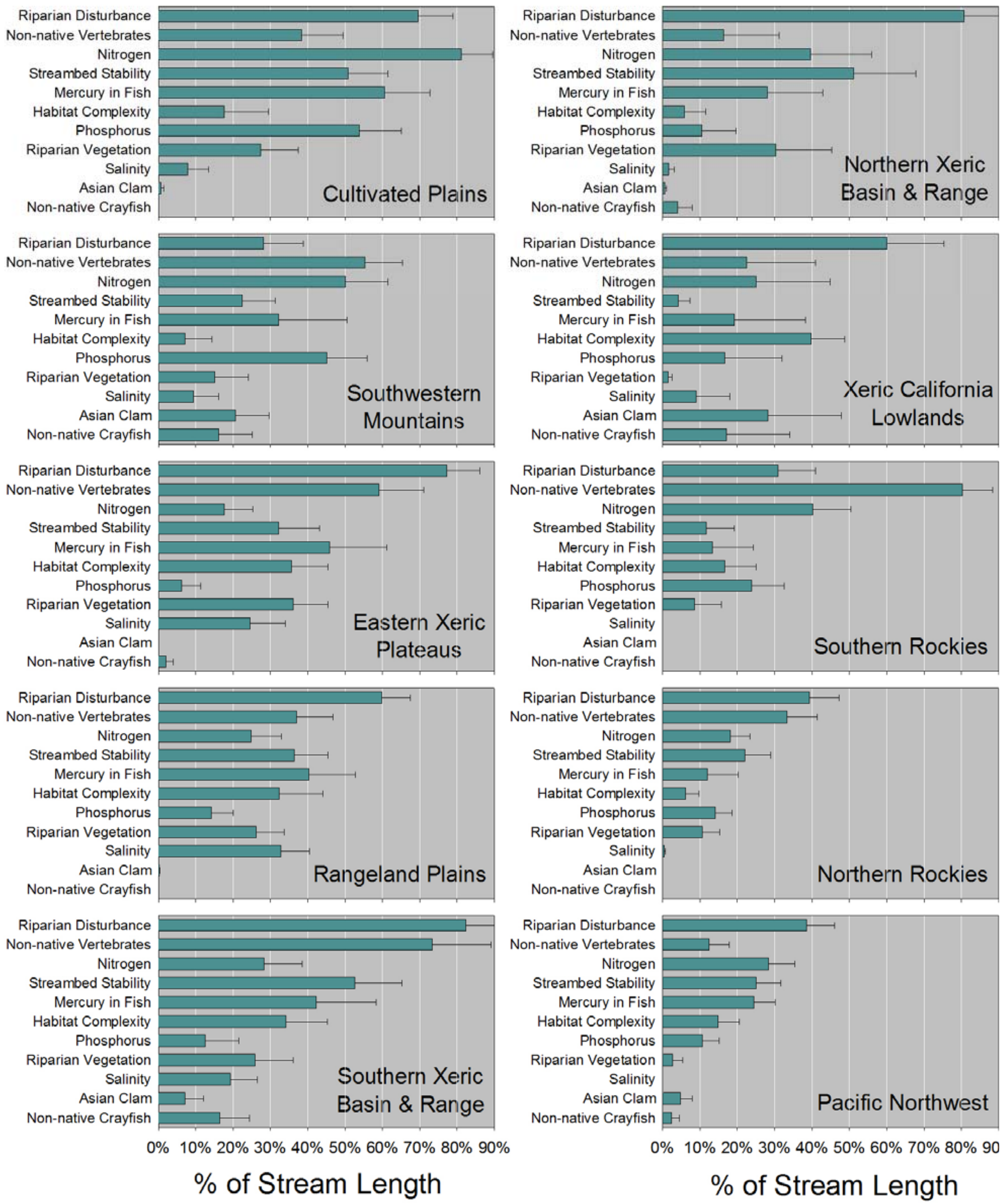


Figure 15. Relative extent of stressors in each ecoregion of the West. Order of stressors is the same as in Figure 9 (set by the west-wide results, with the most common stressors west-wide at the top of each panel).

Appendix D: Reference Condition and Condition Classes

In an assessment of this type there are multiple options for establishing reference condition and deciding where to place the thresholds between condition classes. To some extent, this discussion detracts from the real value of probability data like those collected for EMAP West. The statistical design of EMAP West allows us to extrapolate results for any indicator from a relatively small number of sites to the target population of concern. In many ways, the most quantitative description of the results is the resulting distribution (see Figure 16), or cumulative distribution function (CDF). Once this distribution is established, thresholds can be drawn at any point in the distribution, by any number of methods (e.g., based on best professional judgment, set by societal values, or the distribution approach we describe below). Although presenting EMAP West results in terms of condition classes (most-disturbed, intermediate and least-disturbed) requires us to estimate thresholds, there is additional information present in the CDF beyond the simple estimates of the percentages of stream length in each class. The thresholds we use in this report, which are described in some detail in the following pages, are based on a scientifically justifiable approach, and are repeatable. They have been made by EMAP West scientists, in conjunction with the personnel in EPA Regions 8, 9 and 10. But they are still just the best professional judgment of a small group of people, with the aim of turning a continuous distribution like the one in Figure 16 into a three discrete condition classes. Other methods are possible, and if applied might be equally valid. The main value of a dataset like the one collected in EMAP West is that, in the future, any such alternative thresholds can be applied to the data to produce an Assessment based on a different set of decisions and judgments.

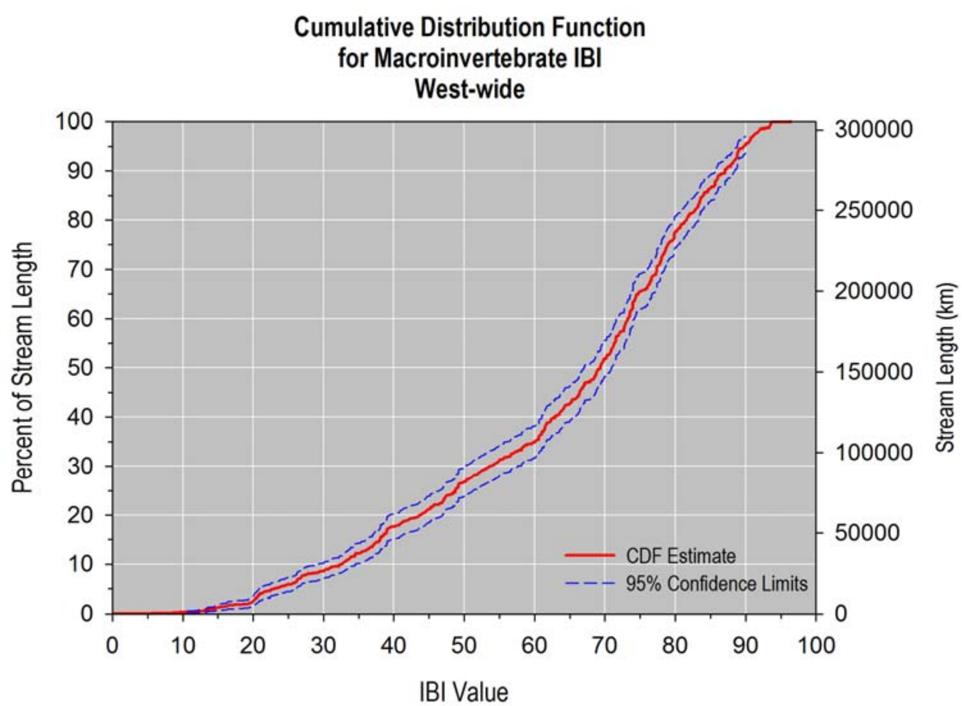


Figure 16. Cumulative frequency distribution for macroinvertebrate IBI in perennial streams and rivers west-wide

For the purposes of this assessment, we have uses a reference site approach[18, 19] to set expectations:

- A collection of Least Disturbed sites in each region is identified using regional reference site screening criteria. These may be either probability sites or hand-picked sites (because they are not used in making population estimates, only to set the reference baseline).
- The Least Disturbed sites are sampled using methods identical to those used at the sites we are trying to assess.
- The range of conditions found in these "reference sites" describe a distribution of values, and extremes of this distribution are used as thresholds to distinguish sites in relatively good condition from those that are clearly not.

Of course, we can't ignore the possibility that using the Least Disturbed sites in each region as references creates a sliding scale—it is very likely that historical development patterns, and types of landuse that predominate in different regions, have created a mosaic of disturbance patterns. Some ecological regions may still be dominated by relatively undisturbed streams, while in others no sites could truly be described as undisturbed. In the case of the West, the Mountain climatic region has a large proportion of its stream length in relatively pristine condition. In the Plains region, on the other hand, it is extremely difficult to find streams that have not been altered by grazing, farming, removal or modification of riparian forests, or roads. "Least Disturbed Conditions" are not equivalent in these two regions.

In order to calibrate these regional differences, we have tried to quantify the relative quality of Least Disturbed reference sites in each of the climatic regions of the West. Two of the indicators we have used to assess reference site quality are illustrated in Figure 17 (watershed disturbance) and Figure 18 (non-tolerant macroinvertebrates). The index of watershed disturbance in Figure 17 is developed by examining aerial photos for each stream's watershed, and tallying the presence or absence of various types of visible human disturbance (e.g., mining, gravel pits, roads, trails, off-road vehicle use, row-crop agriculture, logging, grazing, etc.)[22]. The resulting scores range from 0 (no disturbance visible) to 10 (heavily disturbed). Figure 17 shows the range of disturbance scores in the Least Disturbed sites in each of the 10 ecological regions we examine in the West. Note that the two ecoregions of the Plains have some Least Disturbed sites with scores as high as 9, but no sites with scores of 0 or 1 (in fact the Cultivated Plains had no sites with values below 5). In the mountainous ecoregions, on the other hand, zero scores were common. The range of scores in the xeric ecoregions were generally intermediate between the Plains and Mountains. Remember that these scores are not for all of the stream and river sites in these ecoregions, but only for the very "best of what's left."

Figure 18 shows a similar plot for one of the key characteristics of the macroinvertebrate assemblages in Least Disturbed sites. We calculate the percentage of individuals found at each site that would be classified as non-tolerant (i.e., they are classified as either sensitive or moderately sensitive to pollution). As the biological condition at stream and river sites degrades (either through time, or across a gradient of low to high disturbance), the dominance of the macroinvertebrate assemblage by non-tolerant taxa is expected to decrease[23]. In the case of the Least Disturbed sites in EMAP West, the same pattern observed for disturbance at the watershed level (Figure 17) is evident in the biota—ecoregions in the Plains exhibit a pattern of more disturbance, while ecoregions in the Mountains show relatively little. Least Disturbed sites in the Xeric ecoregions are intermediate between the Plains and the Mountains.

Our approach for deciding what constitutes relatively good vs. relatively poor condition in each of the three major climatic regions needs to incorporate this diminution in reference site quality. In general, our approach has been to use the percentiles described above (the 5th and 25th percentiles of the reference distribution) to establish thresholds for the Mountains and Xeric climatic regions, but to relax these criteria in the Plains. In the Plains most of our indicators are scored using the 25th and 50th percentiles. Actual threshold values for each indicator and the percentages of the reference distribution they represent are shown in Table B-1.

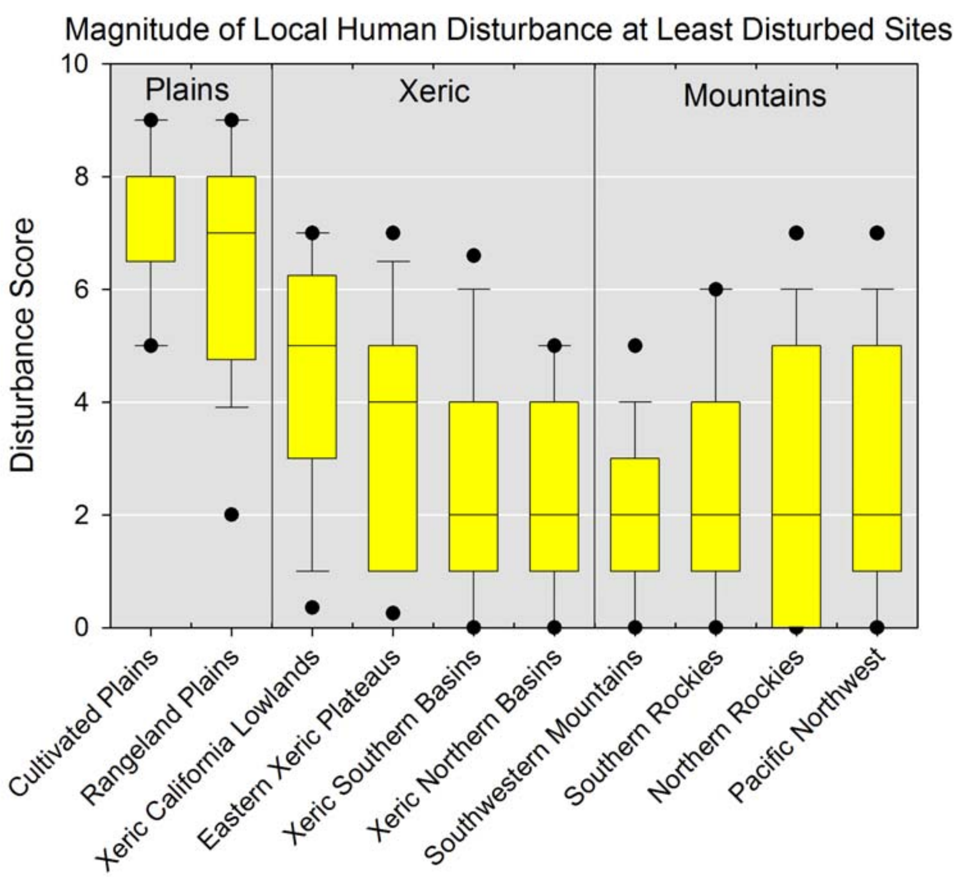


Figure 17. The ranges of watershed disturbance found in Least Disturbed sites in each of the ecological regions of the West. Disturbance scores were developed by examining aerial photos of each watershed for visible signs of human disturbance[22]. Zero values indicate no disturbance (visible in aerial photos), while ten indicates considerable disturbance. Boxes show the median (line) and the 25th to 75th percentiles of each range. Bars show the 10th and 90th percentiles; dots indicate the 5th and 95th percentiles.

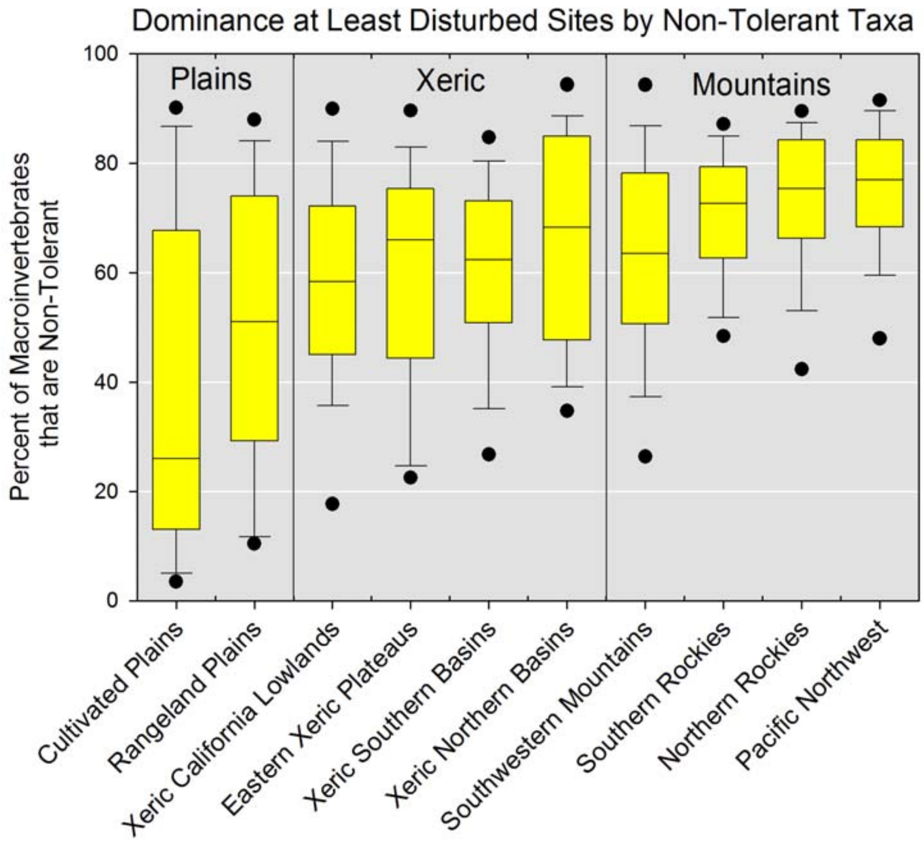


Figure 18. The dominance of Least Disturbed sites in each ecological region by macroinvertebrates considered to be non-tolerant. Low values suggest sites and regions where tolerant taxa are common. High values indicate sites and regions where many taxa are sensitive to human disturbance. Boxes, bars and symbols are as in Figure 17.

One further detail in establishing each threshold is important to explain. For each indicator where the reference distribution was used to estimate thresholds, the reference site selection was carried out without referring to the results for the specific indicator being assessed. For example, thresholds for the biological indicators were developed from a set of Least Disturbed sites determined using the chemical and physical habitat variables only. To avoid circularity, none of the biological data themselves were used. The process for setting thresholds for physical habitat indicators followed a similar philosophy--reference site criteria were redefined using a mixture of chemical and physical variables, but avoiding the variables used in the physical habitat index in question. A similar process was used to estimate thresholds for the chemical stress indicators. The only exceptions to this process (using a reference site approach, and the resulting reference distribution to estimate thresholds) were the following:

- For macroinvertebrate taxa loss (the O/E Index) we used common sense thresholds as criteria. The most-disturbed condition was defined as having lost more than 50% of the expected taxa—most people would recognize a 50% loss of species as significant. The intermediate class was defined as having lost between 20% and 50% of taxa, and the least-disturbed condition class included only sites with less than 20% loss of macroinvertebrate taxa.

- For mercury in fish tissue we used a published wildlife criterion (0.1 µg/g) derived from research on mercury effects on American river otter (*Lontra canadensis*)[24]—any site where any fish species exceeded this concentration was considered to be in most-disturbed condition with respect to mercury.
- For non-native vertebrates, the reference site approach has limited applicability. Because non-native fish and amphibians are so widespread in the West, even sites with the best possible chemical and physical habitat condition are likely to have some non-native species present. For this reason, we again applied a common sense approach to set thresholds for this indicator. We placed any site where more than 10% of the individuals sampled were non-natives in the most-disturbed condition class for this indicator. The intermediate class consisted of sites with non-natives present, but where they represented less than 10% of the individuals sampled. The least-disturbed class had sites where no non-natives were found.
- For non-native crayfish and Asian clams, where only presence or absence could be established, the most-disturbed class consisted of all sites where one of these non-native taxa was found. Non-natives were absent from sites in the least-disturbed class.

Table D-1. Thresholds used in this Assessment to separate condition classes, and the approximate percentage of the reference site distribution they represent. Thresholds were estimated separately for each climatic region; Habitat Complexity and Streambed Stability thresholds were estimated separately at the ecoregion level in the Mountain climatic region. Names in parentheses are variable names from the EMAP West database.

MOUNTAINS	MOST-DISTURBED		LEAST-DISTURBED	
	Threshold	%	Threshold	%
Aquatic Vertebrate IBI (MMI_VERT)	<37	5th	≥62	25th
Macroinvertebrate IBI (MMI_BUG)	<57	5th	≥71	25th
O/E Index (OE_BEST)	<0.5	a	≥0.8	a
Phosphorus (PTL)	>40 µg/L	5th	≤10 µg/L	25th
Nitrogen (NTL)	>200 µg/L	5th	≤125 µg/L	25th
Salinity (COND)	>1000 µS/cm	5th	≤500 µS/cm	25th
Mercury	>0.1 µg/g	b	≤0.1 µg/g	b
Riparian Disturbance (W1_HALL)	>0.95	95th	≤0.35	75th
Habitat Complexity (XFC_NAT)	<0.18 (NRock) <0.14 (PNW) <0.31 (SRock) <0.10 (SWest)	5th 5th 5th 5th	≥0.34 (NRock) ≥0.33 (PNW) ≥0.56 (SRock) ≥0.37 (SWest)	25th 25th 25th 25th
Streambed Stability (LRBS_BW5)	<-1.8 or >0.1 (NRock) <-1.3 or >0.6 (PNW) <-1.6 or >0.3 (SRock) <-1.3 or >0.6 (SWest)	5th 5th 5th 5th	≥-1.1 & ≤-0.4 (NRock) ≥-0.7 & ≤0.1 (PNW) ≥-0.9 & ≤-0.2 (SRock) ≥-0.6 & ≤0.1 (SWest)	25th 25th 25th 25th
Riparian Vegetation (XCMGW)	<0.23	5th	≥0.67	25th
Non-native Vertebrates	>10% of Individuals	c	Absent	c
Non-native Crayfish	Present	c	Absent	c
Asian clam	Present	c	Absent	c

Table D-1, Continued

XERIC	MOST-DISTURBED		LEAST-DISTURBED	
	Threshold	%	Threshold	%
Aquatic Vertebrate IBI (MMI_VERT)	<29	5th	≥40	25th
Macroinvertebrate IBI (MMI_BUG)	<47	5th	≥56	25th
O/E Index (OE_BEST)	<0.5	[a]	≥0.8	[a]
Phosphorus (PTL)	>175 µg/L	5th	≤40 µg/L	25th
Nitrogen (NTL)	>600 µg/L	5th	≤200 µg/L	25th
Salinity (COND)	>1000 µS/cm	5th	≤500 µS/cm	25th
Mercury	>0.1 µg/g	[b]	≤0.1 µg/g	[b]
Riparian Disturbance (W1_HALL)	>0.9	90th	≤0.7	75th
Habitat Complexity (XFC_NAT)	<0.132	10th	≥0.270	35th
Streambed Stability (LRBS_BW5)	<-1.7 or >0.3	10th	≥-0.9 & ≤-0.1	25th
Riparian Vegetation (XCMGW)	<0.32	5th	≥0.60	25th
Non-native Vertebrates	>10% of Individuals	[c]	Absent	[c]
Non-native Crayfish	Present	[c]	Absent	[c]
Asian clam	Present	[c]	Absent	[c]

Table D-1, Continued

PLAINS	MOST-DISTURBED		LEAST-DISTURBED	
	Threshold	%	Threshold	%
Aquatic Vertebrate IBI (MMI_VERT)	<35	25th	≥45	50th
Macroinvertebrate IBI (MMI_BUG)	<41	25th	≥51	50th
O/E Index (OE_BEST)	<0.5	[a]	≥0.8	[a]
Phosphorus (PTL)	>300 µg/L	25th	≤40 µg/L	50th
Nitrogen (NTL)	>1100 µg/L	25th	≤300 µg/L	50th
Salinity (COND)	>2000 µS/cm	25th	≤1000 µS/cm	50th
Mercury	>0.1 µg/g	[b]	≤0.1 µg/g	[b]
Riparian Disturbance (W1_HALL)	>1.3	75th	≤1.0	50th
Habitat Complexity (XFC_NAT)	<0.125	25th	≥0.359	50th
Streambed Stability (LRBS_BW5)	<-2.5 or >0.3	10th	≥-1.7 & ≤-0.5	25th
Riparian Vegetation (XCMGW)	<0.15	10th	≥0.35	35th
Non-native Vertebrates	>10% of Individuals	[c]	Absent	[c]
Non-native Crayfish	Present	[c]	Absent	[c]
Asian clam	Present	[c]	Absent	[c]

[a] Thresholds for O/E Index were not based on the reference site distribution (see text)

[b] Thresholds for mercury were based on a published wildlife criterion

[c] Thresholds for Non-native Taxa were not based on the reference site distribution (see text)

Appendix E: Estimating Relative Risk

Relative risk measures the likelihood that the most-disturbed condition of a biological indicator will occur in streams that are also most-disturbed for a stressor[20, 25]. We define relative risk (RR) as the ratio of two probabilities, or 'risks':

$$RR = \frac{\Pr(\text{most-disturbed biological condition} \mid \text{most-disturbed stressor condition})}{\Pr(\text{most-disturbed biological condition} \mid \text{least-disturbed stressor condition})}$$

where the numerator and denominator are conditional probabilities of most-disturbed biological condition, given that sites are in either most-disturbed (numerator) or least-disturbed (denominator) stressor condition.

Relative risk is calculated from the estimated lengths of stream that have various combinations of biological and stressor conditions. These estimates can be arranged in a contingency table, as illustrated below for Aquatic Vertebrate Integrity versus the Riparian Habitat stressor.

Estimated stream length, west-wide (km)		*Riparian Habitat disturbance class*	
		Least	***Most***
Aquatic vertebrate disturbance class	***Least***	51432	44521
	Most	11112	31188

From this table, the risk of finding a most-disturbed condition for aquatic vertebrates, in streams having most-disturbed riparian habitat, is estimated to be:

$$31188 / (31188 + 44521) = 0.42$$

Similarly, the risk of finding a most-disturbed condition for aquatic vertebrates, in streams having least-disturbed riparian habitat, is estimated to be:

$$11112 / (11112 + 51432) = 0.18$$

Comparison of these two risks shows that a most-disturbed condition for aquatic vertebrates has a greater risk of occurring when riparian habitat conditions are also most disturbed (risk = 0.42) than when they are least-disturbed (risk = 0.18). Relative risk expresses this comparison as a ratio, that is:

$$RR = 0.42/0.18 = 2.33$$

In other words, we are 2.33 times more likely to find a most-disturbed aquatic vertebrate condition in streams with most-disturbed riparian habitat than in streams with least-disturbed riparian habitat.