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Wildfires and Yellowstone's Stream Ecosystems

A temporal perspective shows that aquatic recovery parallels forest succession

G. Wayne Minshall, James T. Brock, and John D. Varley

Few studies have examined the effect of fire on the aquatic biota, and none has adequately addressed major aspects of aquatic ecosystem function. Most of the research has examined the effects of fire on water chemistry (Schindler et al. 1980, Tiedemann et al. 1979). Nevertheless, it is possible to develop a set of predictions regarding the immediate, near-term, and long-term consequences of the 1988 fires in the Greater Yellowstone Area (GYA) by supplementing the existing information base on fire response and general ecological behavior of aquatic ecosystems with knowledge of the response of aquatic systems to logging and to physical disturbances within the channel.

Of the 0.57 million ha of the GYA that burned (Burned Area Survey Team 1988), most (95%) of the area was forest, and the remainder was meadow, grassland, and sagebrush scrubland. Twenty separate river basins or major subbasins were affected by the fires to various degrees (Figure 1). Within Yellowstone National Park (YNP), approximately 32% (1380 km^2) of the stream system was influenced by the fires. In addition, the four large oligotrophic lakes (Yellowstone, Shoshone, Lewis, and Heart lakes), which together make up 94% of the park's water area, had significant portions of their drainages burned (Figure 1). Twenty-eight percent of the Yellowstone Lake watershed, 8% of the Shoshone Lake drainage, 33% of the Lewis Lake drainage, and 50% of the Heart Lake watershed were affected by fire to some degree.

Effects of the fires are likely to be most pronounced in headwaters

In general, loss of vegetation is expected to increase water runoff, but not beyond the normal variability of the hydrologic systems. Due to differences in landscape morphology and in the nature of the fires, streams in the Madison, Upper Yellowstone (above Yellowstone Lake), and Snake river drainages are less likely to be affected by the 1988 fires than the other main river systems in the GYA.

The major effects are expected to parallel the forest recovery and, during the next 300 years, gradually return the aquatic ecosystem to the prefire state. The fires are expected to alter buildup of woody debris, sediment suspension, nutrient cycling, leaf litter input, and the types of aquatic organisms present. These effects are expected to be more pronounced in headwater streams, and they are likely to diminish with increased stream size.

Fire and landscape heterogeneity

The heterogeneous nature of the landscape, due in part to the varying extents of patchiness of the 1988 fires (Figure 1), has important implications for the fire impact on GYA stream ecosystems. The intensity of each fire varied from hot canopy fires (61% of the burned area), to cooler ground fires, to unburned patches of less than 50 ha. Although the percentage of each burn type was remarkably similar among the six major fires, the extent of patchiness varied considerably. Fires early in the summer, when fuel-moisture levels were higher, generally were patchier than those that burned later. After July 21, fires frequently were driven by 65–95 km/hr winds and tended to include wide swathes of continuous canopy burn with spotting by secondary fires to the sides and in front.

Fire impact on different streams is expected to vary proportionally with the intensity and extent of burning of a watershed and the vegetation formerly present. Responses are most likely to be seen in watersheds where the upper portions were heavily forested and were extensively burned (e.g., Lava, Tower, and Blacktail Deer creeks).

The impact also is expected to vary along a given stream system. The greatest impacts of fire probably will be seen in smaller (headwater) streams, and the effects will progressively dissipate downstream, except in reaches where fire-perturbed small tributaries enter a large mainstem

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The Shoshone fire, later reclassified as part of the Snake River complex, seen from Yellowstone Lake shore in late August. Photo: Jeff Henry, National Park Service.

river. The watersheds with small streams (first and second order)[1] commonly burned entirely, whereas watersheds with larger streams (fourth order or larger) rarely did so. Cache Creek and Hellroaring Creek are the only watersheds in which the portions greater than third order received substantial burning. Most of the GYA streams that support a major sport fishery (Firehole, Gallatin, Gardner, Gibbon, Lower Lamar, Madison, and Yellowstone rivers) are larger than fourth order, and thus they were affected little by the fires in their lower reaches.

The impact of the fire in each drainage also is regulated by factors affecting runoff and erosion. These factors include the physical make-up of the area (slope, aspect, elevation, gradient, geology, and soil depth) and climatic variables (temperature, precipitation, insolation, and storm intensity and frequency; Hydrology Assessment Team 1988, Minshall and Brock in press). Increases in flood potential and sediment yield are greatest in the upper subdrainages of Lamar River, Crandall Creek, and North Fork Shoshone River. These subdrainages are characterized by steep slopes (greater than 45%), shallow soils, unstable geology, and intense summer thunderstorms (Hydrology Assessment Team 1988).

In the Madison, upper Yellowstone, and Snake river systems, slopes generally are less steep, valley bottoms wider, and stream gradients lower. Also, the proportion of burned area on steep slopes is smaller. The result is that, even with some increases in water yield due to the reduction of vegetation by fire, the time of concentration of streamflow is lengthened by basin morphology, flood peaks are better regulated, and flooding is less likely (Hydrology Assessment Team 1988).

Temporal responses of stream ecosystems to fire

Stream ecosystem responses are closely linked to terrestrial plant conditions in the surrounding watershed (Hynes 1975, Minshall et al. 1985, Vannote et al. 1980). Therefore, changes in the structure and composition of terrestrial vegetation after wildfire (Arno et al. 1985, Lyon 1984, Romme 1982) may be expected to influence the adjacent streams. Because forest regeneration after wildfire is a long-term process, with a cycle of approximately 300 years, stream ecosystems are likely to respond similarly and shift in concert with temporal changes in plant community structure.

Current understanding of stream ecosystem dynamics provides a rich base from which to postulate specific changes in stream ecosystems as a result of forest changes after wildfire. Paramount to such understanding is the recognition of the crucial link between the food available and the feeding characteristics of the fauna in streams (Cummins 1974, Molles 1982). It is also important to recognize the influence of stream size as a modifier of land-water interactions (Minshall et al. 1985, Vannote et al. 1980).

The effects of fire on aquatic ecosystems can be partitioned into immediate effects that arise directly from the fire (e.g., increased temperature,

[1]In stream terminology, the smallest unbranched tributaries are *first order*. Two first-order streams join to form a second-order stream. The world's largest rivers (e.g., Amazon or Mississippi) are tenth to twelth order.

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altered water chemistry, and abrupt change in food quality) and delayed impacts. Some of these delayed effects are primarily physical disturbances associated with increased runoff. These effects are likely to exert their maximal impact within the first one to four years after a fire. In addition, there are likely to be longer-term alterations associated with the removal and eventual successional replacement of the riparian and terrestrial vegetative cover (Figure 2) and consequent alteration of food resources and retention capacity in the stream (Likens and Bilby 1982, Molles 1982).

Immediate effects. Except in small water bodies (first-order streams and small seeps), the high specific heat of water and replenishment from cool groundwater sources are likely to have prevented the heat from the Yellowstone fires from seriously damaging the aquatic biota. Cushing and Olson (1963) recorded a 10° C increase in temperature for a short time in a small, slow-moving stream after the burning of weeds that covered the stream and its banks. Trout (*Oncorhynchus mykiss,* formerly *Salmo gairdneri*) in wire-mesh cages showed marked distress but did not die. Heat fracturing of the surfaces of rocks in first-order streams and incineration or scorching of exposed and shallowly submerged aquatic plants have been observed in GYA.[2] However, in most cases the fires are thought to have heated the water at most a few degrees (Albin 1979, Ice 1980). In larger streams, such as the Firehole River, shading by dense clouds of smoke actually may have reduced water temperatures compared to those on a clear day (Ice 1980).[3]

Data from previous fire experience indicate that few, if any, adverse effects of the Yellowstone fires on water chemistry are to be expected (Johnson and Needham 1966, Schindler et al. 1980, Tiedemann et al. 1978, Wright 1976). Instead, algal growth may be temporarily stimulated to levels considered beneficial (Albin 1979, McColl and Grigal 1975). However,

[2]G. W. Minshall, 1988, unpublished observation.

[3]E. D. Koch, 1988, personal communication. Idaho State University, Pocatello.

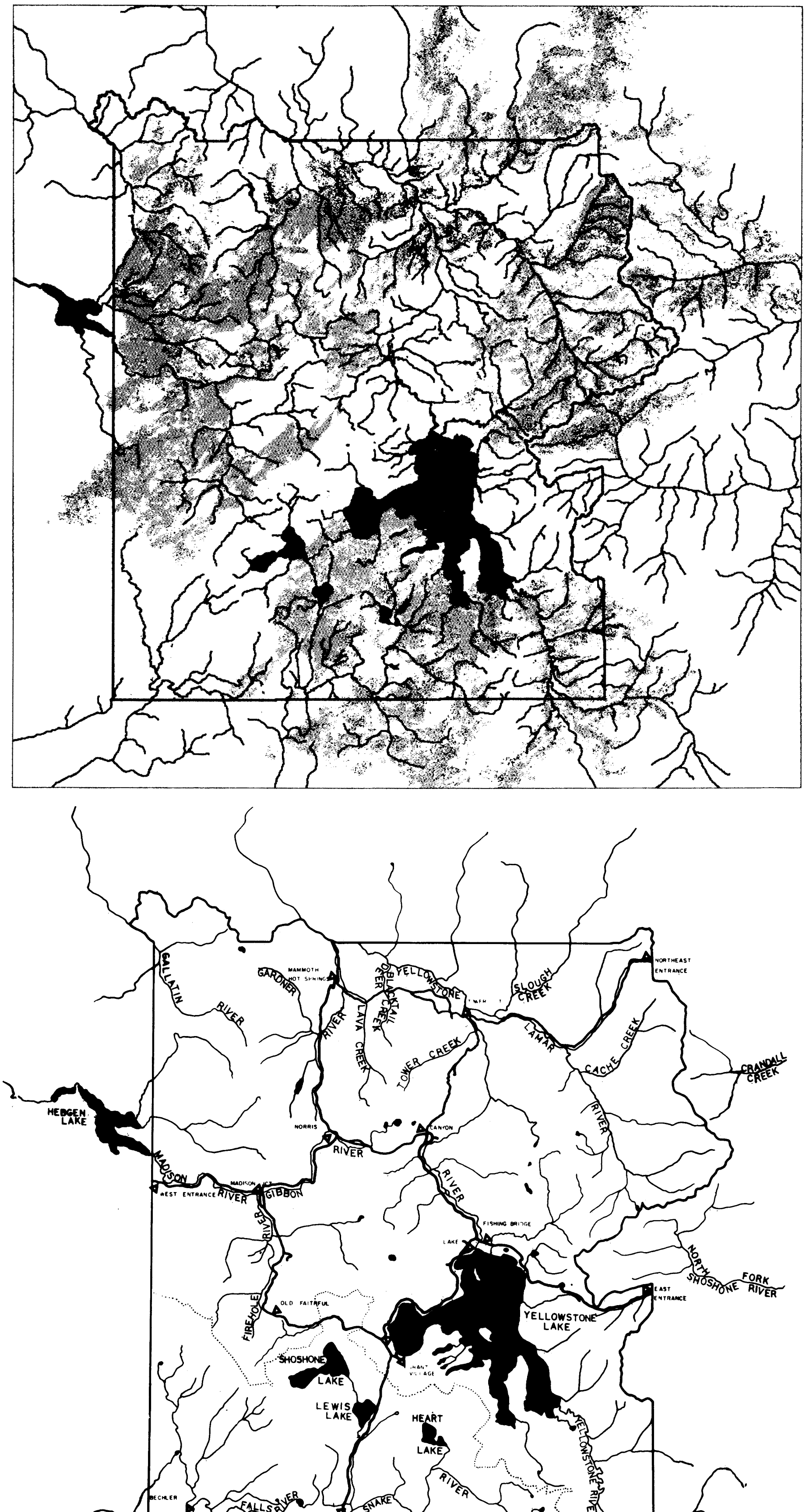

Figure 1. a. Extent of 1988 GYA fires by drainage basin. **b.** Names of lakes and streams. Data from Burned Area Survey Team 1988.

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dead fish were observed in some second- and third-order streams in Yellowstone,[4] which may have been due to increases in certain ions from ash entering the water (Cushing and Olson 1963). In these areas, the fire may have burned more intensely and thoroughly than did those fires previously studied (Schindler et al. 1980). In addition, increased pH may act directly on aquatic organisms or may enhance the toxicity of certain substances, such as ammonia. In some cases (e.g., Little Firehole River), significant fish mortality resulted from accidental drops of ammonium phosphate, a fire retardant, into aquatic habitats.[5]

Midterm effects. The secondary consequences of fire on aquatic ecosystems in GYA may be separated into midterm and long-term effects. Midterm effects are those exerting their maximal impact within the first few years after a fire. Most of the adverse midterm delayed effects are likely to be due to increased sediment levels and turbidity and erosion of stream channels (Minshall and Brock in press). Delayed detrimental influences on water chemistry generally are prevented by chemicals becoming diluted, being taken up by plants, and binding to soil, roots, and debris.

Although moderately burned watersheds may show little or no change in stream chemistry, the combustion of living and detrital plant biomass disrupts nutrient cycling, and the watershed can lose nutrients via stream runoff. Several studies report increased nutrient runoff after wildfires or logging and slash burning (Brown et al. 1973, McColl and Grigal 1975). Other researchers suggest that microbial uptake and absorption on soil particles prevents nutrients from entering aquatic systems (Johnson and Needham 1966). We expect that for several years after the Yellowstone fires, nutrient output (Figure 2) will increase, because terrestrial plant uptake will be reduced and there will be increased mineralization and leaching of elements accumulated in the watershed.

Incident solar radiation initially increases sharply as a result of the fire

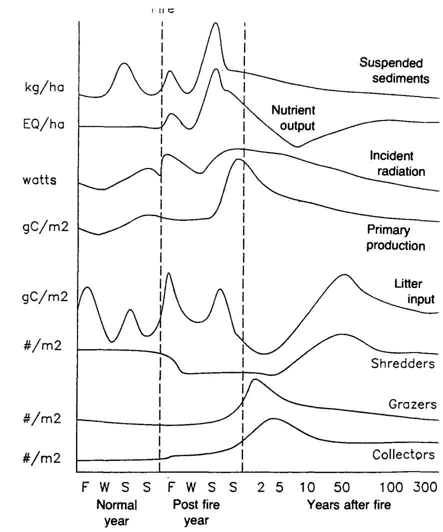

Figure 2. Projected stream ecosystem responses to a wildfire. These hypothetical trajectories illustrate anticipated changes in key physical and biotic factors. Immediate and long-term effects are illustrated by using a logarithmic scale on the abscissa after the first postfire year. Actual values depend on watershed size and edaphic influences such as watershed aspect, slope, bedrock geology, severity of fire damage (intensity and areal extent), and climatic factors such as precipitation and temperature.

due to removal of overstory vegetation, and it gradually diminishes as this vegetation recovers (Figure 2). Increased solar radiation reaching the water after a fire can elevate summer stream temperatures as much as 8–10° C (Brown 1971, Burton and Likens 1973, Helvey 1973). These increases may have a detrimental effect if they exceed critical threshold levels for resident invertebrate or fish populations. However, it is more likely that the slight (2–4° C) increases expected in most cases (Albin 1979), coupled with the increases in light and nutrients, will increase primary and secondary production, including growth of algae, invertebrates, and fish (Murphy et al. 1986, Noel et al. 1986, Wallace and Gurtz 1986). The algae (and subsequent fauna) are expected to retard the downstream movement of nutrients.

These after-fire conditions in severely burned watersheds may result in enhanced production of algae for two to six years, particularly in headwater streams. Low-order streams, which were formerly dependent on exogenous sources for their organic energy, can be expected to shift to autotrophy until riparian communities develop sufficiently to provide shade and adequate litter for a return to dependence on allochthonous (terrestrially derived) organic material (Cummins 1974, Minshall 1978).

Long-term effects. Most of the long-term responses of Yellowstone aquatic ecosystems to the 1988 fires (Figure 2) are likely to be closely allied with the recovery of the forest and understory vegetation (Figure 3; Hynes 1975, Likens and Bilby 1982, Minshall et al. 1985, Molles 1982, Vannote et al. 1980). Eventually, recovery of the forest cover should result in increased shading of streams and decreased runoff and input of nutrients, returning conditions in these habitats to prefire levels. Even within a region the size of the GYA, factors that regulate forest succession, such as elevation and climate, may cause streams to differ in their long-term responses to disturbance from wildfire.

Organic debris dams. Dams of organic debris, incorporating pieces of large wood, serve to retard the downstream movement of particulate organic matter and inorganic sediments (Bilby 1981, Likens and Bilby 1982, Megahan 1982, Megahan and Nowlin 1976). Consideration of the fate of wood in streams of forested watersheds after large-scale disturbances (wildfire or intensive logging) indicates that the diameter and mass of woody debris, and hence its ability to help retain particulate organic matter, should increase progressively with successional development of the forest (Likens and Bilby 1982, Molles 1982).

Large amounts of woody debris accumulate in old-growth forest streams. Because of its high moisture content, most of this material remains intact even after hot fires and is rapidly augmented by branches and trunks brought down by the fire (Figure 4). This material remains in place unless sufficiently high discharges flush out all but the most stable pieces.

Although fallen fire-killed snags continue to accumulate in streams for 20–25 years after a fire, the new growth (through early to middle im-

[4]See footnote 1.
[5]See footnote 2.

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mature forest; Figure 3) in the riparian forest contributes little woody debris (Lyon 1984). Work by Golladay and Webster (1988) suggests that increased stream nitrogen levels, greater invertebrate abundance on woody substrates, and greater stream channel instability may break down woody debris faster in the first few years after a fire than at other times. As the forest matures and natural thinning occurs, additional woody material, increasing in diameter and mass, accumulates in streams. This process accelerates as old-growth forest conditions are attained, and standing stocks of wood in the stream return to prefire levels.

Retention of woody debris is a direct function of the size of the material relative to the width and depth of the stream. Smaller streams begin to recover to prefire levels of wood debris sooner than larger streams, and the frequency of debris dams decreases with increasing stream size (Likens and Bilby 1982). In the GYA, the pattern shown in Figure 4 is most appropriate for headwater through third-order streams; significant woody debris accumulations are absent in most streams greater than fourth order.

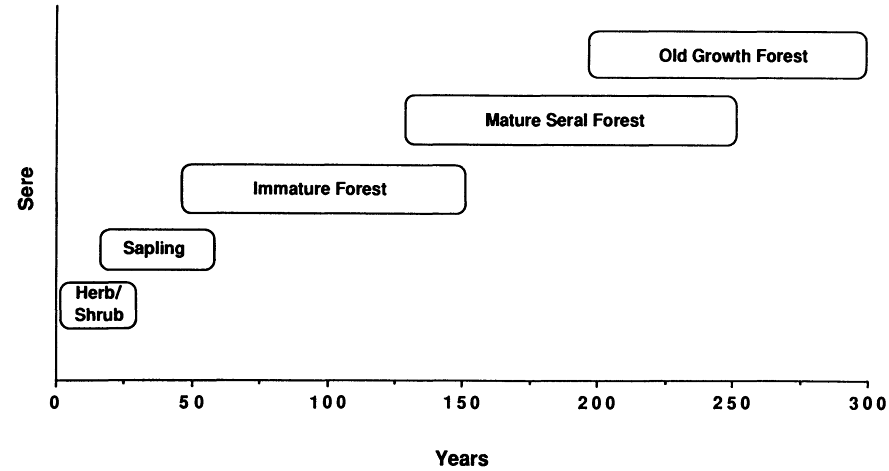

Figure 3. Succession in lodgepole pine (*Pinus contorta*) forest after wildfire (after Arno et al. 1985, Romme 1982).

SUSPENDED SEDIMENTS. Suspended-sediment yield (Figure 2) is normally positively correlated with water discharge, and in the Rocky Mountain region sediment yield follows the general pattern of snowmelt runoff (Bjornn et al. 1977). Mass movement (movement of a portion of the land surface, as in creep, landslide, or slip), wind, and rain are expected to produce an increase in sediment concentration in the months immediately after a fire. Snowmelt runoff is expected to carry abnormally high suspended-sediment loads, which decrease annually as the watershed becomes revegetated (Megahan et al. 1980). Unusually high spring runoff or intense summer thunderstorms after the first year could cause short-term departures from this decreasing trend.

Increased sediment erosion into streams draining burned watersheds, as well as the elevated suspended-sediment levels, invariably result in increased sedimentation in downriver depositional areas. As the burn site revegetates and erosion diminishes in the years after a fire, the deposited fine sediments in mountain streams are expected to be progressively transported downriver by spring runoff. This sequence was observed for the south fork of the Salmon River in Idaho after cessation of logging activities (Megahan 1975, Megahan et al. 1980).

NUTRIENT CYCLING. The initial nutrient pulse is expected to be followed by a gradual decrease in nutrient loss from the watershed, concomitant with high recovery of net photosynthetic rates of terrestrial vegetation (Bormann and Likens 1979). Low nutrient concentrations in the stream 5–10 years after the fire (Brown et al. 1973) are expected to contribute to the decline in autochthonous (within the stream) production.

Although the effect of enhanced light levels in increasing primary production should persist 10–20 years (Hansmann and Phinney 1973, Hawkins et al. 1983, Murphy et al. 1986, Newbold et al. 1980, Noel et al. 1986), low nutrients may override the stimulatory effect of increased light. For example, in Carnation Creek, logging increased the amount of light reaching the water, but primary and secondary production remained limited by low phosphorus (Culp and Davies 1983, Shortreed and Stockner 1982). During later forest succession, we expect nutrient export levels to drop below prefire levels as competi-

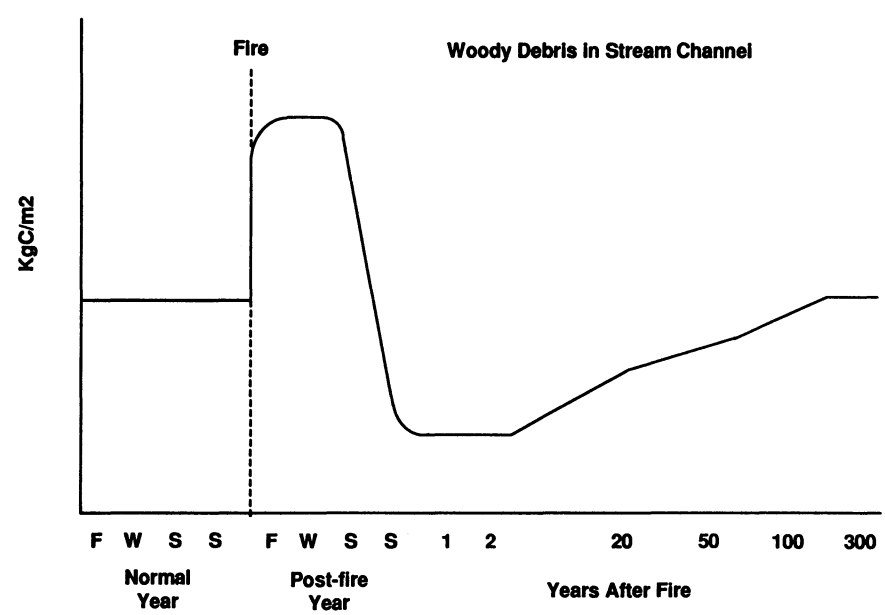

Figure 4. Postulated response of woody debris in lodgepole pine forest after wildfire.

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tion among plants for nutrients intensifies and nutrients accumulate in plant biomass (Bormann and Likens 1979).

The changing nutrient and light regimes are expected to shift temporarily the benthic flora from diatoms and moss to green algae, with brief (2- to 5-year) development of filamentous algal mats (e.g., *Cladophora*). Albin (1979) found no difference between attached algae accumulations in unburned sites and those burned 36 and 45 years previously, thus supporting the pattern shown for recovery of primary production in Figure 2.

Streams should be efficient at retaining nutrients after fires, and the degree of response depends on stream order (Grimm 1987, Meyer 1980, Meyer and Likens 1979, Minshall et al. 1983b, 1985, Newbold et al. 1982, 1983, Vannote et al. 1980). With increasing stream order, the riparian canopy is likely to have a progressively declining effect on instream ecosystem dynamics (Vannote et al. 1980). Most nutrient uptake and growth of algae and other organisms is expected to occur in first- and second-order streams, and little effect of wildfires will be seen with respect to light and nutrient dynamics in streams larger than approximately fourth order. A major exception to this generalization may be the influx of nutrients from tributaries into streams that are fourth order or larger (Minshall et al. 1985).

The two major factors affecting the pattern of dissolved nutrient concentrations in streams are water-borne transport and biotic uptake and release (Minshall et al. 1983b, Newbold et al. 1982). Biotic processes appear to be more important in regulating phosphorus, nitrogen, and potassium, whereas discharge (volume of water per unit time) and related geologic processes are thought to exert the dominant regulatory force on calcium, magnesium, and sodium ions (Henderson et al. 1978). In GYA, physical transport is most important during spring runoff and sporadic summer rain storms, and biotic uptake peaks at midsummer.

In streams in the western United States, the most important nutrient regulating the primary producers often is nitrogen (Grimm and Fisher 1986). Therefore, it is expected that nitrogen entering GYA streams from the watershed will be taken up rapidly and retained tightly by the system (Grimm 1987, Newbold et al. 1983). It also is likely that nitrogen will markedly influence the rate of litter decomposition (Meyer and Johnson 1983). The nitrogen effects on both primary producers and litter decomposition can control secondary production in streams (Grimm 1988).

Measurements from Cache Creek in YNP shortly after the 1988 fire indicate a progressive decline in nitrogen concentration with distance downstream[6] (Figure 5). The greatest change (sixfold) occurred between first- and second-order sites, and then a twofold decrease was observed at each of the subsequent shifts in stream order, continuing through the confluence of Cache Creek with the Lamar River. These results indicate substantial and differential uptake of nitrogen along the course of the stream, even though October is a period of declining light and temperature. The most significant variation in this downstream pattern should occur as a result of the entrance of tributaries draining burned watersheds. We expect the lower-order, nutrient-laden tributaries to stimulate biotic production in the receiving streams for some distance downstream of their confluence. This biostimulatory response should significantly retard the downstream flush of nitrogen. However, severely decreased light levels, due to suspended sediments during storm runoff, could counteract this nutrient enrichment effect.

ORGANIC LITTER INPUT. Organic litter input to the land and stream, including export to and retention by the flood plain adjacent to the stream during runoff, will be elevated during the first year after the fire, but then it will decline as the forest community returns (Figure 2). There is experimental evidence (Otto and Svensson 1981) that aquatic herbivores may be sensitive to differences in secondary compounds in vascular plants. Thus far, the topic has been examined only from the perspective of the coevolution of aquatic grazing invertebrates versus aquatic and riparian plants. Given the aquatic invertebrates' demonstrated ability to distinguish between closely related aquatic and terrestrial plants, it seems quite feasible that changes in secondary compounds in terrestrial vegetation in response to fire could result in changes in the quality of allochthonous leaf litter entering streams, which would affect its use by aquatic detritivores. Because allochthonous detritus is a primary determinant of energy and organic-matter dynamics in streams (Hynes 1975), any significant changes in its quality or quantity are likely to exert profound effects throughout the stream ecosystem.

STREAM FAUNA. Responses of the benthic invertebrates to the aftermath of the Yellowstone fires are expected to vary depending on the degree of sedimentation (Hawkins et al. 1983) and streambed movement that occurs. Increased flows, streambed erosion, and high suspended-sediment concentrations for major snowmelt or rainfall runoff pulses in the first year after the fire may bring about massive invertebrate drift out of streams draining the burned areas. Deposition of fine sediments also may cause diminished invertebrate standing crops in those habitats affected. For example, heavy accumulations of fine sediments will eliminate the mixed gravel-cobble substrate preferred by endemic species, causing recovery to be delayed until sediments are eroded and the benthos is recolonized.

Recolonization of these depopulated areas will depend on the extent of fire-induced disruption of upstream headwater areas, which will serve as seed sources. From previous work conducted on the Teton River in Idaho (Minshall et al. 1983a), we predict that recovery may take three years or more, depending on the severity and extent of scouring due to runoff.

Benthic invertebrates can be divided into groups on the basis of their feeding behaviors. These categories are called functional feeding groups and are expected to respond differently to the effects of fire. They include shredders, which consume streamside, riparian litter after it enters the stream; collectors, which use small particles of organic matter in the water; and grazers (scrapers), which eat attached organic matter, especially algae.

[6]See footnote 2.

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During recovery from a fire, shredder populations (Figure 2) are expected to be almost entirely absent due to the destruction of quality leaf litter sources by the fire. Grazer density should increase after fire, following a pattern similar to that of primary production, on which they directly feed (Murphy et al. 1986, Noel et al. 1986, Wallace and Gurtz 1986).

Once a productive autotrophic community becomes established, amounts of high-quality benthic organic matter will be elevated, thereby enhancing collector populations, although some species may be eliminated due to the higher summer temperatures. Higher levels of transported organic material from both terrestrial (rapidly growing herbaceous and shrubby plants) and in-stream sources (sloughed periphyton and invertebrate feces) will bring about increased densities of filter feeders (a subcategory of collectors), most notably caddisflies (Hydropsychidae, Brachycentridae) and blackflies (Simuliidae). Collector densities consequently will exceed prefire levels during the intermediate postfire years due to elevated levels of endogenous organic material.

As postfire plant regrowth occurs and the canopy closes, we expect to see a shift in the predominant food from algae to terrestrial leaves and needles (Figure 2). High quality (fast decomposition) herbaceous litter, consumed first by shredders and then by collectors, should gradually be replaced by lower quality (slow decomposition) deciduous leaves, which in turn will be supplanted by even lower quality conifer needles and twigs (Figure 3). For example, Molles (1982) postulated that, during postfire forest succession, the recovery of Trichoptera shredders would parallel the accumulation of conifer wood and forest litter in streams. Over time, the shredder populations are expected to recover, whereas those of the grazers will decline to prefire levels.

Further, we expect that the number of debris dams will increase progressively during the first 25 years (Figure 4), resulting in increased retention capacity for allochthonous food resources. For example, Molles (1982) found five times the number of logs in conifer forest streams as compared to aspen forest streams and attributed the order of magnitude difference in detritus standing crop in the conifer streams to this difference in retention capacity. Likewise, Rounick and Winterbourn (1983) found that enhanced physical stability of the stream bed resulted in increased retention of allochthonous inputs and standing crops of shredders and elevated rates of leaf breakdown. Thus, as algal production declines due to reduced light and nutrient availability and as detrital standing crops increase with increasing litter and deadfall accumulations, a shift from low to high shredder:grazer ratios is to be expected (Molles 1982).

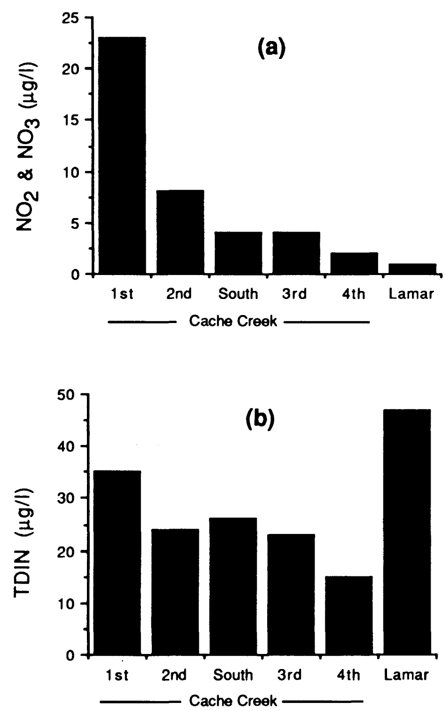

Figure 5. Nitrogen concentrations (mg/l) in Cache Creek, YNP, approximately two weeks after its watershed burned in 1988. **a.** Nitrite plus nitrate. **b.** Total dissolved inorganic nitrogen.

Potential responses to different degrees of disturbance

Fires of a magnitude such as burned during 1988 in GYA can have sweeping effects on the ecology of streams. The extent of the near-term effects of fire on stream ecosystems and the rates of return to prefire conditions are dependent largely on the degree of disruption of the watershed and stream channel in the first few years after fire. The difference (for a given environmental region) appears to be due primarily to the size of the watershed burned and the intensity of the fire. However, the chance occurrence of intense summer storms, common in the Yellowstone area, also is a factor.

In Figure 6, some potential responses to different degrees of disturbance resulting from fire are illustrated for biotic features such as abundance and richness. Three alternative trajectories are illustrated:

- Those streams that because of the smaller fire-affected catchments, greater water retention by the surrounding watershed, or sheer chance avoid high intensity, scouring discharges, will begin the recovery process relatively quickly. In such cases, the stream ecosystems are expected to return relatively rapidly to prefire conditions.
- In those streams in which the watershed becomes heavily eroded and the bed severely scoured, recovery will be delayed and may ultimately follow a different trajectory altogether.
- In severe cases, such as when repeated disturbances of the stream channel occur over a long time, new, lower levels for abundance and richness may be established.

Research needs and opportunities

Although we can speculate on the effects of fires on aquatic ecosystems, insufficient specific information is available to reliably predict their effects over the array of conditions found in GYA. Conditions in aquatic habitats during or immediately after a fire have been documented in only a few cases. Little is known of the factors responsible for the observed fish mortalities, the extent of that mortality, or whether other groups of organisms also were affected.

Previous studies often differ markedly in climatic and topographic conditions from those found in GYA and the other large national parks and wilderness areas of the northern Rockies. Reports of "no adverse effect" in previous studies commonly are clouded by an inadequate database or by unsatisfactory sampling, which may have begun after the disappearance of organisms killed by the

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fire. Likewise, the effect of fire retardants on aquatic habitats, the downstream extent of the effect, and even the extent of the problem are poorly known.

The near-term effects of fire are probably the best described, but these studies have concentrated on chemical conditions in the water. Information on the effects of fires of different degrees of severity on the composition and productivity of algae, invertebrates, and fish are largely undocumented. Little also is known of the internal functional responses of aquatic ecosystems to fire. For example, there is considerable evidence that biological processing and physical retention may serve to retard the downstream movement of nutrients and their loss from a watershed and that these processes may vary with stream size (e.g., Grimm 1987, Minshall et al. 1983b, Newbold et al. 1982, 1983), but these ideas have not been tested.

The lack of information concerning the effects of fire on aquatic ecosystems is especially important for large-scale and long-term situations. Yellowstone offers some especially exciting opportunities for such research. For example, virtually nothing is known of the sequence of events that may occur in aquatic ecosystems after the first year or two after a fire, whether these sequences may differ from one situation to another, or what factors would be responsible for such differences.

Rarely in the history of modern ecology has the opportunity been available to examine the effects of fire on stream habitats in watersheds larger than third order or to compare responses of stream ecosystems to mosaic burns versus nearly complete, intense burns. Because of the scale of the 1988 fires and the variety of stream types and conditions represented, GYA could serve as an excellent natural laboratory for testing ideas and for supplying much-needed information for evaluating current fire management policies, predicting the effects of fire, and planning resource management strategies for stream ecosystems.

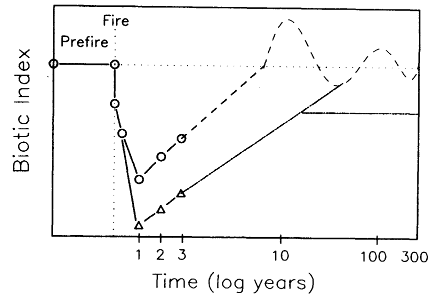

Figure 6. Expected changes in total abundance (numbers or biomass) or species richness after wildfire (from Minshall and Brock in press). Three possible recovery trajectories are shown: circles and dashed lines represent moderate impact and rapid return to prefire conditions; triangles represent relatively severe impact, eventually returning to prefire levels (dashed lines) or attaining a new (lower) equilibrium level (broken horizontal line). The actual pattern of recovery will be determined largely by the extent of disturbance of the watershed and stream channel from runoff in the first few years after the fire.

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