

fires, climate change, and grazing by domestic livestock (which can reduce competition from herbaceous plants for tree seedlings; Dunwiddie 1977). There is also the possibility that tree invasion occurs slowly following some disturbance in the distant past, as, for example, on parts of Libby Flats in the Medicine Bow Mountains (Billings 1969).¹

Ribbon Forests and Snowglades

Drifting snow is another possible cause of meadows. Trees simply cannot become established where snow persists until late in the summer, in part because the soil remains too wet for too long. Buckner (1977), in a detailed study of snowglades in Colorado, listed the following five effects of snow accumulation: a shortened growing season, more pocket gophers, late seed germination or germination failure, the breakage and bending of those few trees that do become established, and a higher frequency of parasitic snow molds. The growing season is short in such areas, and various pathogens (such as the blackfelt snowmold, or *Herpotrichia nigra*) can kill lower branches buried in snow until midsummer (fig. 12.5; Cooke 1955).

The ribbon forest–snowglade pattern takes at least two forms. Commonly, there is just one band of trees and one band of meadow on the lee side of a more extensive meadow, such as in Cinnabar Park, where the late-spring snowdrift may be 15 m deep or more. The origin of the band of trees and single snowglade on the lee side of a meadow is difficult to explain. Billings (1969) suggested that a “forest fire near timberline . . . changes the snowdrift pattern enough that trees in an unburned area to the lee of the burn are killed by late-lying snow during the summer. The dead trees are replaced by a wet type of snowglade meadow.” Support for Billings’s suggestion comes from the observation that huge snowdrifts do form on the lee side of some clearcuts, usually 3–6 m into the uncut forest downwind, and the effect of the drift is to reduce tree vigor. Dead standing trees can be found even though the upwind clearcut is only ten to twenty years old.

Elsewhere, usually near upper treeline, many bands of forest and meadow may occur in sequence (fig. 12.6; Arno and Hammerly 1984).



FIG. 12.5 Tree branches that remain covered with snow late into summer, such as in snowglades, are often killed by blackfelt snowmolds. This photo shows an infected lodgepole pine sapling.

Again, the role of wind and snowdrifting seems obvious because the bands are perpendicular to the prevailing westerly winds and because the deepest snow occurs in the glades. Buckner (1977) concluded that the bands of trees were a result of bands of microsites favorable to tree establishment. Although tree establishment has usually occurred on slightly elevated sites, as young trees grew, they presumably caused drifting to occur downwind, which greatly reduced the chances of tree invasion. Thus, snowdrifting accentuated the pattern. Buckner hypothesized that the pattern should be especially obvious in areas of higher snowfall, such as on the western side of mountain ranges. He found no evidence that his study area had once had a continuous forest cover, and thus disturbance was not a critical factor in the formation of the multiple-band snowglades he studied.

A similar phenomenon has been observed where the trees occur in doughnut- or U-shaped



FIG. 12.6 At higher elevations with strong winds, such as in this area north of Medicine Bow Peak, parallel ribbon forests and snowglades may develop. The trees are predominately Engelmann spruce and subalpine fir; elevation 3,344 m (11,000 ft). Photo by William K. Smith.

groves (see fig. 9.13). These groves, sometimes referred to as timber atolls, may be fringed by aspen, such as on the northern end of the Sierra Madre, or by Engelmann spruce and subalpine fir at higher elevations in northwestern Wyoming (Griggs 1938). These unusual groves are typically surrounded by sagebrush steppe or subalpine meadows, and they probably developed because of the snow-fence effect of the few trees that did become established. As the trees develop, the only sites where new seedlings or sprouts grow is around the edges of the snowbank created by the original trees. Eventually, trees become established around all or most of the snowbank. The persistence of the groves is favored because of the more mesic conditions created by snow that drifts into the center. Although trees cannot survive in the center because the snow persists too long, the

snowdrift provides a more dependable supply of moisture for the trees on the perimeter.

The forest atoll or ribbon forest–snowglade pattern may characterize a small portion of the mountain landscape, but it is a pattern commonly observed from the air. The atolls and snowglades can be of considerable significance economically as a naturally developed high-water-yield ecosystem in which most of the snow accumulates where there is comparatively little transpiration. A common practice of watershed hydrologists to increase streamflow is to create small openings in the forest where snow can accumulate (see chapter 11).

Livestock Grazing on Mountain Meadows

Mountain meadows have long been an important component of the summer range for elk and deer, and during the past century many ranchers have come to depend on such meadows as a way of resting their rangelands. The diversity of the landscape, with rangelands at different elevations, increases the carrying capacity for both wildlife and livestock (Coughenour 1991a, 1991b; Coughenour and Singer 1991). Essentially, there is a wave of new plant growth that the animals can follow from the lowlands in the spring to high mountain meadows later in the summer. Because of topographic diversity, there is always a new supply of nutritious, green forage.

Livestock managers have learned that the grazing season is an important consideration in mountain meadows (Paulsen 1975; Turner and Paulsen 1976; Thilenius 1979; Thilenius and Smith 1985). Ranchers prefer to rest their low-elevation rangelands in the spring, when plants are actively growing and most susceptible to damage by grazing. For this reason, there has traditionally been a desire to move livestock onto the mountain meadows as soon as possible. Unfortunately, late-persisting snow prevents those meadows from being accessible, and when they are available, often the soils are so wet that damage from trampling is possible. Moreover, the mountain plants are subject to damage if grazed excessively in the early stages of their growth, just as in the lowlands.

Today, the grazing of mountain meadows is restricted in many areas to a shorter summer pe-