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Wind in the Forests of Southeast Alaska and Guides for Reducing Damage

A.S. Harris

Author

A.S. HARRIS is a research forester (retired), Forestry Sciences Laboratory, P.O. Box 20909, Juneau, Alaska 99802-0909.

Abstract

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This paper is a review of wind conditions and blowdown in the forests of southeast Alaska based on the literature and the author's experience. Storm winds resulting in damage to forest stands are described, and some ecological and management considerations of wind that are of concern to forest managers are reviewed.

The author made a general reconnaissance of forest conditions on Prince of Wales Island and adjacent islands based on forest-type maps, aerial photographs, and ground and air checks. Forest conditions associated with blowdown are described and are discussed.

Keywords: Wind damage, blowdown, windthrow.

Contents

Introduction

Each year gales sweep through the forests of coastal Alaska and cause considerable damage. The most common damage is from tree uprooting (windthrow) and stem breakage (windsnap). These two forms of damage are referred to here as blowdown. Much blowdown involves individual trees or small groups of trees, so most damage. goes unnoticed except where timber is blown down over extensive areas. Windthrow was considered responsible for 26 percent of the annual tree mortality in southeast Alaska during one 7-year period (Hutchison and LaBau 1975). Wind also damages structures and causes damage to streams by changing channel morphology or blocking anadromous fish. Wind is important in the natural recycling of forest stands and in maintaining and renewing the forest ecosystem.

Wind is an important though elusive consideration for managers of coastal Alaska forests. Past experience says that gale-force winds will occur, yet when or where cannot be predicted. Soil and topographic features that make blowdown more probable can be described, yet stands have occupied such sites for hundreds of years without apparent damage. Individual trees have attributes affecting windfirmness, but whether a particular tree will blow down cannot be predicted.

Despite these uncertainties, forest managers can still do much to reduce losses from wind, although they can never expect to eliminate damage completely or to measure accurately the effectiveness of their program. But by being aware of past experiences and revising plans in the light of new information, the forest manager can at least be satisfied that all possible has been done to reduce losses from wind.

The forest manager is concerned with the effect of wind on other resources besides the direct losses to the timber resource. Streams used by fish for spawning and rearing may be damaged when windfalls block fish passage or cause channel changes and when down trees occupy rearing space. Anchorages used by small boats are often protected from wind by standing timber on shore, and logging plans must be designed to maintain this protection. Layouts for highways and powerlines must be planned to minimize hazard from blowdown of adjacent timber.

Many studies of wind damage have been made in the United States and in other countries. Although investigations have included many forest types with different geography, topography, soil, and climate, some similarities appear throughout the literature (Savill 1983).

Objectives of this report are:

1. To describe the general wind conditions associated with blowdown in the forests of southeast Alaska, with information based on published data and local knowledge.

2. To survey typical blowdown damage in forest stands in southeast Alaska by using aerial-photo interpretation and limited air and ground reconnaissance.

3. To review briefly some of the important management considerations related to wind such as ecological effects, sheltering effects of stands, and factors involving individual trees, stands, and topography.

4. To provide guidelines for timber managers in southeast Alaska based on recommendations in the literature adapted to fit local conditions and on suggestions offered previously (Ruth and Harris 1979).

Terminology used in connection with wind damage has been adapted from that suggested by the Society of American Foresters (Ford-Robertson 1971) and modified by common usage on the Pacific Coast.

Storm Winds in Southeast Alaska

Information on wind is routinely gathered by the National Oceanographic and Atmospheric Administration (NOAA) at three first-order meteorological stations in southeast Alaska: Annette Island, Juneau, and Yakutat. Daily weather observations are made at several other stations, but observers do not routinely include data on wind. Lack of detailed wind observation data and the extremely mountainous topography of the area result in little detailed local information on wind.

Gale-force winds may occur in southeast Alaska during any month; however, the strongest winds are most likely to occur in fall and winter months. (table 1). Records from the three major meteorological stations in southeast Alaska show that strong winds usually blow from the southerly sector; as wind velocity increases the tendency to blow from the southeast increases (table 2). Locally, wind direction may be altered greatly when steep topography channels it.

Over 25 years, sustained "fastest mile" [1] winds of over 45 miles per hour (mi/h) were recorded on 55 days at Annette Island, 17 days at Juneau, and 41 days at Yakutat (table 3). Gusts of greater velocity occur, but they are erratic, of varying duration, and difficult to record. Information on peak gusts is not published regularly by NOAA. Comparison of 10 years of unpublished records for Juneau showed good correlation between the velocity of monthly peak gusts and the corresponding fastest mile windspeeds for speeds of 35 to 50 mi/h (fig. 1). The average ratio of daily maximum gust speed to the recorded fastest mile wind speeds was about 1.4. This is in general agreement with ratios of 1.4 to 1.5 reported in a Scottish gale in January 1968 by Fraser (1971) and somewhat lower than the 1.8 to 2.0 ratio reported for a gale in Yorkshire in February 1962 (Aanensen 1965).

[1] Daily fastest mile wind speed is obtained by measuring and averaging instantaneous wind velocities over 1 minute once each hour. The highest of the 24 hourly measurements for the day is called the fastest mile and is included in published records. Unpublished data on file, National Weather Service, P.O. Box 021547, Juneau, Alaska 99802-1547.

Table 1—Number of days, by month, with winds[a] over 30 miles per hour, Annette Island, Juneau, and Yakutat, Alaska, 1953-78

Area and month	Miles per hour									Total days
	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71+	
Annette Island:										
July	3									3
August	5	4								9
September	11	7	3		1					22
October	67	45	13	4	3					132
November	58	41	5	8	1					113
December	64	39	9	9	2	3				126
January	70	29	5	6	2	2				114
February	60	31	2	8						101
March	25	9	8	4						46
April	32	9	7	2						50
May	8	5	2							15
June	11	1	1							13
Total	414	220	55	41	9	5				744
Juneau:										
July	2	1								3
August	8	2								10
September	34	9	1	1						45
October	49	27	7	2						85
November	54	17	8	1	1	1				82
December	40	14	7	1	2					64
January	40	8	2			2				52
February	36	22	3	2	1	1	1	1		66
March	27	8	1							36
April	29	8	4	1						42
May	8	9								17
June	4									4
Total	331	125	33	8	3	4	1	1		506
Yakutat:										
July	2									2
August	9	3	1							13
September	14	8		3						25
October	35	27	4	4	2		1	1		74
November	20	17	5	2	5	1	3			53
December	45	10	5	2	1		1			64
January	19	14	5	4	2		2			46
February	38	19	5	4	1					67
March	20	8	1							29
April	16	5	4		1					26
May	10	7			1					18
June	5	1								6
Total	233	119	30	19	13	1	7	1		423

[a] Fastest mile wind speed; see text footnote 2.

Table 2—Number of days, by direction of the wind, when winds[a] over 30 miles per hour were reported, Annette Island, Juneau, and Yakutat, Alaska, 1953-78

Area and direction	Miles per hour									Total days
	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71+	
Annette Island:										
North										0
North-northeast	1									1
Northeast	4	2	3							9
East-northeast	12	4		1						17
East	16	6	3							25
East-southeast	54	19	4	1	1					79
Southeast	130	84	18	14						246
South-southeast	138	87	23	23	6	5				282
South	54	15	4	2	2					77
South-southwest		3								3
Southwest	1									1
West-southwest										0
West										0
West-northwest	4									4
Northwest										0
North-northwest										
Total	414	220	55	41	9	5				744
Juneau:										
North	1									1
North-northeast										0
Northeast	1									1
East-northeast										0
East	17	1	2							20
East-southeast	174	81	7	4	2	1				269
Southeast	134	43	23	4	1	3	1	1		210
South-southeast										0
South	3		1							4
South-southwest										0
Southwest	1									1
West-southwest										0
West										0
West-northwest										0
Northwest										0
North-northwest										0
Total	331	125	33	8	3	4	1	1		506
Yakutat:										
North										0
North-northeast										0
Northeast	2									2
East-northeast	10	3	1							14
East	19	4		1						24
East-southeast	62	41	8	7	3	1	3	1	1	127
Southeast	105	59	21	9	7		3			204
South-southeast	22	9		1						32
South	2	1			3					6
South-southwest	2									2
Southwest	3			1						4
West-southwest	2	2								4
West	2									2
West-northwest	1									1
Northwest	1									1
North-northwest										0
Total	233	119	30	19	13	1	6	1	1	423

[a] Fastest mile windspeed; see text footnote 2.

Table 3—Number of days, by year, when winds[a] over 30 miles per hour were reported, Annette Island, Juneau, and Yakutat, Alaska, 1953-78

Area and year	Miles per hour									Total days
	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71+	
Annette Island:										
1953	33	22	8	5	1	1				70
1954	28	28	4	9		2				71
1955	38	20	5	4	2					69
1956	37	10	2	1						50
1957	19	7	2	1						29
1958	25	17	3	5	4					54
1959	20	14	11	4		1				50
1960	23	7	1	1	1	1				34
1961	11	7	1							19
1962	12	5								17
1963	15	8	4	2	1					30
1964	14	7	3							24
1965	13	3	1							17
1966	11	6								17
1967	8	7		1						16
1968	13	8	3	1						25
1969	5	6	2	1						14
1970	11	2								13
1971	14	4	2	1						21
1972	5	6								11
1973	6	9								15
1974	10	3	2	1						16
1975	12	5		1						18
1976	9	4								13
1977	16	4	1	3						24
1978	6	1								7
Total	414	220	55	41	9	5				744
Juneau:										
1953	27	8	4	1		1	1	1		43
1954	23	6	11	2						42
1955	21	4		1						26
1956	21	9	4		1					35
1957	14									14
1958	22	4	1			2				29
1959	5	15	1							21
1960	13	5								18
1961	13	11	1							25
1962	13	1								14
1963	13	12	1	1	2					29
1964	19	7	3							29
1965	23	10		1						34
1966	22	5	1							28
1967	9	4	3	1						17
1968	5	6	3	1		1				16
1969	8	3		1						12
1970	9	6	1							16
1971	7	1								8
1972	7	2	1							10
1973	7	1								8
1974	7									7
1975	3	2	1							6
1976	10	1								11
1977	6	1								7
1978	4	1								5
Total	331	125	36	9	3	4	1	1		510

Table 3—Number of days, by year, when winds[a] over 30 miles per hour were reported, Annette Island, Juneau, and Yakutat, Alaska, 1953-78 (continued)

Area and year	Miles per hour									Total days
	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71+	
Yakutat:										
1953	14	9	2	4						29
1954	17	8	1		2					28
1955	21	11	1	2					1	36
1956	14	17	9	2	7		1			50
1957	9	7	5				1			22
1958	12	12		2	1	1	3	1		32
1959	10	4	2	1	1					18
1960	7	5	1							13
1961	5	5	2							12
1962	8	1		2						11
1963	8	5	1	1			1			16
1964	8	3	1							12
1965	12	4	1							17
1966	14	1								15
1967	6	1								7
1968	5	5			1					11
1969	7	4								11
1970	7	1	1	1	1					11
1971	7	3								10
1972	9	4								13
1973	5	1	1	2						9
1974	5	2	1	2						10
1975	4	2								6
1976	6	2								8
1977	6	2								8
1978	7		1							8
Total	233	119	30	19	13	1	6	1	1	423

[a] Fastest mile windspeed; see text footnote 2.

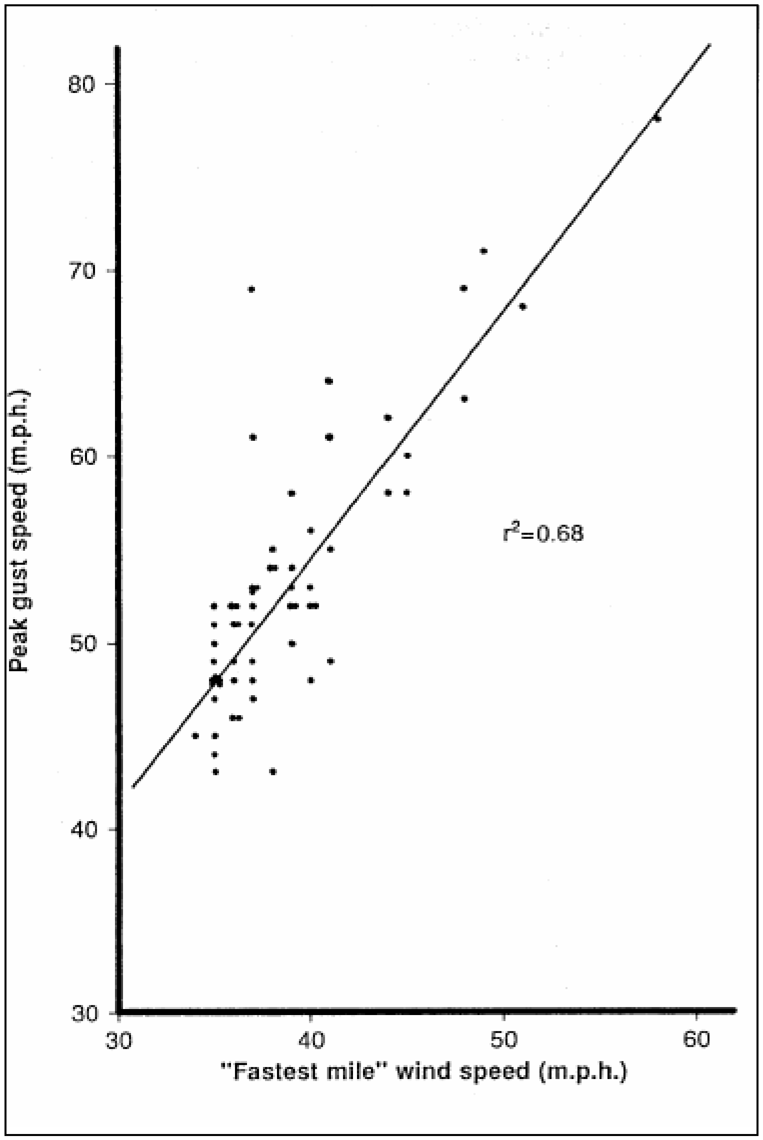

Figure 1—Relation between monthly fastest mile wind speed and the corresponding peak-gust velocity, 1961-70, Juneau, Alaska.

Southeast Gales

Southeast gales[2] are the most damaging fall and winter storms that occur in southeast Alaska. These storms have winds rotating counterclockwise around a central area of low barometric pressure (cyclones). They originate in the western Pacific and follow an east-northeast course across the North Pacific to the west coast of North America. The prevailing storm tracks are generally farther south in February, farthest north in August, and farther south in spring than in fall (Klein 1957). Normal storm tracks along the Aleutian Islands, the Alaska Peninsula, and the coast of the Gulf of Alaska cause these areas to receive most of the storms crossing the North Pacific (Klein 1957, Searby 1968). The Gulf of Alaska leads the northern hemisphere in frequency of cyclones every month from October through May (Klein 1957).

The type of storm producing cyclones begins as a wave development on a cold or occluded front that has passed east of the Coast Range and trails into the Gulf of Alaska near lat. at 50° N., long. 145° W. The wave develops east or southeast of this location and remains weak and fast-moving until it approaches the coast near the Queen Charlotte Islands. At this stage, it deepens rapidly and moves north-northeast at 40-50 mi/h and is often accompanied by gale-force winds. Usually the interval from when the wave is detected until it has moved through the entire Alaska panhandle is only 24-30 hours. This type of storm produces wind gusts at times exceeding 100 mi/h in the southern panhandle and 80 mi/h in the northern sections.[3]

One example of a storm producing extensive damage throughout southeast Alaska occurred on Thanksgiving Day, November 28, 1968. As the storm approached southeast Alaska, the barometric pressure fell rapidly at Annette Island, reaching a low of 28.98 inches of mercury (inHg). Once the frontal system passed Annette Island, barometric pressure there rose quickly while the pressure at Sitka and Juneau continued to plunge and reached a low of 28.53 inHg at Juneau before frontal passage. The intensity of this storm was reflected by the rapid changes in barometric pressure recorded over relatively short distances; for example, barometric pressure at Juneau was still falling even after it started to rise at Sitka, about 100 miles southwest. The storm produced wind speeds up to 50 mi/h with gusts to 90 mi/h near Ketchikan and 78 mi/h at Juneau (see footnote 3).

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[2] The term "gale" is used as a general reference to storm winds frequently experienced in southeast Alaska (table 3). Terms such as "gale," "storm," and "hurricane" refer to specific windspeeds on the Beaufort Scale, a descriptive method of defining windspeed devised by Sir Francis Beaufort in 1805 and still in use:

0	Calm	<mi/h
1	Light air	1-3 mi/h
2	Light breeze	4-7 mi/h
3	Gentle breeze	8-12 mi/h
4	Moerate breeze	13-18 mi/h
5	Fresh breeze	19-24 mi/h
6	Strong breeze	25-31 mi/h
7	Moderate gale	32-38 mi/h
8	Fresh gale	39-46 mi/h
9	Strong gale	47-54 mi/h
10	Whole gale	55-63 mi/h
11	Storm	64-72 mi/h
12	Hurricane	≥73 mi/h

[3] Personal communication, Lief Lie, National Weather Service, P.O. Box 021547, Juneau, Alaska 99802-1547.

Bora and Glacier Winds

During winter, cold, dry winds occur in many places along the Pacific coast. These fall or bora winds develop where steep mountain ranges parallel the coast, which produces sharp climatic differences between the cold interior and warmer coastal areas. Winds of this type are common in coastal mountainous areas throughout the world and are usually known by local names. In Europe, the bora (derived from the Greek Boreas, or north wind) occurs along the Dalmatia coast on the Adriatic Sea. It is the best-known example of a bora wind and serves to identify the type.

Examples from southeast Alaska are the Taku winds near Juneau and the Stikine winds near Wrangell; both are named for local river valleys. Further to the south, the strong wind that occasionally blows down the Columbia River Gorge is another well-known example (Willett and Sanders 1959).

A strong pressure gradient must exist between the interior and coastal areas for boras to develop. This gradient can develop either as the result of an arctic high-pressure area over the interior or as a deep low-pressure area along the coast. In either case, cold continental air is forced across the mountains and spills down the coastal slopes; its force is concentrated as it flows through river valleys. As air flows down, gravity adds velocity to wind influenced by a pressure gradient. The falling cold air gains some heat adiabatically, but this does little to offset the initial extreme temperature difference; the wind reaching the coast is colder than normal air.[4]

In southeast Alaska, perhaps the best known bora is the Taku. Takus blow mainly from the northeast and occur almost exclusively during winter. They are extremely turbulent with gusts often reaching hurricane force.

Near Juneau, extremely gusty winds may result from the downslope flow of cold air from the nearby elevated icefield. During clear winter weather, a shallow layer of extremely cold air is produced over the icefield by radiative cooling. This air may spill over seaward mountain slopes in the form of katabatic (downslope) winds. These local winds often occur during Taku conditions, but it is the large-scale breakthrough of deep, cold arctic air from the Yukon and MacKenzie Basins in northwestern Canada rather than the shallow cold surface air over the nearby icefield that favors development of true Takus (see footnote 4).

Takus may damage property and pose great hazard to boats and aircraft. They occur frequently, however, and vegetation in their path tends to accommodate over time so that widespread blowdown of forest stands from Takus is rare. Annual damage to stem and branch tips results in loss of foliage and abnormal growth habits of trees. Trees tend to be short and highly tapered with extensive roots. Foliage on the windward side of trees is clipped by the wind, and crowns develop primarily on the leeward side (fig. 2).

Trees offer mutual protection, and stands in exposed locations tend to be of uniform height with few individual trees extending above the general level of the stand. In very exposed locations, trees may be gnarled or prostrate and reproduction may be impossible; the tree line is at lower elevations than it is on less exposed sites nearby.

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[4] Kilday, Gordon D. [n.d.] Taku winds at Juneau, Alaska. Unpublished manuscript. On file with: National Weather Service, P.O. Box 021547, Juneau, Alaska 99802-1547.

Figure 2—Foliage on the windward side of trees in exposed situations is clipped by wind; crowns develop primarily on the leeward side.

Thunderstorms

Other types of winds strong enough to uproot trees occur, and these likely cause blowdown not conforming to the pattern established by general airflow. Thunderstorms developing along the squall line ahead of an advancing cold front may produce strong downdrafts during the later stages of a storm. These hit the forest canopy or ground with considerable force and spread out laterally in the direction of least resistance. Velocities may reach 100 mi/h. Thunderstorms decrease northward along the Pacific coast and are rare in the hemlock-spruce forests of southeast Alaska.

Tornadoes

Tornadoes occasionally damage forests and property in the Pacific Northwest. They may destroy forests along a narrow track for several miles, but they do not cause widespread damage. On the average, only one tornado per year occurs in Alaska (Fathauer 1977), and most or all are confined to the interior. None has been reported from southeast Alaska, and no known evidence of past damage to forests exists.

Storm winds flowing over steep cliffs or other broken topography can create vortices (mountain tornadoes) that can damage the forest. Mountain tornadoes may develop rotational velocities over 100 mi/h (Brooks 1949) and may blow down trees in any direction. Their frequency and the extent of damage in southeast Alaska is unknown.

Ecological and Management Considerations

Effects of Wind on Forest Succession

The climax forest vegetation in southeast Alaska is generally considered to be all-aged and dominated by western hemlock *(Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce *(Picea sitchensis* (Bong.) Carr.) (Taylor 1932). Close observation shows, however, that rather than being all-aged, most old-growth stands are composed of groups of more-or-less even-aged trees arranged in complex patterns. These old-growth forests also contain a more diverse plant understory than do more even-aged forests in earlier successional stages (Alaback 1982).

Wild fire is rare in southeast Alaska, and blowdown is the most important natural process in renewing the forest. Gaps or openings in the forest canopy occur when individual trees or small groups of trees blow down. Stands covering many acres may be leveled during strong gales. Small gaps provide light and growing space, which allow tree regeneration to become established and grow rapidly in the understory. When large gaps are created, tree regeneration develops into even-aged forest stands. Eventually these stands are affected by blowdown, which allows new tree regeneration to become established. In this way, the pattern of blowdown plays a major role in determining the structure of old-growth forests. This process, which results in irregular patches of vegetation of different ages, has been studied in detail in forests of the Eastern United States (Lorimer 1977, Oliver and Stephens 1977, Runkle 1981) and has been termed a "shifting-mosaic steady state" (Bormann and Likens 1979). The process allows Sitka spruce, a less shade-tolerant species than western hemlock, to reproduce and grow in openings and thus remain an important component in old-growth stands.

Effects of Wind on Soil and Tree Roots

Blowdown can result in drastic disturbance to the forest soil. In many ways, uprooting of trees can be similar to subsoil plowing (Armson and Fessenden 1973, Shaler 1891), and it results in the mound-and-pit topography so common in southeast Alaska (fig. 3). This process and its effect on soil have been described by many writers (Lutz 1940, 1960; Lutz and Griswold 1939; Lyford and Maclean 1966; Mcintosh 1961; Stephens 1956; van Hise 1904).

When a tree with roots extending into mineral soil is uprooted by wind, a large mass of soil and rock is lifted with the roots thus producing a pit. As the fallen tree decays, the uprooted soil, roots, and stem settle to form a mound. The mound is leeward of the pit in the direction of the tree fall. From the position of mounds and pits, the direction of tree fall can be determined many years after the event, even though most traces of the fallen tree have disappeared. This information is often helpful in determining the long-term blowdown history of an area.

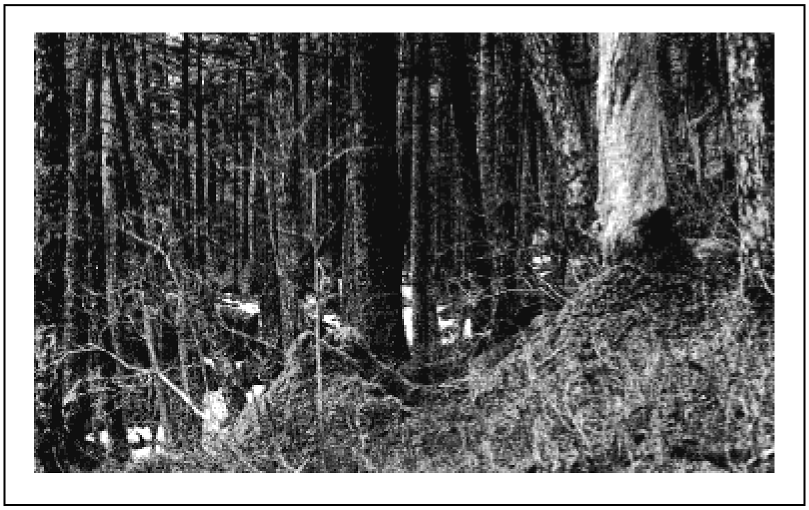

Figure 3— Typical mound-and-pit topography resulting from windthrow.

Mounds may also develop on the forest floor without trees being uprooted. When a tree dies as a result of insect attack, disease, or other causes, it will occasionally remain standing instead of toppling over and gradually deteriorate in place. When this happens, rotten wood and bark slough off and accumulate around the rooted stump and, in time, produce a moss-covered mound of humus. Excavation will usually reveal, however, that such mounds lack rocks or mineral soil and that an associated pit or remains of the prostrate trunk are missing.

Wind, through its effect on uprooting or swaying of trees may trigger soil mass movement on steep slopes (fig. 4). Lutz (1960) concluded that uprooting of trees contributes to movement downslope of the soil and rock mantle and may initiate local gully-type erosion. Swanston (1967a) found that the majority of debris avalanches on shallow, colluvial soils that he studied occurred on timbered slopes and originated in areas of windthrown trees or extensive overhanging rock bluffs. His studies (Swanston 1967b, 1969) relating rainfall to pore-water pressure showed that a shallow till soil will become saturated during a storm that produces over 5 inches of rainfall in 24 hours. The resulting pore-water pressure can reduce internal soil sheer strength by as much as 60 percent (Swanston 1967b, 1969). Such storms occur at 2- to 5-year intervals in southeast Alaska (Miller 1963). Strong winds often accompany heavy rains; when these are combined with reduced rooting strength, the chances for blowdown are greatly increased.

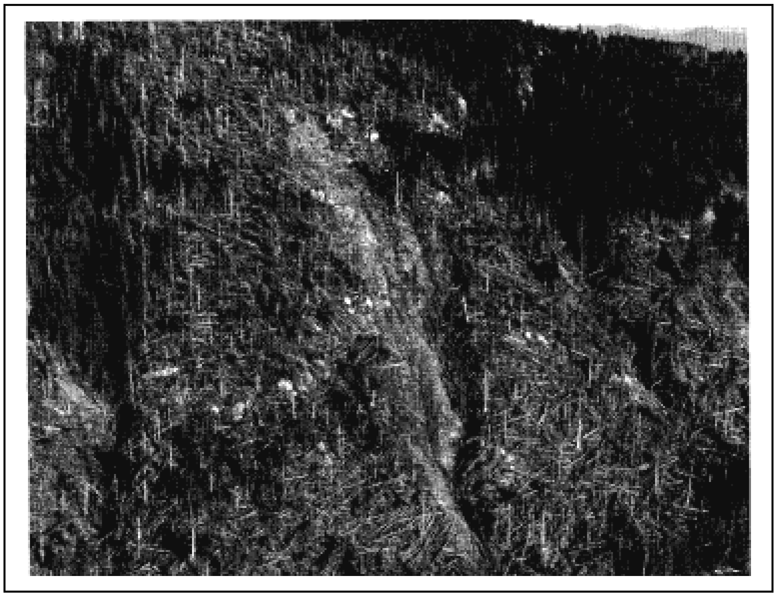

Figure 4—Soil mass wasting associated with blowdown, Farallon Bay, Alaska.

Effects of Wind on Conifer Regeneration and Tree Growth

Uprooting or stem breakage opens the forest canopy and allows for forest renewal. The effect of blowdown on the quality of tree reproduction and subsequent growth is not well understood. Stephens and others (1969) found that the site index of even-aged stands originating after blowdown tend to be lower than the site index for stands originating after fire or logging. They hypothesized that the soil nutrient status is lowered because of reduced soil temperature from shading of the soil by downed trees-the hypothesis has not been tested. On the other hand, recent research has shown that the breaking up of dense spodic horizons and mixing of soil and organic material caused by uprooting of trees improves drainage, increases soil aeration, and favors decomposition of organic material in organic and spodic horizons and subsequent nutrient release. Further studies of this process are underway.[5]

Other factors can affect growth of stands originating from blowdown. If a stand has been partially blown down, the shaded seedbed conditions will favor establishment of western hemlock. Germination of hemlock may also be favored when little soil disturbance has occurred. If the overstory stand was infested with hemlock dwarf mistletoe, *(Arceuthobium tsugense* (Rosend.) G.N. Jones) advance reproduction may be infested as well; this can contribute to slow growth in stands of advancing age.

Even-aged stands resulting from complete blowdown may contain a higher than average proportion of spruce, many of which establish on upturned soil and roots. Trees so established are stilt-rooted and often less windfirm than other trees. Stands originating from blowdown may be predisposed to eventual blowdown.

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[5] Personal communication, B. Bormann, Forestry Sciences Laboratory, P.O. Box 20909, Juneau, Alaska 99802-0909.

In partially blown down stands, mechanical damage to reproduction is likely to occur from falling trees as additional blowdown occurs. Seedlings knocked askew may survive and grow erect through formation of compression wood but can eventually develop into trees with curved pistol butts that are of low quality and not windfirm.

Growth rate of trees may be slowed by the wind pruning foliage-bearing branches and branchlets. Grier (1976) found in a 3-year study that living foliage removed from trees by wind was over one-third of annual net foliage production, not including foliage of whole trees downed by wind. This damage resulted in older stands with leaf area or biomass considerably less than the potential for their environment. Grier speculated that wind pruning is a major factor in the rapid decrease in production by coastal western hemlock stands as they increase in age.

Effects of Wind on Deer and Fish Habitat

Wind provides a winter source of food for deer by making available material from tree crowns. Branchlets are clipped off by the wind, branches are blown down, and foliage becomes accessible when trees are blown down. Edible lichens, such as *Alectaria* sp., *Usnea* sp., and *Labaria* sp., are also blown down. This forage may be important when deep snow limits availability of other food and restricts the movement of deer. In summarizing results of studies on Vancouver Island, British Columbia, Bunnell (1979) noted that arboreal lichens amount to 35.5 percent of a deer's diet in forested areas during winter and spring. Because lichens are especially digestible (75-90 percent), this can be an important source of winter food. Rochelle (1980) found that deer eat lichens during most winters and that lichens might provide enough energy to sustain animals during short periods of severe snow conditions.

Stand openings created by blowdown of single trees or groups of trees allow understory plants to become established and eventually convert stands to a complex age structure suitable for use by deer (Wallmo and Schoen 1980). Blowdown may damage deer habitat, however, if the ensuing tangle of stems, branches, and upturned roots restricts movement in the affected area.

Wind may also affect fish habitat when trees are blown into streams or when streamside shade is removed. Blowdown is one of the principal ways for debris to get into streams (Swanson and Lienkaemper 1978). In the past, concentrations of large organic debris blown into streams were considered detrimental to fish habitat. Extensive stream-clearing operations were conducted to remove down timber, and leaving of narrow streamside timber strips was avoided when the risk of blowdown was considered high. More recently, biologists have recognized that in many circumstances large organic debris in streams can improve fish habitat (Bisson and others 1987). Streams with heavy concentrations of debris are often excellent producers of coho salmon and trout (fig. 5). This knowledge is causing a re-evaluation of the long-term role of streamside timber in maintaining productive fish habitat. More study is needed to understand the effect of wind on riparian trees and stands and to devise better management strategies for stream protection.

Figure 5—Heavy concentrations of logs and other large organic debris can be found in excellent fish-producing streams. Yatuk Creek, Prince of Wales Island, Alaska.

Tree Hazards

A tree can be hazardous if it is in an area frequented by people or adjacent to valuable facilities and has defects that may cause a failure resulting in personal injury, death, or property damage (Wallis and others 1980). Forest managers recognize a responsibility for reducing tree hazards in campgrounds, picnic sites, and other heavily used areas on public lands (fig. 6).

Attempts have been made to quantify hazard situations as a basis for control decisions (California Department of Parks and Recreation 1969; Landis and Johnson 1976; Paine 1971, 1973; Wagener 1963; Wallis and others 1980). Defective trees, tops, or limbs may fail with no apparent triggering force. Heavy snow can cause trees to fall without any wind; however, most damage occurs as a result of wind. Hadfield (1976) found in a study of tree failures in campgrounds in the Pacific Northwest that of 125 failures of hemlock and spruce, 91 percent were hemlock. Wind was a contributing factor in 85 percent of the failures. Most failures involved roots, butts, or lower stems with rot a leading contributing factor.

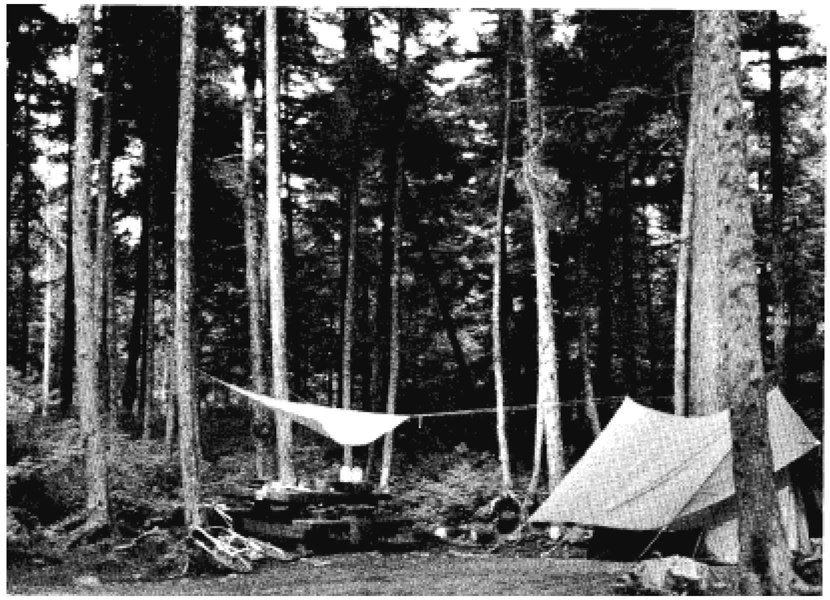

Figure 6— The potential effect of wind must be considered when tree hazards are evaluated. USDA Forest Service campground, Tongass National Forest, Alaska.

In southeast Alaska, most damaging winds occur during fall and winter when recreational use is low. Hunters and others may, however, continue to use cabins or campgrounds through much of the fall and winter when strong winds can be expected. Fortunately, no fatalities have been caused by the failure of defective trees on National Forest lands in southeast Alaska, although recurring damage to cabins, trails, and streams has occurred as the result of wind.

Goals and safety standards have been established for allowable accident rates (Paine 1973). These goals and standards recognize that removing all hazardous trees is neither desirable nor practical. The standards provide a rational and defensible basis for reasonable hazard control by cost, esthetics, and probability of accident.

Recreational planning for campgrounds, picnic areas, cabin sites, and other public areas should include consideration of topography and other factors affecting winds, evaluation of the stand for susceptibility to blowdown, and careful inspection of individual trees for hazards. Many potentially hazardous trees can be removed during road or site construction, thereby reducing the necessity for later removal. Annual or periodic inspection and treatment should be made thereafter to assure that hazard control meets the desired standards.

During periodic inspection, trained specialists should mark apparent hazard trees for removal. These might include trees with large dead limbs, dwarf mistletoe brooms, dead tops, or severe lean or trees with visible defects such as conks, stem canker, exposed roots, or rot. Removal of too many trees, however, can reduce mutual support and increase hazard. The decision to remove defective trees must be based on evaluating the probable direction of fall, the probability that the area struck will be occupied by a person or property, the esthetic contribution of the particular tree, the cost of removal, and the chance of increasing the susceptibility of wind damage to adjacent trees by further opening a stand.

Recommendations for Hazard Reduction

The following are seven recommendations for ways to reduce the hazard from blowdown.

- Examine recreation sites and other developed areas annually to systematically identify potentially hazardous trees; keep in mind the direction of prevailing storms.
- Remove trees with evidence of decay (conks, cracks, stem swellings, rotten wood).
- Remove damaged trees—windsprung trees, leaning, trees with extensive root damage, or trees with heavy limbs.
- Avoid damaging roots and stems with heavy construction equipment, especially cutting roots, compacting soil over roots, and scarring stems.
- Make clearings small; do not remove more trees than necessary.
- Prune to remove brooms and heavy branches that might fall.
- Reduce height of trees by topping; db not remove more than one-third of the live crown.

Shelter Effects of Trees

In southeast Alaska, fishing and pleasure boating are common, and a sheltered anchorage can mean the difference between a restful and a sleepless night. Finding safe anchorage in a gale can be a matter of life or death. The sheltering effect of trees is well known to boaters, and protection of anchorages should be considered in forest-management activities. Trees fringing small anchorages should be protected, and nearby cutting units should be designed to reduce the possibility of blowdown along windward edges that might gradually extend toward an anchorage and weaken or destroy protecting trees.

Studies have not been done to determine the amount of shelter offered by trees adjacent to anchorages, and the effect of shelter is greatly complicated by local topography. A general idea of the shelter effect can be obtained from studies of shelterbelts under field conditions and wind-tunnel tests.

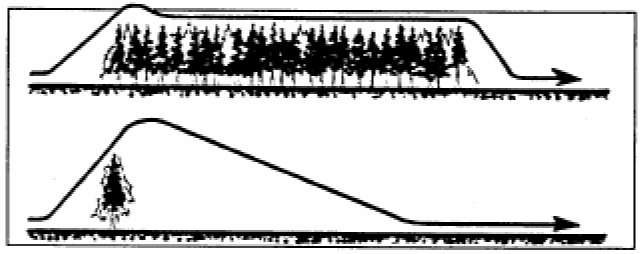

Figure 7—Windflow over a forest block and a narrow shelterbelt. Greater protection to leeward is offered by a narrow barrier.

The amount and extent of shelter depends on the characteristics of the tree barrier, such as height, density, width, position with respect to wind, topography, and many other factors. Wind-tunnel studies have shown that a narrow shelterbelt tends to protect the area to leeward for a greater distance than does a wide shelterbelt (Caborn 1957). Wide shelterbelts or a continuous stand to windward tends to lead the wind parallel to the upper crown surface with a rapid transfer of energy downward after the wind leaves the leeward edge. A narrow shelterbelt tends to lift the wind which results in a transfer of energy upward and a drop further to leeward (fig. 7). A narrow beach fringe would thus seem to be superior to a wider one—but only if the windfirmness of the strip could be assured. Narrow, windfirm beach strips might be developed over time, but a narrow beach fringe of residual forest-grown trees is not generally windfirm in the face of offshore winds. Cutting units, therefore, should be placed well back with their leeward boundaries in windfirm locations.

Wind accelerates as it passes through a shelterbelt open near the ground, often to speeds far in excess of the free wind (Caborn 1957). This should be considered in the logging plan if strips of timber are left for wildlife habitat.

Height of a windbreak (barrier-height) is especially important because the distance protection extends to leeward is proportional to tree height. The percentage of reduction in wind velocity is independent of wind velocity (Reed 1964). Field measurements show that wind velocity was reduced by 20 percent 20 barrier-heights to leeward of medium-to-dense shelterbelts, with some reduction in wind velocity to 30 barrier-heights (table 4). These values, although derived under different conditions from those for southeast Alaska, show the importance of trees in sheltering small harbors. The effect of a shoreline stand 100 feet tall on a boat anchored 2,000 feet offshore, for example, would theoretically be to reduce a 60-knot wind to 49 knots (from table 4). If applicable to southeast Alaska, this reduction could mean the difference between a safe anchorage and disaster.

A great deal more information and experience is needed to assure the protection of small-boat anchorages from wind by timber windbreaks. For now, the best approach is to identify important anchorages, retain shoreline stands to windward as protection, and take care to place leeward cutting boundaries well back in windfirm locations.

Table 4—Summary of the shelter effects of 12 medium to dense shelterbelts

Test number	Wind speed as a percentage of free windspeed by distance leeward of shelter belts (x = barrier height)									Data source[a]
	0	5x	10x	15x	20x	25x	30x	35x	40x	
	Percent									
1	100	30	54	72	82					1
2	100	49	59	73	84					1
3	100	43	56	76	81		92			1
4	100	33	40	68	76					1
5	100	28	57	75	85		93		96	1
6	100	38	49	72	79		90		100	1
7	100	25	43	63	71					1
8	100	33	42	64	78		93		100	1
9	100	45	54	72	88		98			2
10	100	28	49	72	85		95			2
11	100	28	41	65	83		95			2
12	100	34	48	67	82		95			2
Mean	100	34	49	70	81		94		99	

[a] 1 Sturrock 1972; 2 Caborn 1957.

Guides for Reducing Wind Damage

Windfirmness of Individual Trees

Individual trees differ widely in their ability to withstand damage from wind. Being able to select windfirm trees in a stand is important when marking trees for thinning and shelterwood or selection cutting marking boundaries for clearcutting and determining the potential loss of specimen or ornamental trees.

Windfirmness of a tree is determined by the force of the wind on the crown and stem acting in opposition to the resistance of the tree to uprooting or breakage. Several factors are involved (fig. 8). In general, trees become less windfirm as they grow taller, larger, and older (Andersen 1954). As crowns become larger, the force exerted on them by the wind increases; and as trees become taller, turning moment increases with the length of the lever arm (tree height). With age, stems and tops become heavier in relation to the *extent* of rooting. When a tree leans with the wind, the force of gravity on the crown and stem adds to the turning moment. With increasing age, the chance of root and stem rot increases, which may seriously affect strength.

Forces opposing turning moment depend on the mass of soil, rock, or organic matter gripped by roots. This resistance increases with depth of rooting, which in turn relates to soil conditions. Added to this, interlocking root systems may contribute to stability. Roots of Sitka spruce grow deeply when conditions of soil depth, nutrition, and drainage allow (Fraser and Gardiner 1967); however, roots are restricted to the surface when drainage is poor or when soil depth is shallow (fig. 9).

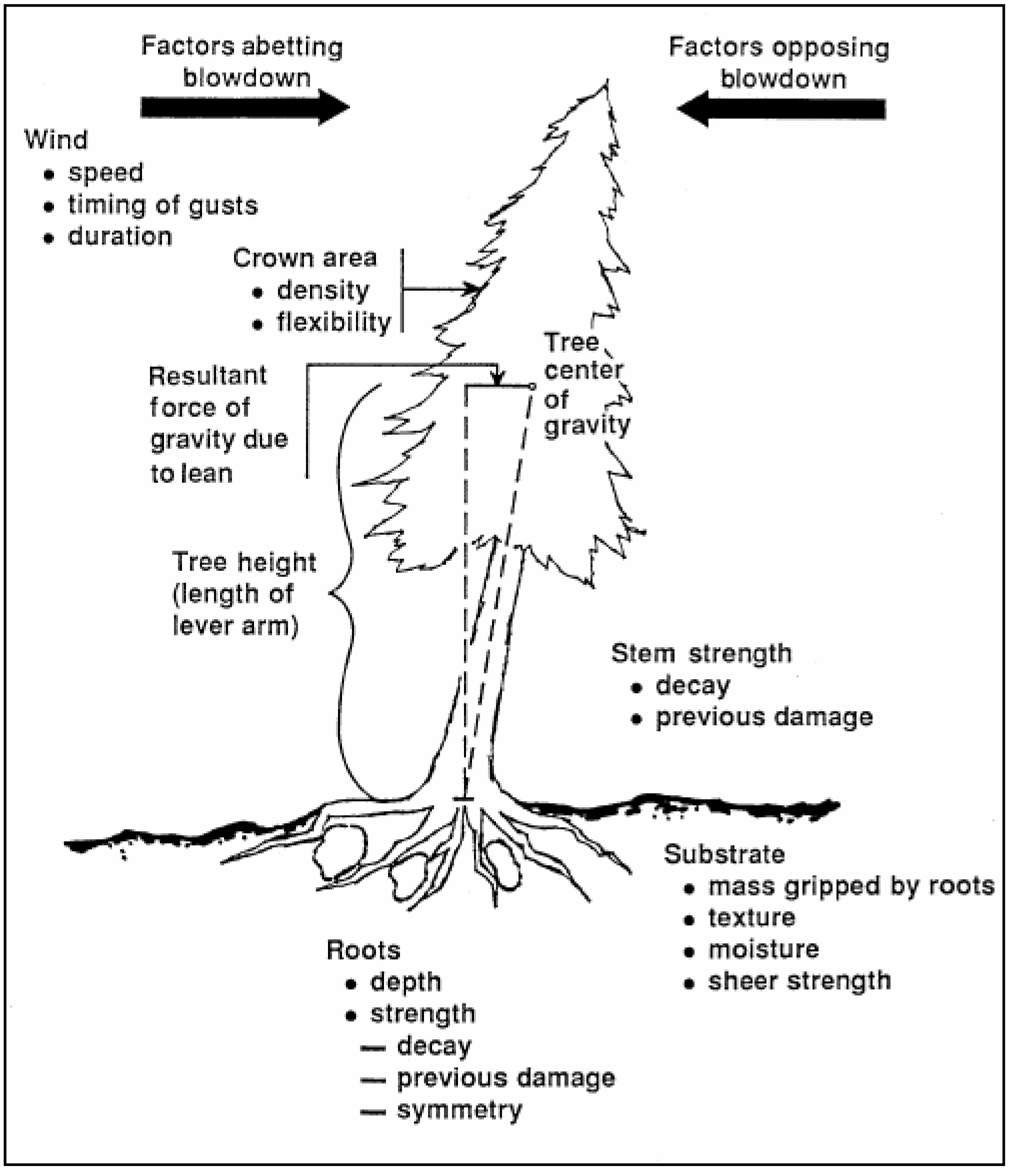

Figure 8—Factors affecting tree stability.

In southeast Alaska, most rooting of hemlock and spruce is shallow (fig. 10). Precipitation is heavy and drainage is often restricted. Soils frequently are shallow over bedrock or cemented glacial till, or they have spodic horizons restricting drainage. Cool soil temperatures reduce root growth, and this further restricts rooting depth. Ross (1932) found that root activity of western hemlock and western redcedar *(Thuja plicata* Donn ex D. Don) ceases at temperatures below 41 °F.

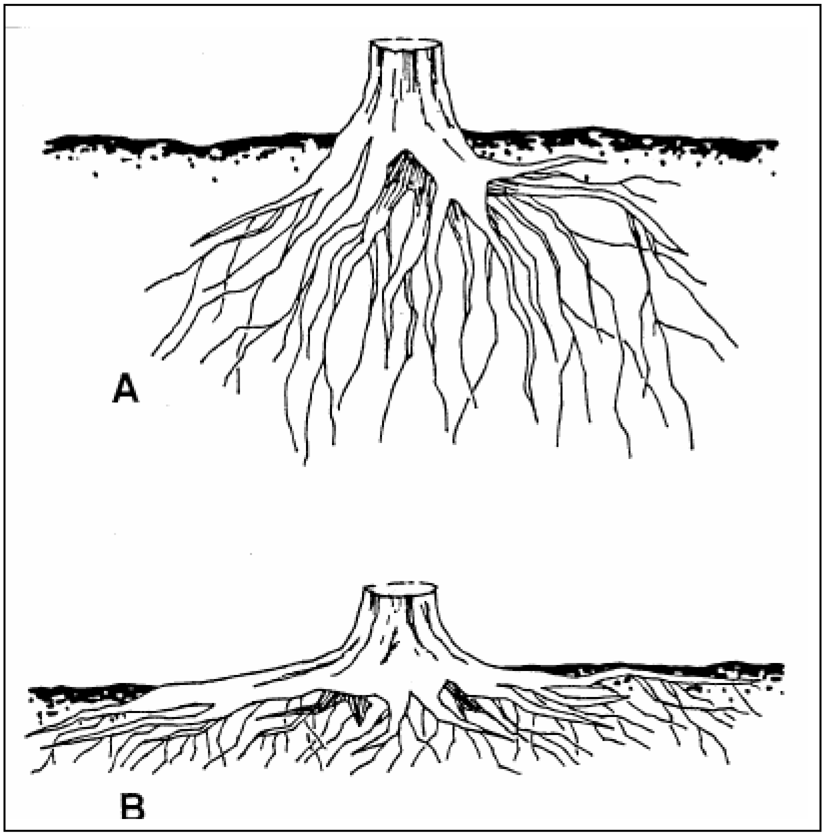

Figure 9—Typical rooting habit of Sitka spruce on two soils (after Fraser and Gardiner 1967): **A—**-Predominantly vertical rooting found on deep brown earth soil with unimpeded drainage; and **B—**Wide and shallow root system found on poorly drained soils.

Figure 10—Shallow roots of Sitka spruce that grew on alluvial soil with high water table.

The degree of exposure of a tree influences windfirmness. Open-grown trees are generally windfirm. They have tapering crowns with a low center of gravity and have developed buttressed roots and strong stems in response to bending stresses from exposure to wind. Increased growth occurs on the lee side of conifers exposed to wind (Andersen 1954, Busby 1965, Laitakari 1929).

Decay of roots or stems weakens trees, thereby making them more susceptible to blowdown. Although decay is often mentioned in the literature in connection with stem breakage, the importance of root rot is often overlooked. Fungi weaken root systems by infecting and decaying the butt and large roots. Half of the roots may be decayed before the tree shows symptoms (Hadfield and Johnson 1977). In tree-pulling tests, Fraser (1962) found that conifers infected with *Fornes annosus* have a reduction of 32.5 percent in mean moment of resistance because of root damage. In a survey of blowdown in 40- to 90-year-old stands in Switzerland, Bazzigher and Schmid (1969) found evidence of decay in 56 percent of thrown or broken trees observed. Advanced decay was associated with fracture of the stem in 3 percent of all trees, at the base in 14 percent, and on the roots in 39 percent. Of the species present, spruce was damaged by wind most frequently and also showed a much greater incidence of decay.

Root and butt rot may also contribute to stem breakage. Stems so weakened are easily snapped off by wind. Hemlock dwarf mistletoe, which causes swellings on stems of western hemlock, is also associated with stem breakage (Wallis and others 1980).

Trees damaged but not blown over in one wind storm may be far more susceptible to blowdown in subsequent storms. Stems may be partially fractured and yet the tree remain standing. This occurs on the leeward side of stems and is caused by compression failure when the wood fibers are compressed beyond the plastic limit (Mergen 1954). The tree responds by forming swellings of compression wood in the wound area (Mergen and Winer 1952, Phillips and Patterson 1965). Stems with this defect are subject to breakage during storms. Breakage of 30-year-old Sitka spruce during a windstorm in Britain was traced to damage caused by excessive bending during a previous storm (Forest Products Research Board 1964). "Root springing," the breakage or disturbance of roots, is a common cause of poor anchorage and often results in leaning trees. Roots of trees growing on rock outcrops, boulders, or bedrock may be abraided by repeated rubbing against rock surfaces when trees sway during high winds (Day 1934, 1949) (fig. 11). This damage weakens roots and allows decay fungi to enter (Stone 1977) .

Microsite conditions contribute to differences in stability of individual trees. In southeast Alaska, where moisture is abundant during the growing season, tree seedlings germinate and survive on many microsites. Trees that become established on upturned roots, elevated logs, stumps, moss-covered boulders, or rock outcrops, are often stilt-rooted with asymmetrical rooting. Rooting stability of these trees decreases with age and size (fig. 12).

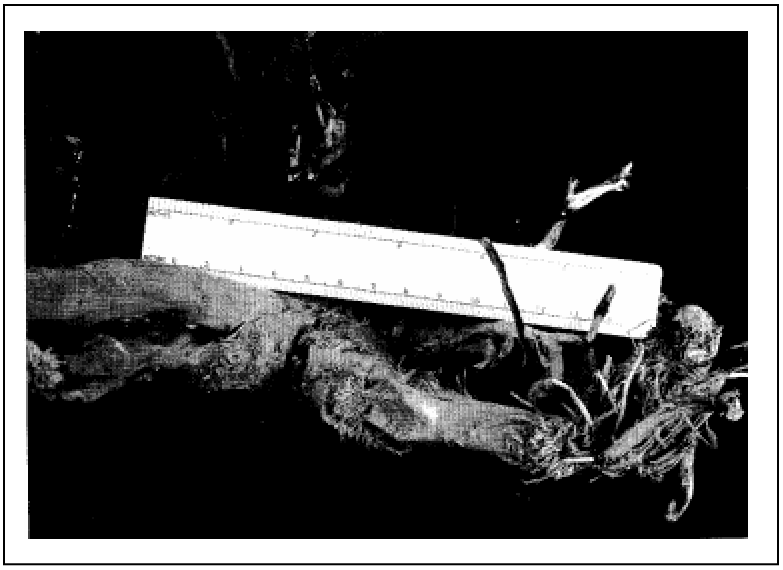

Figure 11—Abrasion of Sitka spruce roots caused by movement of tree against rock during windsway.

Figure 12—Stilt-rooted tree that germinated on elevated roots or stumps may be less windfirm because of asymetrical rooting.

Soil conditions also contribute to differences in stability of individual trees. Soils in southeast Alaska tend to be patchy and seldom are uniform over wide areas. Superimposed on this patchiness is the deep plowing effect of blowdown from past centuries that causes the typical mound-and-pit topography of the forest floor (see "Effects of Wind on Soil and Tree Roots"). Trees growing on such mounds or other well-drained microsites may be well rooted, capable of resisting blowdown, and more likely to outgrow their neighbors and maintain a dominant position in the stand.

Summary: Tree Factors Affecting Blowdown

Trees tending to be windfirm generally have the following traits.

- They are open-grown trees and have been exposed to storm winds throughout life.
- They are dominant trees with crowns well above the average stand height.
- They have a tapered stem and low form class and are short.
- They have prop roots, especially on the leeward side.
- They are straight trees without lean and have a well-formed stem.
- They have sound roots and a sound stem with no evidence of decay or swellings on the stem.
- They are deep rooted on well-drained sites with shallow soil over fractured bedrock.
- Species are western redcedar, Alaska-cedar, and immature alder (*Alnus* sp.).
- Trees not particularly windfirm generally have the following traits.
- They are in dense stands.
- They have intermediate and suppressed trees and are sheltered within the stand.
- The stems have little taper, have high form class, and are tall.
- They have stilt-roots, especially if rooting is asymmetrical.
- They lean, are root-sprung, are pistol-butted, have a forked top, have swelling on stem, or have an infestation of dwarf mistletoe.

- They have decay or injury shown by indicators (conks, stress cracks, stem swelling, or rot.
- They have shallow, platelike rooting, and grow wher(3 drainage is poor or on shallow soil over smooth, unbroken bedrock.
- Species are western hemlock, mountain hemlock *(Tsuga mertensiana* (Bong.) Carr.), and Sitka spruce.

The importance of correctly evaluating windfirmness of individual trees will depend on the circumstances. Greater risk might be more acceptable when windfirm border trees along a remote cutting line are marked than when trees are evaluated for potential hazard in a heavily used campground or near buildings.

Windfirmness of Stands

The tendency of trees to blow down can be influenced greatly by stand conditions. Mutual support offered by adjacent trees is an important factor in tree stability; stand density, height, structure, and species composition are important stand attributes affecting windfirmness. These features can be observed on aerial photographs and can be especially helpful in estimating the probable windfirmness of trees and stands.

Trees in open-grown stands tend to have stems with rapid taper, live crowns that may extend to the ground, and extensive root systems that provide good anchorage. In southeast Alaska, open-grown stands frequently occur where drainage is restricted.

Trees grown in dense stands tend to have stems with little taper and short, live crowns. Their center of gravity is high in the tree, and rooting may be restricted because of competition from neighbors. Trees growing in even-aged stands tend to be of uniform height and must rely on mutual protection for much of their stability. Young, regenerating stands of western hemlock-Sitka spruce on well-drained sites remain open and windfirm until crown closure but thereafter decrease in windfirmness with increasing age and tree height. In Great Britain, where blowdown is a serious problem in young, even-aged Sitka spruce stands, a system of windthrow hazard classification has been developed based on environmental factors; the system indicates stand heights at which blowdown may be expected (Booth 1977, Miller 1985).

Even-aged stands may be quite-windfirm so long as they remain intact and dense. Once opened up by thinning or blowdown, however, they may be vulnerable to additional damage. Studies with Sitka spruce in Great Britain have shown that wind forces on trees in thinned plantations can be doubled by removing adjacent trees and that once 3-4 percent of a stand in windthrown, up to 50 percent of the remainder will succumb within the next 10 feet of height growth (Savill 1983).

Experience suggests that old-growth cedar stands tend to be more windfirm than similar stands of western hemlock or Sitka spruce. Cedar stands tend to be shorter and more open and to have trees that are more firmly rooted with sparser, more flexible crowns.

Within old-growth forest stands, dominant trees tend to be more windfirm than trees in lower crown classes, even though dominant trees are taller and have relatively large crowns. Dominance may indicate deeper or more extensive rooting, which adds to stability. Dominant trees have developed under exposed conditions because their crowns reach above the general stand level. That they have survived buffeting by many gales is a good indicator of their windfirmness. Trees in the lower crown classes must rely on mutual protection from the stand for much of their support. They have not been tested to the same extent as dominant trees and, when exposed, may not prove to be windfirm. Such trees are especially susceptible to blowdown if exposed along a cutting boundary or if left as crop trees after thinning or partial cutting. Residual trees in even-aged stands originating from blowdown may be extremely windfirm if sound and undamaged until, with age, they become weakened from decay.

Windfirmness of a stand can doubtless be increased or decreased by cultural treatment, but experience in southeast Alaska is limited. Work elsewhere suggests that opening of both uneven-aged old-growth stands and older even-aged stands, by thinning or partial cutting, can greatly reduce windfirmness. In contrast, windfirmness of a young stand might be increased by frequent light thinnings that begin early in the life of the stand.

Summary: Stand Factors Associated With Blowdown

Stands tending to be windfirm generally have the following traits.

- They are young, even-aged stands and regenerating stands.
- They are even-aged stands in early successional status and have little defect.
- They are short stands with open stocking on less productive sites, muskeg or scrub stands.
- The stands have a high percentage of cedar and hardwoods (alder or cottonwood).
- They are intact stands with little evidence of recent opening.
- Stands that are not particularly windfirm generally have the following traits.
- They are uneven-aged stands in near-climax successional status with large amounts of defect.
- The stands are tall with dense stocking on productive sites.
- The stands are predominantly hemlock or spruce.
- The stands were previously damaged by blowdown or are even-aged pole or young sawtimber stands opened by thinning or partial cutting.

Topographic Factors Associated With Blowdown

Topographic factors can greatly affect the probability of blowdown. Much general information is available in the literature from mountainous areas in other parts of the world, and summaries are available (Ruth and Harris 1979). The following guidelines drawn from the literature and local experience, apply in southeast Alaska:

Topographic factors tending to increase windfirmness of trees and stands include the following.

- Northerly aspects with topographic protection from storm winds.
- Interior of islands or areas protected from southerly winds by steep topography.
- Lower leeward slopes.

Topographic factors tending to decrease windfirmness of trees and stands include the following.

- Westerly or easterly aspects where storm winds are accelerated around ridges.
- Southerly aspects exposed to onshore winds.
- Sides lopes or flats parallel to water channels oriented in a general northwest-southeast direction, especially along the west side of channels. Flats and valley bottoms at heads of inlets or bays exposed to southerly winds.
- Small islands, promontories, or slopes at constrictions of channels with open water to windward.
- Low ridges or upper leeward slopes.

General Cutting Strategy

Many recommendations for reducing losses from blowdown have appeared in the literature. Most recommendations are concerned with clearcutting, especially with locating windfirm cutting boundaries and general advice on management strategy. The recommendations are based on observation and common sense with little or no experimental data. To what extent application of these recommendations has reduced damage is not known because accurate methods of evaluation have not been devised. When strong gales hit, blowdown is inevitable, and prompt salvage efforts offer the best opportunity to minimize losses. Field foresters should document management decisions about blowdown, periodically evaluate the results, and improve these recommendations based on their experience.

The following provisional guidelines are based on recommendations in the literature and experience in southeast Alaska.

1. Estimate the relative risk of blowdown in a management area by mapping areas of relatively high and low hazard. Virtually all forested areas in southeast Alaska show some evidence of past blowdown, but not all areas are subject to the same level of hazard. For any management area, overlay maps can be made showing areas of relatively high, moderate, and low wind hazard. The maps can be used to define the degree of management intensity appropriate for a given location.

The risk of wind damage at a particular location can be estimated by examining local blowdown history—shown by down trees, stand origin, and stand structure—as well as topography, soil, and drainage. Recent blowdown, if extensive, can be seen easily from the air or on aerial photographs. Forest regeneration soon follows blowdown, however, and in a few years fallen trees are hidden by regrowth. Small even-aged stands resulting from past blowdown may be confused with stands originating from logging or wildfire unless inspected on the ground. Blowdown and probable direction of damaging winds may be recognized on the ground by mound-and-pit topography for many years, even after fallen trees have decomposed (see "Effects of Wind on Soil and Tree Roots").

In southeast Alaska, most damaging winds are from the southeast to southwest and are channeled along waterways. Areas near tidewater along major waterways and the northern ends of long waterways where a long reach to windward combines with restricting topography are often subject to especially damaging winds. Observations by the author suggest that forests on outer islands and mainland areas near the open sea are more subject to blowdown than are those in the protected mainland valleys.

2. Determine the expected direction of damaging storm winds. In southeast Alaska, these winds usually blow from the south-to-southeast sector. Damaging winds can be affected locally by topography. The best clue to probable direction of damaging winds is the direction of past blowdown in the area. Small openings in stands tend to be linear, oriented parallel to the direction of blowdown. This results from trees being knocked down like dominoes. On aerial photographs, these openings often appear narrow in the windward direction and widen to leeward.

3. Plan complete logging and road layout for a drainage for an entire rotation in advance of logging; identify each potential cutting unit and protection stand in advance. The progress of cutting should be planned to take advantage of windfirm boundaries, opportunities for progressively cutting toward the prevailing storm winds, and periodic salvage of blowdown. In theory, all cutting units slated for harvest in the Tongass National Forest during the rotation are designated before logging begins in each drainage area. In practice, improvement in planning before harvest is possible. Installing a complete road system before logging would add to flexibility in scheduling the logging and allow the prompt salvage of blowdown that would otherwise remain uneconomic to remove.

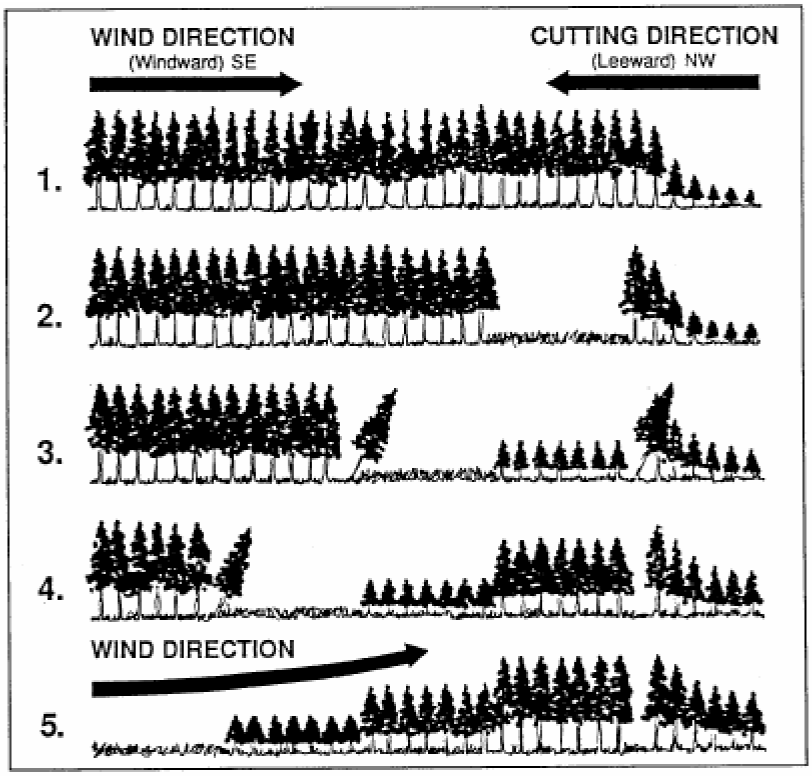

Figure 13— Cutting is done progressively in strips, into the wind, to develop a windfirm stand border: **1**—Situation shown is a stand windward of a naturally windfirm feature, in this example, a scrub-cedar stand. **2**— The first strip is cut as close to the more windfirm stand as economics will allow. **3**— The second strip is cut windward of first strip. Any blowdown that has occurred at the leeward edge of the uncut stand is salvaged. **4**— Strips are cut to the windward; blowdown on the windward edge of uncut stand is salvaged. **5**— As strip cutting continues to windward, the increasing height of the developing stand helps to lift the wind gradually, thereby eliminating an abrupt windward edge.

4. Layout clearcutting units during the first entry so that leeward (downwind of the cutting unit) cutlines most exposed to storm winds are as windfirm as possible, and locate subsequent adjacent cutting units to windward. This is a modification of strip cutting into the wind, a method developed in Europe in the early 19th century (Troup 1952) (fig. 13).

Stable leeward boundaries include open water, bluffs, permanent avalanche tracks, and vegetation that tends to be windfirm such as low-volume stands, scrub or muskeg, clearcuttings, young regenerating stands, or alder stands. Cutting units might be located windward of these features, with additional strips cut in a progressively windward direction. Sites to avoid include ridgetops, saddles, and the upper one-third of lee slopes. This strategy may be difficult to apply because of limitations on the size of clearcuttings and restrictions on the timing of adjacent cuttings. Complete layout of cutting units and roading of an entire drainage before logging should help to increase flexibility in timing of cuttings and salvage of windthrow within the drainage.

5. Make cuttings as large as environmental considerations will allow. To avoid blowdown, large clearcuttings are preferable to smaller units because the ratio of cutting perimeter to the area of timber removed is less. Development of large areas of relatively uniform age classes may not be desirable for wildlife, esthetics, or future timber management.

6. Plan to reduce length of rotation in areas of high wind hazard. Young, short trees are not as likely to blow down, and the time a tree is at risk is reduced. Studies in Great Britain show an increasing tendency for Sitka spruce to blow down with increased height, and recommendations for timing of harvest cuts are made based on tree height (Booth 1977, Miller 1985).

7. When blowdown occurs along cutting boundaries, salvage only down or weakened trees and leave well-rooted but broken trees and undamaged trees. Remaining well-rooted trees may be quite windfirm; as long as they remain standing, they will help to protect the stand to leeward until a more windfirm border develops.

8. In extensive cutover areas, try to develop windfirm stand boundaries for future management. In theory, wind-resistant strips of timber might be developed within young stands through a heavy thinning at an early age with frequent subsequent thinnings at intervals to maintain wide spacing. The resulting more open-grown trees should develop greater taper, wider rooting, and a lower center of gravity and therefore be more windfirm. Thinned strips should be located to take advantage of well-drained soils favoring deep rooting and to take advantage of any shelter offered by topography.

Thinning and Partial Cutting

Interest in using alternative silvicultural systems, intermediate cutting, and thinning is developing in Alaska (Harris and Farr 1974). The probability of wind damage should be considered before even-aged stands are thinned or partial cuttings are done in old growth. Experience with blowdown associated with thinning or partial cutting in southeast Alaska is lacking, and recommendations are based on experience in other areas. In general, thinning of stands where the tree canopy has closed may severely reduce windfirmness. But controlling stand density through frequent thinnings beginning at an early age could improve windfirmness by encouraging good root development. Evidence suggests that thinning must begin early in the life of a stand to be effective.

Six general recommendations follow:

1. Examine stands carefully for evidence of past blowdown. If past damage appears to be major, partial cutting or commercial thinning may be inadvisable.

2. Avoid partial cutting of stands especially exposed to storm winds. Such stands include those on windward slopes facing long reaches of open water and stands on exposed sites such as saddles, ridgetops, noses of ridges, or upper leeward slopes.

3. Avoid excessive thinning of closed-canopy even-aged stands. Removal of more than 30 percent of the basal area is usually considered unsafe.

4. Thin from below to remove trees in lower crown classes or trees that are leaning, are stilt-rooted, have indications of decay, or have been damaged by logging.

5. Avoid damage to the residual stand. Both spruce and hemlock have thin bark and shallow roots, are easily root-sprung, and are subject to decay when injured.

6. Heavily thin young stands at an early age. If feasible, rethin often and remove a small amount of basal area each time. Windfirmness of a stand may be increased overtime if rooting space is provided as trees develop.

Salvage of Blowdown

Down timber deteriorates rapidly, so salvage of blowdown should receive high priority. The rate of deterioration depends on tree species, extent of decay before blowdown, position of the down tree, bark conditions, moisture content, and if the tree is still living, the extent of rooting. Fahey and Cahill (1983) found that the suitability of blown-down spruce and hemlock for production of pulp decreases with time because progressive decay of sapwood increases scaling defect. Scaling defect for western hemlock was 10 percent in freshly logged live trees, 19 percent for trees blown down 3-5 years earlier, and 32 percent for trees blown down 11 years earlier. Yield of viscose pulp from both western hemlock and Sitka spruce was not as seriously affected. Yields of pulp from trees of both species blown down more than 10 years earlier was only about 2 percent lower for blowdown material than for live control trees. Current experience in southeast Alaska shows that utility grade logs may be salvaged for at least 10 years after blowdown.

If left on the ground, down timber interferes with regeneration, reduces site quality, makes future management of the stand difficult, and may reduce access for deer or block streams for fish. Salvage of down timber is possible only if it is economically feasible because logging of down timber is costly and dangerous. Stems are often piled like jack-straws and under stress so may behave unpredictably when cut (fig. 14). Blowdown patches are often small and may be scattered which makes salvage uneconomical. Small amounts of blowdown may be salvaged if easily accessible, such as along an active road system or in connection with current logging. Salvage of a small amount of blowdown often can be made economical only if it is supplemented with the sale of adjacent standing timber. A disadvantage of additional cutting along exposed cutting lines is that the newly exposed edge may continue to unravel.

From a logger's standpoint, partial blowdown is more desirable to salvage than is complete blowdown because damaged stands contain many standing live trees of high quality. Salvage of down timber almost always includes removing residual live trees because many of them have already been damaged by falling trees and more would be unavoidably damaged during logging.

Figure 14—Bucking of down trees into logs is dangerous when stems are under great stress.

If several years have passed since blowdown, tree regeneration will almost certainly have occurred. Within 10 years, regeneration may be 5-10 feet tall; meanwhile, the value of down timber will have decreased. The quality of reproduction after blowdown is affected by past history of the destroyed stand and the size, species, and density of reproduction. The manager must decide whether to save existing reproduction or destroy it and start over. The decision depends on the condition of regeneration after the salvage of blowdown; for example, if part of the stand blew down at one point and the remaining trees blew down later, then tree regeneration will have become established underneath the partially destroyed stand. Final blowdown may then damage or destroy some seedlings and release the rest for rapid growth. Surviving seedlings or saplings knocked askew by falling trees often grow erect through the development of compression wood and continue to achieve good growth. They may develop into trees with curved pistol butts of low quality and be predisposed to blowdown. Western hemlock regeneration established under a stand infested by hemlock dwarf mistletoe may also be infested. Opening of the stand by blowdown may allow the mistletoe to grow rapidly, further reducing the growth potential of the regenerating stand. Then, destroying existing reproduction and starting over with a vigorous, healthy stand might be better than allowing a productive site to remain stocked with inferior trees for an entire rotation.

If a recently windthrown stand was originally dense, little or no advanced regeneration may have occurred under it. At the time of salvage, regeneration established after blowdown will still be small, and conditions affecting germination will favor spruce. Regeneration that is undamaged and free of dwarf mistletoe might be worth saving. If so, careful salvage logging by skyline cable system with full suspension of logs will be best. In any case, reproduction will likely be overly dense and should be precommercially thinned when trees reach 10-15 feet high so that sound and well-formed crop trees are selected to remain.

Factors to consider when salvage of blowdown is planned include accessibility of the area, opportunities for future timber management, quality of reproduction, and value of down timber. A decision to salvage partially damaged stands should be based on a silvicultural examination, and each situation should be considered on its merits.

Photo Reconnaissance of Wind Damage

Methods

As background for this report, I made a photo reconnaissance of a typical portion of forested land in southeast Alaska. The study area included Prince of Wales Island and several smaller islands to the west including Kosciusko, Hecata, Dall, Long, and Tuxekan (fig. 15). Smaller islands within the Maurelle Islands Wilderness Area were not included. The study area included 2,177,009 acres of land, of which 1,295,697 acres (59.5 percent) was classified as productive forest land[6] (van Hees and LaBau 1983). Forest type maps, compiled from aerial photographs, showing blowdown through 1972 were used to locate patches of blowdown;[7] 1,010 patches of blowdown were shown. Much of the damage observed resulted from the storm on November 28, 1968.

Each patch of blowdown delineated on type maps was examined on the maps and viewed stereoscopically on aerial photos. Descriptive factors recorded for each patch included damage to the stand (partial or complete);[8] time of blowdown; area in acres; direction of tree fall in azimuth; stand condition or ground cover to windward; stand situation; topographic position, elevation, aspect, and slope; and soil mapping type. Attributes of the damaged stand were also recorded by timber type, stand-size class, stand-volume class, stand-density class, risk class, and residual-volume class.

Most of the analyses included data from the entire study area. The area of damaged timber, obtained from dot counts on the type maps, and average estimated volumes of timber in damaged areas were used to describe losses from blowdown.

The area of blowdown shown on forest-type maps included all such areas recognized on aerial photos and transferred to the maps. This included patches of complete blowdown larger than 2 acres in which few or no trees remained standing and patches of partial blowdown in which 10-90 percent of the trees remained standing.[9]

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[6] Productive forest land is land that is capable of producing crops of industrial wood with a site quality capable of producing at least 20 cubic feet of wood per acre per year.

[7] Contract no. 01-258, Solicitation R10-74-16, dated May 13, 1974. Forest-type maps compiled from aerial photographs taken during 1971 and 1972. For a description of criteria and definitions used in preparation of forest-type maps see appendix 1.

[8] Definitions used in forest-type mapping are given in appendix 1.

[9] Mapping specifications called for type mapping to a 10-acre minimum size, but areas of blowdown as small as 2 acres were shown on maps.

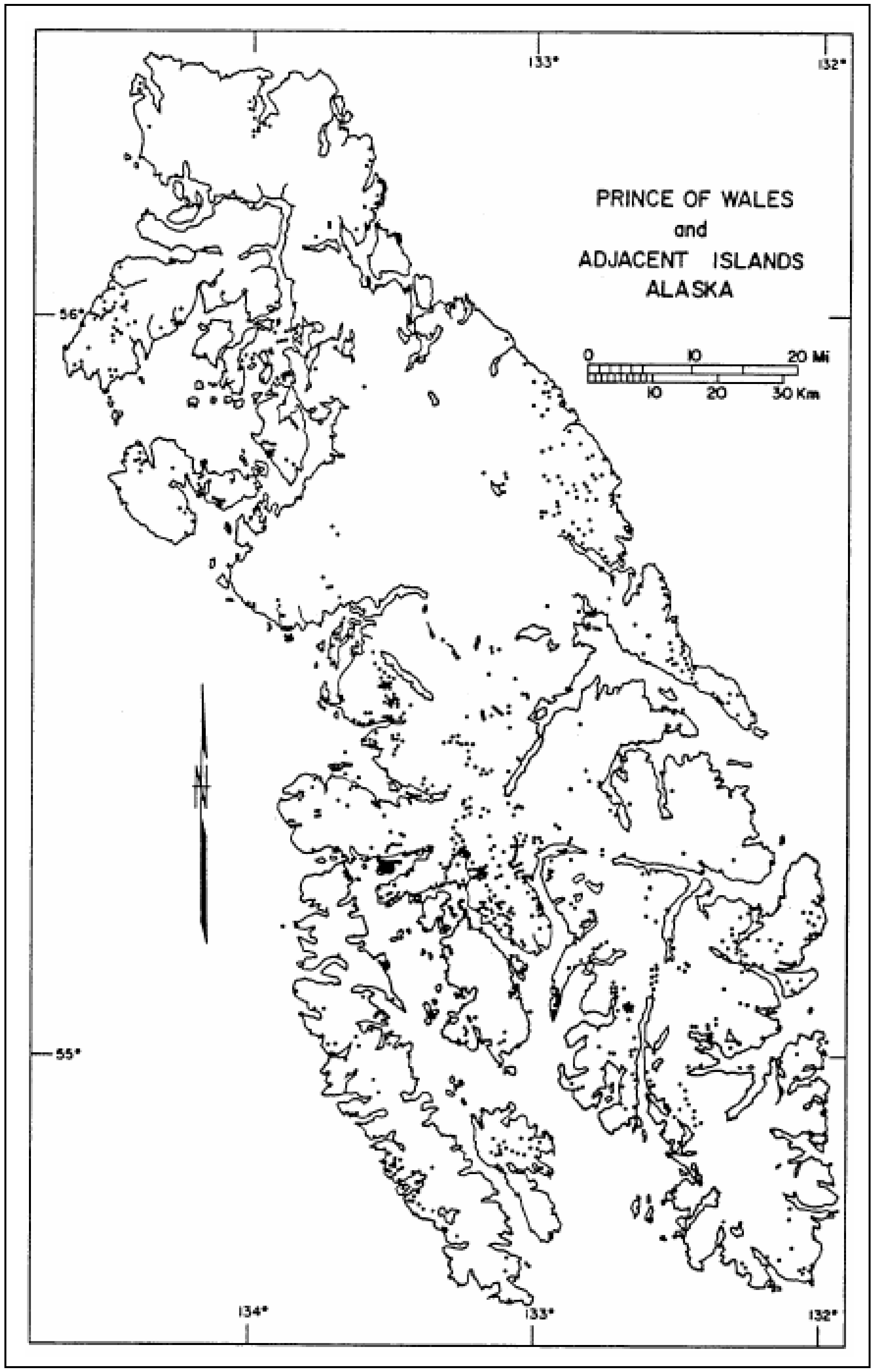

Figure 15—Prince of Wales Island and adjacent islands. The dots show general locations of blowdown as mapped from aerial photographs, 1971-72.

The volume of timber loss in areas of complete blowdown was estimated by applying the per-acre volume classification for adjacent, standing timber. When more than one volume class adjoined the damaged stand, site factors such as topography and aspect were used to infer the appropriate volume class. For areas of partial blowdown, volume loss was estimated as the difference between the stand-volume class before blowdown and the residual volume class of the damaged stand.

Factors such as type of blowdown (partial or complete), area, forest type, risk class, and volume class were obtained directly from forest type maps. The time of blowdown (whether during the 10 years preceding aerial photography or earlier) was estimated from aerial photos and was based on the appearance of down timber and the size and density of conifer regeneration. Topography and direction of blowdown were also determined by interpreting aerial photos. Elevation, aspect, and slope of blowdown patches were estimated from topographic maps.

Soil information for areas of blowdown was obtained from maps prepared by soil scientists of the USDA Forest Service, Alaska Region. The area of blowdown by soil mapping unit was determined for that portion of the study area where maps were available and was applied on a percentage basis to the entire area, on the assumption that the portion of the study area mapped was representative of the total study area. Soil maps were available for 55 percent of the map quadrangles covering the study area.[10] Data on area of timberland by soil classes were based on so-called soil ecosystem types, a method of grouping soils by depth, drainage, and parent material (organic vs. inorganic) in use at the Tongass National Forest.[11]

Whenever possible, forest inventory statistics were used to compare estimates of the area of timber damaged by blowdown with estimates of standing timber. The percentage of area damaged provided an index of the influence of various factors on susceptibilityof stands to damage. Statistics on forest land area by forest type and stand-volume class were obtained from the 1973 timber resource inventory (van Hees and LaBau 1983). Additional information on forest lands was from forest inventory files.[12] Information was sorted with a SPSS breakdown program described by Nie and others (1975).

The accuracy of aerial photo interpretation is unknown, although air and ground checks were made to see that photo interpretation appeared reasonable. The data did not lend themselves to statistical analysis because of the many limitations in sampling.

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[10] Soil type maps. On file with: U.S. Department of Agriculture, Forest Service, Alaska Region, Juneau, Alaska 99802-1628.

[11] Unpublished data. On file with: U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, 201 E. 9th Avenue, Suite 303, Anchorage, Alaska 99501.

[12] Stephen, F.R; Gass, C.R; Billings, RF.; Paulson, D.G. 1969. Soils and associated ecosystems of the Tongass. Unpublished administrative report. On file with: U.S. Department of Agriculture, Forest Service, Alaska Region, P.O. Box 21628, Juneau, AK 99802-1628.

Results and Discussion

Extent of blowdown—Total area of blowdown identified on type maps of Prince of Wales Island and adjacent islands was 18,537 acres, or 1.6 percent of the productive forest land area (table 5). The area damaged was about evenly divided between complete and partial blowdown. More blowdown appeared to have occurred during the 10 years preceding aerial photography than before this period, and the area of partial blowdown shown to have occurred before 1961 was nearly four times that of complete blowdown for the same period (table 5).

Table 5—Extent of blowdown Identified on timber-type maps, Prince of Wales Island and adjacent islands, through 1972

Blowdown category	Total area	Mean area	Range	Standard deviation	Variance	Areas sampled
	- - - - - -	- - - - - -	*Acres*	- - - - - -	- - - - - -	*Number*
Complete:						
1961-72	8,991	14.8	2-138	15.7	261.0	607
Pre-1961	427	10.7	2-22	5.7	32.1	40
Total	9,418	14.6	2-138	15.7	247.8	647
Partial:						
1961-72	7,437	25.0	2-175	24.6	605.3	288
Pre-1961	1,682	22.4	2-130	21.6	465.4	75
Total	9,119	25.1	2-175	24.0	576.9	363
Total	18,537	18.4	2-175	19.8	391.4	1,010

These differences may be the result of difficulties in interpreting aerial photos during preparation of the type maps. Precise dating of blowdown is difficult, and complete blowdown was identified as such on type maps only until downed trees visible on aerial photographs were hidden by regrowth. Older stands originating from complete blowdown were identified progressively on type maps, without regard to stand origin, as seedling and sapling stands, poletimber stands, or young-growth sawtimber stands. If 15 years is taken as a maximum time that complete blowdown was identifiable, then only 5 years would have been included in the pre-1961 period. In addition, patches of blowdown salvaged by logging often lost their identity in the process.

Partial blowdown, on the other hand, remains identifiable for many years because the typical small, usually linear openings in residual stands are clearly visible even though stocked with small trees. Data by time period and type of blowdown (whether complete or partial) were combined for most analyses.

Table 6—Loss of timber volume associated with blowdown as shown on forest-type maps, Prince of Wales and adjacent Islands, 1971-72

Volume class per acre	Average volume per acre	Condition of timberland before blowdown		Condition of timberland after blowdown: Complete blowdown[a]		Condition of timberland after blowdown: Partial blowdown[b]		Change in volume
		Area	Volume	Area	Volume	Area	Volume	
Thousand board feet		*Acres*	*Million board feet*	*Acres*	*Million board feet*	*Acres*	*Million board feet*	
0	0	0	0	9.418	0	0	0	+6.071
8-20	13.0	5,730	74.490	0	0	6,197	80.561	–150.313
21-30	24.8	8,846	219.381	0	0	2,785	69.068	–115.668
31-50	40.8	2,972	121.258	0	0	137	5.590	–55.680
50 +	56.3	989	55.680	0	0	0	0	0
Total		18,537	470.809	9.418	0	9,119	155.219	–315.590

[a] Figures in table reflect the assumption that all live trees were lost on areas mapped as complete blowdown.
[b] Figures in table refer to estimated volume of residual stand after blowdown on areas mapped as partial blowdown.

Most loss of timber occurred as complete blowdown with lesser amounts of loss from partial blowdown (table 6). Most of this timber was scattered over wide areas in patches ranging from 2 to 175 acres. The average-size patch of complete blowdown was 18 acres.

Small areas of blowdown (less than 2 acres) were not included nor were stands where isolated single trees or small groups blew down. Because scattered single trees or small groups of trees often blow down, total blowdown was probably greatly underestimated. Also, timber on an estimated 1,000 acres that blew down in November 1968 was salvaged before the date of aerial photography (1971-72) and thus was not included in the estimate. Most of this timber was near the larger logging camps, often adjacent to areas previously clearcut.

Loss of timber volume—Total loss of timber volume from blowdown was about 320 million board feet (Scribner), or 1 percent of the net sawtimber volume of 30.08 billion board feet in the study area. Most of this timber volume (287 million board feet) blew down during the 10 years immediately preceding aerial photography (1971-72); it was largely the result of the 1968 storm (table 6).

Stand situation—Forest stands damaged by blowdown were characterized by their location in relation to situations of special interest—streams, open water, clearcuts, and roads. The extent to which human activity contributed to blowdown of these stands was not estimated because relative hazard could not be quantitatively assessed. Estimates of damage are probably low because timber salvage frequently masked the extent of blowdown. Loss of individual trees and small groups of trees that commonly blow down along edges of clearcuttings or along roads and remain unsalvaged is not included in these estimates.

Table 7—Extent of damage to timberland by blowdown, by special stand situation, Prince of Wales Island and adjacent islands, 1971-72

Stand situation	Extent of damage to timberland by blowdown			
	Complete	Partial	Total	Total
	----------- *Acres* -----------			*Percent*
Not adjacent to clearcutting	8,009	7,755	15,764	85.1
Edge of clearcutting	1,451	929	2,380	12.8
Leave block in clearcutting	130	78	208	1.1
Beach fringe	34	45	79	.4
Roadside stand	26	30	56	.3
Lakeside stand	0	18	18	.1
Streamside stand	0	32	32	.2
Total	9,650	8,887	18,537	100.0

Most blowdown (85.1 percent) was not associated with the special situations in question (table 7). Of 18,537 acres of timber damaged by blowdown, 2,588 acres (13.9 percent) of down timber was adjacent to clearcut land, in patches abutting the edges of clearcut units, and in leave settings within clearcuttings. Of the blowdown along the outer edges of clearcut units, 1,570 acres (66 percent) was leeward of clearcut units. The remaining area was windward of clearcut units or along sides paralleling the wind. Wind tended to channel along cutting edges, and irregular points of timber projecting into cutting units were often blown down. Blowdown was common at V-shaped or square corners to leeward of cutovers, as mentioned by other investigators (Alexander 1964, Curtis 1943, Gratkowski 1956).

Clearcuttings on the study area tended to be large, sometimes covering hundreds of acres. They were often larger than originally planned because of blowdown and salvage of adjacent timber. The size of clearcut units increased drastically when an intervening block of timber separating two clearings blew down and was salvaged. Salvage of blowdown occurred over several years; accurate information on the amount, area, and location was not available. The relation between original size of clearcuttings and blowdown of adjacent timber could not be accurately interpreted from available timber-type maps and aerial photographs. Other studies in the Pacific Northwest have shown no consistent relation between the size of clearing and the amount of wind damage. Worthington (1953) observed only a minor amount of windfall around small group clearcuttings in old-growth Douglas-fir *(Pseudotsuga menziesia* (Mirb.) Franco) but severe damage around a 130-acre clearcutting. Ruth and Yoder (1953) found that blowdown occurs to leeward of openings as small as one-half acre in the Sitka spruce-weste'rn hemlock-Douglas-fir type. On eight units ranging in size from 11 to 81 acres, they found no correlation between size of clearing and amount of blowdown.

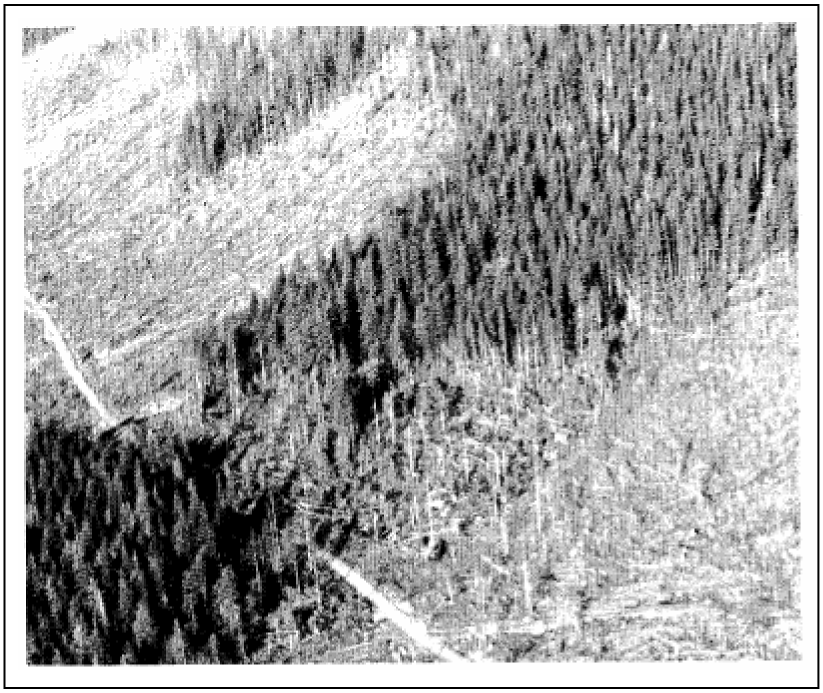

Figure 16—Within large clearcutting units, relatively narrow leave blocks perpendicular to valleys were vulnerable to blowdown, especially where they were crossed by roads.

In general, blowdown was common along cutting lines in commercial forest stands where yarding distance rather than stand quality limited cutting or where standing timber was left for seed blocks, amenity, or other purposes (fig. 16). Cutting lines seemed more windfirm where they abutted low-volume, noncommercial stands made up of short, widely spaced trees. Cutting a mature stand exposes vulnerable trees along cutlines to the full force of the wind, and trees are often windthrown before they can adapt to the change.

Windthrow along edges of clearcuttings is most severe in the first few years after cutting, and the most vulnerable trees may blow down. The remaining exposed trees grow more windfirm with time (Alexander 1964, 1967; Gratkowski 1956; Weidman 1920).

Only 0.3 percent of blowdown (56 acres) was associated with roads. This figure is doubtless low because it does not include scattered accessible blowdown that was salvaged. Other studies have shown, however, that greater concentration of blowdown is associated with roads. In a dense, 90-year-old spruce-hemlock stand at Cascade Head Experimental Forest in Oregon, McComb and Munger (1940) found over four times as much windfall within 100 feet of roads as in the zone 100-200 feet from the roads.

Timber edges that developed naturally along sea and lake shores seemed quite windfirm. When damage occurred from onshore winds, a narrow fringe of timber, at times no more than one or two trees wide, often remained standing, with blowdown beginning just beyond this beach fringe. Narrow beach fringes exposed to offshore winds were more vulnerable to damage.

The fate of strips of timber left along streams for protection or amenity could not be evaluated from this extensive reconnaissance. Virtually no blowdown was observed in streamside strips because most clearcut logging extended to the streams. In the few cases where streamside strips were left, they had blown down and timber had been salvaged. Moore (1977) showed that the windfirmness of streamside strips on Vancouver Island differed depending on the complex interaction of many factors; some strips remained intact after several years of exposure to strong winds, indicating that not all leave strips are equally subject to blowdown.

Direction of blowdown— The direction of tree fall is a useful indicator of the direction of storm winds; often it is the only indicator when direct measurement of wind is not possible. Usually, the predominant direction of damaging wind was evident on aerial photographs.

Predominant tree fall on about one-third of the area of blowdown was in a northerly direction, and one-third was in a northwesterly direction; this was the result of the prevalence of southerly to southeasterly gale-force winds (table 8). The remaining one-third of blowdown was distributed among other directions, with least occurring toward the southwest and east. Blowdown in directions other than prevailing gale direction may be caused by local topography. Winds tend to follow channels, bays, inlets, and valleys and may be deflected up to 90 degrees in constricted locations.

Down trees within 1.6 percent of the area of blowdown showed no single predominant direction of fall, but fell helter-skelter. Mountain tornadoes could account for some of this random blowdown; they can develop rotational velocities over 100 mi/h and the circular motion can cause blowdown in any direction (see "Windfirmness of Individual Trees").

The predominant direction that trees are blown down within a given area is usually a good indicator of the direction of damaging winds. The exact direction of fall of individual trees is influenced by factors other than the predominant wind direction. Trees with nonsymmetrical root systems may swing in one direction or another when uprooted, and falling trees may knock down others at an angle to storm winds. Gratkowski (1956) found that in the Cascade Range of Oregon, 20 percent of downed trees were knocked down by other falling trees. Most of the trees knocked down were hemlock or cedar in the lower crown classes. Trees can even fall against the wind when the timing of gusts coincides with the period of tree sway. If rooting is weak on the leeward side and tree sway becomes excessive, a tree may fall on the back swing when a gust passes. If roots are interlocked, a tree falling in the direction of the wind may force the roots of an adjacent tree out of the ground, thereby causing that tree to fall backwards into the wind. This usually happens only when the combined size or weight of trees falling in the windward direction is greater than that of the tree falling to leeward.

Table 8—Extent of damage to timberland by blowdown, by direction of tree fall, Prince of Wales Island and adjacent Islands, 1971-72

Direction of tree fall	Extent of damage to timberland by blowdown[a]	
	Acres	*Percent*
North	5,598	33.3
Northeast	1,268	7.6
East	561	3.3
Southeast	931	5.5
South	1,138	6.8
Southwest	254	1.5
West	1,244	7.4
Northwest	5,543	33.0
Random	276	1.6
Total	16,813	100.0

[a] Not including 1,724 acres for which data were not available.

Trees can fall without wind, apparently from the weight of snow adhering to crowns. Failure may be either from uprooting or stem breakage, and the direction of fall seems to be related to the direction of the tree's lean and crown shape. Such falls have been observed soon after a period of low temperatures followed by a wet snow. The presence of these down trees complicates the interpretation of past blowdown history.

Stand volume— The extent of blowdown was greatest in stands of the 8,000-20,000 board-foot-per-acre volume class. Rate of blowdown was greatest, however, in stands of the 21,000-30,000 board-foot-per-acre volume class—more than twice that in other classes based on the proportion of productive forest land (table 9). This class includes the average volume for productive forest land on the study area: 25,445 board feet (Scribner) per acre. Little difference was found in rate of damage among other timber volume classes. The reason for the higher rate of damage in the 21,000-30,000 board-foot-per-acre volume class is not known.

Forest type— Hemlock, including here both western and mountain hemlock, is the most common productive forest type in the study area and is followed by cedar, hemlock-spruce, and spruce (table 10). Comparison of areas of blowdown with these distributions suggests that the cedar type, here including both western redcedar and Alaska-cedar *(Chamaecyparis nootkatensis* (D. Don) Spach) is the most windfirm, with only 0.03 percent of stands receiving damage (table 10). This finding is consistent with information from the Pacific Northwest, where western redcedar is reported to be more windfirm than western hemlock (Boyce 1929). Cedar stands tend to be more open than hemlock and spruce stands, and trees are usually shorter and often have tapering stems and buttressed roots, which tend to increase stability. Spruce stands were also fairly windfirm, with blowdown loss of 0.65 percent. Western hemlock stands suffered losses at about twice this rate (1.28 percent).

Table 9— Extent of damage to timberland by blowdown and rate of damage, by per-acre volume of timber, Prince of Wales Island and adjacent Islands, 1971-72

Timber volume class	Extent of timberland[a]		Extent of damage to timberland by blowdown				Total rate of damage
			Complete	Partial	Total	Total	
Thousand board feet per acre	*Acres*	*Percent*	*- - - - - Acres - - - - -*			*- - - - Percent - - - -*	
8-20	504,575	43.0	3,547	2,183	5,730	30.9	1.1
21-30	326,651	27.8	4,435	4,411	8,846	47.8	2.7
31-50	260,454	22.2	1,069	1,903	2,972	16.0	1.1
51+	82,735	7.0	367	622	989	5.3	1.2
All	1,174,415	100.0	9,418	9,119	18,537	100.0	

[a] van Hees and LaBau 1983, p. 16; does not include stands of seedlings, saplings, and poles.

Table 10— Extent of damage to timberland by blowdown and rate of damage, by forest type, Prince of Wales Island and adjacent Islands, 1971-72

Forest type	Extent of timberland[a]		Extent of damage to timberland by blowdown				Total rate of damage
			Complete	Partial	Total	Total	
	Acres	*Percent*	*- - - - - Acres - - - - -*			*- - - - Percent - - - -*	
Hemlock[b]	737,146	62.7	5,084	4,318	9,402	50.7	1.28
Spruce	87,878	7.5	227	346	573	3.1	.65
Hemlock/ spruce	79,576	6.8	4,016	4,455	8,471	45.7	10.64
Cedar[c]	269,815	23.0	91	0	91	.5	.03
Total	1,174,415	100.0	9,418	9,119	18,537	100.0	

[a] Does not include stands of seedlings, saplings, and poles.
[b] Includes western and mountain hemlock.
[c] Includes western redcedar and Alaska-cedar.

In contrast to other timber types, western hemlock-Sitka spruce stands were far less windfirm with stands damaged by blowdown occurring on 10.64 percent of the area in this type. This high rate of damage was unexpected as hemlock-spruce stands usually occur on the more productive upland sites and along stream courses where drainage and soil conditions are conducive to deep rooting and good tree growth. Blowdown often was confined to areas of dense, tall timber with little or no damage occurring in adjacent short, open stands, growing on poorly drained organic soils. Perhaps any greater stability resulting from deep rooting may be offset in old-growth stands by the effect of increased tree height.

Table 11—Extent of damage to timberland by blowdown and rate of damage, by risk class, Prince of Wales Island and adjacent Islands, 1971-72

Timber type class	Extent of timberland[a]		Extent of damage to timberland by blowdown: Complete	Partial	Total	Total	Total rate of damage
	Acres	*Percent*	*- - - - - Acres - - - - -*			*- - - - Percent - - - -*	
High	876,507	74.6	9,388	9,039	18,427	99.4	2.10
Low	297,908	25.4	30	80	110	.6	.04
Total	1,174,415	100.0	9,418	9,119	18,537	100.0	

[a] Forest Inventory Statistics on file, Forest Sciences Laboratory, Anchorage Alaska; does not include stands of seedlings, saplings, and poles.

Few studies are available that compare relative windfirmness of northwest tree species. In western Oregon, Sitka spruce was judged to be more windfirm than western hemlock (Ruth and Yoder 1953). In wind tunnel tests of young trees, western hemlock has a far lower drag coefficient than Sitka spruce, which may mean that hemlock is more windfirm (Mayhead 1973). Experience on Prince of Wales Island did not support this conclusion, perhaps because old-growth timber made up most of the stands.

Risk class—Productive forest stands were delineated on forest type maps on the basis of high and low "risk." Risk in this context refers to the condition of the stand and not to its exposure to damaging winds. It is a classification applied by forest managers to identify stands that are well advanced in successional status, defective, and adding little incremental net growth and are therefore presumed to be more vulnerable to natural damage from wind, insects, or disease.

High-risk sawtimber stands are those beyond an even-age condition and approaching a climax condition, in which individual trees or small groups are dying and being replaced by trees in the understory. Large trees may be several hundred years old, and a wide range of age classes is usually included. High-risk stands also include older, even-aged stands that are diseased, parasitized by hemlock dwarf-mistletoe, or recently damaged by insects or wind. High-risk stands seen on aerial photographs or from a distance have a ragged texture with large variation in tree heights and crown sizes. Snags, dead tops, or small stand openings are common. The stands usually contain a lower than average percentage of Sitka spruce.

Nearly all (99.4 percent) of the sawtimber stands within the study areas were classified as high-risk stands, which reflects the preponderance of old-growth timber in the study area (table 11).

Low-risk sawtimber stands are those still in an even-aged condition, usually below 200 years of age, still increasing in net volume, and relatively free of hemlock dwarf-mistletoe, insect damage, and disease. Low-risk stands seen from the air or on aerial photos have a uniform texture and small variation in tree heights or crown sizes, and lack snags or dead tops. They also tend to contain a higher than average percentage of Sitka spruce.

Within the study area, 2.10 percent of the commercial forest land classified as occupied by high-risk stands showed evidence of blowdown (table 11). In contrast, only 0.04 percent of the area classified as occupied by low-risk stands showed evidence of blowdown. Thus, high-risk stands seem much more susceptible to blowdown than are low-risk stands. Factors responsible for greater blowdown in high-risk stands include advancing tree age and the resulting increased incidence of root and stem rot that weakens roots or increases the possibility of stem breakage, tall trees, and less uniform stand canopy.

The majority of low-risk stands damaged by blowdown were tall, dense, high-volume stands averaging over 50,000 board feet per acre. Their age and height probably contributed to blowdown.

Topographic effects—Topographic position of each area of blowdown was determined from aerial photographs and topographic maps. In situations involving wind, such as windward and leeward slopes, the direction of damaging wind was inferred from the direction of fallen timber as seen on aerial photographs.

Topographic position could be determined by photo interpretation, but only one topographic position was assigned for each area of blowdown. Where large areas of blowdown covered complex topography, topography was described only in general terms. For this reason, subtle differences were not always recognized; for example, when blowdown began on windward slopes near a secondary ridgetop and continued over the ridge and down the leeward slope in a complex pattern, where a relatively large contiguous area of blowdown covered two or more distinct topographic positions, or where blowdown began on a windward slope and continued up and over one or more low-lying features. These and similar positions were classed as "broken or rolling topography" (fig. 17).

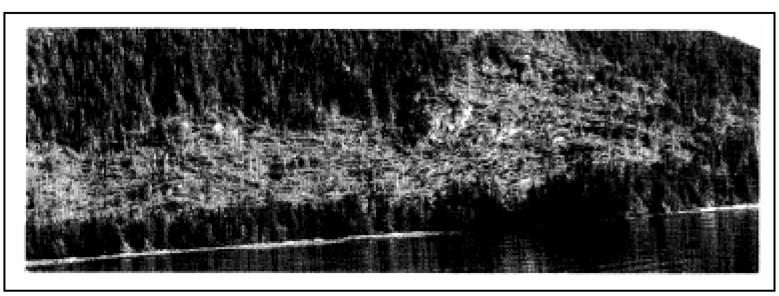

Figure 17—Blowdown beginning on the windward side of a ridge and extending to leeward. The beach fringe remained standing.

Table 12—Extent of damage to timberland by blowdown, by topographic position, Prince of Wales Island and adjacent islands, 1971-72

Topographic position	Extent of damage to timberland by blowdown			
	Complete	Partial	Total	Total
	Acres			*Percent*
Flat	1,622	2,620	4,242	22.9
Side slope parallel to wind	2,497	1,736	4,233	22.8
Broken topography	1,445	1,494	2,939	15.8
Windward slope	902	667	1,569	8.5
Ridge top	776	486	1,262	6.8
Lee slope	599	476	1,075	5.8
Knob	645	378	1,023	5.5
Narrow valley bottom	337	242	579	3.1
Saddle	256	276	532	2.9
Nose of ridge	218	183	401	2.2
No data	121	561	682	3.7
Total	9,418	9,119	18,537	100.0

Aerial photo interpretation showed that 22.9 percent of the blowdown area occurred on flat topography (table 12), usually on valley bottoms or benches. An equal area (22.8 percent) was on the side slopes of large valleys, with blowdown tending to be parallel to the slope. The third most extensive position (15.8 percent) occurred on broken or rolling topography. These three categories comprised 64 percent of the observed blowdown. Where topographic positions were described more specifically, windward slopes received the greatest damage (8.5 percent) followed by ridgetops (6.8 percent), lee slopes (5.8 percent), and knobs (5.5 percent).

Other topographic positions also received damage, apparently as a result of local topography causing wind acceleration. Constrictions in topography, such as the narrowing of a valley, the nose of a ridge lying perpendicular to the wind, and saddles, all contributed (fig. 18).

Heavy wind damage on ridgetops and upper slopes has been reported for many forestec;t areas. Comparing experience in this study with others is difficult because the extent of damage associated with various topographic features has rarely been quantified. Also, problems arise from differences in assigning damage on complex topography to a single topographic category.

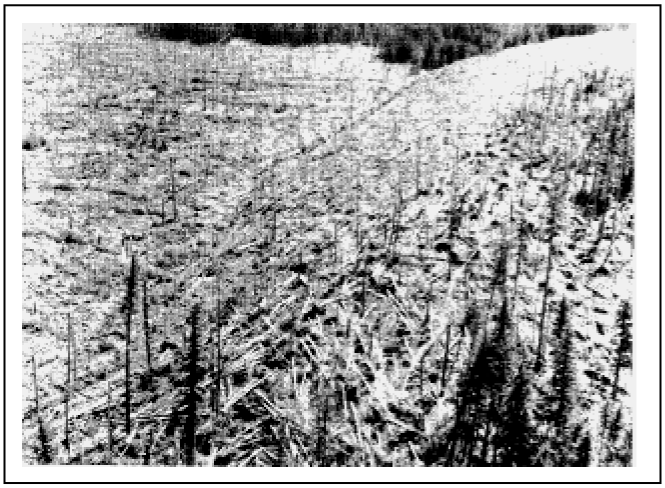

Figure 18—Blowdown beginning at a cutline on a ridge and extending to a leeward slope.

In general, topographic features impeding general wind flow can be expected to increase blowdown (fig. 19). Topographic features that protrude up into the wind stream form obstructions and cause vertical convergence of streamlines. As free air passes over an obstruction, such as a ridge, its speed increases (French 1951), and wind damage consequently occurs near the crest (Smith 1946). Many studies show that blowdown frequently occurs where wind velocity accelerates and turbulence increases because of local topography (Alexander 1964, Gratkowski 1956, Hutte 1968, Moore 1977, Ruth and Yoder 1953, Weidman 1920).

Damage to timber on lee slopes is emphasized in the literature (Alexander 1964, Gratkowski 1956, Neustein 1971, Ruth and Yoder 1953). Lee flow, or streamlines that closely follow the lee slope, can develop when wind flowing across mountainous topography at least 300 feet high reaches a speed of 29 mi/h or more and is strongest when the wind flows at right angles to mountain barriers (Jenkins 1952).

With wind up to 40-50 mi/h, lee flow closely follows the lee slope where that slope is relatively smooth and the steepness does not exceed 30-35 percent (Manley 1945). Winds at higher speeds may parallel lee slopes with grades as steep as 70 percent (Ruth and Yoder 1953).

On Prince of Wales Island and adjacent islands, windward slopes received somewhat greater damage than did leeward slopes (8.5 percent of damage on windward slopes vs. 5.8 percent on leeward slopes). Information on the distribution of productive forest land by topographic position was not available for comparison.

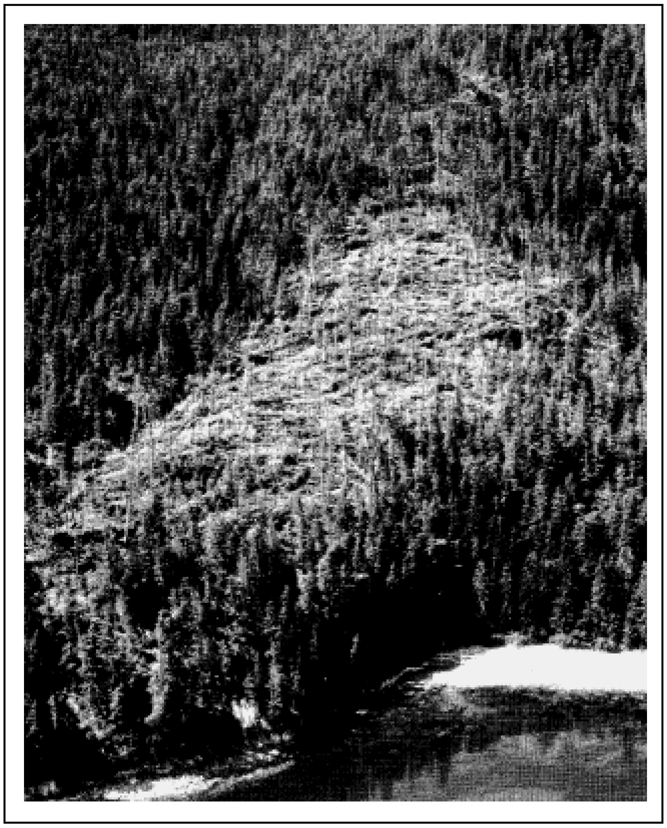

Figure 19—Blowdown damage on a low ridge perpendicular to wind direction.

Slope—The extent of blowdown shown on type maps was roughly equal on slopes up to 45 degrees (table 13). Comparison with distribution of timberland from forest-inventory statistics showed that the rate of blowdown increased with slope, from 1.02 percent on slopes of 0-15 degrees to 2.36 percent on slopes of 31-45 degrees. On slopes steeper than 45 degrees, only a small amount of blowdown (442 acres) was shown on forest-type maps, about 2.4 percent of the area blown down. Forest-inventory statistics for area of timberland could not be used to determine the rate of blowdown on slopes greater than 45 degrees because of differences in elevation classes used in reporting.

Association of windthrow with slope reported from other studies was variable, and because different methods of investigation were used, data were difficult to compare. Kennedy (1974) found that windthrow decreases as slope angle increases, but that windsnap does not correlate with slope.

Neustein (1971) reports that in a severe Scottish gale in January 1968, storm damage did not occur on slopes greater than 30 degrees, possibly because of the development of so-called back pressure on these windward slopes.

Table 13—Extent of timberland, extent of damage to timberland by blowdown, and rate of damage, by slope class, Prince of Wales and adjacent Islands, 1971-72

Timber slope class	Extent of timberland[a]		Extent of damage to timberland by blowdown				Total rate of damage
			Complete	Partial	Total	Total	
Degrees	*Acres*	*Percent*	- - - - - - - - - *Acres* - - - - - - - - -			- - - - *Percent* - - - -	
0-15	575,081	49.0	2,749	3,148	5,897	31.8	1.02
16-30	348,824	29.7	3,406	2,873	6,279	33.9	1.80
31-45	250,510	21.3	3,081	2,838	5,919	31.9	2.36
45+			182	260	442	2.4	
Total	1,174,415	100.0	9,418	9,119	18,537	100.0	

[a] Forest Inventory Statistics on file, Forest Sciences Laboratory, Anchorage, Alaska; does not include stands of seedlings, saplings, and poles.

Alexander (1964) found that windfall losses are below average along cutting boundaries located on flats and gentle slopes and above average along boundaries on moderate to steep slopes (12-31 degrees). Ruth and Yoder (1953) found that on leeward slopes downslope winds cause little damage if the slopes are steeper than 35 degrees.

Aspect—Most blowdown occurred on east-facing aspects, with west-to-southeast-facing aspects also receiving heavy damage (table 14). Least damage occurred on north-facing aspects. Comparison of this distribution with distribution of productive forest land showed that the rate of blowdown was high on the sector from southeast to southwest with rate of damage also high on easterly and westerly aspects (table 14). The general orientation of Prince of Wales Island is south-southeast to north-northwest, which is parallel to prevailing storm winds (fig. 15). The heavy damage on easterly and westerly slopes may be the result of high wind speed around the exposed flanks of mountain features, where winds tend to be accelerated by topography. In contrast, north-facing aspects were damaged at a far lower rate.

Elevation—The timberline on Prince of Wales Island extends to 3,000 feet, although stands of productive timber volume rarely extend above 2,000 feet. Most productive forest land is at lower elevations.

Most blowdown occurred at low elevations, and in general, damage decreased with increasing elevation. Of the area damaged, 55.8 percent was below 400 feet in elevation; 74.1 percent was below 600 feet (table 15).

Comparison of blowdown with distribution of productive forest land showed that the highest rate of blowdown (2.86 percent) occurred below 200 feet in elevation. This high rate could be because stands at low elevations tend to be taller and denser than stands at higher elevations. Rooting depth may also be limited by high water-tables on flat areas, which occur more frequently at low elevations. A similar situation was noted in Ireland by Kennedy (1974), who concluded that reduced rooting strength at low elevations more than offsets the advantage of greater protection from the wind.

Table 14—Extent of timberland, extent of damage to timberland by blowdown, and rate of damage, by stand aspect, Prince of Wales Island and adjacent Islands, 1971-72

Stand aspect	Extent of timberland[a]	Extent of damage to timberland by blowdown[b]		Rate of damage
	- - - - - - - - - *Acres* - - - - - - - -		- - - - - *Percent* - - - - -	
North	188,346	335	1.9	0.18
Northeast	163,462	1,218	7.0	.74
East	93,601	3,999	23.1	4.27
Southeast	70,409	2,657	15.3	3.77
South	105,615	2,516	14.5	2.38
Southwest	152,550	2,439	14.1	1.60
West	81,870	2,345	13.5	2.86
Northwest	118,490	828	4.8	.70
Flat	200,072	1,011	5.8	.50
Total	1,174,415	17,348	100.0	

[a] Forest Inventory Statistics on File, Forest Sciences Laboratory, Anchorage, Alaska; does not include stands of seedlings, saplings, and poles.
[b] Not including 1,189 acres for which data were unavailable.

Table 15—Extent of damage to timberland by blowdown and rate of damage, by elevation, Prince of Wales Island and adjacent Islands, 1971-72

Stand elevation	Extent of timberland		Extent of damage to timberland by blowdown[a]		Rate of damage
Feet	*Acres*	*Percent*	*Acres*	- - - - *Percent* - - - -	
0-200	206,379	17.5	5,899	31.8	2.86
201-400	316,874	27.0	4,455	24.0	1.41
401-600	170,313	14.5	3,391	18.3	1.99
601-800	199,493	17.0	1,171	6.3	.59
801-1,000	76,277	6.5	718	3.9	.94
1,001-1,200	58,674	5.0	1,257	6.8	2.14
1,201-1,400	76,275	6.5	487	2.6	.64
1,401-1,600	29,335	2.5	566	3.1	1.93
1,601-1,800	17,464	1.5	335	1.8	1.92
1,801+	23,331	2.0	258	1.4	1.11
Total	1,174,415	100.0	18,537	100.0	

[a] Forest Inventory Statistics on file, Forest Sciences Laboratory, Anchorage, Alaska; does not include stands of seedlings, saplings, and poles.

Table 16—Extent of damage to timberland by blowdown and rate of damage, by broad soli-system class, Prince of Wales Island and adjacent Islands, 1971-72

Soil system class, by symbol	Extent of timberland[a]		Extent of damage by to timberland by blowdown[b]				Rate of damage
			Complete	Partial	Total	Total	
Symbol	*Acres*	*Percent*	*Acres*			*Percent*	
F1	295,418	25.1	2,685	429	3,114	49.4	1.05
F2	234,698	20.0	974	73	1,047	16.6	.45
F2r	82,146	7.0	744	111	855	13.5	1.04
F4	445,089	37.9	458	25	483	7.7	.11
F5	82,137	7.0	294	114	408	6.5	.50
F6	34,927	3.0	286	110	396	6.3	1.13
Total	1,174,415	100.0	5,441	862	6,303	100.0	

[a] Forest Inventory Statistics on file, Forest Sciences Laboratory, Anchorage, Alaska.
[b] Includes roughly one-half of survey area.

At high elevations, stands tend to be short and open, factors that should increase windfirmness, although more dense and productive stands do occur. High rates of blowdown were experienced at 1,001-1,200 feet and at 1,401-1,800 feet. The high rate of blowdown at these elevations might be due to increased exposure, especially on ridgetops, saddles, and other topographic positions where windflow is restricted, and to the prevalence of shallow soils. Heavy wind damage at upper elevations is reported by several investigators for locations where upper slopes support dense and productive stands of timber (Alexander 1964, Gratkowski 1956, Pegues 1959).

Soil-Information on soils was obtained for the northern part of Prince of Wales Island and adjacent islands from soil-type maps prepared by USDA Forest Service soil scientists. 13 Mapping classes were complexes of soil series with similar characteristics. The rate of blowdown damage related to soils was determined by grouping mapping classes by a broad soil-classification system currently in use at the Tongass National Forest (see footnote 12 and appendix 2) for comparison with forest inventory data for soils of Prince of Wales Island and adjacent islands. Soil maps were available for only about half of the study area, which included 6,303 acres mapped as partial or complete blowdown on forest-type maps. The assumption was made that the area mapped was representative of the entire study area. Blowdown data were compared with forest-inventory statistics to express rate of blowdown by broad soil system classes (table 16). The highest rate of blowdown (1.13 percent) occurred in stands growing on F6 soils. Forest inventory data show that these soils occur on only 3.0 percent of productive forest land. They are found on steep slopes, usually at elevations of 1,500-2,000 feet. They are shallow to bedrock, very stony, and somewhat poorly drained mineral soils often occuring on knobs and near timberline in exposed situations. Despite the shallow rooting, old-growth stands growing on these soils can reach heights of 100 feet. Shallow rooting and increased exposure to winds may increase the risk of blowdown, especially in the taller stands.

[13] Maps. On file with: U.S. Department of Agriculture, Forest Service, P.O. Box 21628, Juneau, Alaska 99802-1628.

The second highest rate of blowdown (1.05 percent) occurred in stands on F1 soils. These are freely drained, productive soils, 2-5 feet deep, that generally support the taller old-growth stands. In contrast, only 0.45 percent of stands on soils designated F2 were damaged by blowdown. These soils are freely drained, similar to F1 soils but shallow—less than 10 inches deep over bedrock. Although deeper soil and better drainage are factors usually thought to contribute to deeper rooting, and hence to windfirmness, the greater depth of F1 soils did not seem to be associated with increased windfirmness. The greater tree heights often found on F1 soils may have offset any advantage toward stability gained by deep rooting. Few data are available on depth of tree rooting in southeast Alaska, but most rooting is thought to be shallow. Ten inches of mineral soil over bedrock seems to be enough for tree growth to achieve maximum site productivity (Heilman and Gass 1974).

A relatively high rate of blowdown (1.04 percent) also occurred on soils mapped F2r; they are very shallow, freely drained mineral soils, 0-2 inches deep over bedrock and often consist of only a duff layer where rooting takes place. They are often found on very steep valley side slopes associated with cliffs and rock faces below 1,500 feet in elevation.

The fourth highest rate of blowdown (0.50 percent) occurred on F5 soils. These soils are poorly drained and organic, usually with 3 inches to 1 foot of duff over a layer of peaty muck. A water table usually is within 1 foot of the duff, and tree rooting is restricted to the duff. Productivity is poor, stands are open, and trees tend to be short and scrubby. Western redcedar and Alaska-cedar frequently make up a sizable proportion of the old-growth stands occupying these soils.

The lowest rate of blowdown (0.11 percent) occurred on F4 soils—deep mineral soils with somewhat poor drainage and frequently with a seeping water table 1.5-2 feet from the surface. F4 soils occur from sea level to 1,500 feet in elevation. Stands of cedar frequently occupy these soils. The high incidence of cedar stands, which tend to be shorter and more open than stands of western hemlock or Sitka spruce, may be associated with increased windfirmness.

Soils may have considerable influence on tree stability in southeast Alaska, although only hypotheses can be developed from the reconnaissance described here. Most of the broad soil-system classes, for which data on timberland areas were available, include several soil series or complexes, and often a disproportionate amount of blowdown occurred on one. In stands located on F1 soils, for example, nearly half of the blowdown recorded on type maps occurred within the Ulloa-Sarkar complex. Data on the extent of productive timberland by soil complex or series were unavailable for comparison, so the rate of blowdown could be obtained only for broad soil classes (F1, F2, and so on) in use at the Tongass National Forest (see footnote 13). These broad soil classes seem to be too general for detailed assessment of blowdown in relation to soil.

Another limitation in a reconnaissance of this type is inherent in the soil-mapping process. In heavily timbered areas, soils are not visible on aerial photos; vegetation and landform provide the main clues for inferring soil conditions. In old-growth, near-climax forests, stand conditions are usually linked with soil type, so stand conditions as well as soil conditions affect stand stability. The contribution each makes to stability is not easily separated.

Summary

Damaging winds can be expected to occur nearly anywhere in southeast Alaska. They are associated with low pressure in the Gulf of Alaska and usually come from the south in fall or winter months. Strong winds are usually accompanied by heavy rain, and saturated soil contributes to blowdown. Most stands blow down in a north to northwesterly direction, which reflects the predominance of south to southeasterly storm winds.

A reconnaissance was made of Prince of Wales Island and adjacent islands based on aerial photographs taken in 1971-72 and forest-type maps prepared from these photos.

A total of 1,010 patches of partial or complete blowdown that occurred before 1971-72 were identified; they ranged from 2 to 175 acres. The blowdown identified occurred on 18,537 acres, or 1.6 percent of the area of productive forest land occupied by sawtimber. About 319 million board feet of timber was estimated to have blown down-about 1 percent of the net sawtimber volume in the study area. This figure is conservative because it includes only patches of about 2 acres and larger that were easily identifiable on aerial photos. Losses of individual trees or small groups were common but were not included. Blowdown was most common in the 21,000- to 30,000-board-foot per-acre volume class.

Hemlock stands suffered greatest areal loss from blowdown. Hemlock-spruce stands appeared to be the most susceptible to blowdown; cedar stands appeared to be the most windfirm.

Nearly all blowdown occurred in stands classified as "high-risk" stands; that is, uneven-aged stands in advanced successional condition or previously damaged in some way. High-risk stands appeared highly susceptible to blowdown; low-risk stands, in contrast, were generally windfirm.

Most blowdown occurred as patches in old-growth stands not associated with disturbances, such as road construction or clearcutting. About 14 percent of blowdown was next to a clearcutting. This estimate may be low, however, because areas where blowdown was salvaged in the past could not be easily identified. About 66 percent of this blowdown was leeward of cutover units. Blowdown was rare next to bodies of water. Trees adjacent to salt water were quite windfirm in the face of onshore winds, less so from offshore winds. Windfirmness of streamside leave strips was not evaluated because so few areas were identified on aerial photos.

Topography appeared to affect blowdown. Stands on flats, on sideslopes parallel to the direction of storm wind, and on broken or rolling topography were most susceptible. Stands on windward slopes received more blowdown than those on leeward slopes. The method of classifying blowdown may have obscured the effect of slight topographic features in low-lying areas of gentle but complex topography. Saddles, knobs, narrow valley bottoms, and exposed ridges were associated with 20.5 percent of the area damaged.

Apparently topographic protection is an important factor in stand stability. Stands with east-to-southeast aspect received most damage; west and southwest-facing stands also received considerable damage; north-facing aspects were lightly damaged.

Most damage occurred at low elevations, and the extent of damage generally decreased with elevation, probably because most commercial stands occur at low elevations. The higher rates of damage found at higher elevations might be attributable to increased exposure and to the thin, rocky soils.

Soils seemed to influence blowdown although evidence was far from conclusive. The highest incidence of blowdown occurred in stands on shallow, rocky soils at higher elevations. Increased exposure may have contributed to this. The next highest rate of damage occurred on deep, well-drained soils, where deeper rooting might be expected. Trees on these soils are often taller than on other soils, though, and this could contribute to more blowdown. Stands on organic soils and somewhat poorly drained mineral soils tended to be fairly windfirm. Old-growth stands typically found on these soils tend to be shorter, more open, and have a greater percentage of cedar than those on other soils.

The broad soils-system classes used here appeared to be an insensitive measure of tree stability. The heterogenous occurrence of soils and resulting inclusion of many soil complexes within system types, use of broad-scale typing with low resolution, and probable linking of soil and stand conditions contributed to difficulties.

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Appendix 1

Definitions Used In Forest-Type Mapping

Blowdown, complete—Productive forest land that is poorly stocked (less than 10 percent of crown closure) with commercial tree species as a result of blowdown.

Blowdown, partial—Productive forest land that is poorly stocked (11-39 percent of crown closure) with commercial tree species as a result of blowdown.

Forest types—Forest types are classified by the species group accounting for the major portion of the stand in terms of basal area in sawtimber stands and number of stems in other stands:

Sitka spruce—Forest in which Sitka spruce is predominant.
Hemlock-spruce—Forests in which 50 percent or more of the stand is either western hemlock or mountain hemlock, but in which Sitka spruce comprises 30-49 percent of the stand.
Hemlock—Forests predominantly either western hemlock or mountain hemlock, except when Sitka spruce comprises 30-49 percent of the stand.
Cedar—Forest predominantly either Alaska-cedar or western redcedar in any combination.

High-risk stands—Stands are well past maturity, no longer vigorous, and in poor condition. The crown canopy is severely broken up and a multistory stand may exist. These stands will no longer gain in volume and quality if allowed to grow.

Low-risk stands—Stands are still vigorous and in good condition. The crown canopy has not yet started to break up severely. These stands will gain volume and quality if allowed to grow.

Sawtimber stands—Stands are at least 10 percent stocked with growing-stock trees and with half or more of this stocking in sawtimber ($\geq$ 11 inches in diameter at breast height) or pole timber trees; sawtimber stocking must at least equal pole timber.

TImberland—Forest land that is producing or capable of producing crops of industrial wood. This land could produce$>$ 20 cubic feet per acre of annual growth under management. In old-growth forests of coastal Alaska, these are stands with a net timber volume of 8,000 board feet per acre.

Appendix 2

Definitions Used In Soil Classification [1]

F1—Freely drained forested soils 2-5 feet deep

Mapping unit features:

Dominant soil series—Kupreanof, Karta, Tokeen, and Ulloa
Major inclusions—Wadleigh, Tolstoi, and Sarkar
Dominant soil texture—very gravelly loam
Average slope—5-75 percent
Depth to bedrock—2-5 feet
Depth to water table—>2 feet
Drainage class—moderately well to well
Coarse fragment content—50-80 percent

Soils:

Soils usually have thick (6-12 inches) surface organic layers over a thin (0.5-2 inches), gray siltloam surface mineral layer. Beneath this is 15-40 inches *of* splotched reddish-brown and yellowish-brown, very gravelly loam overlying bedrock or basal till material. Soils are derived mostly from glacial till and colluvium. Infiltration and permeability rates within the solum are rapid.

Setting:

The setting is gentle to steep slopes on valley lowlands and footslopes. Slopes are often complex and rock outcrops may occur. These soils occasionally occur on benches at higher elevations.

F2—Freely drained forested soils, less than 1 foot deep

Mapping unit features:

Dominant soil series—Tolstoi and Tokeen
Major inclusions—Kupreanof and McGilvery
Dominant soil texture—very gravelly loam
Average slope—5-35 percent
Depth to bedrock—6-12 inches
Depth to water table—> 12 inches
Coarse fragment content—60-90 percent

Soils:

Tolstoi soils have a thick (4-6 inches) duff layer over thin to absent surface gray mineral horizons. Beneath this is 6-20 inches *of* reddish-brown, very gravelly loam overlying bedrock.

Setting:

The setting is scoured ridges, benches and rocky shorelines, very steep cliffs, and upper sides lopes below the alpine.

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[1] Source: USDA Forest Service, Alaska Region, P.O. BOX 21628, Juneau, Alaska 99802-1628.

F2R—Complex of freely drained forested soils and rock outcrops

Mapping unit features:

Dominant soil series—Tolstoi
Major inclusions—McGilvery, Kupreanof, and Karta
Dominant soil texture—very gravelly loam
Average slope—> 75 percent
Depth to bedrock—Q-2 feet
Depth to water table—Q-2 feet
Drainage class—well
Coarse fragment content—60-80 percent

Soils:

Soils are the same as for F2 soil.

Setting:

The setting is very steep valley sides lopes often associated with cliffs and rock faces.

F4—Somewhat poorly drained forested soils, 2-5 feet deep

Mapping unit features:

Dominant soil series—Wadleigh and St. Nicholas
Major inclusions—Tolstoi, Karta, Maybeso, and McGilvery
Dominant soil texture—Very gravelly loam
Average slope—75 percent
Depth to bedrock—2-5 feet and more
Depth to water table—Q.5-1 foot
Drainage class—somewhat poor
Coarse fragment content—50-80 percent

Soils:

Wadleigh soils have thick (6-12 inches) duff layers over a moderately thick (1-3 inches), gray, gravelly silt loam layer. Beneath this is 12-15 inches of dark brown, very gravelly silt loam overlying compact glacial till. St. Nicholas soils are similar except bedrock occurs within 20 inches of the surface mineral layer. F4 soils occupy about 65 percent of this mapping unit.

Setting:

The setting is gently sloping timbered landforms at all elevations below timberline but predominately under 500 feet.

F5—Poorly drained forested organic soils

Mapping unit features:

Dominant soil series—Maybeso and Kaikli
Major inclusions—Kina and Wadleigh
Dominant soil texture—woody, mucky peat
Average slope—5-50 percent
Depth to bedrock—2-5 feet and more
Depth to water table—Q-0.5 foot
Drainage class—poor
Coarse fragment content—0 in surface 20 inches; variable below this

F5—Poorly drained forested organic soils (continued)

Soils:

Maybeso soils typically have 5-7 inches of reddish-black mucky peat over 8-12 inches of black woody peat overlying several inches of reddish-brown woody sedge peat. Beneath this are several feet of compacted till or marine deposited silts. Kaikli soils are similar, except the lower sedge peat horizon rests on bedrock. F5 soils occupy about 70 percent of this mapping unit.

Setting:

The setting is gentle sloping to steep, usually concave landforms at all elevations. The soils are usually discernible by the presence of many dead-topped trees.

F6—Somewhat poorly drained forested soils, high-elevation phase

Mapping unit features:

Dominant soil series—St. Nicholas (high-elevation phase)
Major inclusions—Tolstoi, Maybeso, and Alpine soils
Dominant soil texture—Gravelly loam
Average slope—5-100 percent
Depth to bedrock—0.5-2 feet
Depth to water table—0.5 foot
Drainage class—somewhat poor
Coarse fragment content—60-80 percent

Soils: .

St. Nicholas soils usually have 4-8 inches of rooty organic material over a 1- to 2-inch gray surface mineral layer. Beneath this is 6-18 inches of dark brown, gravelly or cobbly loam resting on bedrock. Soils have a seeping water table within 6 inches of the mineral surface. St. Nicholas soils occupy about 60 percent of this mapping unit.

Setting:

The setting is high-elevation timbered mountain sides lopes immediately below the alpine. These sites are usually snow covered from November until May.

Harris, A.S. 1989. Wind in the forests of southeast Alaska and guides for reducing damage. Gen. Tech. Rep. PNW-GTR-244. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 63 p.

This paper is a review of wind conditions and blowdown in the forests of southeast Alaska based on the literature and the author's experience. Storm winds resulting in damage to forest stands are described, and some ecological and management considerations of wind that are of concern to forest managers are reviewed.

The author made a general reconnaissance of forest conditions on Prince of Wales Island and adjacent islands based on forest-type maps, aerial photographs, and ground and air checks. Forest conditions associated with blowdown are described and are discussed.

Keywords: Wind damage, blowdown, windthrow.

Pacific Northwest Research Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

U.S. Department of Agriculture
Pacific Northwest Research Station
319 S.W. Pine Street
P.O. Box 3890
Portland, Oregon 97208