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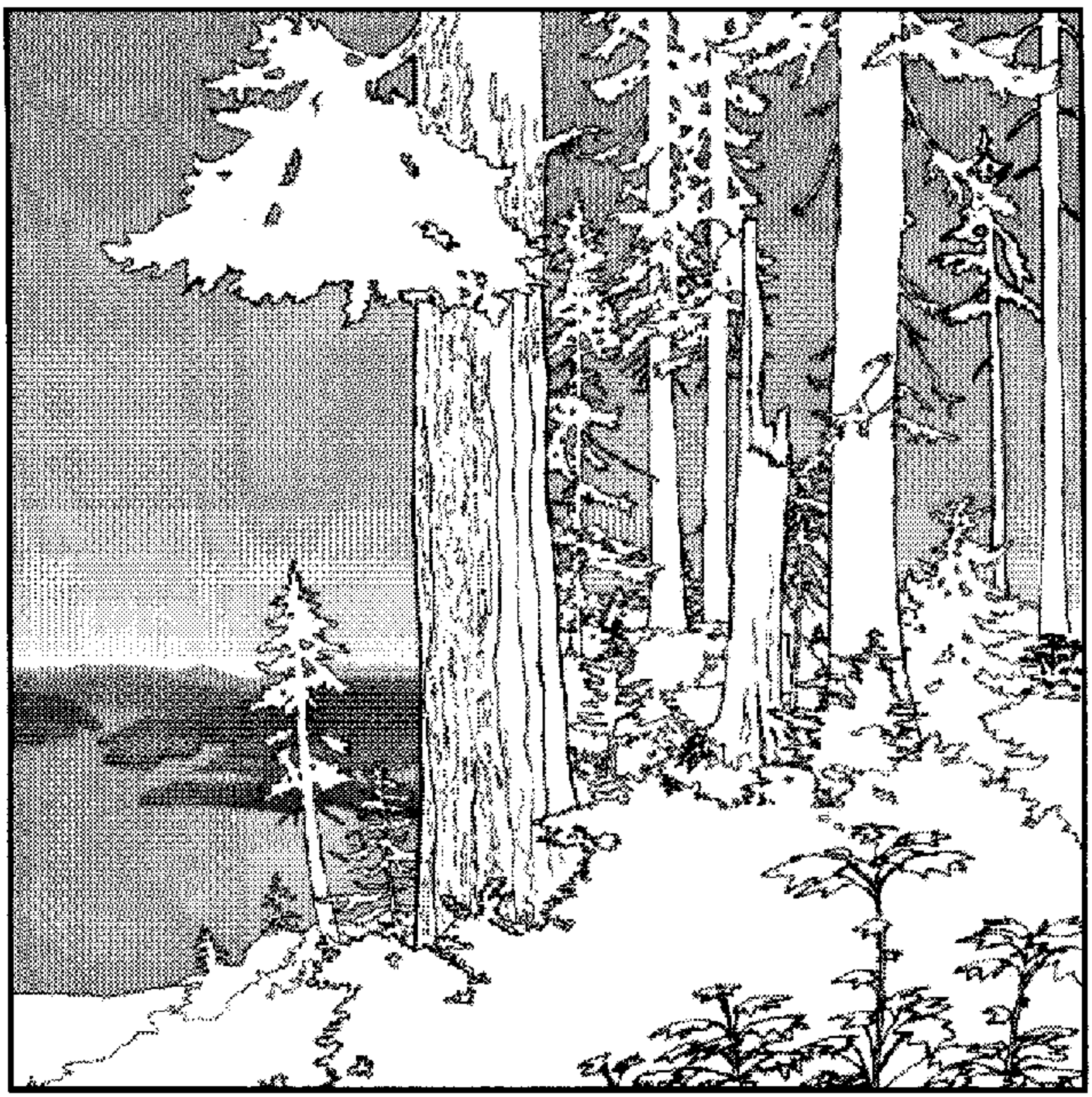

Authors

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Conservation and Resource Assessments for the Tongass Land Management Plan Revision

Charles G. Shaw III, Technical Coordinator
Kent R. Julin, Editor

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Abstract

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Wind disturbance plays a fundamental role in shaping forest dynamics in southeast Alaska. Recent studies have increased our appreciation for the effects of wind at both large and small scales. Current thinking is that wind disturbance characteristics change over a continuum dependent on landscape features (e.g., exposure, landscape position, topography). Data modeling has revealed the existence of distinct wind disturbance regimes, grading from exposed landscapes where recurrent, large-scale wind events prevail to wind-protected landscapes where small-scale canopy gaps predominate. Emulating natural disturbances offers a way to design future management plans and silvicultural prescriptions consistent with prevailing ecological conditions.

Keywords: Tongass National Forest, old growth, forest development, small-scale canopy gaps, large-scale catastrophic blowdown, predictive windthrow model, silviculture.

Introduction

The role of natural disturbance in shaping forest structure and function is recognized globally (Attiwill 1994, Perry and Amaranthus 1997, Pickett and White 1985). Management activities tailored to maintain natural disturbance processes provide a basis for ecosystem management (Alverson and others 1994, Campbell and Liegel 1996); for instance, by examining disturbance regimes under which forest systems have evolved, land managers may be able to predict forest response and recovery following human disturbance. With this information, silvilculturists could match harvest methods to the prevailing ecological conditions governing tree regeneration and growth (Franklin and others 1997). Although a variety of disturbance agents exist in southeast Alaska, wind is the most pervasive force shaping forest composition and structure (Harris and Farr 1974). Its ubiquity and varying intensity over the land (compared to the localized nature of landslides, avalanches, and flooding) make wind an environmental factor with considerable relevance to management. As such, mapping wind disturbance patterns across the landscape may provide a useful template for developing and evaluating land management practices. This paper synthesizes results from wind disturbance studies and unpublished data sets in southeast Alaska and discusses their possible implications for forest management.

Background

The vast expanses of relatively unaltered temperate rain forest in southeast Alaska present an exceptional opportunity to study the effects of disturbance on forest development and succession (Alaback 1988). An understanding of these interrelations can be used to evaluate and, if considered desirable, design silvicultural and land management practices to promote ecosystem function and vigor, biodiversity, and wildlife habitat availability. For example, if management activities were tailored to emulate disturbances common to an area, then natural processes may be maintained and thresholds above which adverse environmental impacts are likely can be identified and avoided (Hansen and others 1991, Swanson and Franklin 1992). This approach also provides an opportunity to restore ecosystem function in highly modified landscapes (Kimball and others 1995).

A variety of natural disturbances occurs in forests, including wind and ice storms, droughts, fires, landslides, avalanches, floods, insect and disease outbreaks, and animal browsing (Harris and Farr 1974, Rogers 1996). Disturbances affect forested ecosystems through tree mortality and the reallocation of resources such as light, water, nutrients, and growing space (Franklin and others 1987). In contrast to most North American ecosystems where fire is the predominant disturbance agent (Agee 1993, Pyne 1982, Wright and Bailey 1982), the cool, maritime climate of southeast Alaska greatly suppresses fire (Noste 1969); here, wind is the most widespread and ecologically important agent of large-scale natural disturbance (Harris 1989).

The impact that a wind event can have on a forested landscape depends on a combination of biotic factors (stand composition, canopy structure, size, age, and vigor) and abiotic factors (wind severity and direction, soil and site properties, and orographic effects on wind flow) (Harris 1989, Ott 1997). The interaction among these factors is complex, making wind disturbance particularly difficult to characterize and predict (Attiwill 1994, Everham 1996, Fosburg and others 1976, Harris 1989). Effects of wind disturbance often change over a continuum, grading from areas where chronic, single- or small multiple-tree openings prevail in forest canopies to areas exposed to recurrent, large-scale blowdowns (Attiwill 1994, Foster and Boose 1992).

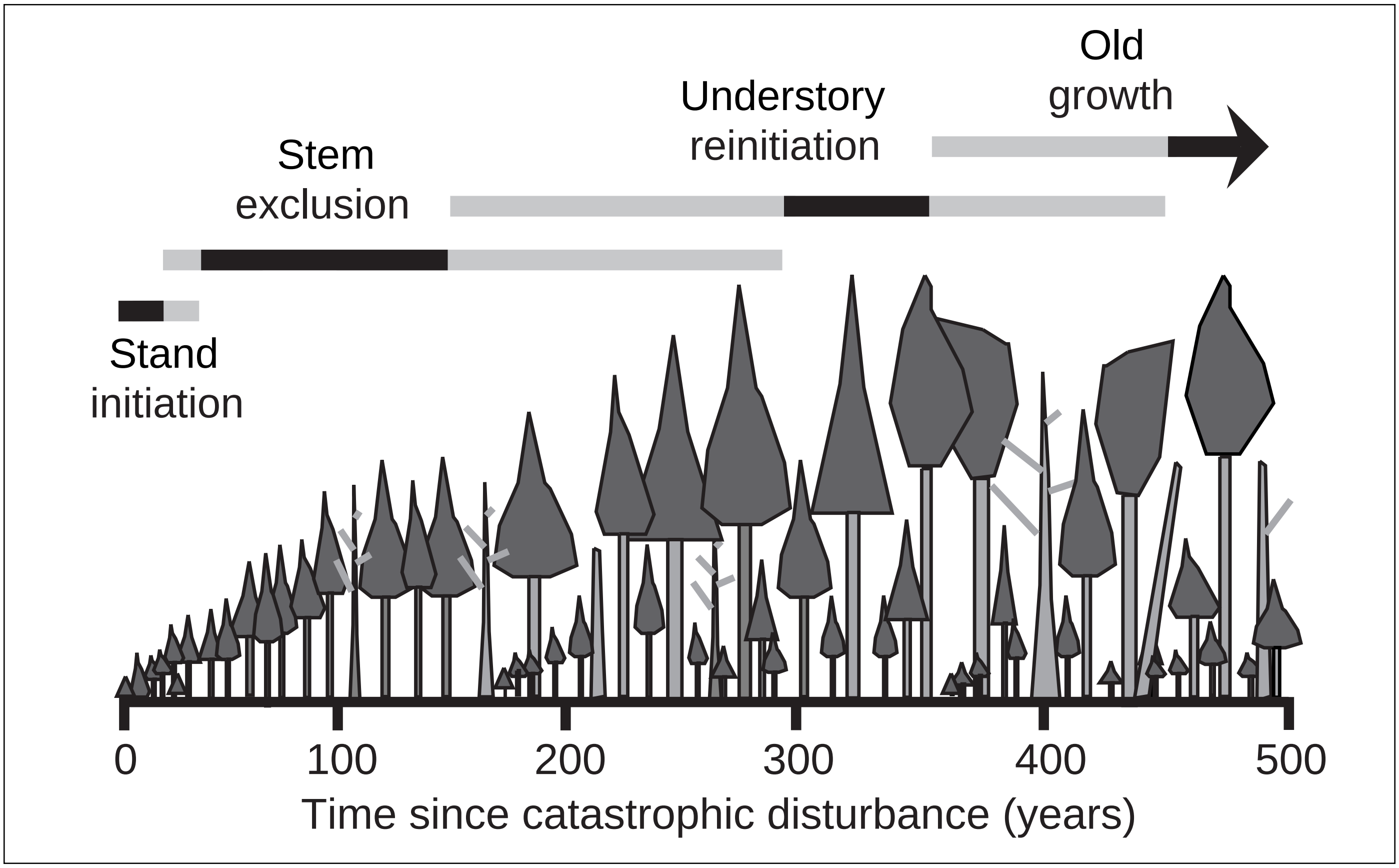

Figure 1—A conceptual timeline portraying developmental stages for temperate rain forests of southeast Alaska. Shaded bars represent temporal overlap among developmental stages.

To evaluate the effects of disturbance on forest pattern and process, it is imperative to understand the basic structural changes undergone by forests over time. Four developmental stages are conceptually recognized in temperate forests (Alaback 1982, Bormann and Likens 1979, Oliver and Larson 1996) and widely cited in ecological literature. Oliver and Larson (1996) refer to these stages as “stand initiation,” “stem exclusion,” “understory reinitiation,” and “old growth.” From this model, a conceptual developmental timeline has been constructed that is specific to southeast Alaska (fig. 1); it is based on empirical information (stand age-understory relations; fig. 2) and field observations of Kissinger,[1] Garvey,[2] Barkhau,[3] and the authors. Differing rates of forest development due to site conditions (i.e., forest development unfolds more rapidly on high-productive sites as compared to low-productive sites) account for the temporal overlap among stages shown in figure 1.

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[1] Personal communication. 1997. E. Kissinger, soil scientist, Stikine Supervisor’s Office, Petersburg, AK 99833.

[2] Personal communication. 1997. T. Garvey, GIS coordinator, Chatham Supervisor’s Office, Sitka, AK 99835.

[3] Personal communication. 1997. K. Barkhau, forester, Sitka Ranger District, Sitka, AK 99835.

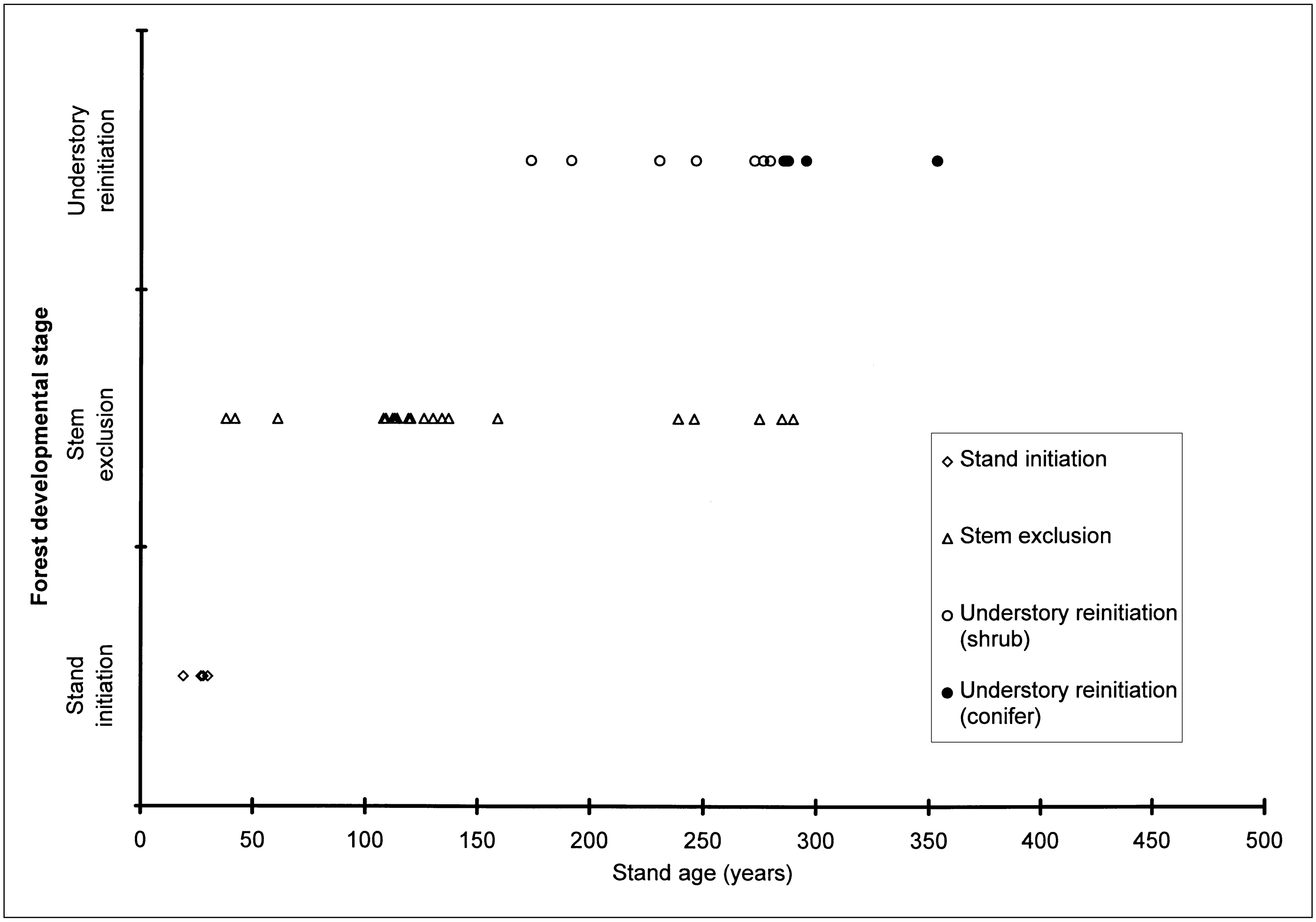

Figure 2—A timeline of forest stands categorized by developmental stage based on data from northeast Chichagof Island (see footnote 4).

The stand-initiation stage begins after catastrophic disturbance eliminates the former overstory and progresses until a complete tree canopy forms (≈25-35 years; Alaback 1982). The stem-exclusion stage is characterized by high tree mortality and a precipitous drop in understory biomass due to resource limitations (light, growing space). Site monopolization declines after about 100 years of self-thinning as interstitial space arises among canopy trees. Increased availability of resources (light, growing space) allows the revival of understory plants and transition to the understory-reinitiation stage.

Within the understory-reinitiation stage, two substages have been observed in southeast Alaska: an early “shrub” substage, where primarily herbs and shrubs recolonize, and a later “conifer” substage where tree regeneration occurs (fig. 2). The latter substage seems to correspond with the emergence of larger canopy gaps, which are not subject to closure by lateral extension of the overstory. The enduring nature of these gaps allows enough light and growing space for trees to establish and grow (i.e., gap-phase replacement). A two-aged, two-layered stand initially takes shape during this substage, and eventually succeeds to a multiaged, multilayered stand with continuing gap-phase replacement. The old-growth stage appears when the tree component is principally derived from gap-phase replacement (Oliver and Larson 1996). At this time, age and size distributions approximate inverse J-shapes and mortality generally balances growth. Stand-structure characteristics traditionally associated with old growth exist, including large and decadent trees with heavy and craggy limbs, standing snags, multiple canopy layers interspersed with overhead gaps and regeneration patches, and coarse woody accumulation on the forest floor and in streams (Franklin and others 1981). Maximum lichen diversity and biomass also are reached during the old-growth stage (Neitlich 1993). The absolute age when forests become old growth differs with site and forest type. It seems reasonable, however, that about 350 years is required to achieve the old-growth conditions characterized above.

Studies of Wind Disturbance

To characterize wind disturbance regimes within the Tongass, we focused on studies conducted within the “perhumid” rain forest zone of North America (Lawford and others 1996), which spans a rugged coastline from Yakutat Bay, Alaska, south to the northern tip of Vancouver Island, British Columbia. This zone is typified by cool summers with abundant precipitation and mild winters where snow is usually transient at lower elevations. Conifer domination of these rain forests is truly impressive, with western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) dominating uplands and mixing with shore pine (*Pinus contorta* Dougl. ex Loud. var. *contorta*), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), western redcedar (*Thuja plicata* Donn ex D. Don), and Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) on wetlands (Pojar and MacKinnon 1994). Mountain hemlock representation generally increases with elevation.

Small-Scale Canopy Gap Dynamics

Small-scale canopy disturbances are typical in older forests displaying high structural complexity (understory reinitiation and old-growth stages) (Lertzman and others 1996, Spies and others 1990). Although wind, gravity, and winter snow loading are the forces that physically bring down trees, often it is other agents, such as decay, that weaken and predispose trees in old-growth forests to fall. Hennon (1995) found heart-rot fungi to be a primary factor contributing to small-scale disturbance in southeast Alaska. Heart rot increases as trees and stands age, reaching high levels in all old-growth forests where they lead to frequent but scattered tree mortality by stem snap. The process may be cyclical as falling trees wound adjacent trees, leading to fungal infection, heart rot, and further stem snap. This link between fungi and treefall (structural failure causing trees to fall) was recognized by early researchers in the Pacific Northwest (Hubert 1918).

Although the dynamics of small-scale disturbance have received considerable attention in North America (e.g., mixed mesophytic and northern hardwood forests: Barden 1980, 1981; Canham 1988; Fox 1977; Runkle 1981, 1982), disturbance processes that cause canopy gaps in perhumid rain forests have only recently been studied. Hocker (1990) studied small-scale gap dynamics in a 300- to 500-year-old (old-growth) forest (Lemon Creek site, Juneau) and a 169-year-old (mature) forest of blowdown origin (Heintzelman

Table 1—Canopy gap and gap-maker attributes of mature and old-growth stands of perhumid rain forests, southeast Alaska

			Canopy gap characteristics					Gap makers					
Stage	Forest type	Source and site name	Total area	Size-class distribution shape	Size range	Mean size	Median size	Trees/ gap, range	Trees/ gap, mean	Dead standing	Stem-snap	Up-rooted	Other/ un-known
			Percent		– – – – – – – – *Feet* – – – – – – – –					– – – – – – – *Percent* – – – – – –			
Mature	(169 yr) *Tsuga-Picea*	Hocker 1990 (Heintzelman)	3.8	Bell	269-2,625	1,162	1,076	1-5	2.4	NA	87	13	NA
OG[a]	*Tsuga*	Hocker 1990 (Lemon Creek)	12.6	Skewed or neg. exp.	495-16,22	3,788	2,238	1-6	2.3	NA	99	1	NA
OG	*Tsuga*	Ott 1997 (Lemon Creek)	5.8	Skewed or neg. exp.	140-2,841	710	516	1-5	2.0	0	95	5	0
OG	*Tsuga*	Ott 1997 (Outer Point)	7.8	Skewed or neg. exp.	247-1,840	753	570	1-7	2.7	15	64	19	2
OG	*Tsuga*	Ott 1997 (Sitka)	12.6	Skewed or neg. exp.	65-2,281	560	409	1-6	2.6	4	69	25	2
OG	*Tsuga*	Ott 1997 (3-site mean)	8.7	Skewed or neg. exp.	65-2,841	678	495	1-7	2.4	6	76	17	1
OG	*Picea*	Ott 1997 (Fish Creek; Douglas Is.)	NA	NA	NA	NA	NA	NA	NA	25	59	16	0
OG	*Tsuga-Chamaecyparis*	Ott 1997 (NW Baranof Is.)	23.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OG	*Tsuga-Picea* complex	Ott 1997 (Eaglecrest; Douglas Is.)	7.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OG	*Tsuga-Picea-Chamaecyparis* complex	Ott 1997 (NW Baranof Is.)	33.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA = Data not available or reported.
[a] OG = Old growth.

site, Juneau). Results from this study are summarized in table 1. Gap-size range and distributional shape differed notably between the two stands. Although the mean number of trees per gap were virtually the same, the mean gap size was more than three times larger in the old-growth forest compared to the mature forest. Overall, a greater percentage of canopy gaps were in old growth than in the mature forest. Based on radial growth trends of subcanopy trees, intervals between episodes leading to canopy gaps were shorter in old growth than in the mature forest. The mode of treefall (and the creation of gaps) was principally stem snap in old-growth and mature forest. Thirty-five percent of the gap makers in the old-growth forest had heart rot or fungal infection whereas only 5 percent did in the mature forest. The general orientation of gap makers in a west-southwest direction parallels katabatic winds (Taku winds) blowing off the Coast Mountains. Wind and fungal heart rot were considered primary and proximal disturbance agents, respectively, in causing canopy gaps to form.

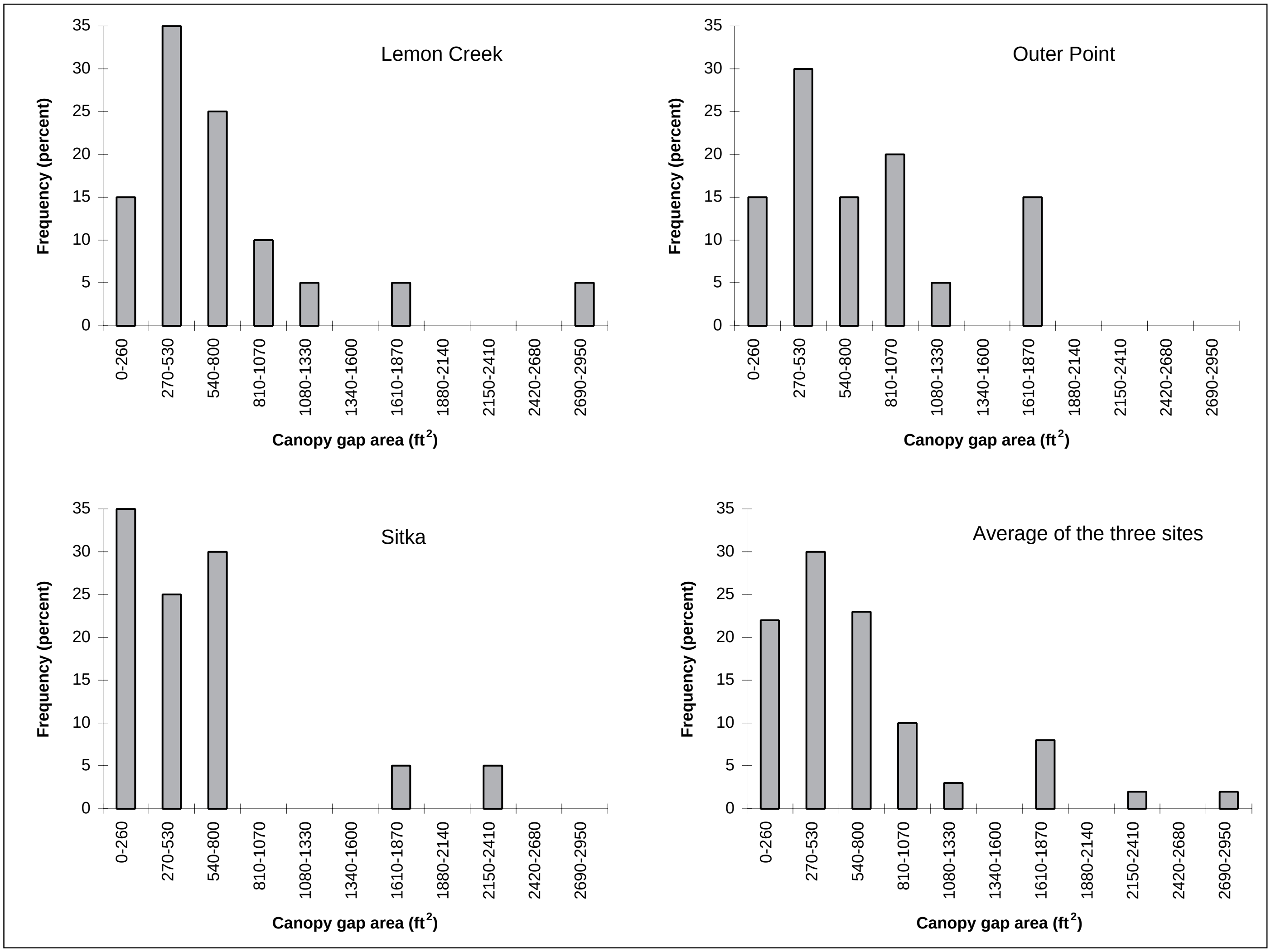

Figure 3—Size-frequency distribution of canopy gaps for western hemlock forests in the Chatham Area, Tongass National Forest, Alaska (slightly modified from Ott 1997:chapter 2).

Ott (1997:chapter 2) describes canopy gap characteristics for three old-growth western hemlock stands in the northern portion of the Tongass. These stands represent a range of small-scale disturbance levels from relatively protected areas (Lemon Creek site, Juneau) to areas with some exposure to prevailing southeast gales (Outer Point site, Juneau and Sitka site, Sitka). The proportion of forest in canopy gaps ranged from 6 to 13 percent among sites (9 percent average; table 1) and seemed to increase with exposure to prevailing winds. Gap processes in old-growth forests can vary considerably within the same plant association, but canopy gaps tended to be small with 52 percent being less than 540 square feet and 85 percent less than 1,080 square feet.

Gap-size distributions were rightward skewed or negative exponential in shape (fig. 3) with medians of 409 to 570 square feet. Most canopy gaps (about 82 percent) are created by the loss of three or fewer overstory trees (gap makers). On average, the majority of gap makers were snapped stems (76 percent), about 17 percent were uprootings, and the remainder were standing dead or leaning trees. Based on the high degree of stem-snap, firmly rooted trees with significant heart rot probably abound in these old-growth stands. Stem-snap and uprooting were inversely related, with increased representation of uprooting on windier sites (up to 26 percent of total gap makers). Overall, the mode of treefall seems to be linked to soil drainage and depth (determines rooting depth and anchorage), size and structural integrity of component trees, and wind exposure.

Ott (1997:chapter 3) also studied relations between prevailing winds and treefall in two old-growth stands (Lemon Creek and Outer Point sites). Tree crown “flagging” (asymmetrical crowns pointing leeward) and orientation of terminal leaders in overstory western hemlocks were used to determine prevailing wind direction. At Outer Point, the mean direction of gap-maker treefalls (291°) was significantly aligned with the direction of prevailing winds, thereby indicating that canopy gaps were formed by southeast gales. Prevailing Taku winds originating over the Juneau Icefield was confirmed at the Lemon Creek site. This site was relatively steep (slopes up to 34°) and faced southeast. The mean direction of gap-maker treefalls (190°) and its 95-percent confidence interval was equidistant between the prevailing wind direction (blowing southwest at 225°) and aspect (112°). Ott (1997) concludes that both prevailing wind direction and slope (gravity) contributed to the orientation of treefalls at the Lemon Creek site.

The studies summarized above suggest that small-scale disturbances in mature and old-growth stands result in minimal soil churning, because stem-snap is the principal mode of treefall and gap formation. As such, disruptions to the forest floor may be largely restricted to periods of intense, large-scale disturbance when uprooting is more probable. Canopy gaps in the mature forest were smaller, were of shorter duration, and appeared less frequently than in old-growth stands. This makes intuitive sense given that younger forests are comprised of small-canopied trees which, upon death, result in no gaps (subordinate trees) or gaps of limited size and persistence (see Spies and others 1990). As forests age, heart rot increasely contributes to gap formation by weakening or killing trees (Hennon 1995, Hocker 1990). However, it is wind, snow-loading, and gravity, alone or in combination, that ultimately brings trees down and initiates secondary treefall via tree-to-tree collisions.

Large-Scale Wind Disturbance

Catastrophic winds cause large-scale blowdown commonly throughout southeast Alaska (Deal and others 1991, Harris 1989, Lawford and others 1996). Depending on intensity, wind can create single-generation stands with uniform canopies or multi-generation stands with diverse canopy and size structures. These catastrophic winds can affect site productivity through tree uprooting and subsequent soil churning, which increase soil permeability and nutrient cycling (Bormann and others 1995). Also, exposure of mineral soil caused by uprooting has direct effects on forest composition, particularly in facilitating Sitka spruce regeneration (Bormann and others 1995, Deal and others 1991).

Intensive studies of large-scale wind disturbance have only recently been conducted within southeast Alaska. Through aerial photointerpretation, wind-generated stands of 2 acres or larger (unless stated otherwise) were identified and described in four locations: northeast Chichagof Island,[4] southeast Chichagof Island[5] (1-acre minimum size), Kuiu Island,[6] and Prince of Wales and associated islands (Harris 1989).

Garvey (see footnote 4) examined partial and complete blowdowns on 275,000 acres that included both National Forest System and Huna Totem lands on northeast Chichagof Island. Aerial photos taken before extensive clearcutting were used to delineate patches of blowdown. Blowdown polygons were described in terms of age, structure, and remnant cover. Similar protocols were used to collect blowdown data for 260,000 acres on southeast Chichagof Island (see footnote 5). Kissinger (see footnote 6) delineated stands originating from partial and complete blowdown as far back as 500 years. This data set was analyzed and described by Kramer (1997). Harris (1989) studied partial and complete blowdown patches that originated mostly from the Thanksgiving Day storm of 1968. Due to inherent differences in objectives, photointerpretation methods, timing, location, and areas sampled, data from these four studies are not necessarily equivalent in type or quality; hence, one should view any summaries and comparisons of these studies with these differences in mind.

These studies indicate that blowdowns in southeast Alaska range widely in size (1 to 1,000 acres; table 2) and disproportionally occur as smaller patches (typically <50 acres) as depicted by size distributions on Chichagof Island (fig. 4).

Harris (1989) working on Prince of Wales and associated islands and Kramer (1997) on Kuiu Island found blowdowns to be concentrated on certain topographic locations (table 2). Areas prone to blowdown often were south-facing slopes directly exposed to prevailing winds. Blowdown patches frequently extend onto east- and west-facing slopes where winds tend to accelerate as they round mountain flanks (Harris 1989). These areas often support multiple-age stands indicative of repeated disturbance by medium-intensity winds (Kramer 1997). In general, trees growing on topographic features impeding airflow are quite susceptible to blowdown (Harris 1989). In particular, high-intensity blowdowns frequently occur on exposed areas, often on hilltops and along ridge noses (Harris 1989). South-southeast gales during fall and winter probably are the primary cause of blowdown in southeast Alaska (Harris 1989; Ott 1997:chapter 3). Harris (1989) concluded that areas least prone to large-scale blowdown occur within wind shadows along north- and northwest-facing slopes or in the lee (northward, in this case) of high mountains that deflect wind. High-velocity katabatic winds coming off the Coast Mountains during winter also can cause local, large-scale blowdowns along the entire mainland coast (Harris 1989; Ott 1997:chapter 3). At some locations, southeasterly cyclonic storms and strong katabatic winds from the opposing direction may contribute to blowdown, such as on northeast Chichagof Island (Ott 1997:chapter 3).

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[4] Garvey, T. 1996. Unpublished data and map from Chichagof Island blowdown study. On file with: Chatham Area Office, 204 Siginaka Way, Sitka, AK 99835.

[5] Thomas, J.M.; Shephard, M.; Winn, L.A. [and others]. 1997. Southeast Chichagof Island landscape analysis (draft). Sitka, AK: USDA Forest Service Technical Report R10-TP-68.

[6] Kissinger, E. 1995. Kuiu Island/Rocky Pass blowdown stands [GIS polygon map]. Petersburg, AK: Stikine Area, Tongass National Forest.

Table 2—Characteristics of large-scale wind disturbance from 4 study areas in southeast Alaska

Characteristics	Southeast Chichagof Island[a]	Northeast Chichagof Island[b]	Kuiu Island[c]	Prince of Wales and associated islands[d]
Blowdown statistics:				
Number studied	1,118	444	1,886	1,010
Size range (acres)	1-250	2-770	2-1,000	2-175
Mean size (acres)	10	35	39	18
Median size (acres)	5	19	14	NA
Blowdown prone areas:				
Prevailing wind direction (degrees)	NA	45 + 135	135-225	135-180
Topographic position	NA	NA	Ridge noses and flanks	Valley bottoms, side slopes, and rolling terrain
Aspect (degrees)	45-225	45-225	135-225	90-270
Elevation (feet)	0-500	0-500	0-600	0-600
Slope (percent)	20-60	0-40	≈10-40	60-100
Soils	NA	Nonhydric	Nonhydric	Shallow or highly productive
Vegetation type	NA	Western hemlock forests	Western hemlock forests	Western hemlock / Sitka spruce forests
Net board feet/acre	NA	8,000-30,000	21,000-30,000	21,000-30,000

NA = Data not available or reported.
[a] See footnote 5 in text.
[b] See footnote 4 in text and Ott 1997.
[c] Kramer 1997.
[d] Harris 1989.

Forest susceptibility to blowdown may be highest during wet, stormy periods, when gusty conditions are prevalent and soil stability is reduced by saturation (Foster 1988, Harris 1989). Other site-specific edaphic and physiological factors that can influence blowdown susceptibility include rooting characteristics and tree height. In southeast Alaska, productive western hemlock and western hemlock-Sitka spruce forests are the least windfirm. These productive forests are particularly susceptible to blowdown because of large, top-heavy canopies and tall tree heights (Foster 1988, Foster and Boose 1992, Lohmander and Helles 1987). In contrast, cedar-dominated forests (western redcedar and Alaska-cedar) growing on wet sites are most windfirm (Harris 1989). The windfirmness of wetland forests, where canopies are rather open and trees are short and tapered, has been recognized elsewhere (Foster and Boose 1992).

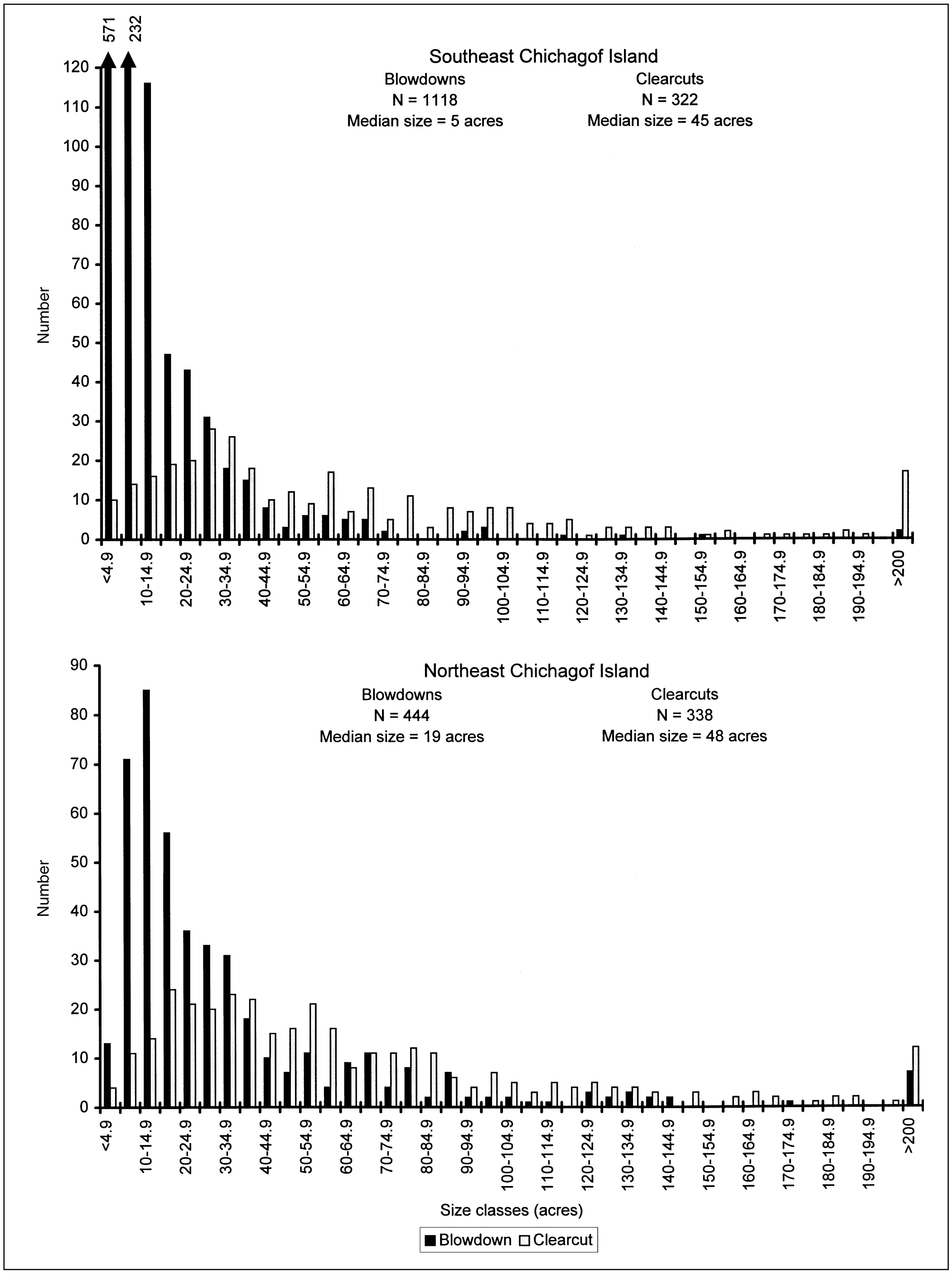

Figure 4—Comparative size distributions for harvest and blowdown patches on southeast Chichagof Island (see footnote 5) and northeast Chichagof Island (see footnote 4).

Table 3—Ordinal categories (from lowest to highest) for slope, elevation, soil, and exposure, used for the predictive windthrow model, southeast Alaska

Ordinal category (increasing value)	Slope	Elevation	Soil stability (stability class)	Storm exposure (by inflection angle)
	Percent	*Feet*		
1	0	0	0	never exposed
2	1.00	200	1	14
3	2.15	400	2	12
4	4.60	600	3	10
5	10.00	800	4 (highest)	8
6	21.50	1,000	—	6
7	46.40	1,200	—	4
8	100.00	1,400	—	2
9	1,000.00 (steepest)	3,650 (highest)	—	0 (most exposed)

Source: Kramer 1997.

In contrast to treefall caused by stems snapping, which was found to cause the majority of gaps in the old-growth forests studied (Hocker 1990; Ott 1997:chapter 2), uprooting may be the most prevalent form of treefall in large blowdown patches (Peterson and Pickett 1991). This concept is consistent with tree-wind mechanics and soil saturation during high-velocity storms (Foster 1988), although specific data are lacking for perhumid temperate rain forests.

Long-Term Gradient of Storm Damage Patterns on Kuiu Island

To test the hypothesis that a long-term storm damage gradient exists on Kuiu Island, Kramer (1997) developed a spatially explicit predictive windthrow model based on four abiotic factors: topographic exposure to prevailing storm direction, soil stability, slope, and elevation. From Kissinger's delineations of large-scale blowdown (see footnote 6), every 2-acre cell on the forested landscape was labeled as being either windthrown or non-windthrown. Each 2-acre forested cell was then attributed with ordinal values generated for each of the four abiotic factors (table 3). Topographic exposure to prevailing storm direction was determined from a modification of the model EXPOSE developed by Boose and others (1994). The final, best candidate model included all four abiotic factors, interactions, and second-order terms. The model was validated by extrapolating the Kuiu model coefficients to nearby Zarembo Island and constructing an independent large-scale windthrow data set, based on the same methods as used by Kissinger for Kuiu Island (see footnote 6). The abiotic factors accounted for 72 percent of the variation in large-scale blowdown patches on Zarembo Island.

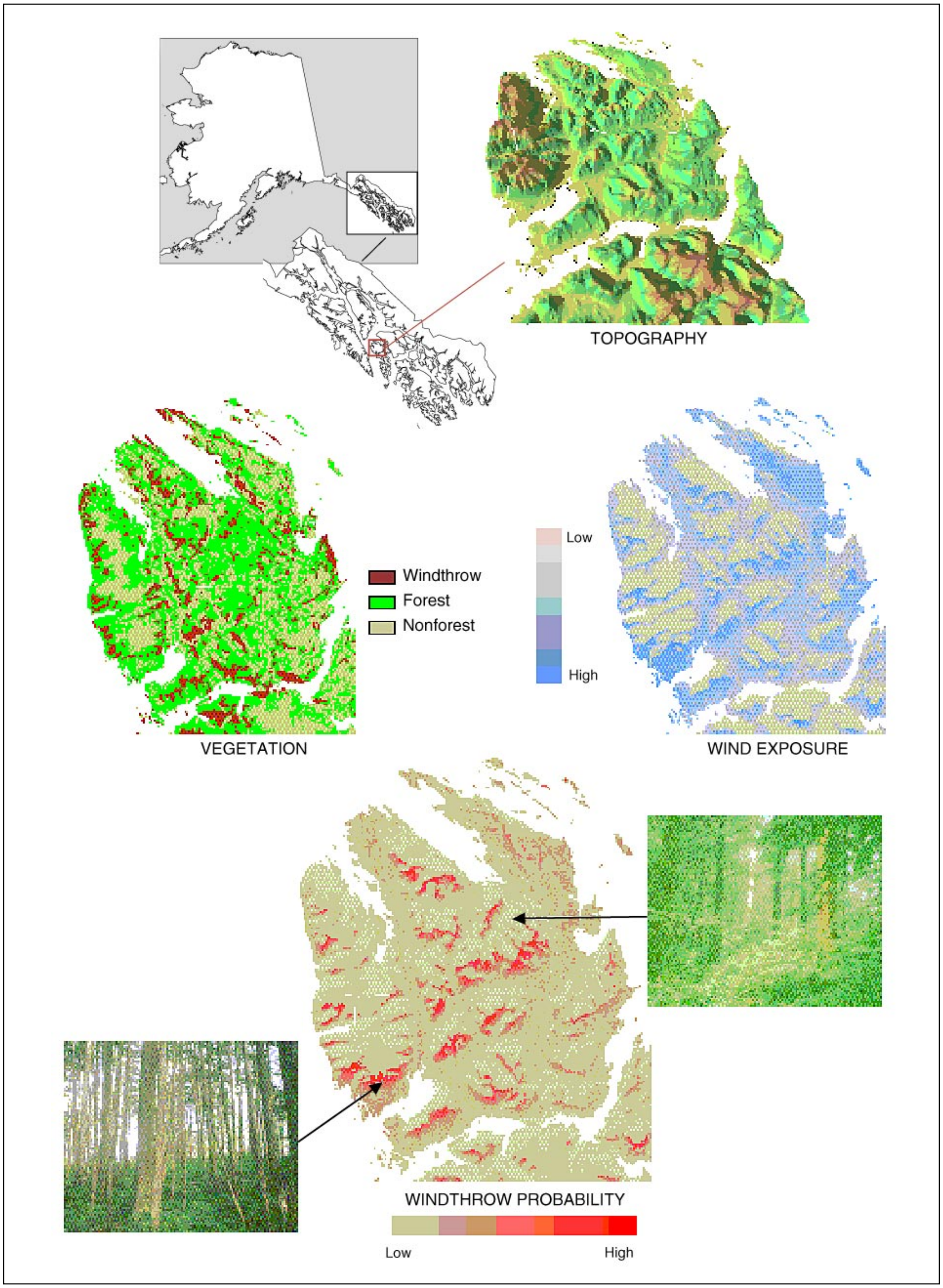

Figure 5—Topography, vegetation, wind exposure, and windthrow probability for each forested acre on Kuiu Island, southeast Alaska. Light orange areas have the lowest probability of large-scale windthrow, whereas dark orange areas have the highest probability of large-scale windthrow. Source: Hunter (in press).

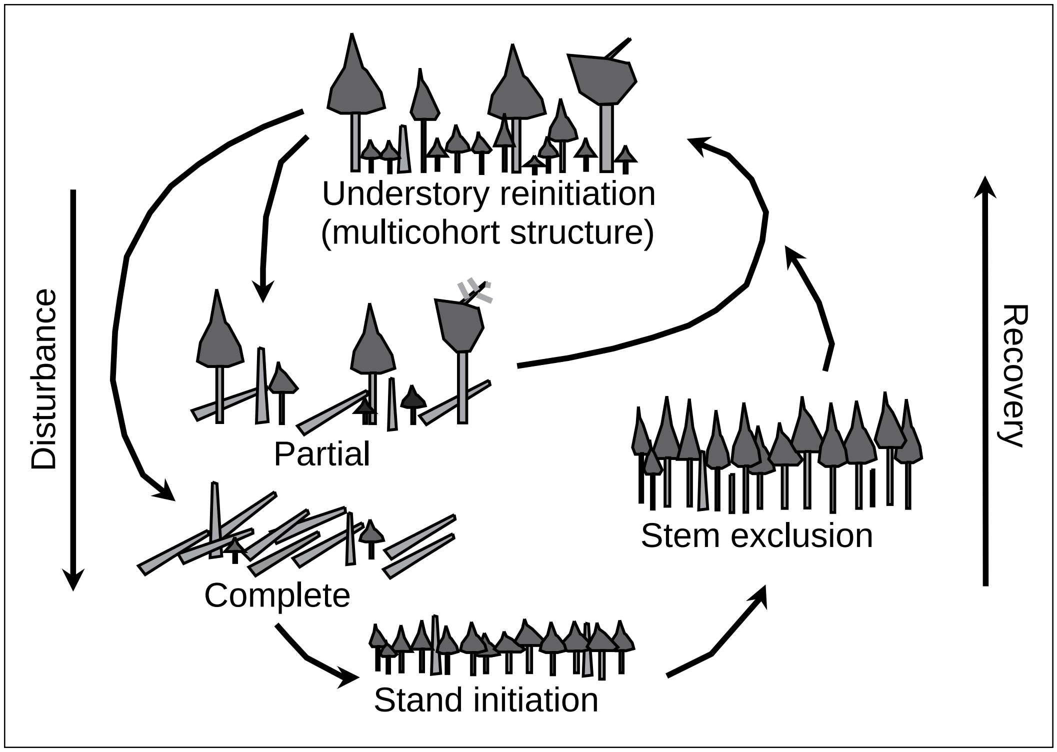

Figure 6—Disturbance and recovery cycles in temperate rain forests of southeast Alaska that occur on wind-exposed landscapes where large-scale processes predominate.

A color map showing gradations of windthrow probability was generated from the Kuiu Island model (fig. 5). Darker colored areas represent those forested sites most likely to be affected by high-intensity wind. Sites least susceptible to destructive winds were theorized to be places where small-scale disturbance processes were likely to prevail. Data from 122 plots in storm-prone and storm-protected landscapes were collected in 1996 to verify the model in the field. Exploratory regressions between the age and size characteristics of forest plots and the probability of windthrow occurrence suggest that stands show increasing homogeneity as a function of increasing probability of windthrow.

Forests that completely blow down cycle through stand initiation, stem exclusion, and understory reinitiation stages sequentially before attaining an old-growth state (ca. 350 years; fig. 1). Kramer (1997) found that on wind-exposed landscapes, storm intervals seem to be frequent enough to restrict forests to the first three stages of development (fig. 6). Depending on intensity and prevailing forest conditions, wind events can cause complete or partial blowdown that give rise to single- or multiple-aged forests, respectively. It is often difficult to distinguish the latter forests from old growth: They differ in having distinct age groups of trees (cohorts) directly linked to periodic exogenous disturbance, whereas old-growth forests have continual tree recruitment associated with endogenous, gap-phase processes (see Oliver and Larson 1996). Many stands previously designated as "old growth" in southeast Alaska may in fact be multicohort or very old, single-cohort stands (Deal and others 1991, Harris 1989). On Kuiu Island, for example, wind-prone landscapes with mainly single-cohort and multicohort stands comprise about 15 percent of the productive forest land (Kramer 1997).

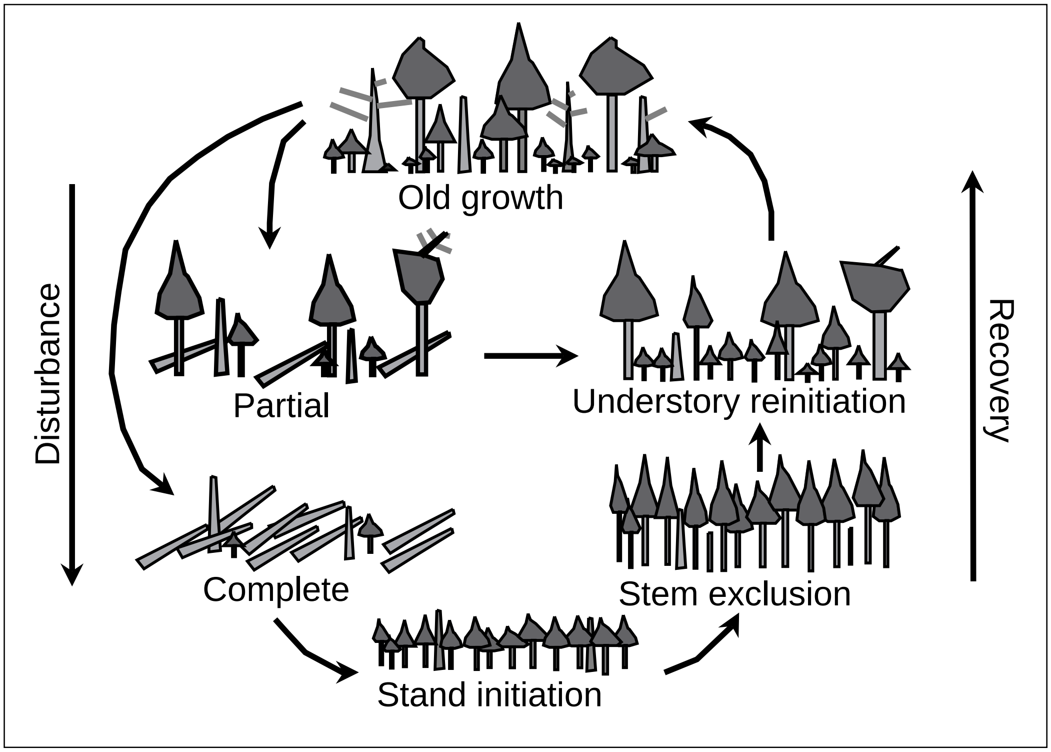

Figure 7—Disturbance and recovery cycles in temperate rain forests of southeast Alaska that occur on wind-protected landscapes where small-scale gap processes predominate.

For landscapes least prone to large-scale blowdown, Kramer (1997) concluded that the storm interval is sufficiently long to allow forests to achieve old-growth status (ca. 350+ years) (fig. 7). These areas are akin to the northern hardwoods ecosystem described by Bormann and Likens (1979) where forests undergo long periods free of catastrophic disturbance and eventually attain old-growth states where carbon gain and loss are balanced. On wind-protected landscapes in southeast Alaska, frequent canopy gaps created by autogenic processes described by Hocker (1990) and Ott (1997:chapter 2) prevail over extended periods, until interrupted by intense, exogenous disturbances such as wind storms. As a result, forest canopies are partially or wholly destroyed. Eventually, these stands cycle back to old-growth conditions, unless preempted by another large-scale natural disturbance or by timber harvesting. About 35 percent of the productive forest land on Kuiu Island occurs within landscapes least prone to large-scale blowdown (Kramer 1997).

Kramer (1997) concluded that the remaining 50 percent of the forested landscape (150,000 acres) on Kuiu Island is a mix of both small- and large-scale disturbances where a variety of forest structures and successional pathways probably exist. Forest structures representative of wind-protected, intermediate, and wind-exposed landscapes are best characterized by the “Rose,” “Hawk,” and “Yankee Basin” stands of Deal and others (1991).

A New Paradigm of Forest Dynamics

Traditional ecological theory, based on stability and equilibrium, has dominated ecological thinking over the last century (Glenn-Lewin and others 1992, Pahl-Wostl 1995, Reice 1994) and seems to have profoundly influenced early research in the temperate rain forests of southeast Alaska. With fire and human disturbance (prior to European arrival) relatively minor, the idea that climax, old-growth conditions prevailed over the forested landscapes of southeast Alaska went undisputed. So pervasive was the stability and equilibrium mindset that even recent vegetation classification adopted the plant association approach in southeast Alaska (Martin 1989), whereby succession is considered orderly and deterministic and proceeds to stable, self-perpetuating communities (Clements 1936). Under this model, disturbance is simply an element that "resets" succession to an earlier state. Contrary to this view, there is evidence that disturbance plays an important, multifaceted role in forest dynamics and succession (Christensen 1989, Pickett and White 1985), a role that varies across the landscape (Foster and Boose 1992). A disturbance continuum driving forest processes exists over southeast Alaska (Kramer 1997), spanning landscapes ranging from those buffeted by recurrent large-scale wind disturbance (fig. 6) to those protected from catastrophic wind where autogenic, gap-phase processes operate (fig. 7).

This new paradigm raises questions concerning data interpretations of previous ecological studies; for instance, how representative were previous studies in collecting data that actually captured steady-state "climax" conditions for plant association classification and old-growth modeling? Were multicohort stands often used unknowingly to characterize successional endpoints or to quantify old-growth conditions? In the future, sites should be evaluated for principal modes of disturbance (large vs. small scale) through field reconnaissance and tree-age data before full-scale research or data analysis is conducted. Indeed, tree-age data are essential for understanding forest dynamics and developing robust, process-based, old-growth definitions in the future (Blozan 1994, Hayward 1991, Nowacki and Abrams 1994, Roovers and Rebertus 1993).

Management Considerations

Current timber practices in southeast Alaska favor large-scale clearcutting at ca. 100-year rotations. Important ecological implications arise when this cutting regime occurs on wind-protected landscapes where small-scale gap processes prevail. Under this type of management, tree canopies are completely removed in contiguous blocks (averaging 40 to 60 acres) and forest development is restricted to the two earliest stages: stand initiation and stem exclusion (fig. 1). These practices are in marked contrast to the natural disturbance regime under which these forests evolved and attendant species adapted. Clearcutting greatly reduces structural diversity and eliminates large-tree habitat for wildlife species (Hanley 1991, Parker and others 1996). Although some intense blowdowns result in complete overstory destruction, most cause only a partial loss of overstory trees and considerable forest legacy is retained in standing snags and down woody material. Large, simply configured clearcuts reduce landscape diversity, sever forested wildlife corridors, and curtail gene flow as well as fragmenting, isolating, and reducing old-growth patches (Franklin and Forman 1987). These effects may be most pronounced in areas already consisting of highly fragmented forest mosaics (Kramer 1997). The short cycling of forest development through short-rotation clearcutting prevents structural characteristics associated with older trees from occurring and may eliminate certain understory species (Alaback 1982, Halpern and Spies 1995). Many understory plants invest considerable energy in their root systems, adapting vegetative strategies for reproduction rather than seeding (Alaback 1982). Due to intense shading and resource monopolization by trees during the stem exclusion stage, understory species often drop out of stands under short-rotation management. They may be extirpated from these sites when development of stands into understory reinitiation and old-growth stages does not proceed. To date, thinning of young-growth stands has not effectively maintained understory shrubs and herbs important to various wildlife species (Alaback and Tappeiner 1991, Deal and Farr 1994).

Clearcuts contrast most sharply with the natural disturbance regime when they occur on wind-protected landscapes where large-scale disturbance is infrequent. Large clearcuts and the resulting single-cohort structure greatly reduce two types of disease—heart rot and hemlock dwarf mistletoe (*Arceuthobium tsugense* (Rosendahl) G.N. Jones)—both of which appear to play key roles in the small-scale gap processes in old-growth systems.[7] On wind-prone landscapes, clearcut harvest differs physically from postblowdown conditions through woody biomass removal (both standing and down debris) and lack of deep soil churning. On certain sites, the latter may lead to possible paludification (waterlogging) through the formation of soil layers impermeable to water (Bormann and others 1995).

Harvesting and the Natural Disturbance Regime

Partial forest harvests, where the more valuable timber trees were usually removed, predominated early logging activities in southeast Alaska (Harris and others 1974). These operations shifted abruptly in the 1950s, when emphasis was placed on large-scale timber removal using clearcutting. The ecological effects of this silvicultural method can be evaluated by comparing it to large-scale wind disturbances, its closest natural analogue. Incongruities between clearcut harvests and wind disturbance patterns are given below.

Landscape disturbance patterns—Clearcutting practices rarely emulate prevailing wind disturbance patterns and processes in southeast Alaska. For example, on Kuiu Island more than 50 percent of the timber harvest units are in areas where small-scale gap processes are likely to predominate (Kramer 1997). Timber harvest in these areas has an additive effect; that is, old-growth stands are converted to young-growth stands that may not develop beyond the stem exclusion stage under planned cutting schedules. These early developmental stages are historically infrequent on such landscapes. In contrast, only 20 percent (5,000 acres) of the timber harvest units on Kuiu Island occurred in areas where large-scale blowdowns are likely to predominate.

Patch size and configuration—The size, distribution, and shape of past clearcut units differ considerably from blowdowns. Clearcut size contrasts with that of natural blowdowns by having a normal distribution that peaks around 45 to 50 acres (fig. 4). Most blowdowns are small (≤ 50 acres) and scattered. In general, clearcut patches were normally larger and more geometric relative to their natural wind-generated counterparts (Kramer 1997).

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[7] Personal communication. 1997. P. Hennon, research forest pathologist, Forest Sciences Laboratory, Juneau, AK 99801.

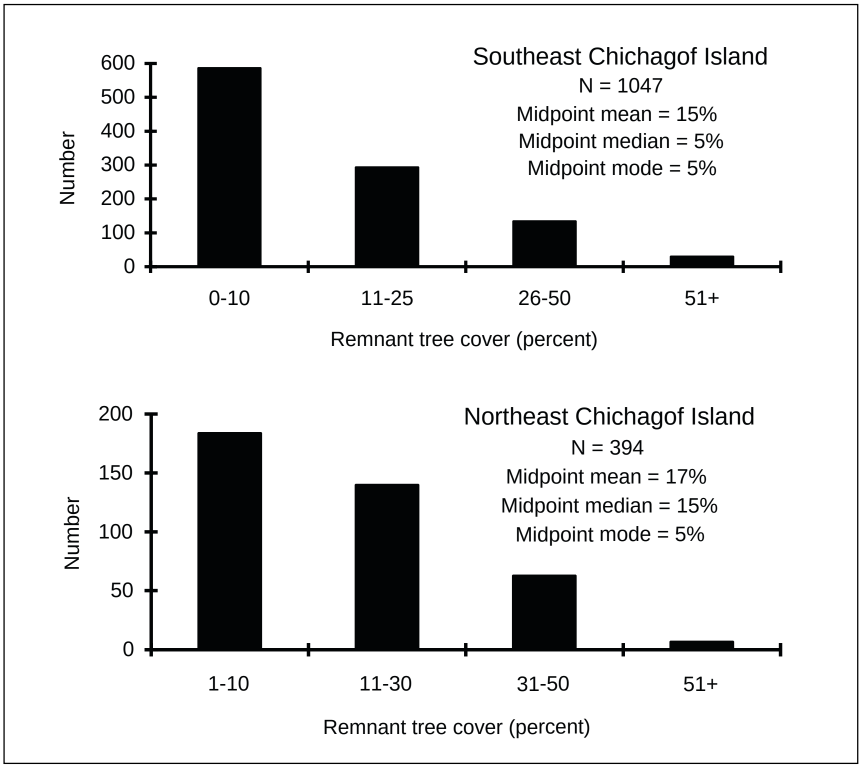

Figure 8—Number of blow downs by remnant-cover class on southeast Chichagof Island (see footnote 5) and northeast Chichagof Island (see footnote 4).

Residual biomass—Clearcutting leaves less remnant tree cover than does most blowdown. Clearcutting removes most trees from a site, whereas a wide range of structural conditions exist following blowdown events. Only occasionally are most standing trees eliminated from a site by wind disturbance (fig. 8). Immediately after disturbance and during the stem exclusion stage of stand development, remnant trees may serve several important functions, such as seed sources for regeneration, habitat structures for animals, and shade for light-sensitive understory plants (Halpern and Spies 1995). Large-scale wind disturbance creates considerable large woody material, whereas clearcutting and yarding removes most of it from the site.

Soil mixing—Uprooting associated with wind disturbance may have important ecological benefits for maintaining forest productivity (Bormann and others 1995). In contrast to wind-generated disturbances, tree yarding associated with clearcuts removes large woody material and normally results in limited soil disturbance confined primarily to the surface. With most blowdowns, uprooting causes considerable soil disturbance at lower depths. Bormann and others (1995) surmised that soil churning caused by uprooted trees during intense wind storms may be critical for maintaining site productivity. Soil churning breaks apart impermeable horizons that may otherwise lead to paludification and can enrich soil through mechanical mixing of organic and mineral horizons. Possible disruptions to disturbance-productivity processes by clearcutting are most probable on landscapes where periodic, catastrophic wind disturbance and uprooting prevail.

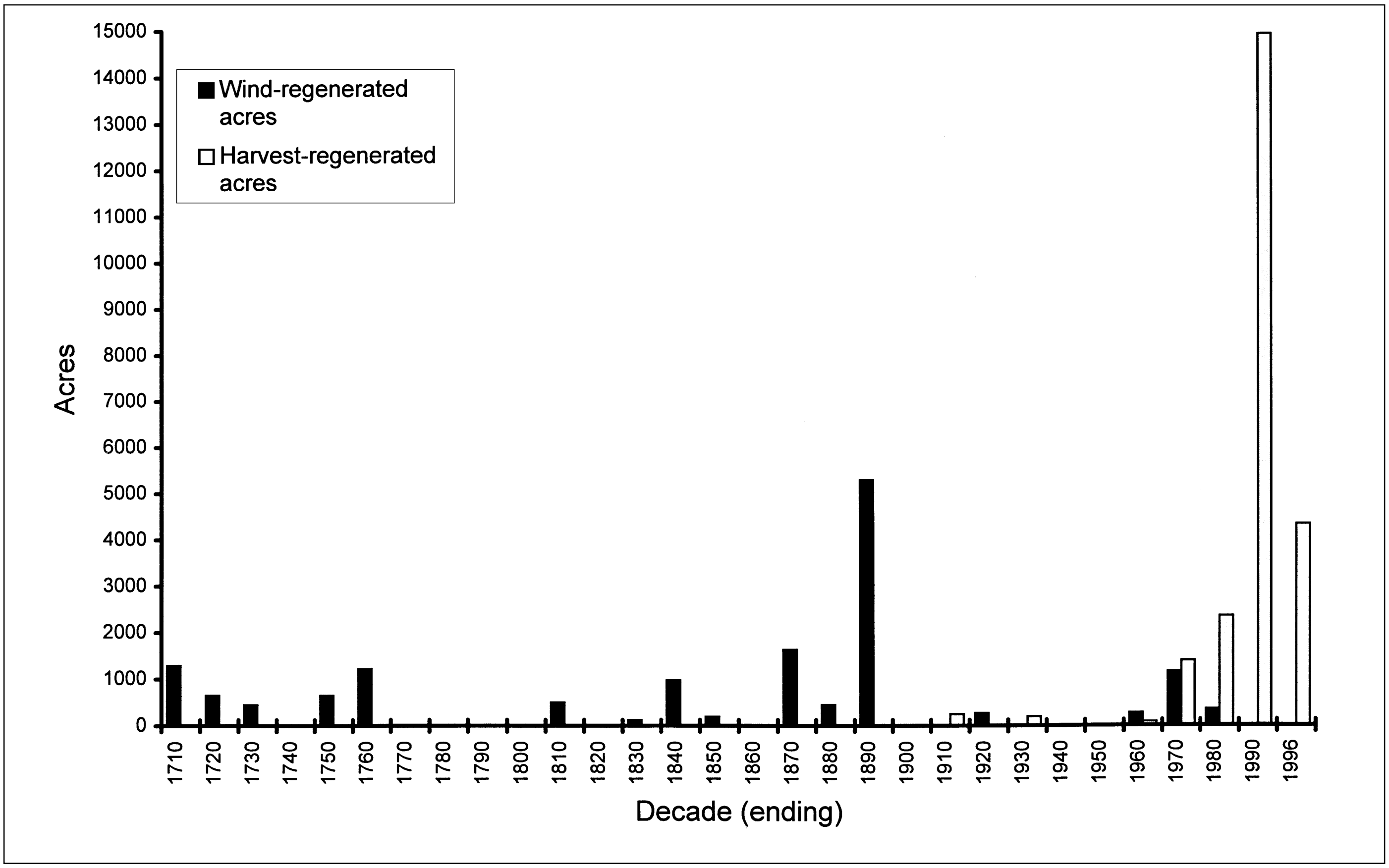

Figure 9—A frequency distribution of wind- and harvest-regenerated areas by decade across all land ownerships on northeast Chichagof Island (see footnote 4).

Disturbance frequency rate comparisons—Analysis of blowdown patches on northeast Chichagof Island (see footnote 4) indicates that tree regeneration related to wind disturbance has been relatively constant since the 1700s (fig. 9). One notable spike occurred in the 1880s, which affected about 3 percent of the productive forest land. A definite shift away from this regime of limited stand-replacement occurred with the onset of widespread clearcutting (1960s), with up to 9 percent of the productive forest land being harvested between 1980 and 1990. The area clearcut has exceeded the area that blew over by some 4 to 17 times on Chichagof Island (table 4). Similar trends are evident on Prince of Wales and Kuiu Islands, where clearcutting has proceeded at a rate four and nine times, respectively, of that recorded for high-intensity or complete blowdown (table 4). The disparity between blowdown and clearcut acres is of particular significance on Prince of Wales Island considering that the timeframe used to calculate blowdown acreage spans a time of major large-scale disturbance in 1968. Calculating actual blowdown acreages is difficult because logging may have masked the true extent of blowdown (Harris 1989). In addition, reoccurring windthrow events may have affected some sites by obscuring earlier events (Kramer 1997). Owing to the magnitude of rate differences between wind and clearcutting, however, the general trends indicated by the data are considered reasonable.

Table 4—Comparative harvest and blowdown statistics for productive forest land from 4 studies in southeast Alaska

Disturbance type by island	Analysis period or length	Productive forest land		Area affected per century	Ratio of clearcutting to blowdown
		Acres	*Percent*	*Acres*	
Southeast Chichagof Island: [a]		150,897	100.0		
Clearcut	~100 yr	21,569	14.3	21,569	
Clearcut	~30 yr	19,918	13.2	66,393	
Blowdown	~300 yr	11,844	7.8	3,948	5:1 and 17:1
Northeast Chichagof Island: [b]		166,625	100.0		
Clearcut	1900 to 1996	23,577	14.1	24,559	
Blowdown	1700 to 1996	15,492	9.3	5,234	5:1
Blowdown	1800 to 1996	11,230	6.7	5,730	4:1
Blowdown	1900 to 1996	2,064	1.2	2,150	11:1
Kuiu Island: [c]		320,000	100.0		
Clearcut	~last 100 yr	26,000	8.1	26,000	
High-intensity blowdown	~last 500 yr	14,000	4.4	2,800	9:1
Medium- and high-intensity blowdown	~last 500 yr	63,000	19.7	12,600	2:1
Prince of Wales and associated islands: [d]		1,062,462 [e]	100.0		
Clearcut	1980-1995	63,164	5.9	421,093	
		1,295,697 [f]	100.0		
Complete blowdown	1961-1972	9,418	0.7	94,180	4:1
Partial and complete blowdown	1961-1972	18,537	1.4	185,370	2:1

[a] See footnote 5 in text.
[b] See footnote 4 in text.
[c] See footnote 6 in text and Kramer 1997.
[d] Productive forest land acreage differs because separate analyses were conducted; total acreages for blowdown statistics from Harris (1989) and clearcut statistics from Tongass land management plan database.
[e] Tongass land management plan database.
[f] Harris 1989.

Emulating Natural Disturbance Regimes

To adequately assess the effects of past and current harvest practices on ecological systems, the forest should be evaluated within the context of the natural disturbance regime (Walker and others 1996). Theoretically, the response and resiliency of constituent species have been at least somewhat shaped by the prevailing disturbance regime (Leibowitz and others 1992). For example, systems that have evolved with periodic, intense disturbance should possess inherent qualities that allow harvesting of similar frequency, intensity, and magnitude (Walker and others 1996). Long-term management practices that are consistent with past environmental conditions thus may help to maintain the ecological integrity of the land and provide for future management options. Effects on animal and plant communities may increase as spatial and temporal disparity between natural and human disturbance regimes widen.

The amount of forest in the later stages of stand development will be noticeably reduced if current harvest trends continue in southeast Alaska. Placing greater emphasis on single-tree or small-group selection harvesting in areas where gap-phase forests occur would serve to more closely emulate natural processes. One tradeoff, however, is that more frequent entries over larger areas and additional roads would be needed to maintain a set harvest volume.

The scale of events contrasts markedly between current harvesting and the natural disturbance regime in southeast Alaska (fig. 9; table 4). Natural disturbance frequency decreases sharply as patch size increases. Larger blowdown patches on Kuiu Island often resulted from multiple wind events occurring at different times (Kramer 1997). In this context, intense, large-scale canopy disturbances are relatively infrequent events that occur periodically. The relatively frequent harvest of large-sized patches over a continuous period departs substantially from the natural disturbance regime. On wind-prone landscapes, repetitive harvest entries may convert the disturbance regime from a phased to an unphased condition, and thus may have unexpected impacts on species diversity (Abugov 1982). Relatively short harvest rotations, moreover, effectively eliminate windthrow from occurring where it otherwise might, which may reduce site productivity through increased surface-organic accretion and potential waterlogging (Bormann and others 1995).

If managers wish to mimic natural disturbance regimes, then they could apply the following guidelines:

- Practice limited uneven-aged management through single-tree or small-group selections in areas where gap-phase processes predominate (wind-protected landscapes). This approach requires preharvest survey data to accurately identify such sites.
- Leave remnant trees within harvest units in densities representing a range of conditions consistent with natural blowdown (fig. 8).
- Decrease the size of clearcut units and the frequency of harvest entries, and locate clearcut units in wind-exposed landscapes where natural stand replacement events are common.
- Extend rotation lengths of clearcut units to allow the later forest stages to develop; avoid restricting managed stands to only the stand-initiation and stem-exclusion stages.
- Give consideration to topographic locations most susceptible to recurrent stand-replacement episodes when prescribing clearcuts. These locations are generally south-facing slopes, hilltops, and ridge noses. In a harvesting system designed to emulate natural processes, north-facing slopes and other wind-protected locales seem optimal for selection or partial harvests. Because emphasis is placed on old-growth-forest conditions for maintaining species viability, wind-protected landscapes harbor the best prospects for locating concentrations of old-growth patches for long-term protection (i.e., old-growth reserves).

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Wind disturbance plays a fundamental role in shaping forest dynamics in southeast Alaska. Recent studies have increased our appreciation for the effects of wind at both large and small scales. Current thinking is that wind disturbance characteristics change over a continuum dependent on landscape features (e.g., exposure, landscape position, topography). Data modeling has revealed the existence of distinct wind disturbance regimes, grading from exposed landscapes where recurrent, large-scale wind events prevail to wind-protected landscapes where small-scale canopy gaps predominate. Emulating natural disturbances offers a way to design future management plans and silvicultural prescriptions consistent with prevailing ecological conditions.

Keywords: Tongass National Forest, old growth, forest development, small-scale canopy gaps, large-scale catastrophic blowdown, predictive windthrow model, silviculture.

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