

Pacific Forest  
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# Evaluation of Aerial Forest Pest Damage Survey Techniques in British Columbia

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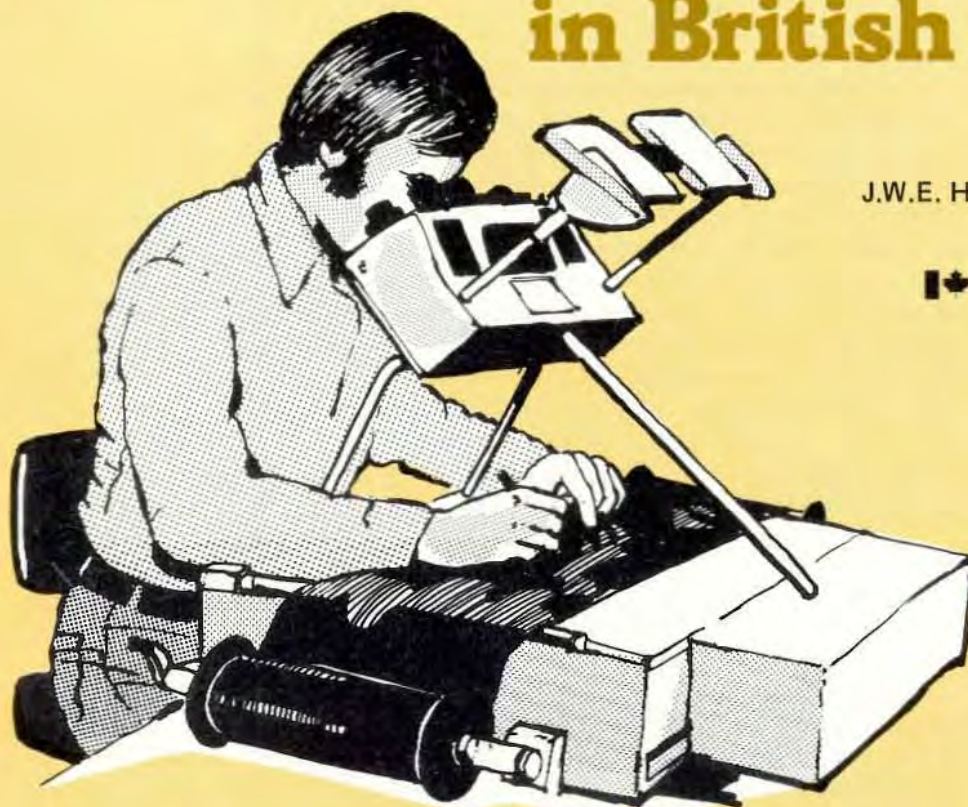


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### ABSTRACT

Detection and appraisal of forest pest damage in British Columbia is done, in part, by aerial surveys from small aircraft. Observers sketch areas of forest that are defoliated, discolored, or have dead trees onto topographic maps; they estimate the numbers of affected trees and sometimes take photographs for more detailed examination. A study comparing sketch-mapping and aerial photography showed that the two methods often yielded different results. Surveys using either method were useful if one understood their limitations. Improved sketch-mapping procedures, supplemented by aerial photography, should continue to be a useful forest pest survey technique.

### RÉSUMÉ

La détection et l'évaluation des dégâts des ravageurs forestiers en Colombie-Britannique se font, en partie, au moyen de relevés aériens à partir de petits aéronefs. Les observateurs tracent des croquis topographiques des régions forestières défoliées, décolorées ou comportant des arbres morts. Ils évaluent le nombre d'arbres malades et prennent parfois des photographies qui serviront à un examen plus détaillé. Une étude comparative de la cartographie sommaire et de la photographie aérienne a démontré que les deux méthodes produisent souvent des résultats différents. Les relevés utilisant l'une ou l'autre méthode se sont avérés utiles dans la mesure où l'on comprenait leurs limitations. Complétée par la photographie aérienne, la méthode de cartographie sommaire devrait continuer à être une technique utile d'évaluation des ravageurs forestiers.

## INTRODUCTION

Detection and appraisal of forest pest damage in British Columbia are done by the Forest Insect and Disease Survey (FIDS), Canadian Forestry Service, in cooperation with Provincial land management agencies. Various annual surveys are undertaken, including those that assess tree damage from the air. Damage is seen as discolored trees, with varying numbers of needles damaged or missing.

The most detailed surveys of damaged trees are made on the ground, but it is impossible to cover adequately the extensive forest areas of the Province by such means. Aerial sketch-mapping surveys, in which outlines of damaged areas are sketched onto maps by observers in aircraft, permit an overview of tree damage, extending detailed ground observations. Such surveys were first done in Canada in 1920, in Ontario (Swaine and Craighead 1924) for spruce budworm, *Choristoneura fumiferana* (Clemens), and have been used increasingly by FIDS and forest management agencies since that time. Aerial photography is a more recent innovation, used to supplement aerial observations, particularly in areas of extensive damage. Equipment used has ranged from small-format cameras held out of open aircraft windows, to vertically mounted, larger cameras, and resource satellites.

Aerial surveys are expensive, but as forest management becomes more intensive in response to higher forest values, such techniques are justified. However, because of the expense, one must make these techniques as efficient as possible. This study evaluates sketch-mapping and aerial photography.

## EXISTING AERIAL TECHNIQUES

### *Sketch-mapping Surveys*

Most aerial surveys of forest pest damage in North America involve sketch-mapping (Wear and Buckhorn 1955), which is the principal technique used in British Columbia. Observations, made by one or more persons in fixed-wing aircraft or helicopters, are of infestation boundaries or affected-tree numbers, which are marked onto maps.

The flight path of a survey aircraft is planned by one of two methods: for flat terrain, it follows either a random or systematic pattern; for rough,

mountainous terrain, it follows the contours. The latter is the usual method in much of B.C. The aircraft flies along main valleys, several hundred metres above the creek or river below, with detours into smaller side valleys, where necessary (Fig. 1). Selection of the areas to be visited is usually based on earlier ground examinations, aerial surveys or examination of aerial photographs.

There are two major types of damage:

1. Defoliation. Defoliation may be caused by such factors as insects feeding on the foliage, or foliage disease. Remnants of needles left on trees first give them a yellow-to-red discolored appearance, although not usually as intense as with bark beetle damage and, except in extreme cases, the natural green of the remaining foliage gradually masks the discoloration as the affected needles drop. Timing for mapping defoliation damage is critical because peak discoloration occurs during a relatively short period, usually during July and August.

2. Dying or dead trees. Such damage usually is characterized by yellow or red crowns that eventually turn grey as needles drop. Mortality frequently results from bark beetle or disease. During surveys, dead trees are counted and their locations and numbers are recorded on maps. Single trees or small groups of trees often are combined. In extensive outbreaks, large areas of damaged trees are outlined on maps, but often cannot be counted with the resources available. Bark beetle surveys do not record current infestations, because trees usually do not discolor until at least 1 year after attack. Bark beetle and defoliator aerial surveys usually can be combined, because bark beetle-killed trees, infested the previous year, generally have discolored by the peak period of defoliator feeding.

The accuracy of sketch-mapping results is difficult to assess. Waters *et al.* (1958) sketched spruce budworm defoliation, finding reasonably close agreement with ground assessments, but missed some dead trees from the air. Aldrich *et al.* (1958), in the southern Appalachians, found aerial sketch-mapping results to compare favorably with a careful 100% aerial survey for *Dendroctonus frontalis* Zimm. Heller *et al.* (1955) sketched pine beetle damage onto panchromatic aerial photographs and, after a limited ground survey, concluded that the greatest difficulty from the air was in seeing single trees or groups smaller than one-quarter acre.

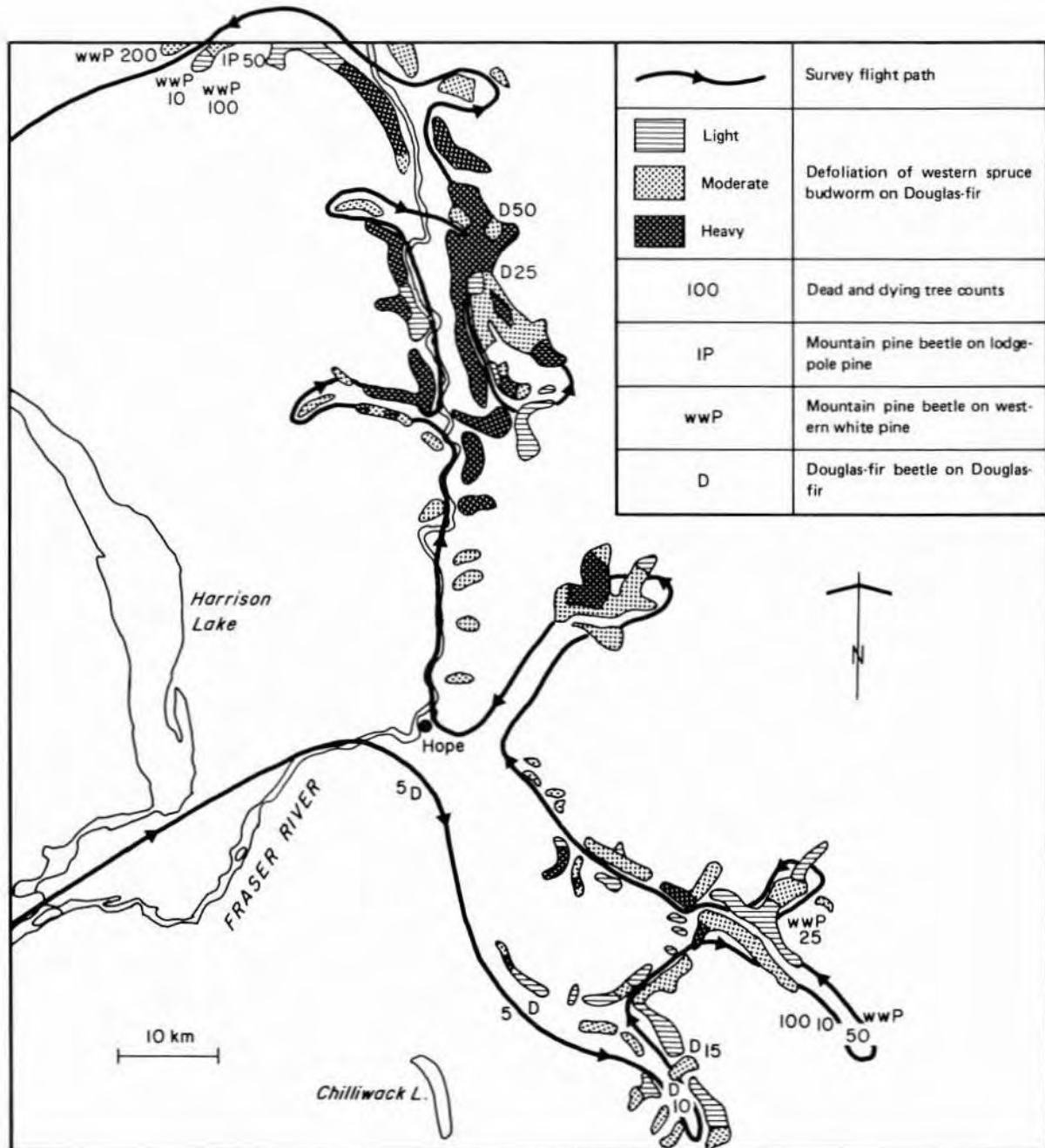


Figure 1. Aerial survey, 1976, Vancouver Forest Region. An example of a typical sketch-map survey showing both defoliation levels and dead and dying tree estimates.

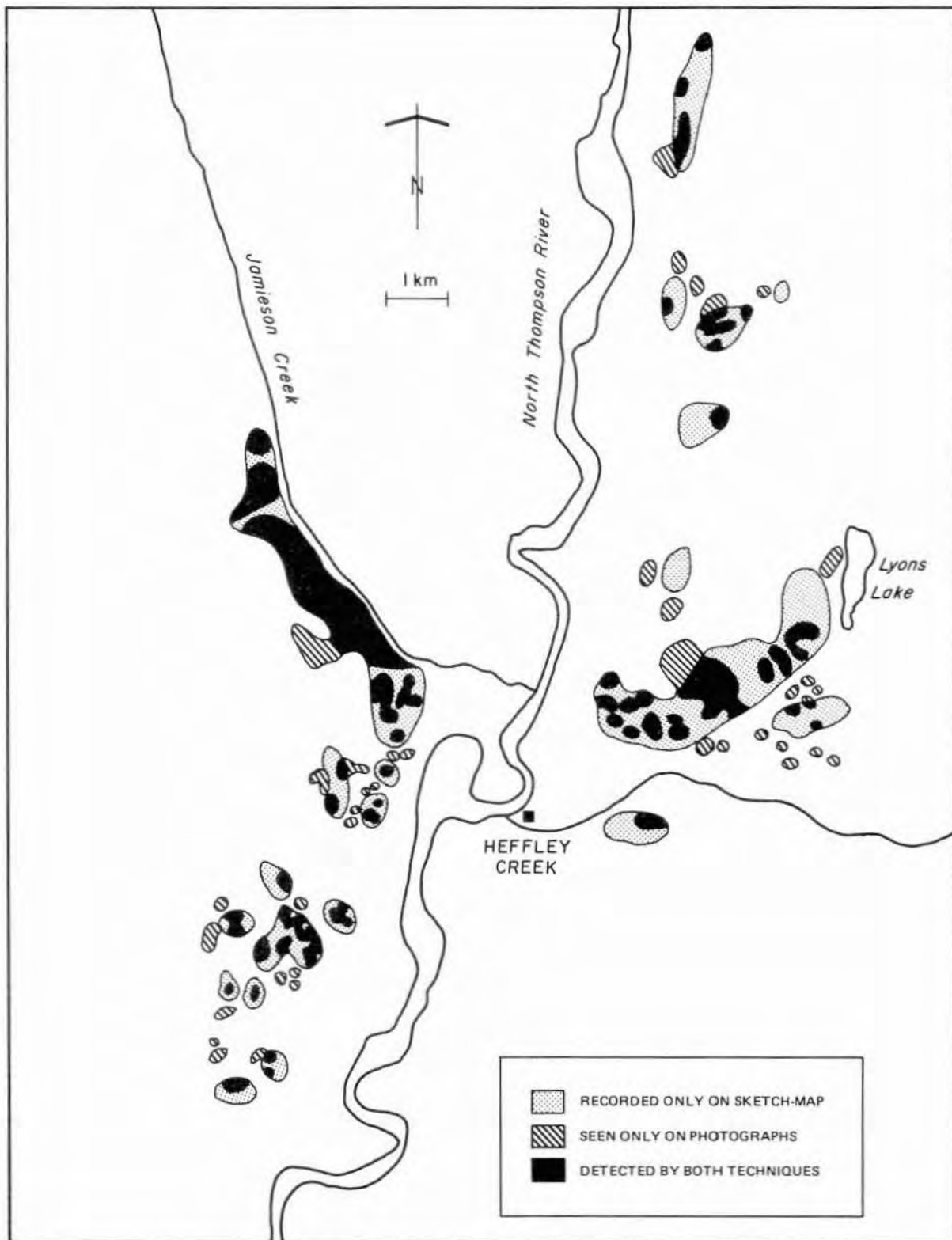


Figure 2. Douglas-fir tussock moth aerial survey, North Thompson River, B.C., 1974, contrasting sketch-mapping and small-scale aerial photographs.

### Aerial Photographic Surveys

Aerial sketch-mapping surveys have sometimes been supplemented with aerial photography. Even the simplest color photograph (small format, hand-held oblique) can provide a permanent, accurate record of anything visible to a sketch-mapping survey, and the photograph has the advantage of permitting examination in greater detail at any time. Photographs, however, are more expensive and there is a delay before they can be printed (Harris 1971, 1972, 1974; Klein 1973).

There have been comparisons of photographic surveys with ground surveys and with sketch-mapping. Areas defoliated by spruce budworm were sometimes missed on aerial photographs, but most dead trees were found (Waters *et al.* 1958). Wert and Wickman (1970) compared Douglas-fir tussock moth, *Orgyia pseudotsugata* McDunnough, defoliation on aerial photographs with an extensive ground cruise and found that estimates of mortality and top-killing were similar using both methods, and the aerial method resulted in a 67% saving in man hours.

Wear *et al.* (1964) found photography and sketch-mapping gave similar results, with trees killed by Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, but both methods missed trees with intermingled or shadowed crowns when compared to ground surveys. It was noted, however, that the effect of missing trees on total volume was minimal, because they were usually small trees. Klein (1973) used a 35-mm camera to assess tree mortality caused by the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, and obtained high correlation with actual ground counts.

## METHODS

### Aerial Sketch-mapping vs. Aerial Photography

Between 1972 and 1977, various regular aerial sketch-mapping survey flights were accompanied by one of the authors, who took oblique and vertical, large-scale aerial photographs of infested areas, using hand-held 70-mm and 35-mm cameras. Vertical, small-scale imagery (1:70,000 to 1:120,000) also was taken of some of the infestations by the Canada Centre for Remote Sensing, Ottawa.

The pest damage evaluated was moderate

to heavy defoliation by western blackheaded budworm, *Acleris gloverana* Walsingham; western spruce budworm, *Choristoneura occidentalis* Freeman, western false hemlock looper, *Nepytia freemani* Munroe, and Douglas-fir tussock moth, and mortality by mountain pine beetle and Douglas-fir beetle.

From the photographs, defoliated areas were mapped and discolored bark beetle-killed trees were mapped and counted, using a stereoscope and a Bausch and Lomb Zoom Transferscope, which permitted the viewing of superimposed map and photographic images. Observation survey sketch-maps (1:125,000 and 1:250,000 topographic maps) were compared with the aerial photograph data in location and size of each damaged area. When a similarly shaped damaged area was found on a map and corresponding photograph, they were accepted as the same although the observer may have failed to exactly locate the damage.

### Simulated Counts of Dead and Dying Trees

Bark beetle mortality was simulated by projecting 35-mm color slides of damaged areas. Observers, seated in a room, counted and recorded discolored trees from the screen, and their counts were compared with "actual counts" derived from detailed examination of the film. Forty oblique and vertical slides at scales similar to those encountered during regular aerial surveys were viewed. Thirty observers counted dead trees in 20 slides and 12 examined 20 additional slides. Observers were classified as having "considerable experience" if they had done aerial surveys routinely during recent summers, "limited experience" if they had done surveys, but not on a regular basis, or "no experience" if they had not done surveys.

## RESULTS

### Defoliation

Aerial mappers produced sketches of defoliated areas (Figs. 2-5) which usually were larger than the discolored areas seen in the photographs, particularly in the case of the tussock moth and false hemlock looper outbreaks. The total areas of defoliation in the four cases examined were from 18 to 164% higher on the sketch maps than in the photographs (Table 1).

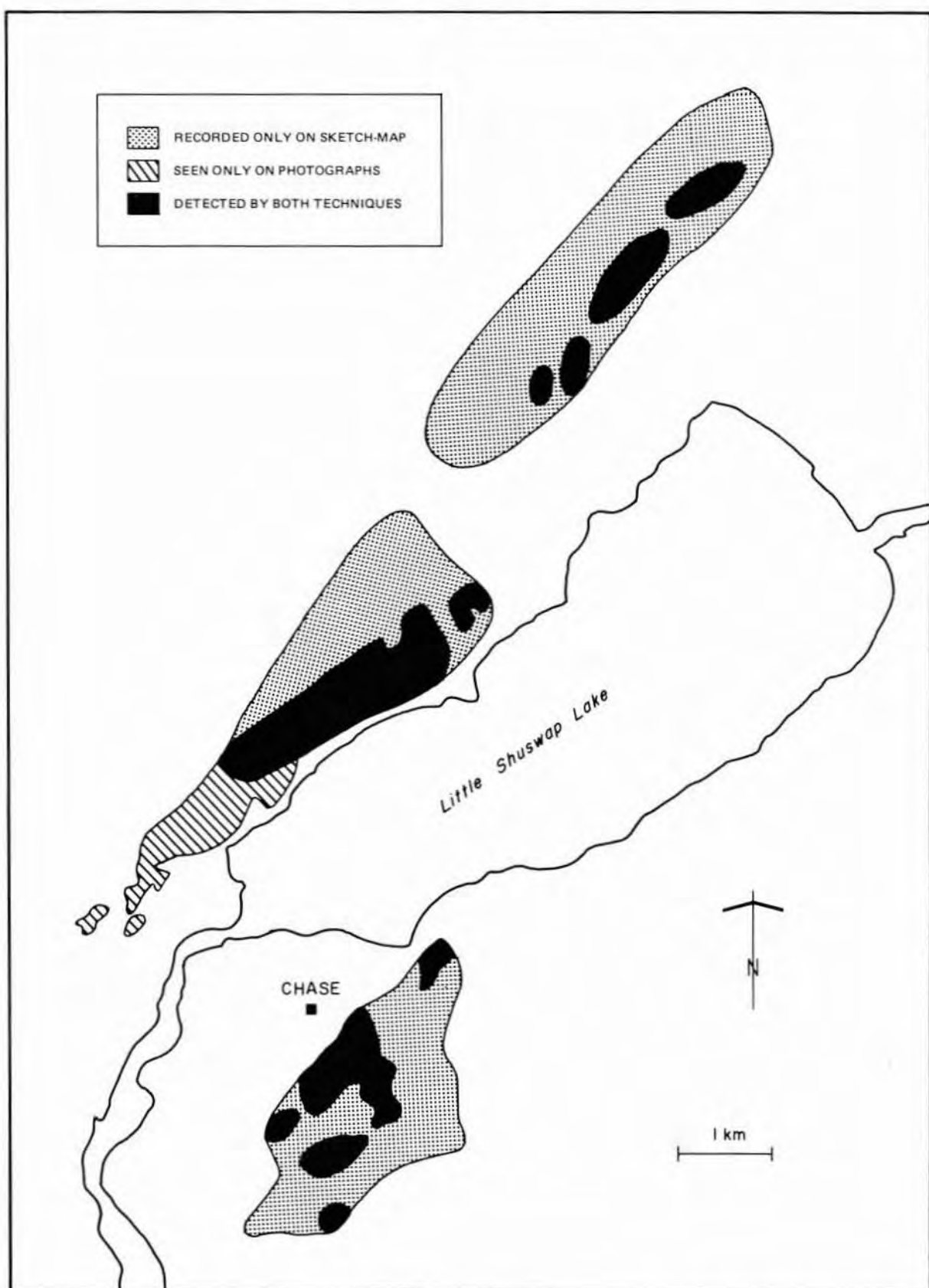


Figure 3. Western false hemlock looper aerial survey, Little Shuswap Lake, B.C., 1974, contrasting sketch-mapping and small-scale aerial photographs.

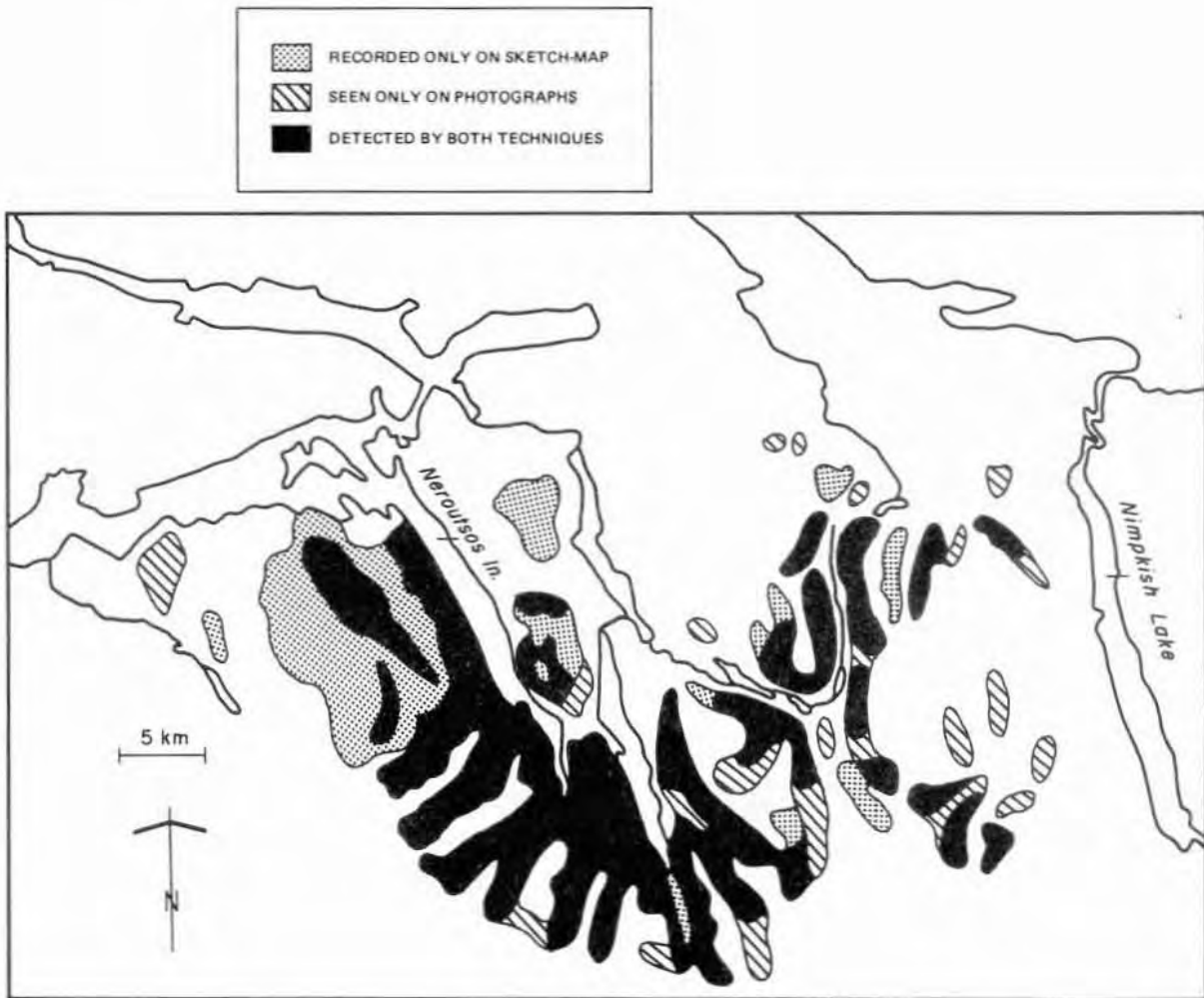


Figure 4. Western blackheaded budworm aerial survey, Neroutsos Inlet, Nimpkish Lake, B.C., 1972, contrasting sketch-mapping and small-scale aerial photographs.

#### *Dead and Dying Trees*

Aerial sketch-mapping estimates of "red-topped" dead and dying trees underestimated by an average of 39% the corresponding "actual" airphoto counts (Appendix I), but there was a strong linear relationship between estimates and counts (Fig. 6), indicating that underestimation was consistent throughout the range of photo counts of dead trees. These data are mapped in Figures 7-9. Figure 7 shows part of an aerial survey of mountain pine beetle in which the total area affected was approximately 34% larger than measured on photographs. Figure 8 shows red-top aerial estimates and airphoto counts for part of another survey for mountain pine beetle, and Figure 9, for a Douglas-fir beetle survey.

#### *Simulated Counts of Dead and Dying Trees*

Actual counts of trees on the film in individual scenes ranged from 11 to 600 trees. Counts made by observers from individual projected slides deviated markedly from actual counts (Table 2), the average deviation ranging from -42% to 73%. The mean % deviation (8%) for inexperienced observers ( $E_1$ , Table 3) in the first trial was similar to that for experienced (7%), and would have been similar with limited experience observers, except for one (77%). There were strong logarithmic relationships between the observer estimates and the actual counts for both trials (Figs. 10 and 11). Although accuracy improved somewhat with the second set of slides ( $E_2$ ), the correlation coefficients, the slopes and the inter-

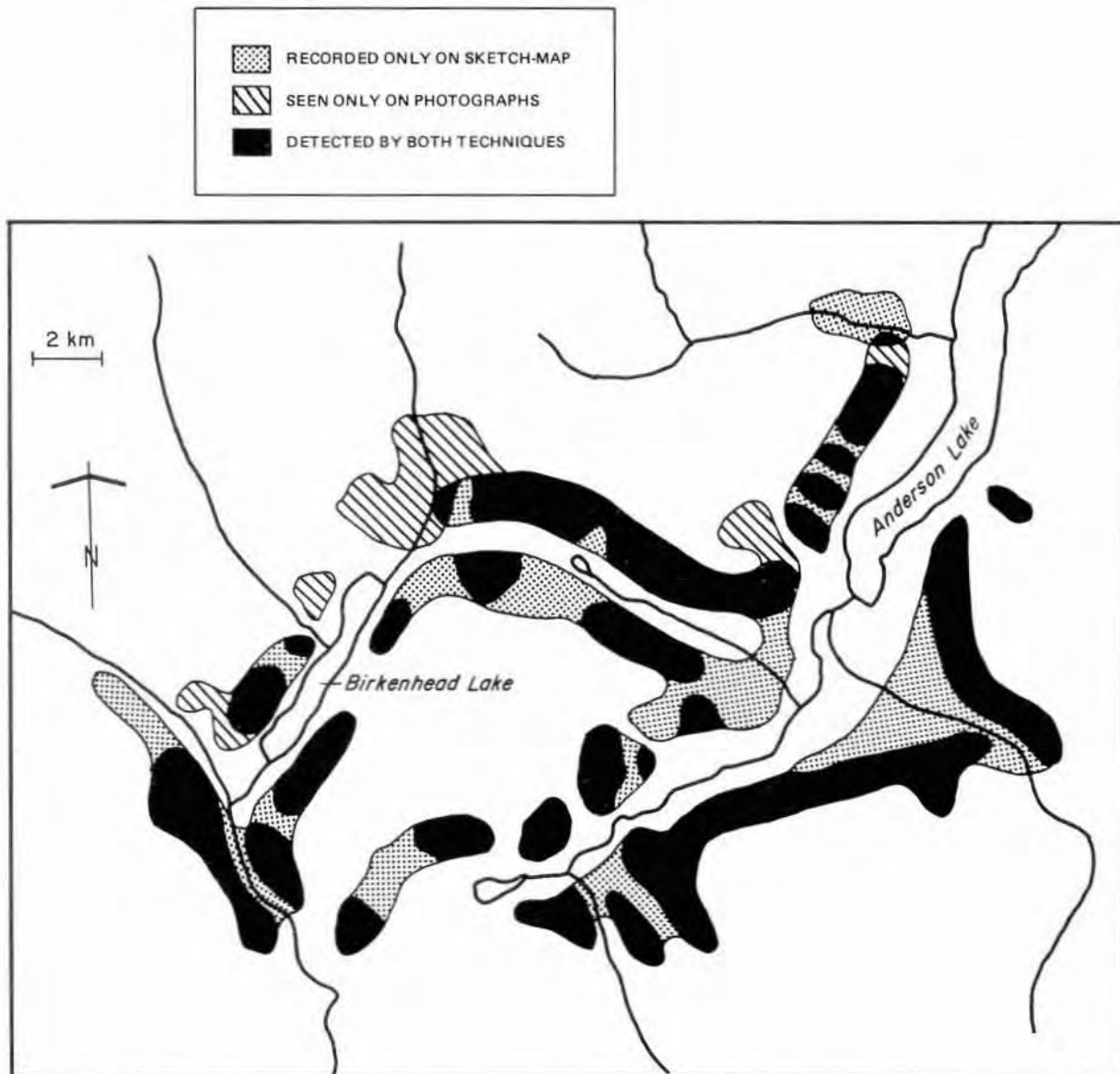


Figure 5. Western spruce budworm aerial survey, Anderson Lake, Birkenhead Lake, B.C., 1972, contrasting sketch-mapping and small-scale aerial photographs.

cepts of the relationships in Figures 10 and 11 were nearly identical. These relationships indicated that, on average, observers tended to underestimate actual dead tree counts more with increasing dead tree density.

## DISCUSSION

We have examined two techniques for assessing forest pest damage in B.C., aerial sketch-mapping

and photography, to identify their shortcomings and suggest improvements. We have assumed that sketch-mapping and photography record the same or nearly the same data, but acknowledge that neither method records the true ground situation because trees whose crowns intermingle or are overtopped by larger ones cannot be seen from above by either method. Extensive surveys by ground observers are prohibitively expensive, but a limited ground cruise can provide support data for photographs or sketch maps in a multiple-stage sampling program, permitting the

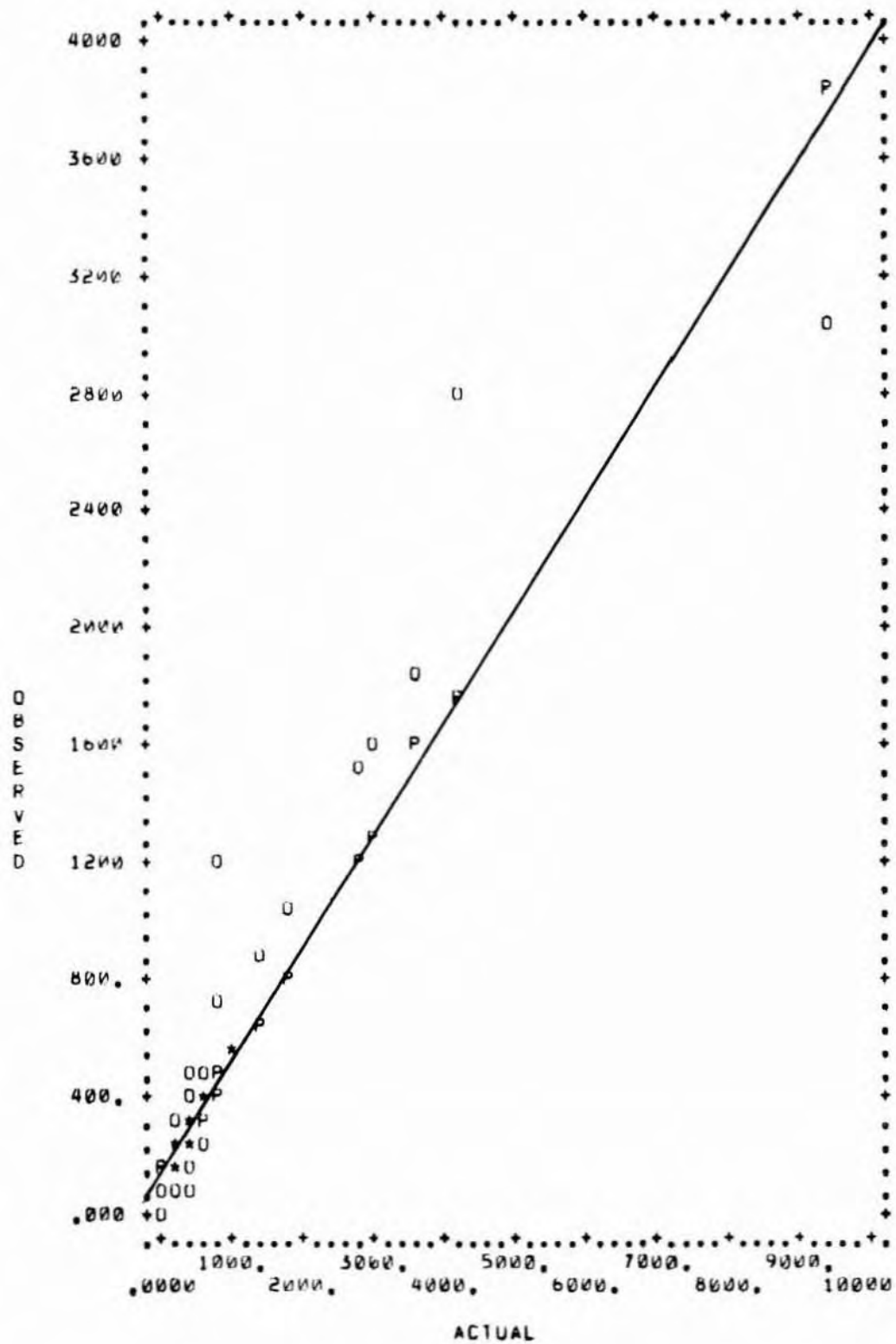


Figure 6. Relationship between dead and dying tree counts made during aerial sketch-mapping surveys (OBSERVED) (estimated numbers) and counts from aerial photographs (ACTUAL).  $Y = 141.85 + .392X$ ,  $r = 0.92$ ,  $n = 63$ .

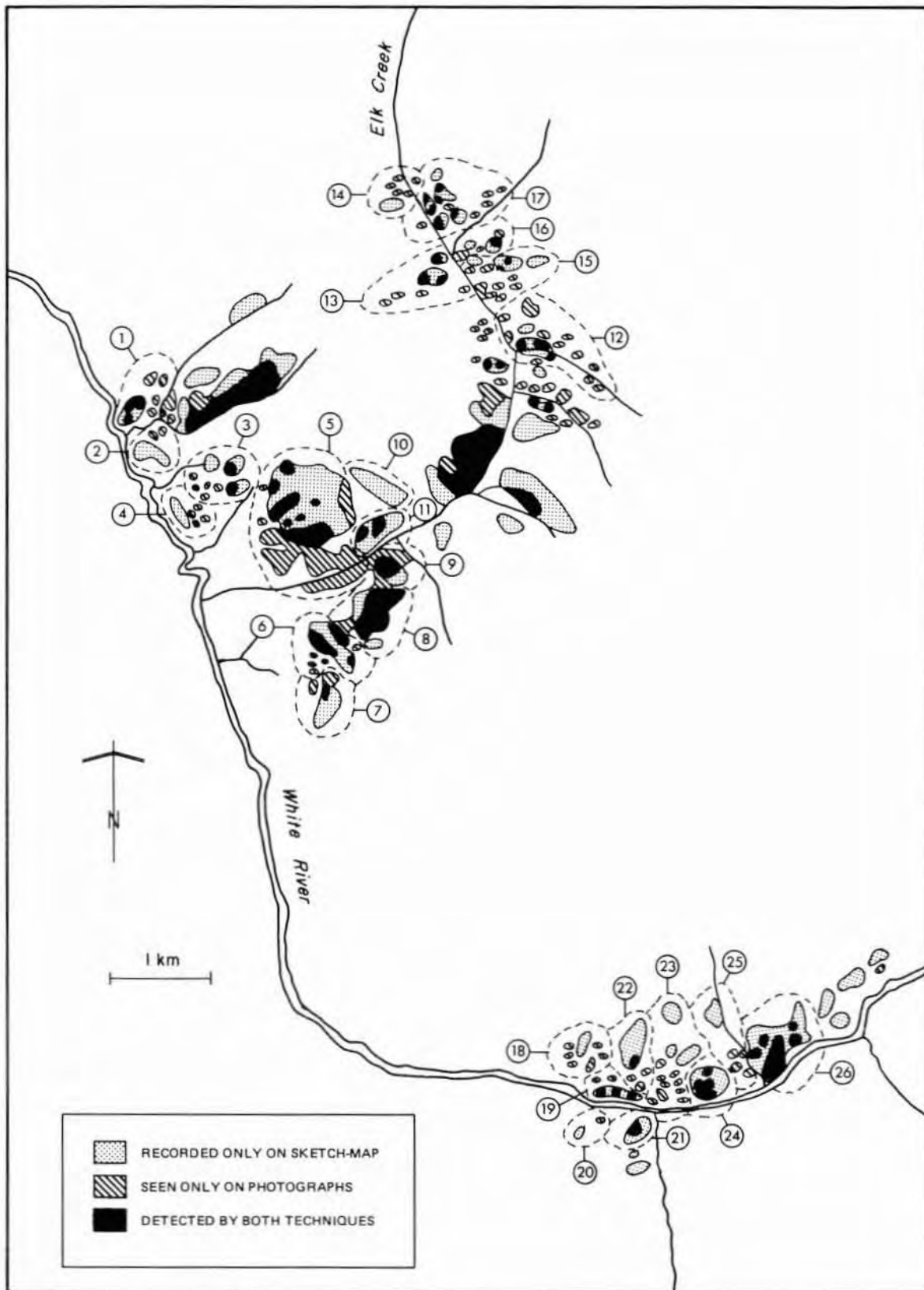


Figure 7. Mountain pine beetle aerial survey, Elk Creek-White River, B.C., 1974. Locations of dead and dying lodgepole pine sketch-mapped and oblique photographed. Circled numbers are locations in Appendix I.

addition of an estimated number of unseen trees.

Problems with sketch-mapping are that the method depends heavily on the observer's abilities, which relate to training and fatigue. Problems with photography include difficulty in discerning light defoliation or subtle color changes, owing to haze, smoke and too small a scale, or poor exposure. Aerial observations are somewhat more tolerant of adverse weather or lighting than photography, and the observer can select the best vantage point, continuing until satisfied. The photo interpreter, however, can spend more time and can also be checked as a matter of routine.

The most serious limitation of aerial sketch-mapping is the lack of time to record details. Such limits, imposed by the high costs of aircraft charter, particularly affect difficult-to-define areas and counts of larger groups of trees. This is handled by estimating the area rather than actually outlining it in detail, or by counting sample areas and extrapolating to an overall estimate. Sampling error associated with this estimate accounts for some of the differences between sketch-mapping and photography.

Sketch-mapping also commonly fails to exclude non-susceptible forest types, such as logged areas or rock and water bodies, and there is a tendency to combine small areas, resulting in overestimates of damage compared with what can be carefully measured on photographs.

A combination of sketch-mapping and photography is often the most acceptable solution. The linear relationship between sketch-mapping and photographic estimates of red-topped dead and dying trees indicates that sketch-mapped estimates could be corrected for bias using a double sampling system involving both methods.

Costs of supplementing aerial pest surveys with simple, hand-held large-scale photography are low. Two observers are normally involved for sketch-mapping. One of the two can handle a 35-mm or 70-mm camera, given a few hours of training and practice. The cost of a 13 x 13-cm color print, including film, processing and printing, currently is about \$1.00. Not included are costs for aircraft rental (\$80-\$165 per hour for fixed wing; \$360 per hour for helicopter) and salaries and field expenses, in addition to the regular sketch-mapping requirements.

Most observers felt the 35-mm slide projection

test approximated the actual conditions; the most notable difference was that the observer could not vary the amount of time looking at each area, or the angle of observation, to suit himself. In actual practice, under the pressures of an extensive survey, this is often not done, even if desirable. The experienced observers did not fare much better than the inexperienced ones in the slide tests, probably because experienced observers had never before had standards with which to relate their estimates.

## CONCLUSIONS

Errors in forest pest surveys may lead to erroneous conclusions, resulting in unnecessary, expensive management decisions, and affect the credibility of other surveys. We conclude that for many pest surveys, better tree count and area estimation data can be obtained using airphotos to supplement aerial sketch-mapping, but costs of obtaining photographs and interpreting damage on them must be weighed against the additional value received.

Sketch-mapping is a simple, quick, inexpensive way of gathering rough estimates of damage. To maximize the return from this technique, it seems desirable that standards of defoliation measurement be developed and that a training program for observers be instituted. One method could utilize photographs or slides as in this study, or test areas where survey crews could compare their figures with known ones, giving them a basis for more accurate estimates.

Other useful improvements in sketch-mapping would be the use of large-scale maps and up-to-date aerial photographs showing logging, burns and other details that observers might want to exclude from healthy timbered areas.

Color aerial photography, a desirable adjunct to aerial surveys, is slower and more expensive, but often gathers better, more easily checked data. It merits consideration as a survey tool whenever one is planning to gather large quantities of forest damage data that heretofore would have been acquired using aerial sketch-mapping alone.

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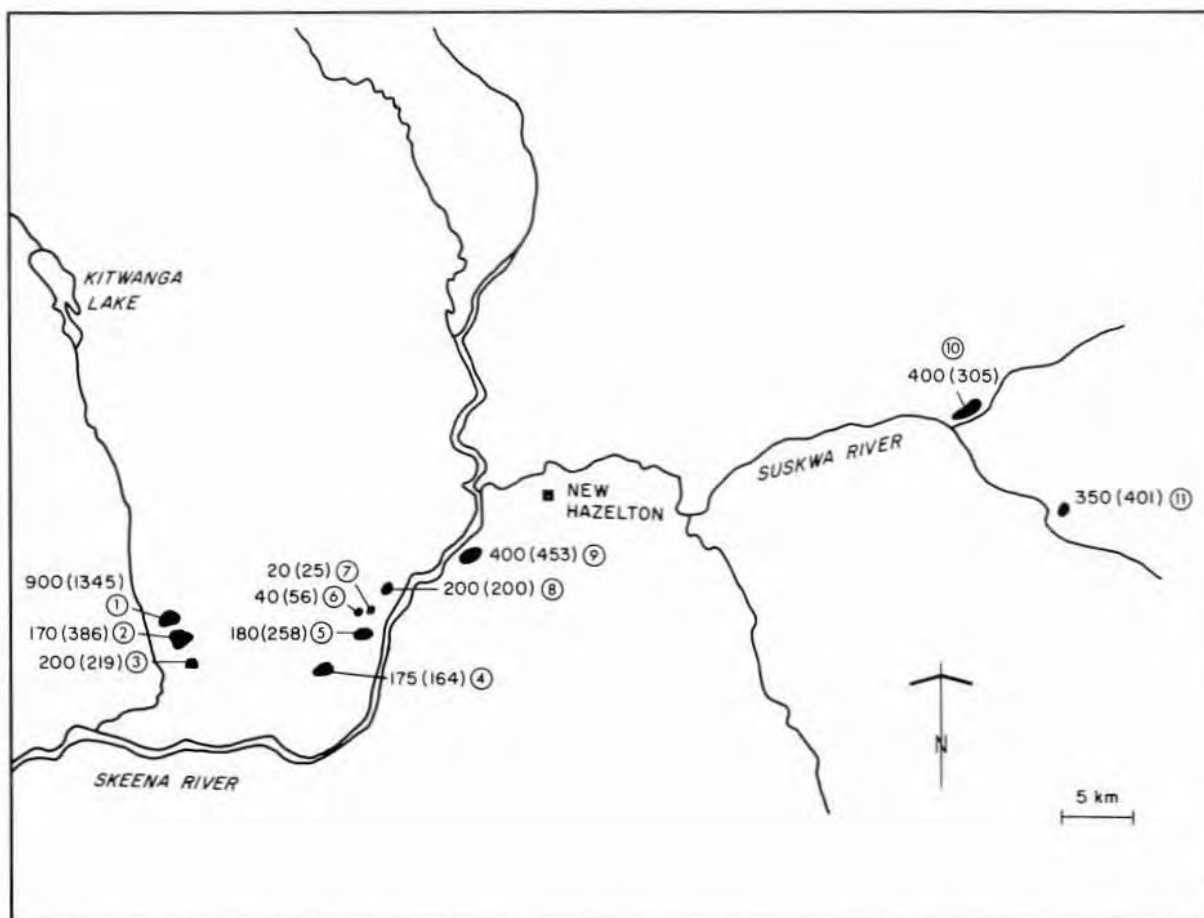


Figure 8. Mountain pine beetle aerial survey, Prince Rupert Forest Region, 1973. Numbers of dead and dying lodgepole pine estimated from the air followed by actual oblique photographic counts (in parentheses). Circled numbers are locations in Appendix I.

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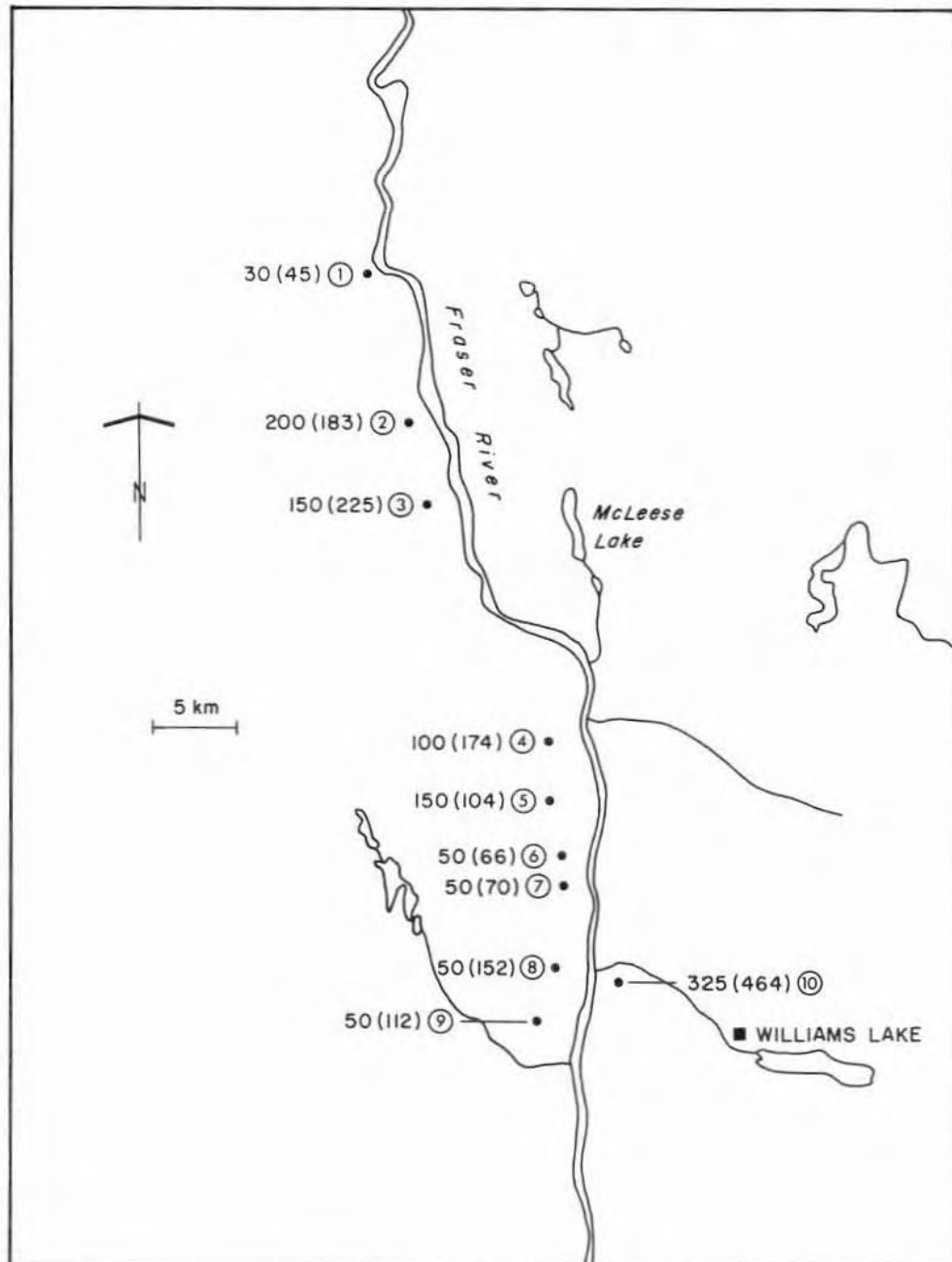


Figure 9. Douglas-fir beetle aerial survey, Cariboo Forest Region, 1975. Numbers of dead and dying Douglas-fir estimated from the air, followed by actual photographic counts (in parentheses). Circled numbers are locations in Appendix I.

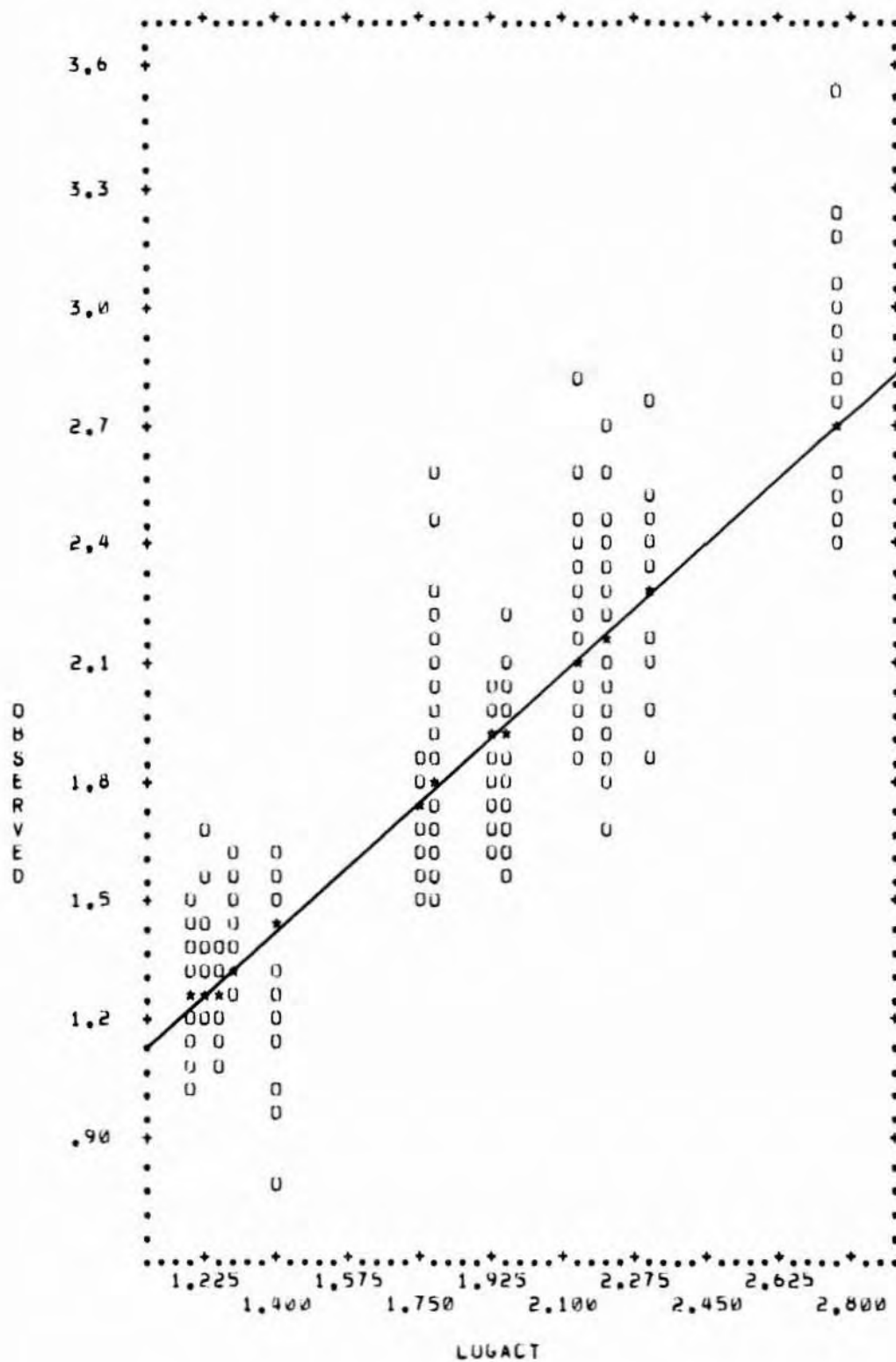


Figure 10. Relationship between dead and dying tree estimates made by 30 observers (OBSERVED) and actual counts made by interpreters (LOGACT) from 20, 35-mm slides. Logarithmic scale. See Table 3, E<sub>1</sub>.  
 $\log(Y + 1) = .115 + .931 \log(X + 1)$ ,  $r = 0.92$ ,  $n = 600$ .

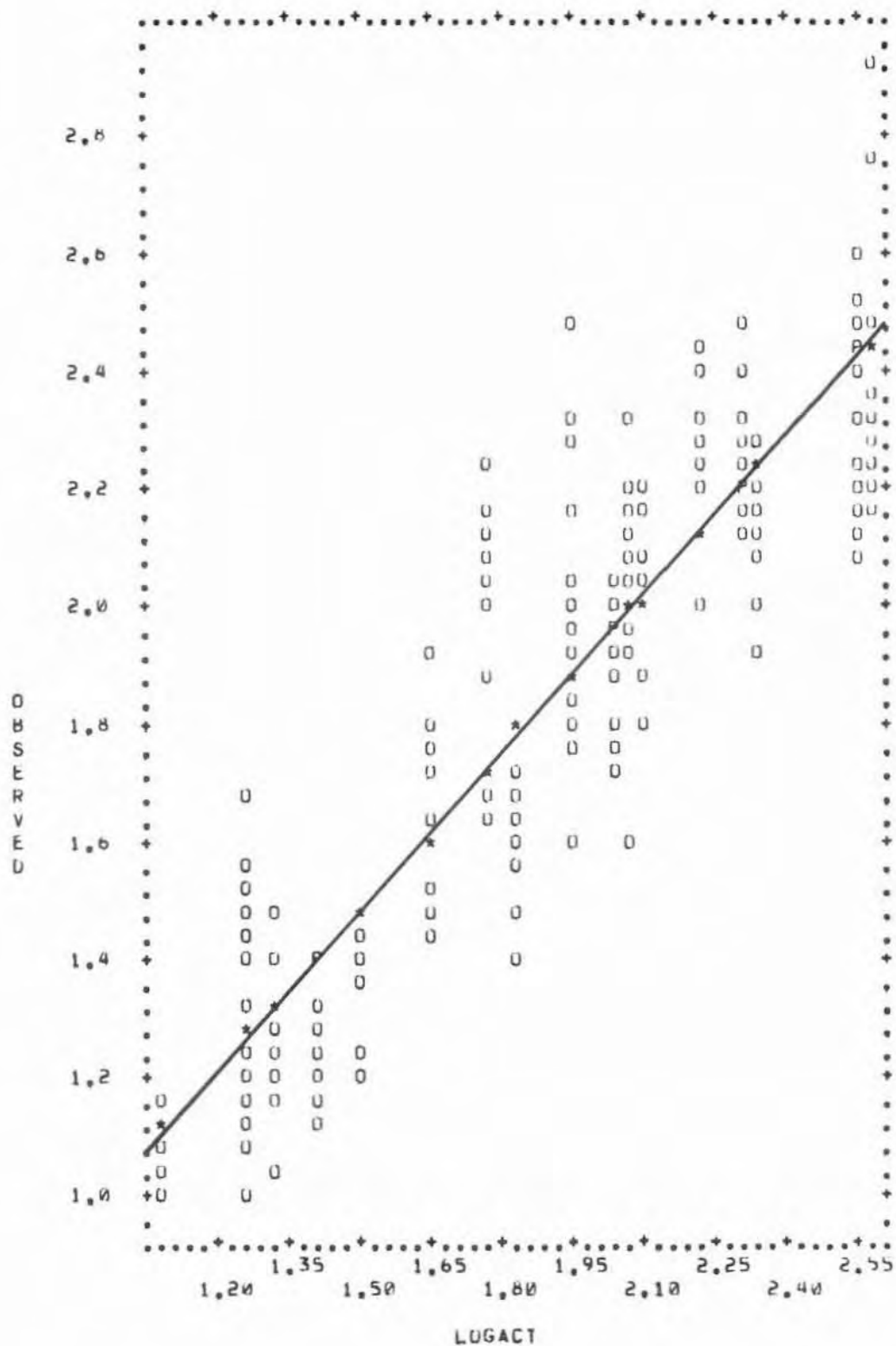


Figure 11. Relationship between dead and dying tree estimates made by 12 observers (OBSERVED) and actual counts made by interpreters (LOGACT) from 20, 35-mm slides. Logarithmic scale. See Table 3, E<sub>2</sub>.  
 $\log(Y + 1) = .132 + .899 \log(X + 1)$ ,  $r = 0.92$ ,  $n = 240$ .

Table 1. Comparison of defoliated forest areas by sketch-mapping and aerial photography.

Pest species	Map reference	Location	Area of infestation as mapped (hectares)			
			By both sketch-mapping and photography (1)	Additionally by sketch-mapping only (2)	Additionally by photography only (3)	% sketch-mapping results larger than photography <sup>1/</sup> (4)
Douglas-fir tussock moth	Fig. 2	North Thompson River	385	475	65	91
Western false hemlock looper	Fig. 3	Little Shuswap Lake	330	725	70	164
Western blackheaded budworm	Fig. 4	Neroutsos Inlet-Nimpkish L.	22,920	9,925	3,150	26
Western spruce budworm	Fig. 5	Anderson L. Birkenhead L.	5,990	2,575	1,270	18

$$1/ \frac{[(1) + (2)] - [(1) + (3)]}{(1) + (3)} \times 100 = (4)$$

Table 2. Comparison of counts from microscopic examination of 35-mm film of bark beetle killed trees with mean estimated count by observers from projected image of film.

"Actual" counts on photos	Count by observers, from screen		Mean % deviation	Standard deviation <sup>1/</sup>
	Mean	Range		
Slide Set 1 (30 observers)				
15	20	13-30	34.0	30.9
15	17	10-27	10.9	33.5
16	23	14-50	43.5	51.4
17	14	13-24	15.1	12.1
17	17	11-18	2.2	14.9
18	28	17-40	53.9	36.6
25	20	5-42	-18.3	34.0
54	53	30-75	- 1.2	24.0
60	103	29-400	72.4	134.3
62	68	30-200	9.5	50.0
86	68	40-110	-20.5	18.9
90	58	35-110	-35.1	15.5
90	61	40-90	-31.7	18.5
92	84	50-160	- 9.1	26.7
137	156	70-300	35.7	82.2
137	186	80-675	13.6	42.8
158	149	45-385	- 5.9	52.0
161	190	60-475	18.1	63.5
205	211	75-570	2.8	47.0
600	730	250-3500	21.6	108.4
Slide Set 2 (12 observers)				
11	11	9-14	1.5	11.5
17	16	12-20	- 6.9	15.2
17	29	17-47	70.6	50.7
17	15	9-27	-10.3	27.3
20	19	10-30	- 3.3	29.4
24	17	12-20	-30.2	9.8
30	22	15-30	-26.4	15.8
44	47	27-80	7.2	34.6
59	102	42-170	72.6	70.0
68	40	24-60	-41.9	15.4
90	84	40-190	- 6.3	43.1
91	127	65-300	39.5	77.9
109	82	52-110	-24.8	18.4
120	119	40-200	- 1.0	36.0
124	114	60-160	- 8.0	29.1
166	194	96-280	17.0	31.6
208	192	130-290	- 7.5	20.9
217	146	85-193	-32.7	15.6
363	217	120-400	-40.3	24.3
373	293	140-800	-21.3	54.3

$$1/ \text{ Standard deviation} = \sqrt{\frac{[\sum (\% \text{Dev.})^2] - \frac{[(\sum \% \text{Dev.})]^2}{N}}{N - 1}}$$

N = no. of observers

Table 3. Mean % deviation of dead-tree counts, estimated on screen, from "actual counts" on film, for observers viewing projected 35-mm slides.

Experience of observers	Observer no.	Mean % deviation		Standard deviation	
		E <sub>1</sub> <sup>1/</sup>	E <sub>2</sub>	E <sub>1</sub>	E <sub>2</sub>
No experience	1	17		49	
	2	4		36	
	3	15		44	
	4	2		32	
	5	2		50	
	6	- 9		34	
	7	42		41	
	8	-26		32	
	9	24		138	
Average		8		51	
Limited experience	10	- 9		43	
	11	- 5		32	
	12	- 6		27	
	13	9		35	
	14	77	24	124	65
	15	19	- 1	50	48
	16		-20		44
Average		14	1	52	56
Considerable experience	17	22	-11	49	39
	18	60	17	108	52
	19	18	-13	41	33
	20	- 9	- 6	40	33
	21	-30	-20	24	31
	22	-17	-18	25	31
	23	17	19	45	44
	24	35	18	105	43
	25	14		32	
	26	-31		26	
	27	22	15	51	62
	28	14		34	
	29	- 5		43	
	30	10		32	
	31	- 4		54	
Average		7	0.1	47	38
Overall average		9	0.3	49	52

<sup>1/</sup> E<sub>1</sub> - Estimate of 20 slides; E<sub>2</sub> - Estimate of second set of 20 slides.

## Appendices

Appendix I. Comparison of dead and dying, red tree counts from sketch-mapping surveys with counts from aerial photographs.

A. Elk Creek and White River; mountain pine beetle on lodgepole pine, 1974 (Fig. 7).

Location of counts	Sketch-mapping count	Airphoto count	Difference <sup>1/</sup>	
			Number of trees	%
1	150	146	+4	+3
2	100	21	+79	376
3	200	238	-38	-16
4	100	112	-12	-11
5	1500	2798	-1298	-46
6	200	530	-330	-62
7	150	188	-38	-20
8	1600	2950	-1350	-46
9	1000	1700	-700	-41
10	500	384	+116	+30
11	300	214	+86	+40
12	225	266	-41	-15
13	125	109	+16	+15
14	25	19	+6	+32
15	300	234	+66	+28
16	50	78	-28	-36
17	110	179	-69	-39
18	40	59	-19	-32
19	50	188	-138	-73
20	10	4	+6	+150
21	50	54	-4	-7
22	75	98	-23	-23
23	115	350	-235	-67
24	150	126	+24	+19
25	75	97	-22	-23
26	500	690	-190	-28
Total	7700	11832	-4132	-35

## B. Skeena River/Suskwa River; mountain pine beetle on lodgepole pine, 1973 (Fig. 8).

Location of counts	Sketch-mapping count	Airphoto count	Difference <sup>1/</sup>	
			Number of trees	%
1	900	1345	-445	-33
2	170	386	-216	-56
3	200	219	-19	-9
4	175	164	+11	+7
5	180	258	-78	-30
6	40	56	-16	-29
7	20	25	-5	-20
8	200	200	0	0
9	400	453	-53	-12
10	400	305	+95	+31
11	350	401	-51	-31
Total	3035	3812	-777	-20

## C. Other comparisons; mountain pine beetle on lodgepole pine.

Whiteman Cr., 1972	750	782	-32	-4
Haylmore Cr., 1973	200	369	-169	-46
Trout Cr., 1973	2800	4220	-1420	-34
Blackwater Ridge, 1973	1800	3675	-1875	-51
Palliser R., 1974	350	460	-110	-24
Riske Cr., 1974	3000	9445	-6445	-68

## D. Other comparisons; mountain pine beetle on western white pine.

Location of counts	Sketch-mapping count	Airphoto count	Difference <sup>1/</sup>	
			Number of trees	%
N. Barriere L., 1972	500	550	-50	-9
Blue River, 1972	1200	754	+446	+59
Saddle Mtn., 1973	150	270	-120	-44
Pingston Ridge, 1973	500	589	-89	-15
Rogers Pass, 1973	200	345	-145	-42
Shuswap R., 1973	400	617	-217	-35
Manning Park, 1973	250	295	-45	-15
Kookipi Cr., 1973	575	1092	-517	-47
Blackwater Cr., 1973	100	91	+9	+10
Blackwater Cr., 1975	420	361	+59	+16

## E. Fraser River near Williams Lake; Douglas-fir beetle on Douglas-fir, 1975 (Fig. 9).

1	30	45	-15	-33
2	200	183	+17	+9
3	150	225	-75	-33
4	100	174	-74	-43
5	150	104	+46	+44
6	50	66	-16	-24
7	50	70	-20	-29
8	50	152	-102	-67
9	50	112	-62	-55
10	325	464	-139	-30
Total	1155	1595	-440	-28

<sup>1/</sup> % Difference =  $\frac{\text{Sketch-mapping count} - \text{Airphoto count}}{\text{Airphoto count}} \times 100\%$

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