Standing Dead Tree Dynamics Extracted from Growth and Yield Permanent Sample Plots in British Columbia[1,2]

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Abstract

Permanent sample plots established to study the growth and yield of live trees can provide valuable information on standing dead tree dynamics. Even if dead trees were not traditionally measured, a subsequent measurement of dead trees enables extraction of information on past dynamics. In British Columbia (BC), Canada, the Ministry of Forests administers over 5,500 growth and yield permanent sample plots that could provide important information on dead tree dynamics. In this paper we discuss the standing dead tree information obtainable from these plots, the time needed for and costs of measuring, and current findings on standing dead tree dynamics in BC.

Introduction

In British Columbia (BC), Canada, the ecological value of wildlife trees (i.e., standing dead trees and defective live trees) is well recognized within forest management and operational practices. The BC Wildlife Tree Committee, established in 1985, has worked to improve the conservation of wildlife trees while addressing the legislative needs for safety in forest operations. Legislation and associated guidelines under the Forest Practices Code of British Columbia Act identify and require the conservation of wildlife trees through reserve and management zones.

Knowledge and tools about the dynamics of standing dead trees (e.g., fall rates) can assist forest managers with decisions at the tree level (e.g., safety concerns of individual trees) to the landscape level (e.g., characteristics of wildlife tree patches). These dead tree decisions can influence and are influenced by decisions made for other resources including timber and wildlife. Tools to assist dead tree decisions must be integrated with both traditional forest management tools for timber values (e.g., growth and yield models) and for non-timber values (e.g., habitat suitability indices). However, basic information on the dynamics of standing dead trees that would enable

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[2] This paper reflects government organization, legislation, or policy as of December 1999.

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appropriate projections for forest management and silvicultural planning is generally lacking.

Backhouse and Lousier (1991) and Caza (1993) noted the potential of BC's extensive growth and yield (GY) permanent sample plot (PSP) program to provide information on dead tree dynamics. A GY PSP is typically a fixed area in which trees of a minimum size are permanently marked and regularly remeasured at a fixed interval between 2 and 10 years. Minimally, the individual trees are measured for species, diameter at breast height (DBH), and a few other characteristics. On a subset of trees, more detailed measures such as height and age may be included. On more intensive PSPs, the location of individual trees will be recorded and each tree will be measured in greater detail.

In BC and elsewhere, GY PSPs have historically provided information only on the live tree dynamics of forest stands. The measurement of a tree typically stopped at its death. With increased ecological concerns, the continued monitoring of a tree past its death is now a more common practice. Fortunately, the repeated measures nature of a PSP enables some of the past dynamics to be extracted immediately upon the first measurement of standing dead trees in an existing plot.

The initial measurement of standing dead trees on an established GY PSP creates a cohort data set of standing dead trees identified as dead in each of the past remeasurements. These data can be analyzed or modeled by many methodologies—some more appropriate than others. The data may be fit to a negative exponential decay function, and general decay (i.e., fall rates) can be reported (Harmon and others 1986). A life-table or transition matrix approach can be used to present rates of fall (Huggard 1999, Krebs 1978, Raphael and Morrison 1987). Lee (1998) extracted the dynamics of fall for aspen trees in Alberta with failure analysis techniques on a large PSP data set. Logistic regression models have also been used to predict dead tree fall both at the tree and stand levels (Raphael and Morrison 1987, Stone 1996).

Standing dead trees provide a link between forest stands and many animal habitat/population dynamics. Standing dead tree models have been structured to enable input from forest stand growth and yield models and provide output useful for habitat/population models (Raphael and Morrison 1987). Marcot (1992) directly linked the fall model, Snag Recruitment Simulator, with habitat requirements of woodpeckers (Ohmann and others 1994, Schuster and others 1993). Fall models built into growth and yield models such as Tree and Stand Simulator (TASS) (Mitchell 1975, Stone 1996) or as extensions such as the Forest Vegetation Simulator Fire and Fuels Extension (Beukema and others 1997) have been linked to habitat suitability type models to look at the impacts of direct management regimes (Greenough and Kurz 1996, Greenough and others 1999). Standing dead tree models are not limited to fall dynamics only. They may provide other characteristics, such as decay stage, important to habitat linkages (Huggard 1999, Raphael and Morrison 1987).

Underlying the usability of any standing dead tree model are the basic data of dead tree dynamics. In this paper, we discuss the information about standing dead trees currently collected on GY PSPs in BC and further describe an example of standing dead tree data from one of BC's earliest growth and yield sample plots. We note that our viewpoint is primarily from the perspective of the Ministry of Forests' Growth and Yield programs and might not reflect other programs (e.g., those of the forest industry).

PSP Dead Tree Measurement in British Columbia

The BC Ministry of Forests (MOF) has an extensive GY PSP program (> 5,000 PSPs), typically establishing and remeasuring between 200 and 700 plots annually. The earliest PSPs were established as part of research studies in the 1920s, although much of the PSP program was established after the 1960s:

Period	Number of PSPs established[1]
1920-39	90
1940-49	487
1950-59	319
1960-69	2,163
1970-79	1,528
1980-89	994
1990-97	1,412

[1] The number of PSPs shown represent those maintained by the Ministry of Forests, Resources Inventory Branch.

GY PSPs are established and remeasured by several programs within the MOF. The Resources Inventory Branch (RIB) administers the largest program that is conducted through regional offices. These PSPs tend to be in unharvested rather than treated forests. Researchers from Research Branch and Regional Offices maintain PSPs within research installations and silvicultural systems trials that have a wide range of research objectives and treatments. Industry and academia also have established PSP programs adding over 4,000 PSPs to the provincial PSP program.

The Forest Productivity Council (FPC) of BC—whose members are from government, industry, and academia—has taken a lead role provincially to coordinate PSP establishment and remeasurement. The FPC maintains a matrix of forest stand conditions in which existing PSPs in BC are located, thus enabling the determination of where best to place new PSPs. The FPC also maintains provincial minimum standards for GY PSP installation and measurement that are mostly followed by government and industry.

Information collected on dead trees has changed from early PSP establishment in the 1920s to the present. Early PSP measurements may have identified simply that a tree had died. This was later modified to some indication of the merchantable condition of a tree at death through the use of a standardized "tree class" measure assigned to a tree on each remeasurement. Three of the six tree classes concern dead trees: cut (removed by human activity); dead potential (>50 percent sound wood by volume and > 10 cm DBH and 3 m height or length); and dead useless (not cut or dead potential). As interest in dead trees increased in the 1990s, further information on dead trees has been collected within the MOF RIB GY PSP program. In 1991 a tally of standing dead trees by DBH size class was added to the establishment procedures. In 1994, a measure indicating whether a tree that had recently died was standing or fallen was added, as it was not previously possible to differentiate this. These data provided information on dead tree recruitment and inventory at plot establishment. However, little information on dead tree dynamics could be obtained as trees were not revisited after being recorded dead.

In the mid-1990s, several organizations started using GY PSPs to obtain information on dead tree dynamics in BC. In 1993/94, the BC MOF Research Branch initiated the collection of information on standing dead trees from a limited number of PSPs in research trials to determine basic fall rate information *(table 1)*. Wells (1996) analyzed a subset of PSPs of MacMillian Bloedel Ltd. in coastal western hemlock forests to investigate developmental trends of stand structure and tree mortality. Large silvicultural systems trials were initiated during this period in which PSPs were installed and dead tree information was collected (Holstedt and Vyse 1997). Further during this time period, wildlife/danger tree assessment was initiated and standing dead trees were included in new resource inventory standards (Stone and others 2002).

Table 1—*British Columbia Ministry of Forests research trial growth and yield permanent sample plots on which standing dead trees have been measured.*

Research Trial	Treatment	Species[1]	Number of PSPs	Date established	No. of measurements	Date of first dead tree measure
Aleza Lake EPs	Residual cutover	Se, Bl	17	1926-1936	7-9	1998
EP364	Commercial thinning	Fd	12	1950	8	1996
EP368	Species trial	Fd, Hw, Cw, Bg, Ba, Ss, Co	49	1958	7	1998
EP370	Partial cutting	Pw, Hw, Lw, Fd	20	1957	6	1994
EP384/385	Thinning	Pl	12	1953	7	1994
EP388	Commercial thinning	Hw	20	1953	5	1997
EP429	Espacement	Fd, Cw, Bg	18	1963	6	1999
EP534	Juvenile spacing	Fd	46	1959-1963	8-11	1995
EP554	CCT trial	Fd	47	1959	9-11	1997
EP571	Espacement	Fd, Cw, Ss, Hw	157	1962	5-8	1998
EP703	Thinning/ fertilization	Fd, Hw	940	1971-1975	8	1994-2000
EP1065	Pruning	Hw, Cw, Fd	102	1990-94	3	1997-1998
EP1097	Thinning/ fertilization	Hw	36	1992	2	1996
EP1177	Biosolids	Fd	32	1992	4	1998

[1] Ba: Amabilis fir *(Abies amabilis),* Bb: Subalpine fir *(Abies lasiocarpa),* Bg: Grand fir *(Abies grandis),* Co: Port-Orford-cedar *(Chamaecyparis lawsoniana),* Cw: Western red cedar *(Thuja plicata),* Fd: Douglas-fir *(Pseudotsuga menziesii),* Hw: Western hemlock *(Tsuga heterophylla),* Lw: Western larch *(Larix occidentalis),* Pl: Lodgepole pine *(Pinus contorta),* Se: Engelmann spruce *(Picea engelmannii)* Ss: Sitka spruce *(Picea sitchensis).*

Despite the above initiatives, the need for broader information on standing dead tree dynamics was identified by BC dead wood experts (Stone 1997). Measuring standing dead trees within the provincial GY PSPs was potentially an economical method to obtain such information. To determine the feasiblity of this need, the FPC through the MOF RIB conducted a pilot study in 1998 to investigate the cost of including dead tree measures as a minimum GY PSP standard (Forest Productivity Council 1999). We discuss this pilot study later. As a result of the study, the FPC added standing dead tree measures to provincial GY PSP standards and the MOF RIB GY program commenced measuring standing dead trees in the fall of 1999. A review of the standards and the use of the information will be conducted in 2001.

Example Data

In August 1927, George H. Barnes established a 0.405 ha (1 acre) permanent sample plot (this permanent sample plot was originally identified as EP [Experimental Plot] 82 and is currently identified as 6-01L-2R by the Resources Inventory Branch, Ministry of Forests, Victoria, BC) in an unmanaged stand in the municipal Mount Douglas Park (Saanich, British Columbia). Over the past 70 years, the BC MOF has measured this PSP 10 times for tree species, DBH, and selected heights and ages of live trees until their death *(table 2)*. Currently the PSP is predominantly Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) with a small component of big-leaf maple *(Acer macrophyllum).*

Table 2—*The number of live Douglas-fir stems per plot on Mt. Douglas Park (Saanich, British Columbia) growth and yield permanent sample plot. The plot size is 0.405 ha (1 acre). The site index is 27 m @ 50 years (Bruce 1981).*

			Trees per plot by DBH (cm) class				
Measurement year	**Stand age**	**Stems (>7.5 cm) per plot**	**<20**	**20-30**	**30-40**	**40-50**	**50+**
1927	70	282	40	130	73	29	10
1933	76	262	28	117	66	40	13
1937	80	247	25	106	64	45	17
1943	86	222	14	76	62	48	27
1947	90	208	5	63	50	52	38
1953	96	195	4	50	46	44	51
1957	100	195	4	49	45	42	55
1967	110	174	1	30	41	31	71
1977	120	163	1	23	36	18	85
1987	130	154	0	15	33	18	88
1997	140	154	1	15	29	18	91

In the fall of 1998, all standing dead trees (> 1.3 m height) were recorded on the PSP. The individual trees were identified either by the presence of a tag or by comparison with the information for trees known to have died. The height (ocular estimate) and several characteristics (e.g., bark presence, wood condition, branch condition) were measured for each tree. In the description below we discuss only Douglas-fir dynamics. Other conifers are a minor component of this stand. Hardwoods were not included in the PSP measurement until 1987.

Data such as found on this PSP may be analyzed and presented in several formats. A raw summary of the 10 cohorts (based on the number of years since the tree's death was recorded) shows some common features of this type of information *(table 3)*. We note that the size distribution of the dead trees lags behind the size distribution of the live tree dynamics (i.e., trees that die are usually growing slower), and no dead trees have been standing longer than a certain age (i.e., 60 years in this data set). These data can also be graphed as survival curves *(fig. 1)*. Studies such as Harmon and others (1986) report the decay rate derived from simple negative exponential models. For Mt. Douglas data we find a decay rate of 0.035 per annum (standard error [s.e.] = 0.007) for dead trees in the 21-30 cm dbh range. Similarly, the data could be fit to a logistic regression model (Raphael and Morrison 1987). One such fitted model for the Mt. Douglas data is Prob[yrs,DBH] = 1/(1+ EXP(-0.459 + 0.046*yrs – 0.028*DBH)) where Prob[yrs,DBH] is the probability that a dead tree with a given diameter (DBH in cm) will be still standing after x years (yrs).

Table 3—*The number of Douglas-fir stems per plot on Mt. Douglas Park (Saanich, British Columbia) growth and yield permanent sample plot that had died since the previous measurement and the number of dead Douglas-fir that remain standing in 1998. The plot size is 0.405 ha (1 acre). Values in parentheses indicate trees that were cut and thus excluded from fall calculations. A dead standing tree must be at least 1.3 m tall.*

Measurement year	Number of trees in plot that died since previous measurement period by DBH (cm)				Years since death recorded	Number of standing dead trees still standing in 1998 by period of death and DBH (cm)			
	<20	20-30	30-40	40-50		<20	20-30	30-40	40-50
1927	0	0	0	0	71	0	0	0	0
1933	11	8 (1)	0	0	65	0	0	0	0
1937	3 (5)	3 (5)	0	0	61	0	0	0	0
1943	5 (4)	13 (1)	0	(1)	55	2	4	0	0
1947	5	9	0	0	51	2	2	0	0
1953	1	9	3	0	45	1	3	1	0
1957	0	0	0	0	41	0	0	0	0
1967	2	15	3	0	31	0	7	0	0
1977	0	8	2	0	21	0	2	1	0
1987	1	6	3	0	11	0	3	2	0
1997	0	8	9	0	1	0	5	7	0
1998	0	0	1	0	0	0	0	1	0

However, as is well recognized, the robustness and interpretation of the results of any method is dependent upon the underlying data and how they were obtained. These Mt. Douglas data provide a small data set, probably insufficient for most analyses including the above, and are from a single site that would unlikely be representative of a larger population of interest. Appropriate sampling schemes should be employed or, alternatively, a good understanding of the potential biases is needed if the results are to be applied for management purposes.

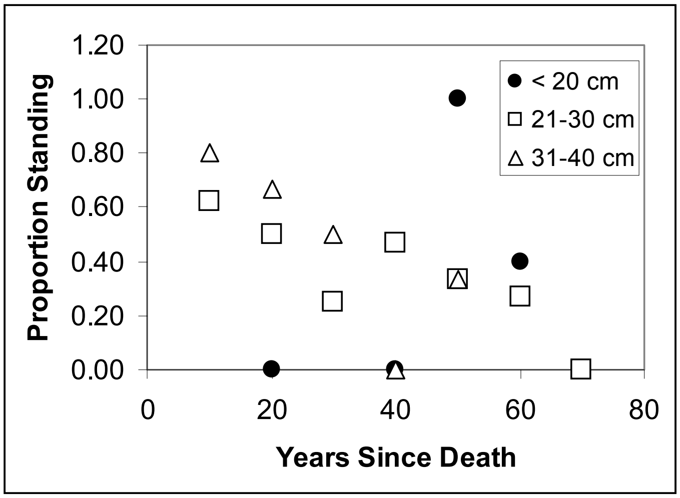

Figure 1—The proportion of dead Douglas-fir stems still standing in 1998 by age group (i.e., years since death) on the Mt. Douglas PSP. The data have been grouped into 10 year periods.

Time Trial

To estimate the cost of obtaining dead tree information within the Ministry of Forests' GY PSP program, we conducted a pilot study (Forest Productivity Council 1999). Nine existing plots that covered a range of characteristics in terms of stand density, age, and time since establishment were chosen. Four plots were located in the Kamloops Forest Region of interior British Columbia and five plots in the Vancouver Forest Region of coastal British Columbia. On each plot, all standing dead trees were located and measured for a variety of characteristics. These measures included base (e.g., standing or fallen, height to breakage, wildlife tree appearance) and special informational needs (e.g., bark condition, lichen loading), as identified in a needs assessment by 44 individuals interested in dead tree data in British Columbia (Stone 1997).

The time study found that for the base set of measures (species if needed, DBH if needed, tag identification if needed, vertical position [standing or fallen], breakage, height to break if needed, and wildlife tree visual appearance), the average time required per tree was 51 seconds (s.e. = 2.0). For the typical tree (i.e., has a tag and does not require DBH or species), the average time required to collect these base measures was 19 seconds (s.e. = 0.7).

The PSPs in the pilot study were selected to sample a range of conditions, not to be representative of the entire sampling program. The average number of dead trees per plot of the MOF PSP sampling program is expected to differ from the average of the pilot study. To determine an estimate of the standing dead trees that might be found on an average MOF PSP, we randomly selected 100 PSPs with at least two remeasurements (i.e., 20 years since establishment) from the active provincial sampling program. From these 100 PSPs (mean size 0.087 ha), we obtained an average of the expected number of trees over 10 cm DBH at a remeasurement (8.6 per plot, s.e. = 0.72) that died since the previous measurement. We then estimated that 10.7 (s.e. = 0.79) trees per plot that died before the previous measurements would still standing. The latter was estimated by applying, as a best guess, a logistic fall model for Douglas-fir to tree mortality information in each PSP (Stone 1996).

We were interested in the incremental costs of measuring all standing dead trees during the regular PSP remeasurement. If we assume that the 1998 average contracted bid price for plot measurement in the MOF GY PSP program was $1,000 for 10 hours per plot, we find that the inclusion of the base measures for dead trees greater than 10 cm DBH added $29 to $39 to the cost of measurement. This low cost was also reflected in the MOF Research Branch coastal research PSP program. In the second year of the collection of dead tree measures in 1997, accepted bid prices were similar to those in 1993 for the same plots when no dead tree measures were collected (de Montigny 1998). However, in the initial year of the collection of dead tree measures, an increase in bid cost did occur probably due to the uncertainty among contractors about the costs of dead tree measures.

Use of PSP Data in BC

Dead tree information needs in British Columbia have been identified in various reviews (Backhouse and Louiser 1991, Caza 1993, Lofroth 1998, Machmer and Steeger 1995). These needs can be summarized into four categories: the development of policy and management guidelines; understanding the ecological role of dead trees; understanding the status and dynamics of dead trees; and operational forest management (Stone 1997). Most uses of dead tree information in current forest management practice (e.g., wildlife/danger tree assessment, residue and waste surveys, wildlife tree patch determination and mapping) involve a static field identification of dead wood resources. However, most of the identified needs require information on the dynamics of dead trees and the linkages to their ecological roles.

Information from PSPs can satisfy many of the basic needs on dead tree dynamics. Simple summaries of fall rate information by species and forest type will provide insight for researchers and forest managers needed for developing prescriptions related to wildlife tree reserves. Fall and breakage rates in relation to live and dead tree conditions can assist in assessing wildlife/danger tree assumptions. Data from the MOF PSP program are publicly available. Researchers might make use of the PSPs to collect further non-destructive measures to address specific information needs (e.g., decay development, bark sloughing) and potentially correlate these to the larger PSP information base.

The primary identified use of the raw data from the MOF GY PSP program will be for the development of empirical models of dead tree fall included within the MOF growth and yield models TASS, TIPSY, and PrognosisBC (for description of the models, see http://www.for.gov.bc.ca/research/gymodels). TASS is an individual tree distance-dependent growth model that is currently suitable for modeling BC's major commercial species in single species even-aged stands (Di Lucca 1999, Mitchell 1975, Stone 1996). The model enables silvicultural treatments such as thinning, fertilization, and pruning and has a wide array of outputs. However, the model is not publicly distributed. TIPSY is a publicly distributed model that interpolates yield tables derived from TASS. TIPSY has a limited set of silvicultural options but provides a wide range of growth and yield outputs as well as economic summaries. PrognosisBC is a BC derivative of the Forest Vegetation Simulator

(FVS) that has been parameterized for use in several ecosystems of southeastern BC (Robinson 1997).

The empirical dead tree fall models currently used in TASS and TIPSY are logistic models derived from a limited number of PSPs in BC for Douglas-fir, western hemlock *(Tsuga heterophylla),* and lodgepole pine *(Pinus contorta) (table 4)*. Other species either use Douglas-fir parameters as a default or have been modified to reflect a perceived relative rate of fall as compared to Douglas-fir. The logistic models used time since tree death and DBH at death as the independent variables. While both TASS and TIPSY use logistic models, they are applied in different manners. In TASS the models are applied to individual trees and if the probability of fall is greater than a randomly assigned value, the tree is considered to have fallen. In TIPSY the models are applied to stand level information (average DBH class and time since death) and the probability is treated as the percentage of the number of trees in that class that will have fallen during a time period. These fall models will be reparameterized as new data become available. Furthermore, the dead tree model structure in TASS is also expected to change to reflect greater biological/mechanical relationships.

Table 4—*Standing dead tree logistic fall models incorporated as default parameters within dead tree fall models of the Ministry of Forests' growth and yield model TIPSY. The model is ProbStanding = 1/(1+ EXP(b0 + b1*YearsSinceDeath + b2*DBHatDeath)). Only non-treated plots dominated by the species of interest were used.*

Source	Establish-ment date	Dead tree measure-ment date	No. of PSPs	DBH range (cm)	Species	Standing dead trees	Total trees died since establish-ment	b0	b1	b2
EP703[1]	1971-75	1994-95	46	4.2 - 54.6	Fd	1,518	3,986	-1.369	0.132	-0.063
EP703[1]	1971-74	1994-95	16	4.9 - 48.8	Hw	1,063	2,137	-2.094	0.169	-0.057
EP384/85[2]	1953	1994	2	3.3 – 26.9	Pl	28	255	0.662	0.146	-0.074

[1] EP703 consists of 940 PSPs located at 85 installations on Vancouver Island and the coastal mainland of British Columbia (Darling and Omule 1989, Stone 1996). Species composition of these PSPs varies but is dominated either by Douglas-fir (Fd) and/or western hemlock (Hw).

[2] EP384/85 consists of 12 PSPs located near Canal Flats, BC. These installations are composed of lodgepole pine (Pl) with scattered western larch.

PrognosisBC can use the FVS Fire and Fuel Extension model to generate standing dead tree information. For a planning study in Nelson Forest Region of BC, Greenough and others (1999) adjusted this extension based on fall information from a limited set of regional PSPs. The standing and fallen dead tree information was linked to a number of indicators to provide an environmental assessment. The Fire and Fuel Extension has not been parameterized for use in other areas.

Discussion

The integrated collection of dead and live trees on PSPs enables a tree to be followed through its entire development and breakdown. Knowledge of the source of death or timing of decay onset provides valuable information for understanding the breakdown of a dead tree. Likewise, the management of dead trees is tied to the management of live trees as a source of dead tree recruits. The integrated collection provides direct data ties for modelling the growth and yield of live and dead trees.

The measurement of standing dead trees in conjunction with live trees on GY PSPs is also more economical, as much of the measurement cost is associated with travel to the site. Furthermore, within the BC RIB GY PSP program we made a tradeoff between information and cost by measuring only standing dead trees greater than 10 cm DBH, while live trees are currently measured down to 2 cm DBH. The 10 cm limit reduces the variability of the number of dead trees per plot to measure and, therefore, the contractor uncertainty about the number of trees that will be measured.

The use of existing GY PSPs to obtain dead tree information is not without potential problems. As with any sampling, the user of the information must determine whether the information and any biases are appropriate. Biases may exist in plot placement. In BC, areas with forest health problems tended to be avoided when the PSP objective was assessment of potential tree growth. PSPs also tend to be located in areas with easier access (i.e., roads hopefully are not randomly located). Biases might also be caused by the physical act of measurement. In certain PSP programs in BC, at least until the mid-1970s, some sampling crews tended to push over standing dead trees to simplify plot establishment and measurement as dead trees were not considered important at the time.

The collection of dead tree information on PSPs must serve a use, whether it is a current need or a perceived future need. Managers must ensure that data are properly collected, stored, and summarized so that they are available to the users. The users must demonstrate to the managers that the data are serving a purpose and provide feedback to collection or data management needs. Furthermore, to ensure the success of a long-term information collection program, managers and users both must communicate the value of PSPs in the face of changing information needs to those who ultimately fund the program.

PSPs should be considered as one source for information on dead tree dynamics. PSPs may not be able to provide all needed information, some of which may have to be obtained by destructive methods. The small size of PSPs and their placement will most likely be inappropriate for investigating the role of standing dead trees in relation to organisms with larger space needs, and the appropriate linkages must be made through other knowledge and sampling tools. Additionally, information obtainable on PSPs might be obtained by other methods sooner (e.g., Huggard 1999). In BC, we still have a large need for basic dead tree information, and we need to use all the tools possible.

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