density of superfluous skid trails reported in the concession by Jackson et al. (2002).

In an attempt to maximize the efficiency of labor, machine, and forest resource use, the harvesting system employed in Block 3 included all operations described in Section 2.1, normal harvesting operations, plus the planning of all secondary and tertiary skid trails. Following felling operations, but prior to log skidding, a forest laborer demarcated optimal log extraction routes using orange flagging tape. When necessary, the forest laborer had sawyers cut down-and-dead logs into sections to facilitate skidder access. The forest laborer was instructed to make straight skid trails that intersected one another at obtuse angles and to avoid well-formed advance regeneration when possible (but FCTs were not marked prior to harvest).

3. Methods

3.1. General assessment of felling technique

The implementation of directional felling requires that sawyers are fully capable of felling trees in any predetermined direction (ITTO, 1996c). To assess the technical ability of the concession's timber fallers, both were observed in the felling of approximately 40 trees selected at random. They were asked to indicate the specific direction in which they intended to fell the tree, and that azimuth was recorded using a compass prior to the tree's fall. After felling, the azimuth of the tree's actual fall was recorded and notes were taken at the stump regarding the placement and dimensions of the face cut, back cut, and holding wood (the cut and uncut sections of wood that control the speed and direction of a tree's fall). The difference between the intended and actual direction of the tree's fall was then calculated for each observation, and an average margin of felling error was calculated for each sawyer, diameter class, and species observed.

3.2. Assessing FCT damage associated with felling operations

Approximately 30 single tree fall sites were selected at random from both the normal harvesting and FCT flagging blocks, and the FCT damage incurred at each site was tallied (methods modified from Johns et al. (1996)). Damage to FCTs was recorded according to the cause of damage (i.e., felling or skidding) and the location and severity of the wound (Table 2, modified from Jackson et al. (2002)). F-tests were used to test the homogeneity of variances, and equal variance t-tests were used to test for differences in FCT damage between harvesting systems. Differences were considered statistically significant at $P \leq 0.05$.

3.3. Assessing FCT damage associated with skidding operations

All skid trails in each of the three 45-ha experimental blocks were mapped and delineated into four classifications: (1) primary skid trails, where more than 10 trees had been skidded, (2) secondary skid trails, where 2–10 trees had been skidded, (3) tertiary skid trails, where only one tree had been skidded, and (4) other skid trails, where skidders had traveled but no logs had been skidded—i.e. dead ends and low-intensity access routes (from Jackson et al. (2002)). The lengths of individual skid trails were measured, and FCT damage was tallied along the entire length of all primary, secondary, tertiary, and other skid trails according to the cause of damage (i.e., felling or

Table 2
Classification of damage sustained by FCTs along skid trails and in felling gaps (modified from Jackson et al. (2002))

Damage type	Bole	Root	Crown
Severe	Snapped at base, bent, or severely leaning	Uprooted	Loss of entire crown; loss of less than entire but more than two-thirds of crown
Moderate	Exposed and damaged cambial tissue	Exposed and damaged cambial tissue	Loss of less than two-thirds but more than one-third of crown
Minor	Exposed cambial tissue but no damage, bark scrape	Exposed cambial tissue but no damage, root scrape	Loss of less than one-third of crown