Comparison of forestry-based remote sensing methodologies to evaluate woodland caribou habitat in non-forested areas of Newfoundland

by Brian E. McLaren[1] and Shane P. Mahoney[2]

Forest inventory maps and a manual interpretation of forestry-enhanced Landsat imagery are compared to the results of a detailed aerial photograph interpretation used to map habitat for caribou (*Rangifer tarandus terra novae*) in a relatively unforested region of Newfoundland. This comparison serves as an illustration of the pitfalls inherent in using readily available remote sensing technologies in applications for which they were not intended. The non-forest classes in the Newfoundland Forest Inventory are too broad to describe single vegetation communities, and only rarely are vegetation communities found entirely within a single forest inventory class. For example, "bog" is relatively well associated with wetland vegetation classes and "barren" with upland classes, but "scrub" is a misleading term used to describe both forest and non-forest communities. An earlier (global) forest classification for Newfoundland has a more reliable association of scrub with forest, but a less reliable identification of bog than later updates to the forest inventory in the study area. Landsat imagery applications for forest inventory updates do not appear useful in identifying non-forest vegetation communities. Caution should be taken in using forest inventory maps in wildlife habitat applications when the habitat includes important non-forest components.

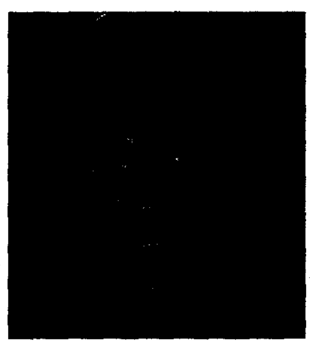
Key words: forest inventory, habitat classification, Landsat imagery, mapping, remote sensing

Les cartes d'inventaire forestier et l'interprétation manuelle des images Landsat adaptées à des fins forestières sont comparées aux résultats d'une interprétation détaillée de photographie aérienne utilisée pour cartographier l'habitat du caribou (*Rangifer tarandus terra novae*) dans une région relativement sans couvert forestier de Terre-Neuve. Cette comparaison sert d'illustration des écueils inhérents dans l'utilisation des techniques actuellement disponibles de télédétection dans le cas d'applications pour lesquelles elles n'ont pas été conçues. Les classes d'absence de couvert forestier selon l'inventaire forestier de Terre-Neuve sont trop générales pour décrire les communautés composées d'une seule espèce, et les communautés de végétation sont rarement retrouvées complètement sous une seule classe d'inventaire forestier. À titre d'exemple, un « marécage » est facilement associé aux classes de végétation de milieu humide et « dénudé » avec les classes en élévation, mais « arbuste » constitue un terme imprécis utilisé tant pour les communautés forestières que les non forestières. La classification antérieure (générale) utilisée à Terre-Neuve contient une association plus fiable des arbustes avec la forêt, mais une identification moins fiable des marécages que le sont les mises à jour récentes de l'inventaire forestier dans la région étudiée. Les applications de l'imagerie Landsat pour la mise à jour des inventaires forestier ne semblent pas être utiles dans l'identification des communautés de végétation non-forestière. Il faut prendre des précautions lorsqu'on utilise des cartes d'inventaires forestiers pour des applications reliées aux habitats fauniques lorsque ces habitats comprennent des composantes non forestières importantes.

Mots clés: inventaire forestier, classification de l'habitat, imagerie Landsat, cartographie, télédétection

Introduction

Investigations of wildlife habitat required for a number of purposes (e.g., protecting species under legislation) can turn to remotely sensed data to assess extensive areas too costly or difficult to evaluate by the initiation of new fieldwork. Frequently, forest inventory systems are suggested for such purposes, as they often represent the only standard, detailed description of landscape-scale vegetation that is readily available. Such systems may prove to be useful, particularly where wildlife habitat types can be compared to inventory features using existing "ground-truthed" information. For example, moose (*Alces alces*) habitat, if classified by forest age, can be quickly assessed using stand age interpretation on forest inventory maps, and this assessment will have an accuracy determined from previous random field checks of the inventory information (Proulx and Joyal 1981). However, other features, especially attributes or polygons unrelated to the inventory of the principal timber-producing species, may be poor or misleading proxies for wildlife habitat. Animal species primarily dependent on non-forested landscapes or on habitats not classically identified in standard forest inventories become another challenge. For example, a ground-truthing exercise using pine marten (*Martes americana*)



Brian E. McLaren

Shane P. Mahoney

[1]Department of Geography, Memorial University of Newfoundland, St. John's, Newfoundland A1C 5S7. E-mail: bmclaren@mun.ca
[2]Government of Newfoundland and Labrador, Department of Forest Resources and Agrifoods, Inland Fish and Wildlife Division, P.O. Box 8700, Bldg. 810, Pleasantville, St. John's, Newfoundland A1B 4J6.

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habitat suitability index (HSI) model parameters and the Québec Forest Inventory showed that stand age and tree height were well predicted by the inventory data for dominant tree species, but a weak relationship was found between mapped stand cover density and actual tree crown closure; also, accuracy was lacking in aerial photo identification of subdominant tree species (Potvin *et al.* 1999). As a result, the authors involved in this exercise generally recommended caution in applying forestry maps to wildlife habitat inventory.

In Newfoundland, Forest Inventory staff have developed an extensive timber inventory database and documented both its standards and accuracy (Gillis and Leckie 1996). Furthermore, there has been continuous effort in ground-truthing and subsequent refinement of information in forested stands since the first comprehensive, "global" inventory was developed in the 1960s (e.g., van Kesteran 1996). The Newfoundland Forest Inventory data have been used to identify habitats selected by moose (McLaren *et al.* 2000), and studies using these data to interpret habitat selection by other species are becoming more common. However, the extent to which the inventory data can be used to correctly reference non-forest areas has not been tested, although non-forest areas—in so-called "non-productive forest" or "non-forest" classes in the Newfoundland Forest Inventory—provide many plant and animal species with seasonal or year-round habitats in this Province. We describe an attempt to test the way in which remote sensing technologies common in forestry applications can be adapted to assess non-forest areas of woodland caribou (*Rangifer tarandus caribou*) range in south central Newfoundland, by comparing maps derived from an independent habitat assessment with forestry maps. This study is limited to the use of existing datasets to determine if there are cost-effective ways to inventory caribou habitat by adapting forest inventory information.

Following human settlement, woodland caribou declined throughout North America and many populations are now classified as threatened, vulnerable or endangered. Populations on the island of Newfoundland (*R. t. terra novae*) are an exception and are thriving. Nevertheless, management of these herds at high density requires a detailed understanding of habitat and forage availability at a large scale. Most woodland caribou spend only part of the year in forested habitat, and require non-forested areas at other times of the year. We describe and cross-reference the partially forested habitats used by the Grey River caribou herd on the south coast of Newfoundland (Fig. 1) using four sources of information: an early (global) forest inventory for the Province, a more recent inventory for purposes of timber management, a manual Landsat image classification used for forestry applications in the Province, and a mapping exercise used in habitat assessment of the spring and summer ranges of the Grey River herd (Meades and Meades 1983). Only the latter source provides habitat detail for non-forested areas, describing two areas used during and immediately after caribou calving (Fig. 1, Table 1). We compare map classes from the forestry databases with those communities we considered as "standards" in Meades and Meades' (1983) classification. We use the resulting cross-tabulations to test congruency in each potential habitat assessment and, in this way, evaluate the potential use of forestry data in an island-wide Newfoundland caribou habitat inventory. Cost comparisons depend on what stage is used to begin the exercise (i.e., are the black and white photographs to be used in a new habitat assessment already available or do they have to be purchased?). We compare all potential costs for repeating this exercise by obtaining similar datasets from the point of new imagery (Table 2). Independent efforts to map specifically caribou habitat, other than by Meades and Meades (1983), are mentioned in our discussion.

Statistical analyses to gauge the accuracy of Forest Inventory data in predicting the caribou habitat classes we called "community standards" followed the approach of van Kesteran (1996). This was determined to be the most straightforward fashion of comparing overlap of map classes. To evaluate correspondence between the databases and compare to random overlap, we calculated a log-linear likelihood ratio based on the G^2 approximation of the χ^2 distribution. We partitioned the resulting G^2 statistic for each map cross-tabulation to Meades and Meades (1983) by way of an iterative process. Cells with the largest standard deviations (the largest relative errors of omission or commission, i.e., non-overlap of map classes with expected congruency) were reduced to structural zeros (small positive values of 0.005%) in the original contingency tables. When G^2 was no longer significant ($p<0.05$), cells identified by such an iterative process likely indicated correspondence between classes in two maps. Thus, matches between map classes were considered significant at $p<0.05$. Cramer's V is an associated relative index of association that was reported for each G^2 statistic. Potentially corresponding map classes were based on authors' descriptions of each remote sensing exercise described below. Calculations used SAS version 6.12 (SAS Institute Inc., Cary, NC).

Meades and Meades' (1983) Classification

A preliminary habitat map of the range of the Grey River caribou herd was classified by interpretation of homogeneous areas on 1:15 840 black and white aerial photography made available in 1982 (Meades and Meades 1983). Vegetation communities within these areas were identified using a relevé plot system (Mueller-Dombois and Ellenberg 1974) for "ground-truthing," along randomly selected transects. A full list of plants including phanerogams and cryptogams was used in determining associations. Caribou habitat types were classified from this list, ecologically, based on literature descriptions of caribou food habits and habitat preference, and vegetatively, based largely on consistent plant height strata. These plant communities were then interpreted using stereoscopy in 156 photographs along 16 flight lines, with no further ground-truthing (cost of interpretation and not ground-truthing is included in Table 2). The communities identified included 11 non-forest vegetation types of woodland, swamp, marshes, barrens and peatlands (Table 1) and 15 forest types. These classifications were categorised more generally by Meades and Meades (1983) as "wetland," "barren" and "forested" classes. Two difficulties were reported in the final mapping exercise: it was impossible to distinguish sedge fens from cinquefoil fens, although the latter appeared to have a better developed shrub layer; and it was difficult to separate tuckamore communities from other barren types. Tuckamore was usually found in association with woodlands, and the two types were distinguished by height. Tuckamore was identified as thickets where trees were <3 m height, while woodlands were defined as open forests where trees were >3 m height and ca. 10–15% cover. Tuckamore is a commonly referenced habitat type, similar to

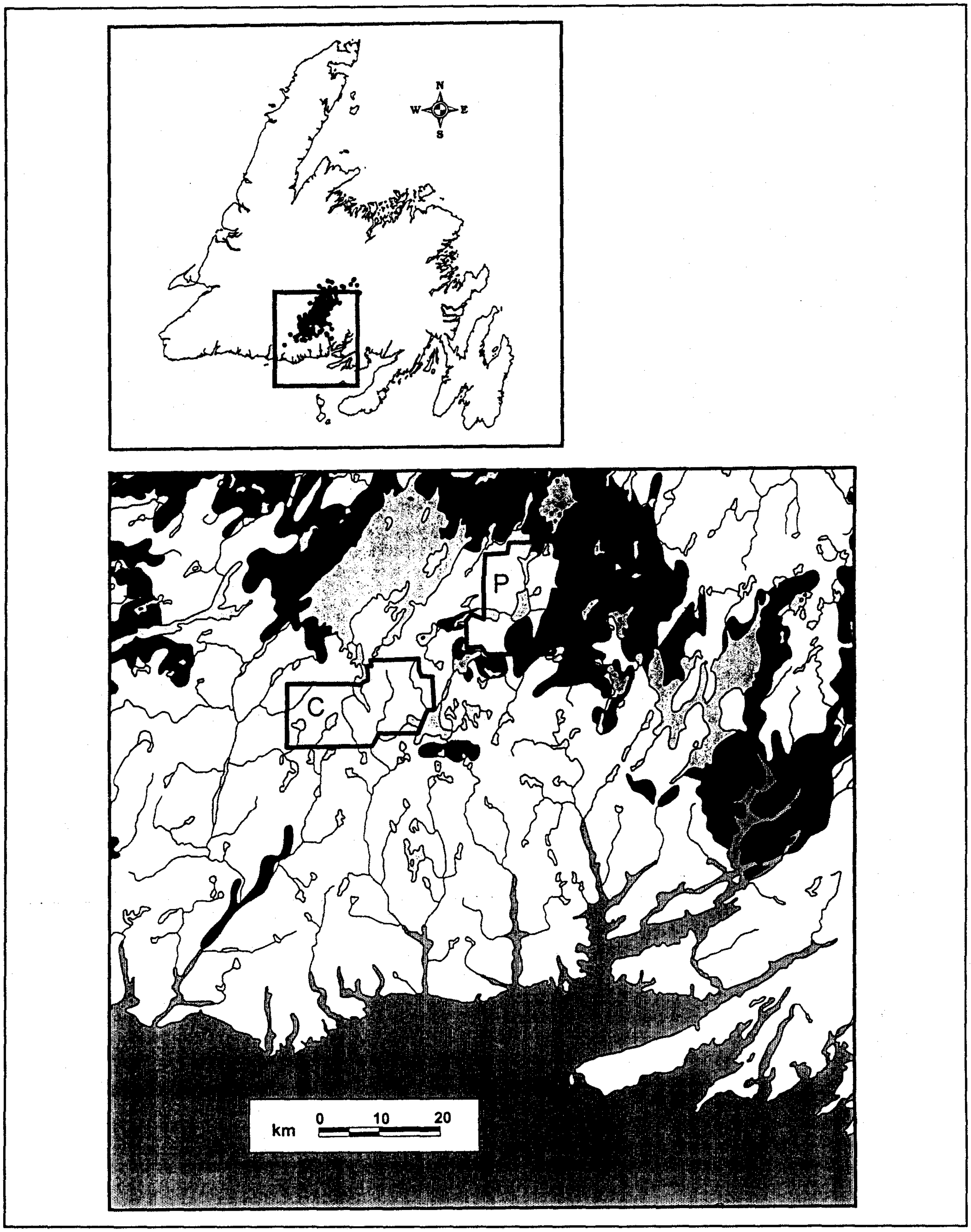

Fig. 1. Study area, showing portions of the calving (C) and post-calving (P) ranges of the Grey River caribou herd, mapped by Meades and Meades (1983). Regions with heavy shading are approximate areas of productive forest (lighter shading in water bodies). In the inset map of Newfoundland, the points shown near the study area are spring locations of collared Grey River caribou during 1983–84.

Table 1. Vegetation communities in the calving and post-calving areas of the Grey River caribou herd, by number of occurrences (n) and percent of total area (%), with possible matches to Forest Inventory categories

Community	Calving Area		Post-calving Area		Category[1]	Match
	n	%	n	%		
Alder Swamp	0	0	146	0.8	WETLAND	BOG
Dwarf Birch Fen	399	16.4	162	3.5	"	"
Sedge Fen[2]	692	8.4	1101	4.7	"	"
Deergrass Bog	667	25.8	1010	18.1	"	"
Ericaceous Bog	22	0.5	208	4.5	"	"
Marsh	487	3.1	589	3.2	"	"
Tuckamore	4165	15.3	1952	21.1	BARREN	SCRUB
Woodland	127	0.6	789	8	"	"
Kalmia Barren	260	1.2	1509	12.3	"	BARREN
Crowberry Barren	3456	19.2	63	0.1	"	"
Various Forest Types	1686	9.5	3175	23.7	FOREST	

[1]Categories are according to Meades and Meades (1983); matches to Forest Inventory are based on more detailed definitions in this report.
[2]This map category includes the separate cinquefoil fen community, which could not be distinguished using aerial photography.

Table 2. Comparison of costs per ha ($) of obtaining datasets like those used in this study

Dataset	Purchase of new images	Interpretation[1]	GIS mapping
Non-Timber Habitat Assessment[2]	0.08	0.87	0.80
Newfoundland Forest Inventory	0.11	0.87	0.80
Manual Landsat Classification	0.07	0.11	0.80

[1]Costs of interpretation and mapping are based on current (2000) salary dollars for in-house work, and include computer support, e.g., mapping itself is $0.62 per ha, but computer support adds $0.18.
[2]An assessment like Meades and Meades' (1983) is meant in the generic sense, using black and white photography – this cost can then be applied to a new exercise repeating the Global Forest Inventory.

"krummholz," and occurs along windswept coastal areas of Newfoundland, where plant height growth is limited by wind action and freezing precipitation.

All original photographic interpretation was scanned and registered to 1:50 000 National Topographic Series (NTS) data and vectorised using Mapinfo software (Mapinfo Inc., Troy, NY), at a cost similar to mapping of inventory data (Table 2). Twenty sampling points per photograph were used in the registration, and polygons in adjacent photos were edge-matched to create two continuous areas of land classification as shown in Fig. 1. This database formed the baseline for cross-tabulation, excluding all water bodies. Some small areas of burned forest in the post-calving region were considered as forest in the analysis.

Global Forest Inventory

A set of forest stand characteristics has been mapped for all areas of insular Newfoundland (10.16 M ha), with the last revision occurring in 1972, culminating a period of unprecedented national effort to inventory Canada's forests (Gillis and Leckie 1996). Because this effort was the only comprehensive vegetation-based inventory for Newfoundland, it is still a common reference for mapping unforested areas of the province. Maps for this inventory came to be archived with the Newfoundland Forest Service as mylar prints at 1:50 000 scale, geo-referenced to NTS data at the same scale, each showing areas of 15′ latitude by 15′ longitude. Black and white aerial photographs were used until 1969 for this inventory, at one of two scales, 1:12 500 or 1:15 840. The mapping was comprehensive for all stands of merchantable timber, with softwood content and crown cover each estimated in four percentage classes, and height estimates, sometimes provided for two storeys. Although a class existed for forests of 0–10% crown cover, sparse mature forest was in practice assigned to a "scrub" category, unless it was considered disturbed and regenerating (immature) productive forest. (The only forest stands assigned to this category in our study area were the burned forest in the post-calving region.) All mature forests of incomplete (<10%) crown cover or low (<10') height (e.g., tuckamore) were classed together as non-productive forest (softwood or hardwood scrub). Unforested, undeveloped areas were mapped as either soil barren or rock barren (although only the former occurred in the current study area), or bog, marsh and treed bog (usually mapped together in one category). There was ground-truthing for productive forest in this inventory, but not for unproductive forest or non-forest categories, and not in this study area. The mylar sheets at 1:50 000 were scanned and the sampling areas from this Global Forest Inventory (Fig. 2) were vectorised as described for the aerial photographs forming the baseline data, with the same cost (Table 2).

Updated Forest Inventory

The current forest inventory used by the Newfoundland Forest Service is rarely based on information in the Global Forest Inventory. Rather, new colour aerial photographs are taken of areas to be updated and images are transferred directly to mylar at 1:12 500 scale, then photo-interpreted to maps archived at a reduced scale, usually 1:25 000. More attention is paid to stand species composition, where up to three forest components are listed if each species comprises ≥30% of the stand's basal area. Crown density is measured in three classes for mature forest and coded separately for immature forest, with the first class beginning at 26% crown density (compared to 11% for the Global Inventory). Forest stands are also cat-

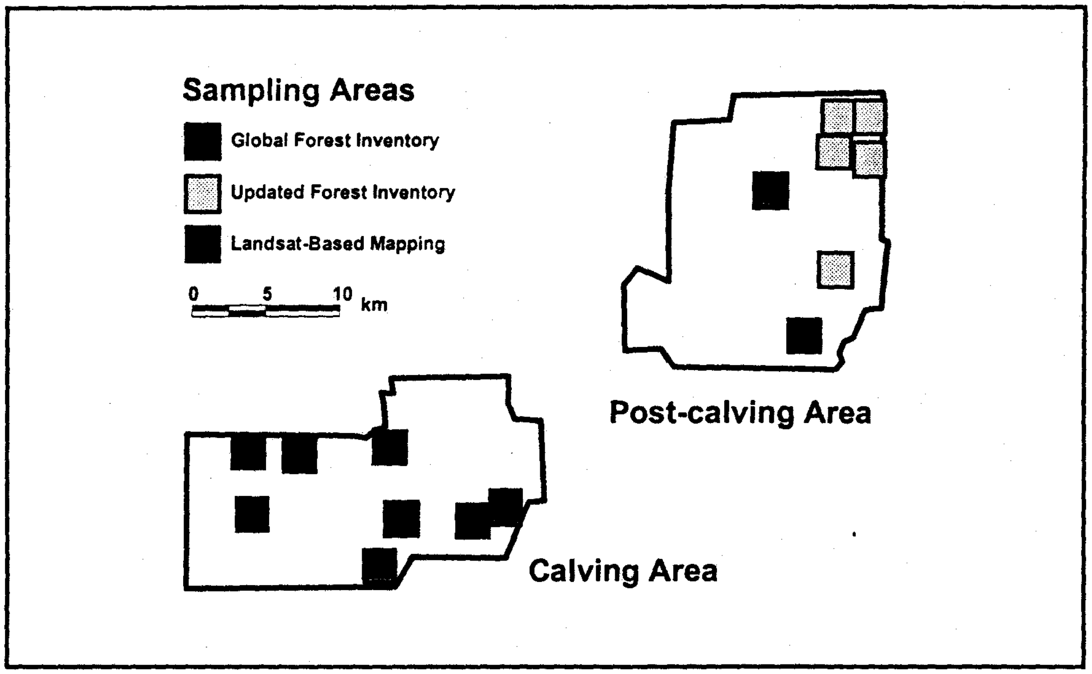

Fig. 2. Sampling locations within the Grey River study area used in cross-tabulating forestry maps.

egorised by site index based on soil potential (poor, medium, good and high productivity), and by age in 20-year classes. Another change is the introduction of SI units for tree height and stand area. Non-forested areas are categorised exactly as they were in the Global Inventory. For this study, archived mylar sheets at 1:30 000 were scanned and the sampling areas were vectorized from an updated (1986) inventory, available only in the western (road accessible) portion of the post-calving region (Fig. 2). Because this inventory is based on colour photography, cost is slightly higher than the adjusted cost for the 1969–72 inventory (Table 2).

Forestry Landsat-Based Mapping

Mapping of new areas of clearcut and insect damage, and updates to the forest access road inventory on existing forestry maps have been a routine annual procedure using manual interpretation of Landsat TM imagery purchased by the Newfoundland Forest Service (Gillis and Leckie 1996). There have also been proposals for the application of TM data to remote age classification of softwood stands (Drieman 1994), and for the mapping of moose habitat using Landsat imagery (Oosenbrug *et al.* 1988), with mixed success. Landsat data have been suggested for many other uses, primarily because the imagery exists in a ready-to-use format (colour mylar), as an extensive database covering most of insular Newfoundland at a lower cost than aerial photographs (Table 2). Costs are particularly lower for interpretation, which is computer assisted (Table 2). Currently, Bands 3, 7 and 4 (blue, green, red) are purchased from Radarsat International for areas of interest in mostly forested regions of the Province, during a leaf-on period between May and September. The bands are visually enhanced in an algorithm developed to show maximally young stands, areas of insect damage and other cleared areas, and to distinguish forest type and age for the purposes of annual update. The enhanced data are delivered in a colourized mylar overlay showing approximately 85–90 km coverage, at a 1:500 000 scale (quarter-scene). In this paper, colour-enhanced TM data purchased as cloud-free images between 1995 and 1997 were applied to the largely unforested calving area of the Grey River caribou range. The enhancements were created according to the normal requirements for update of clearcuts, insect damage and roads. Using a Procom unit and a 1:50 000 Global Inventory base map for geo-referencing, regions of continuous colour were identified within the database. Five samples of these manually interpreted regions (eight classes in total) were scanned, vectorised and compared to the baseline data as described above (Fig. 2). While this test was admittedly a limited use of the full extent of Landsat data, it was directed toward a very accessible form of mapping using remote sensing by satellite.

Results

Forest inventory classifications are less reliable at predicting non-forest vegetation communities than they are at their intended use in categorising forest stands. The category matches in these comparisons produce overall $G^2_{df=9}=62.73$ for the Global Inventory and $G^2_{df=9}=59.53$ for the Forest Inventory. Cramer's $V=0.477$ and $V=0.456$ respectively, suggesting similar predictive capabilities for the two inventories, and rejecting the null hypothesis of no correspondence between the habitat classification and the inventories in the Grey River area ($p<0.001$). However, partitioning of the G^2 statistic to test individual category matches results in p ($G^2_{df=9}=10.48$)=0.31 after removing only the correlations between the Global Inventory and the Meades and Meades (1983) classifications with respect to forest stands, forest scrub and forest stands[3], forest scrub and alder swamp, tuck-

[3]Alder swamps are recategorised as forest scrub in this comparison (unlike the initial match suggested in Table 1), based on the results of the more detailed cross-tabulations (Tables 3 and 4).

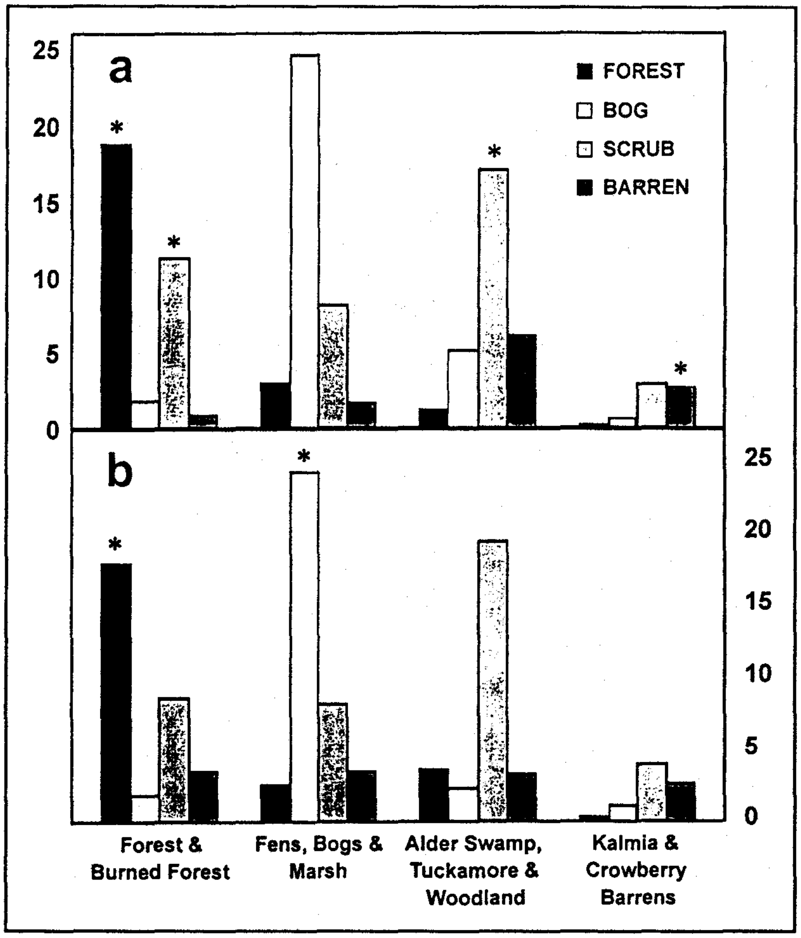

Fig. 3. Cross-tabulation of aggregate habitat classes in the Grey River area (Table 1) with (a) Global Forest Inventory and (b) updated Forest Inventory map classes. Vertical axes show percent overlap in the combined sampling areas (Fig. 2), and asterisks indicate significant contribution to the overall G^2 statistic for matches with positive standard deviates, i.e., occurring in a map class more often than expected under the null hypothesis of no association.

amore and woodlands, and corresponding barren communities (Fig. 3a). That the scrub category occurs as a significant correspondence for two broad vegetation types (forest stands combined, and alder swamp, tuckamore and woodland combined) with further occurrences in wetlands and barrens, and secondly that the barren category includes more alder swamp, tuckamore and woodland than areas typed by Meades and Meades (1983) as barrens, and finally that fens, bogs and marsh fall into no Global Inventory category more than expected due to random chance, all suggest a poor match between these maps. The updated forest inventory is better than the Global Inventory at predicting bogs as the communities typed as fens, bogs and marsh (Fig. 3b), but this is the only broadly matching category other than the match between forest stands that is significant in establishing correspondence between the maps, such that removal of these correlations results in $p\ (G^2_{df=9}=5.10)=0.82$.

Some of Meades and Meades' (1983) vegetation communities are predicted better than others when individual types are compared to the forest inventories. For example, alder swamps fall reliably within areas classified as scrub, such that scrub defines 88% of their area in the Global Inventory (Table 4) and 70% of their area in the updated inventory (Table 5). Bogs are more often types found within the bog category than are fens and marsh combined (78% and 81% by area *versus* 58% and 47% by area for the two inventories). Likewise, ericaceous bogs (89% and 91%) relative to deergrass bogs (76% and 75%) are consistently better classified as bogs, as are dwarf birch fens (69% and 72%) relative to sedge fens (60% and 41%). Barrens are reliably associated with upland communities, particularly

Table 3. Cross-tabulation of vegetation communities by percent (%) in four categories of the Global Forest Inventory

Community	Bog	Scrub	Barren	Forest
Alder Swamp	0.0	87.9	4.0	8.1
Dwarf Birch Fen	69.1	23.6	1.8	5.4
Sedge Fen	59.6	25.1	2.2	13.0
Deergrass Bog	76.3	13.4	7.1	3.2
Ericaceous Bog	88.6	9.5	0.0	1.9
Marsh	36.0	41.6	7.3	15.1
Tuckamore	23.7	63.2	8.4	4.7
Woodland	2.6	72.5	19.5	5.4
Kalmia Barren	8.7	39.9	49.2	2.3
Crowberry Barren	23.1	76.9	0.0	0.0
Various Forest Types	5.6	34.4	2.0	58.0

Table 4. Cross-tabulation of vegetation communities by percent (%) in four categories of the updated Forest Inventory

Community	Bog	Scrub	Barren	Forest
Alder Swamp	1.9	70.5	6.1	21.5
Dwarf Birch Fen	61.6	1.4	2.8	34.2
Sedge Fen	41.4	29.6	21.3	7.7
Deergrass Bog	75.0	19.9	3.3	1.8
Ericaceous Bog	91.2	8.0	0.1	0.6
Marsh	50.7	29.6	13.4	6.3
Tuckamore	10.5	67.8	18.5	3.1
Woodland	7.4	66.8	4.1	21.7
Kalmia Barren	13.6	51.5	32.3	2.6
Crowberry Barren	no occurrences in sampling areas[1]			
Various Forest Types	6.0	26.8	10.8	56.5

[1]Associations with zero occurrences are not shown, and are replaced with 0.005% in the calculation of the G^2 statistic.

Table 5. Cross-tabulation of vegetation communities by percent (%) in eight classes manually interpreted from colour-enhanced Landsat TM data

Community	1	2	3	4	5	6	7	8
Alder Swamp	no occurrences in sampling areas [1]							
Dwarf Birch Fen	9.5	17.3	63.5	0.0	5.5	1.4	2.8	0.0
Sedge Fen	18.3	32.3	23.1	0.1	20.0	0.8	5.0	0.4
Deergrass Bog	1.2	27.0	56.8	0.0	11.4	0.3	2.8	0.5
Ericaceous Bog	2.0	44.9	38.8	0.0	14.3	0.0	0.0	0.0
Marsh	0.8	24.8	60.1	0.0	5.5	5.5	2.5	0.8
Tuckamore	20.6	17.7	16.2	0.3	34.7	0.8	7.9	1.9
Woodland	64.4	8.2	0.0	0.0	27.4	0.0	0.0	0.0
Kalmia Barren	20.2	20.2	8.1	0.0	46.1	0.0	5.5	0.0
Crowberry Barren	19.1	12.2	32.2	0.3	19.9	12.6	3.6	0.0
Various Forest Types	25.2	5.8	4.5	1.1	6.4	0.0	54.7	2.2

[1]Associations with zero occurrences are not shown, and are replaced with 0.005% in the calculation of the G^2 statistic.

in the Global Inventory mapping, such that they rarely overlap wetland types in the habitat classification (i.e., barren is 2% by area in bogs, 2% in fens, and 7% in marshes, comparing the Global Inventory, and 2% in bogs, 17% in fens, and 13% in marshes, comparing the Forest Inventory). Less tuckamore (3% by area) occurs in forest than woodland areas in forest (22% by area) in the Forest Inventory samples (Table 5), but not in the Global Inventory samples (5% by area for both types, Table 4). Generally, the scrub category is least well defined, barren better defined, and bog most reliably defined when comparing either forest inventory database. Forest and scrub as a combined category, however, are more reliably associated with forest communities in the Global Inventory relative to the Forest Inventory (Fig. 3).

Satellite data are not usefully associated with the vegetation mapping by Meades and Meades (1983) when all the original communities in the habitat classification are compared to the colour-enhanced Landsat image, in which p ($G^2_{df=63}$=57.56)=0.67 (Table 5). Comparing the remote sensing exercise against the broader habitat categories of wetland, barren and forest results in rejection of the null hypothesis of no association, with $G^2_{df=21}$=45.80 (p<0.001) and Cramer's V=0.420, but due only to their common identification of forest (colour 7); i.e., when this correlation is removed, the match is lost, p ($G^2_{df=21}$=24.70) =0.26. Although not a statistically significant match, one colour (6) is remarkably well associated (81% by area) with crowberry barrens (Table 5). However, Kalmia and crowberry barrens themselves are not well typified by any combination of colours, and this is true for all Meades and Meades' (1983) vegetation communities.

Discussion

Our exercise illustrates the limitations of Forest Inventory information in classifying wildlife habitat generally, and in classifying non-forested areas specifically. Generally, the non-forest classes in the inventory are too broad to describe single vegetation communities, although there may be instances when extensive forest inventory mapping helps restrict the area chosen to delimit certain habitats. For example, in this study, ericaceous bogs were almost entirely restricted to bog areas in the Forest Inventory, while alder swamps were almost entirely restricted to scrub areas. These are not useful restrictions, however, for identifying the maximum extent of these areas on the landscape, because the bog and scrub classes typically involve broad areas of mapping in unforested regions. Specifically, the Newfoundland Forest Inventory is most limited by the poorly defined scrub class. When this class has been applied to describe parts of any forest or non-forest community (Fig. 3)—except perhaps the insignificant component of ericaceous bog included as scrub (Tables 3, 4)—then stratification of the inventory into any unique habitat type is limited; i.e., most every community mapped by Meades and Meades (1983) was partially mapped in the Inventory as scrub. We did not uncover evidence to suggest that satellite data may be used to enhance wildlife habitat classifications in the same fashion that Landsat imagery is used to enhance Forest Inventory maps. However, development of unique interpretations of aerial photography and/or satellite data for specific habitat classifications may still be recommended. Other such attempts have been limited, presumably due to high investments (Table 2) for low success (e.g., Petersen 1987).

There have been several varying attempts to assess the range extent and habitat use of woodland caribou in Canada. One of the first national approaches for summer barren habitat began in Newfoundland with Ahti (1959), who consulted with caribou managers in other provinces (e.g., Ahti and Hepburn 1961) to map areas based on their lichen cover from estimates in relevé plots at widely-ranging points on the landscape. This approach has continued to be used for some remote areas in recent years (e.g., Morneau 1999). However, many wildlife managers still rely on a subjective interpretation, like the Land Capability Classification for Ungulates (Environment Canada 1972), which was derived from expert assessments of range use by deer in Canada, but not directly from ground-based research. When groundcover is estimated from remote sensing (e.g., Petersen 1987), results have been mixed. In his exercise to map the range of the Beverly caribou herd, Petersen (1987) used Landsat TM Band 5 data with some success in identifying recently burned areas, but with limited success in identifying lichen mats. This author recommended the approach of visual analysis of colour-enhanced images from the data (as in this paper), as more accurate and cost-effective than a supervised digital classification. Some authors (e.g., Bradshaw *et al.* 1995, Stuart-Smith *et al.* 1997, Anderson 1999) have chosen to rely on peatland or wetland inventory data to assess primarily non-forested range. Unfortunately, in some of this work, there is no ground-truthing or error investigation for such maps, and selection of habitat is based on the assumption that the inventories represented by the map data are entirely accurate—ground-truthing or a map comparison exercise like ours would be a minimum recommendation to provide an error estimate for the use of any remotely sensed data. An accurate investigation of this type was performed by Rettie *et al.* (1997), and they found canopy cover data from Saskatchewan's

Forest Inventory to be very suitable in predicting forest vegetation communities, which they ground-truthed in a detailed caribou habitat assessment. However, their study strictly investigated the forested component of caribou range. From our study, we recommend caution outside such parameters.

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