A comparison of forest resource inventory, provincial land cover maps and field surveys for wildlife habitat analysis in the Great Lakes – St. Lawrence forest

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ABSTRACT

In a portion of central Ontario, Canada we assessed the classification agreement between field-based estimates of forest stand composition and each of two mapped data sources used in wildlife habitat studies, the Forest Resource Inventory (FRI) and satellite-image derived Provincial Land Cover (PLC). At two study areas, Algonquin Provincial Park (APP) and Wildlife Management Unit 49 (WMU49), we surveyed 119 forest stands and 40 water and wetland stands. Correspondence levels between FRI and field classifications were 48% in APP and 44% in WMU49 when assessing six forest cover types. With only four simplified forest cover types, levels improved to 77% in APP and 63% in WMU49. Correspondence between PLC and field classifications for three forested stand types was approximately 63% in APP and 55% in WMU49. Because of the poor to moderate level of correspondence we detected between map and field classifications, we recommend that care be exercised when FRI or PLC maps are used in forest and wildlife research and management planning.

Key words: forest resource inventory, FRI, provincial land cover, PLC, Landsat Thematic Mapper, map accuracy, map correspondence, map agreement, Ontario, wildlife habitat

RÉSUMÉ

Nous avons évalué dans une région du centre de l'Ontario au Canada, l'entente de classification entre les estimés réalisés sur le terrain de la composition des peuplements forestiers et chacune des deux sources de données cartographiques utilisées dans les études d'habitats fauniques, l'Inventaire des ressources forestières (IRF) et la Classification provinciale du territoire (CPT), dérivée des images satellites. Sur les deux sites d'étude, le parc provincial Algonquin (PPA) et l'unité d'aménagement faunique 49 (UAF49), nous avons examiné 119 peuplements forestiers et 40 peuplements de milieu humide. Les niveaux de correspondance entre l'IRF et la classification sur le terrain atteignaient 48 % dans le PPA et 44 % dans l'UAF49 pour ce qui est de l'évaluation de six types de couvert forestier. Dans le cas de seulement quatre types simplifiés de couvert forestier, les niveaux se sont améliorés à 77 % pour le PPA et à 63 % pour l'UAF49. La correspondance entre la CPT et les classifications sur le terrain dans le cas de trois types de couvert forestier était d'environ 63 % pour le PPA et de 55 % pour l'UAF49. À cause du niveau de correspondance allant de faible à modéré que nous avons relevé entre les classifications cartographiques et celles provenant du terrain, nous recommandons que des précautions soient prises lorsque les cartes de l'IRF ou de la CPT sont utilisées pour la planification de la recherche et de l'aménagement de la forêt et de la faune.

Mots clés : inventaire des ressources forestières, IRF, classification provinciale du territoire, cartographie Landsat, précision cartographique, correspondance cartographique, entente de classification, Ontario, habitat faunique

Introduction

Assessing wildlife–habitat relationships is an important element of understanding wildlife ecology and for directing human land uses to mitigate effects on wildlife populations. The validity of these analyses depends on the accuracy of the habitat data used to identify and estimate these relationships, yet an accuracy assessment of habitat data is rarely part of these studies.

Accuracy of mapped data can be reduced to two related components: classification accuracy and positional accuracy (Congalton and Green 1999). Classification accuracy refers to the degree to which the recorded attributes of a feature

correspond to the actual attributes of the feature on the ground. For instance, that a forest stand classified as poplar is composed of at least 50% poplar and overall canopy composition is greater than 70% hardwood. Positional accuracy refers to the correct location of features on a map or in a database. For example, the degree to which stand boundaries, encoded as a line on a map or as a sequence of latitude/longitude pairs, deviate from their true location on the ground. These two errors are not independent of each other, since at a very fine spatial grain positional errors might be interpreted as errors in classification (e.g., image pixels at the edge of a stand).

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Understanding the nature and magnitude of errors in maps used in habitat modelling is important, as these errors may contribute sufficient variation to make model parameter estimation impossible or the results meaningless in terms of the habitat classification used. If classification errors are distributed randomly among habitat classes, then parameter estimates will have reduced precision and the significance of habitat effects will be underestimated. If the errors are greater for some classes than others, parameter estimates will be biased. In either case, if these errors are unevaluated they will undermine the knowledge gleaned from analysis and the soundness of management decisions based on these models.

Forest cover maps are commonly derived through manual or digital interpretation from aerial photographs or satellite images. In Ontario, Forest Resource Inventory (FRI) maps are based on interpretation of 1:20 000 aerial photographs calibrated with field sampling; they provide tree species information at the forest stand level. At the time of this study, FRI maps were created for each forest management unit on a 20-year cycle (OMNR, 2008) and, on Crown land, were updated more frequently with harvest and wildfire data. These maps are used to plan timber harvesting while also considering the needs of associated wildlife through habitat suitability models (Naylor *et al.* 1999, Elkie *et al.* 2007). Provincial Land Cover (PLC) maps are based on Landsat 7 Thematic Mapper (TM) satellite imagery, have a lower spatial resolution than FRI maps, and are interpreted to more general cover classes based on the spectral reflectance values of individual 30 m pixels (Spectralanalysis Inc. 2000).

Conventional accuracy assessments of these types of map data products rely on a comparison of map data with data collected in the field. These field data are often referred to and treated as “ground truth”, in effect without error; examples include Dussault *et al.* (2001), Cunningham (2006), and Thompson *et al.* (2007). However, there is a strong argument and, in fact, a shift in terminology in the literature (e.g., Pinto *et al.* 2007, Booth *et al.* 2008), to a recognition that field-based estimates of stand characteristics such as species composition, age, stocking density, and height, also contain errors. Thus, correspondence between data derived from these two sources, while useful for assessing validity, and offering insight into the likely nature and magnitude of error, is not accuracy analysis *per se*. Field-based estimates include measurement errors (e.g., misidentification of species), processing errors (e.g., data recording and transcription errors), and sampling error. Plot- or transect-based field measurements used for estimating “ground truth” for stand characteristics are samples drawn from stands of interest, and so sampling error is inherent in these data and should be considered when making inferences about any particular stand, or group of stands. Field-based sampling is usually of insufficient intensity to permit precise stand boundary delineation. In fact assessment of stand boundary location is rarely a component of forest map accuracy assessments. For these reasons we will refer to our assessments in terms of consistency and agreement between the remote sensing map classifications and the field classifications of stand types, recognizing that the conventional usage of map “accuracy” terminology is still found in the literature.

Studies that assessed the overall accuracy of forest maps in determining forest composition have yielded variable results, ranging from 29% to 88% (Potvin *et al.* 1999, Dussault *et al.*

2001, Coady 2005, Koen 2006, Pinto *et al.* 2007, Thompson *et al.* 2007). Three studies evaluated FRI maps in Ontario, and reported overall agreement of field and map data of 36% in the boreal forest for stand species composition and 70% for a four category stand classification (Thompson *et al.* 2007), 54% in the northern part of the Great Lakes – St. Lawrence forest for seven stand types (Pinto *et al.* 2007), and 75% for four land classes in a settled part of southeastern Ontario (Koen 2006). A study assessing Landsat 7 TM imagery on the Bruce Peninsula in southern Ontario found field and map data to be 88% consistent in classifying nine broad cover types (Coady 2005). Postulated reasons for map discrepancies include time delays between map creation and validation (Dussault *et al.* 2001, Pinto *et al.* 2007, Thompson *et al.* 2007), different forest classification criteria from the ground relative to aerial photography (Pinto *et al.* 2007, Thompson *et al.* 2007), and difficulty in photo interpretation due to mixed, rather than single species forests (Potvin *et al.* 1999, Thompson *et al.* 2007).

The primary objective of our study was to assess the correspondence of stand classification based on species composition on FRI maps with field-based estimates for analysis of habitat use by American black bears (*Ursus americanus* Pallas) and moose (*Alces alces* Linnaeus) in the Great Lakes – St. Lawrence forest region of central Ontario, Canada. We chose FRI as our principal habitat layer because it provided the most detailed forest information available and because it is also used to manage forests and associated wildlife in the province. Our secondary objective was to apply our collected ground data to evaluate the Ontario PLC in our study areas. Although the PLC provided less detailed forest composition information, it was based on more recent data from satellite imagery and so might have demonstrated a closer agreement with field data than the FRI.

Methods

Study areas

We conducted our study in two areas in the Great Lakes – St. Lawrence forest of Ontario: western Algonquin Provincial Park (APP) and Wildlife Management Unit 49 (WMU49), as designated by the Ontario Ministry of Natural Resources (OMNR) (Fig. 1). Although these areas are in close proximity (~75 km apart), we considered them as separate sampling areas in our analysis because they differed in terms of land use and tenure, landscape characteristics, and wildlife management approaches.

The western portion of APP lies on the Canadian Shield and comprises part of the Algonquin Dome, which has relatively high elevations (up to 590 m above sea level) and soils of poorly drained glacial till (Crins *et al.* 2008). The forest is dominated by tolerant hardwoods such as sugar maple (*Acer saccharum* Marsh.) and American beech (*Fagus grandifolia* Ehrh.), accompanied by eastern hemlock (*Tsuga canadensis* (L.) Carrière) and semi-tolerant hardwoods including yellow birch (*Betula alleghaniensis* Britt.) and red maple (*Acer rubrum* L.) (Crins *et al.* 2008). The majority of APP is contiguous Crown land with silviculture dominated by selection and shelterwood systems.

WMU49 also lies on the Canadian Shield and is characterized by relatively low elevations with soils of silty clay and sand resulting in a greater proportion of mixed and coniferous forests than found in western APP (Crins *et al.* 2008).

Fig. 1. Study areas of Algonquin Provincial Park (APP) and Wildlife Management Unit 49 (WMU 49) of central Ontario, 2007.

Dominant tree species include sugar maple, American beech, basswood (*Tilia americana* L.), yellow birch, eastern hemlock, white pine (*Pinus strobes* L.), red maple, and white ash (*Fraxinus americana* L.) (Hills 1976). In WMU49 60% of the land is privately owned and the remaining 40% is Crown land composed mostly of low-lying wetland areas (Crins *et al.* 2008). As in APP, timber harvest on WMU49 Crown land is primarily under selection and shelterwood regimes.

Forest Resource Inventory maps

Aerial photographs for the FRI maps for our study areas were taken in 1989 at a scale of 1:20 000 and maps were updated with Crown land harvest data through 2006. The FRI maps showed productive forests to the stand level with a minimum stand size of 4 ha in this area (OMNR 2001). From aerial photographs, tree species composition of stands was visually interpreted to the nearest 10%, and additional stand attributes including stand age, height, site class, and stocking density were estimated. Stands were assigned to standard forest units based on species composition; in the Great Lakes – St. Lawrence region there were 25 standard forest units and eight non-productive forest units (Elkie *et al.* 2007). We collapsed these into eight cover types: northern hardwoods (HWDN), southern hardwoods (HWDS), poplar-white birch (POBW), mixed woods (MIX), hemlock (HE), conifers (CON), wetlands, and water by combining forest units representing less than 5% of the cover in both study areas with similar forest units based on species composition, as shown in Table 1. We pooled remaining non-productive land cover types into an “other” cover type, which was not field-sampled.

Field data

To evaluate the correspondence between the FRI map- and field-based estimates of stand-level tree species composition, we assessed 159 stands in the summer of 2007 by sampling 10 stands of each cover type in each study area, except for the HWDS cover type in WMU49 where we sampled nine stands. We randomly selected stands within 1 km of a driveable road. Sampled stands ranged in area from 4.7 ha to 810.2 ha ($\bar{x} = 35.7$ ha, $SD = 79.5$); excluding water polygons, stand area ranged from 4.8 ha to 234.8 ha ($\bar{x} = 24.8$ ha, $SD = 26.8$).

Within forested stands we measured tree species composition at 10 points spaced at 20 m on a randomly located 180-m transect. To minimize the effect of positional errors in delineating stand boundaries and the effects of edges on sample homogeneity, we ensured that no part of a transect lay closer than 50 m to the stand edge. As a result, the remaining proportion of stand areas available for sampling ranged from 0.07 to 0.89 ($\bar{x} = 0.37$, $SD = 0.16$); excluding water polygons, the remaining proportion of stand area available for sampling ranged from 0.07 to 0.71 ($\bar{x} = 0.37$, $SD = 0.15$). Despite the relatively small portion of stand areas remaining for sampling, we felt it was essential to minimize the effect of the ecological gradient near stand boundaries and we therefore maintained the buffer distance at 50 m. We used a geographic information system to delineate each transect by randomly selecting a starting point at least 50 m from any stand edge. Then, from a list of randomly ordered 180-m candidate transects radiating from the starting point, we selected the first transect that fell entirely within the buffered interior of the stand. In the event that a selected stand could not be surveyed, due either to lack of permission for access or to a barrier to access such as a lake, we randomly selected an alternate stand of the same type. To minimize observer bias, field crews were not informed of the stand classification prior to visiting the stand, except for the water and wetland cover types.

In the field, we located the stands and transect starting points using a compass and a hand-held Global Positioning System (GPS) unit. We then traversed the selected transect by following a bearing and pacing the distance between sample points. At each sample point on transects in forested stands, we identified all live trees larger than 10 cm in diameter at breast height (DBH) included in a metric basal area factor 2 (BAF2) prism sweep (OMNR 2004). To estimate the observed stand classifications, we summed the number of trees by species included in each prism sweep over the 10 sample points on each stand transect, and expressed each as a percentage of the total number of trees observed on the transect. From this we assigned each stand to the appropriate standard forest unit and associated cover type (Elkie *et al.* 2007; Appendix A).

We visited some water and wetland plots by ground and assessed them in a similar manner to forested stands, but we assessed most from a fixed-wing aircraft (Cessna 172). In the latter case, we navigated to the starting point using a hand-held GPS and circled at an average height of 518 m. We visually assessed water and wetland transects as either open water or wetland, with the latter defined as a wet area of grasses, sedges, mosses, and other herbaceous cover, shrubs and possibly stunted trees, but with no large stems.

Provincial Land Cover database

Although we developed our sampling protocol specifically to evaluate the FRI, we subsequently used the same field data to meet our secondary objective of assessing the Ontario PLC database, Second Edition (Spectranalysis Inc. 2000). The PLC database was developed from spectral reflectance analysis of Landsat 7 TM imagery collected between 1999 and 2002 at a resolution of 30 m, and provided 27 land cover classes assigned by supervised classification with a minimum feature size of 0.5 ha (Spectranalysis Inc. 2000).

We assessed the correspondence of the supervised PLC classifications to those based on our field data. Due to the raster configuration of the PLC data compared to the discrete

Table 1. Cover type classification and description including landscape guide forest units, dominant species, and availability (%) within the study areas of Algonquin Provincial Park (APP) and Wildlife Management Unit 49 (WMU49), in central Ontario.

Cover type	LGFU	Description	Dominant species ^a	% land cover	
				APP	WMU49
HWDN	<i>Total</i>	<i>Northern Hardwoods</i>	–	46.0	34.7
	HDSL1	Tolerant hardwood selection	Mh	39.0	30.1
	HDUS	Tolerant hardwood shelterwood	Mh – Bw – Po	3.9	4.5
	BY	Yellow birch	By – Mh	3.1	0.2
HWDS	<i>Total</i>	<i>Southern Hardwoods</i>	–	7.8	8.5
	HDSL2	Mid-tolerant hardwood	Mh – Be	7.7	5.6
	OAK	Red oak	Or – Ms	0.1	3.0
POBW	<i>Total</i>	<i>Poplar–White Birch</i>	–	5.4	2.6
	PO	Poplar	Po – Bw	2.4	1.7
	BW	White birch	Bw – Po	2.9	0.9
MIX	<i>Total</i>	<i>Mixedwoods</i>	–	9.0	12.2
	MWR	Rich upland mixedwood	Po – Ms – Bw – Bf	5.6	5.7
	MWUS	Rich upland mixedwood	Bw – Ms – Mh – Po – Ce	3.2	5.7
	MWD	Poor upland mixedwood	Po – Bw – Pj	0.2	0.8
	LMWM	Lowland mixedwood	Ab – Ms – Ce	0.4	0.8
HE	HE	Eastern hemlock	He – Mh – By	5.9	0.8
CON	<i>Total</i>	<i>Conifers</i>	–	4.9	10.5
	PR	Red pine	Pr	0.1	0.7
	PWST	White pine/Red pine	Pw – Po – Bw – Pr	0.5	1.0
	PWUS4	White pine shelterwood	Pw	0.4	0.5
	PWUSC	White pine/Red pine mix	Pw – Pr	0.2	0.3
	PWUSH	White pine/Red pine mix	Pw – Po – Bw	0.2	0.4
	PWOR	White pine/Red oak	Pw – Or	0.0	0.4
	SB	Pure black spruce	Sb	0.9	0.3
	SF	Spruce/Fir mix	Bf – Sw – Sb – Ce	1.8	5.5
	SP1	Upland black spruce, mixed	Sb – Pj – Bw	0.4	0.1
	CE	Lowland conifer, mixed	Ce	0.2	0.6
	LC	Lowland conifer, mixed	Sb – La – Ce	0.2	0.7
	PJ1	Jack pine, pure	Pj	0.0	0.1
	PJ2	Jack pine/Black spruce mix	Pj – Sb	0.0	0.0
Wetlands	<i>Total</i>	<i>Wetlands</i>	–	6.8	7.3
	BSH	Brush and alder	–	2.4	2.3
	OMS	Open muskeg	–	3.7	3.3
	TMS	Treed muskeg	–	0.7	1.7
Water	WAT	Water	–	12.8	9.9
Other	<i>Total</i>	<i>Other classes – not ground truthed</i>	–	1.1	12.9
	DAL	Developed agricultural land	–	0.0	4.6
	RCK	Rock	–	0.1	4.4
	UCL	Unclassified	–	1.0	4.0
	Roads	Roads	–	not reported	–

^aSpecies codes: Ab – black ash; Be – American beech; Bf – balsam fir; Bw – white birch; By – yellow birch; Ce – cedar; He – eastern hemlock; La – larch; Mh – hard maple; Ms – soft maple; Or – red oak; Pj – jack pine; Po – poplar; Pr – red pine; Pw – white pine; Sb – black spruce; Sw – white spruce

stand boundaries of the vector-based FRI data, we calculated the percentage of each PLC cover type within a 20-m buffer on each side of the ground transect lines. Because the cover types developed for the FRI evaluation do not precisely match those of the PLC database, we merged classes within both datasets to produce a common set of cover types. Each transect was characterized by the proportions of these common cover types.

Correspondence analysis

We used a confusion matrix to compare field classifications with the mapped cover type classifications, and calculated the overall classification agreement and the Kappa coefficient (KHAT) (Congalton and Green 1999). The Kappa coefficient quantifies the level of agreement between observed and expected classifications, where KHAT values less than 0.40

indicate poor agreement; those between 0.40 and 0.80 indicate moderate agreement; and those greater than 0.80 indicate strong agreement (Landis and Koch 1977). We assessed differences between study areas in the frequencies of agreement and disagreement between stand classifications using Fisher's exact test with $\alpha = 0.05$.

For the PLC evaluation, we used a confusion matrix to compare the proportions of the merged PLC classes within the buffered stand transects with the field-based stand classifications. We assessed overall differences between study areas in the percentage agreement by area in stand classification using a t-test paired by common cover type with $\alpha = 0.05$. In addition, we qualitatively assessed the nature of disagreements between map- and field-based estimates of cover classifications, in particular which cover types were least consistently classified.

Results

Forest Resource Inventory

Overall correspondence among the observed field data and expected FRI classifications of the eight ground-assessed cover types in APP and WMU49 was 61.3% (KHAT = 0.557) and 55.7% (KHAT = 0.493), respectively (Table 2). The water and wetland classes were in 100% agreement in APP and 90% in WMU49. With these non-forested cover types omitted, correspondence among cover types decreased to 48.3% (KHAT = 0.380) in APP and 44.1% (KHAT = 0.328) in WMU49. The proportion of stands classed as the same cover type, including or excluding water and wetland classes, did not differ between study areas (Fisher's exact test; $P = 0.52$ and $P = 0.39$, respectively).

Although most cover types yielded agreement levels greater than 50%, the HWDS and POBW cover types corresponded with FRI stand classifications in only 10% and 30% of cases, respectively. Accordingly, we combined these stand groups *post-hoc* with those most closely related (i.e., HWDN

and MIX, respectively) to produce a model with improved correspondence levels. Although HE stands were also classed differently by remote and field methods, with only 50% of stand classification in agreement, they were confused with different groups in the two study areas. Field-estimated HE stands in APP were classed as HWDN by FRI and those in WMU49 were confused with MIX and HWDN; therefore, we could not logically pool HE with any other cover type. After combining HWDS with HWDN and POBW with MIX, overall agreement including the water and wetland classes increased to 82.5% (KHAT = 0.782) in APP and 69.5% (KHAT = 0.621) in WMU49, and correspondence among forested classes increased to 76.7% (KHAT = 0.669) in APP and 62.7% (KHAT = 0.469) in WMU49 (Table 3). Again, the proportion of stands grouped into the same classes by both remote and field data, including or excluding water and wetland classes, did not differ between study areas (Fisher's exact test, $P = 0.09$ and $P = 0.15$, respectively).

When weighted with reference to coverage across the study area (Table 1), 69.4 % of the APP landbase and 51.9 % of the WMU49 landbase were classified by FRI in agreement with field data. Excluding water and wetland classes, agreement decreased to 49.8 % and 36.4 % of the landbase in APP and WMU49, respectively. With collapsed classes, 85.9 % and 66.1 % of the landbase in APP and WMU49 was similarly classified by FRI and field data; excluding water and wetland classes, correspondence decreased to 66.3 % and 50.6 % of the landbase.

Provincial Land Cover database

Eleven of 27 PLC classes were represented on the sampled transect areas. To compare the ground-truthed cover types and the PLC habitat categories, we grouped closely related PLC categories and FRI cover types into seven common cover types (Table 4). We omitted two of these groups from the analysis: "other", for which we did not collect field data, and "sparse forest", a PLC category for which there was no equiv-

Table 2. Confusion matrix of cover type classifications of forested and non-forested stands in Algonquin Provincial Park (APP) and Wildlife Management Unit 49 (WMU49) in central Ontario. The numbers of identically classified stands are presented in boldface.

Study area	Original map classification ^a	Number of stands	Field-based classification ^a							
			CON	HE	HWDN	HWDS	MIX	POBW	Water	Wetland
APP	CON	10	7	–	–	–	3	–	–	–
	HE	10	–	5	4	1	–	–	–	–
	HWDN	10	–	1	8	1	–	–	–	–
	HWDS	10	–	1	9	0	–	–	–	–
	MIX	10	–	–	4	–	5	1	–	–
	POBW	10	–	–	–	–	6	4	–	–
	Water	10	–	–	–	–	–	–	10	–
	Wetland	10	–	–	–	–	–	–	–	10
WMU49	CON	10	4	1	2	–	3	–	–	–
	HE	10	–	5	1	–	4	–	–	–
	HWDN	10	–	–	6	2	2	–	–	–
	HWDS	9	1	–	5	2	1	–	–	–
	MIX	10	1	–	1	1	7	–	–	–
	POBW	10	–	–	3	1	4	2	–	–
	Water	10	–	–	–	–	–	–	9	1
	Wetland	10	–	–	–	–	–	–	1	9

^a Classification codes: CON – conifers, HE – hemlock, HWDN – northern hardwoods, HWDS – southern hardwoods, MIX – mixedwoods, POBW – poplar-white birch

Table 3. Confusion matrix of combined cover type classifications of forested and non-forested stands in Algonquin Provincial Park (APP) and Wildlife Management Unit 49 (WMU49) in central Ontario. The numbers of identically classified stands are presented in boldface.

Study area	Original map classification	Number of stands	Field-based classification					
			Conifer	Hemlock	Hardwood	Mixed	Water	Wetland
APP	Conifer	10	7	–	–	3	–	–
	Hemlock	10	–	5	5	–	–	–
	Hardwood	20	–	2	18	–	–	–
	Mixed	20	–	–	4	16	–	–
	Water	10	–	–	–	–	10	–
	Wetland	10	–	–	–	–	–	10
WMU49	Conifer	10	4	1	2	3	–	–
	Hemlock	10	–	5	1	4	–	–
	Hardwood	19	1	–	15	3	–	–
	Mixed	20	1	–	6	13	–	–
	Water	10	–	–	–	–	9	1
	Wetland	10	–	–	–	–	1	9

Table 4. Common cover types derived from the FRI-based cover types and the Provincial Land Cover classes. Categories marked with an asterisk (*) were not included in statistical analysis.

Common cover type	FRI-based cover types ^a	Provincial Land Cover classification
Deciduous	HWDN HWDS	Forest – dense deciduous
Mixed	MIX POBW HE	Forest – dense mixed
Coniferous	CON	Forest – dense coniferous
Wetland	Wetland	Bog – open Bog – treed
Water	WAT	Water – deep clear
Sparse forest*		Forest depletion – cut Sparse forest
Other*		Agriculture Settlement/infrastructure Cloud/shadow

^aClassification codes: CON – conifers, HE – hemlock, HWDN – northern hardwoods, HWDS – southern hardwoods, MIX – mixedwoods, POBW – poplar-white birch

alent FRI classification. Average agreement between the PLC database and our field-based data was 58.5% in APP and 54.0% in WMU49 (Table 5). Water was the most consistently classified class; however, only 6.0% and 5.4% of wetland areas in APP and WMU49, respectively, were classified consistently. The field data collection areas of the three forested habitat classifications corresponded with, on average, 62.6% and 54.8% of the PLC classified pixels in APP and WMU49, respectively. Overall correspondence levels did not differ between the study areas (paired *t*-test; $P = 0.51$, $t = 0.73$, $n = 5$).

When weighted with reference to coverage across the study area, 66.3 % of the APP landbase and 63.7 % of the WMU49 landbase was classified by PLC in agreement with field data. Excluding water and wetland classes, agreement decreased to 61.8 % and 61.1 % of the landbase in APP and WMU49, respectively.

Discussion

Generally, we observed a moderate level of agreement of forest classification between FRI and satellite-based land cover maps and independent ground data on our two study areas. However, there was a poor level of agreement between the FRI and ground data in both study areas when non-productive forest units were removed from our original eight category analysis. When we reduced the number of forested cover types to four by combining HDWS and POBW with closely related cover types, we achieved moderate agreement between the FRI classifications and ground data.

Thomlinson *et al.* (1999) indicated that land cover maps should provide a minimum of 85% overall accuracy and 70% accuracy within each class to be acceptable for their application in global models of ecosystem structure and function; our results fell well below these thresholds. Nonetheless, our overall agreement levels were within the range of those reported in other studies that evaluated forest maps (Dussault *et al.* 2001, Coady 2005, Koen 2006, Pinto *et al.* 2007, Thompson *et al.* 2007). Pinto *et al.* (2007) evaluated the FRI from the Nipissing Forest Management Unit, which is also located in the Great Lakes – St. Lawrence forest region, and found correspondence levels similar to those in our study, with 54% agreement between the FRI and field data when assessing seven forest classes. Other studies have suggested that forest maps are considerably more similar to field estimates for coniferous forest types

Table 5. Confusion matrix presenting percentages of transect areas as classified by field-based data and the Provincial Land Cover Database in Algonquin Provincial Park (APP) and wildlife management unit 49 (WMU49) in central Ontario. Percentages of identically classified areas are presented in boldface.

Study area	Field-based classification	Number stands	Provincial Land Cover classification						
			Deciduous	Mixed	Coniferous	Sparse forest	Wetland	Water	Other
APP	Deciduous	27	62.7	33.9	2.0	1.4	–	–	–
	Mixed	26	12.6	58.2	25.2	2.5	–	1.5	–
	Coniferous	7	–	28.0	69.9	1.1	1.1	–	–
	Wetland	10	9.2	32.8	30.5	17.6	6.1	3.8	–
	Water	10	–	–	–	–	–	100.0	–
WMU49	Deciduous	24	61.7	27.8	–	8.6	–	–	1.9
	Mixed	29	15.5	64.1	9.0	3.6	2.6	1.3	3.9
	Coniferous	6	–	30.0	38.8	31.3	–	–	–
	Wetland	10	0.8	24.8	0.8	51.2	5.4	10.1	7.0
	Water	10	–	–	–	0.7	–	99.3	–

than for mixed or deciduous forest types (Dussault *et al.* 2001, Thompson *et al.* 2007). Given that 74.4% of APP and 59.6% of WMU49 were classified by the FRI as deciduous or mixed forest, lower levels of agreement for our study areas were expected.

Our PLC analysis revealed lower levels of agreement than a previous study that assessed the accuracy of Landsat 7 TM imagery in the Great Lakes – St. Lawrence forest region, which reported 88% overall consistency between PLC and field data for nine habitat classes, including water and wetlands (Coady 2005). In addition, after simplifying our FRI analysis to a coarser classification of cover types similar to that of the common cover types of PLC, the overall FRI agreement level exceeded that of the PLC. Other studies comparing land cover classification by FRI and Landsat TM reported variable results (Hyypä *et al.* 2000, Brown *et al.* 2006). Hyypä *et al.* (2000) found that aerial photographs quantified forest stand characteristics better than Landsat TM, whereas Brown *et al.* (2006) found that FRI maps and Landsat TM varied in their ability to describe different vegetative features.

Three major factors may have contributed to the observed discrepancies between map- and field-based classifications. First, we may have inadequately sampled the study areas. To meet our objective of evaluating the two FRI maps for use in wildlife habitat studies, we sampled a larger number of stands as opposed to intensively sampling fewer stands. As a result, we assessed species composition on single contiguous transects rather than a truly random set of scattered points throughout each stand. Our sample design increased the likelihood of missing significant elements of tree species composition in larger stands, and this design also sampled proportionately smaller areas of larger stands. Therefore, we might have expected to see an effect of stand size on classification correspondence, with larger stands classified less consistently, with respect to field data, than smaller stands. To test this hypothesis, we performed a *post-hoc* logistic regression of stand size versus classification accuracy. We found no significant relationship ($P = 0.501$ for all sampled stands; $P = 0.468$ for all stands excluding water and wetland cover types), indicating that our sampling method was adequate, and classification agreement was not influenced by stand size. In addition,

we established our methods from those presented in similar studies, and we sampled at a similar intensity (Dussault *et al.* 2001, Pinto *et al.* 2007, Thompson *et al.* 2007).

Second, measurement methods in the field and from aerial photographs were substantially different, although they both estimated the same fundamental phenomenon: tree species composition at the stand level. Differences in classification will arise because the field methods are sample-based and estimate composition from within-stand species-specific quantitative measures of basal area at breast height. FRI stand classification is based on visual interpretation of proportions of tree species derived from canopy characteristics for whole stands, calibrated with field checks. Neither is necessarily more correct from a wildlife habitat point of view, but both possess information about vegetation characteristics to which wildlife may respond.

Third, during the 18 years between the time of the original aerial photographs and our field study, substantial change in the forest may have occurred as a result of natural succession and ecological processes. However, because it was not possible to quantitatively assess the effect of forest succession, we cannot attribute the inconsistencies between the FRI database and ground data to any one source of error.

Despite these factors, our analysis of agreement has allowed us to indicate the general magnitude of error shared between the existing FRI and ground-based assessments and identify for which cover types those errors are likely greatest. Additionally, because the PLC cover types are a coarser classification resolution than the species resolution of the FRI, our field methods, though not developed specifically for the purpose of evaluating the PLC, provided a sound general evaluation.

Our study raises concerns for both forest and wildlife management and research, and further demonstrates the necessity of assessing the accuracy of forest maps, even if only through assessment of correspondence between field and remote sensing data sources, before applying them to habitat studies. Since we observed low levels of agreement at a coarse classification resolution of eight cover types, it is likely that when considering all 33 cover classes of the FRI, levels of correspondence would be considerably worse. This suggests that

FRI maps should be used only at a coarse scale of cover classification rather than for specific species composition. Unfortunately, at this scale, map and cover classification resolutions become limiting in studying wildlife-habitat relationships and analyses should be restricted to broader classifications to avoid drawing spurious conclusions.

In terms of our associated studies on habitat use by black bears and moose, the FRI remained useful when answering questions that required only broad cover classes and large spatial units, but its inconsistencies restricted our ability to investigate detailed habitat use and requirements. For example, in the Great Lakes – St. Lawrence forest region, black bears have tree species-specific seasonal foraging patterns, most evident in autumn when associated with hard-mast-producing trees such as American beech and red oak (McLaughlin *et al.* 1994, McDonald and Fuller 2005). Reproductive success and reproductive synchrony in black bears is strongly influenced by beechnut abundance (McLaughlin *et al.* 1994), and cub survival may be affected by acorn abundance (McDonald and Fuller 2005). An understanding of the abundance and distribution of these tree species is therefore important to understanding demographics of black bear populations in the Great Lakes – St. Lawrence forest. Hemlock stands may be an important source of cover for moose in our study areas (Minzey and Robinson 1991, Forbes and Theberge 1993), and distribution of cover can limit the range of available feeding area and therefore the quantity of viable moose habitat (Thompson and Vukelich 1981, Allen *et al.* 1991, Dussault *et al.* 2005). In the same region of Ontario, life history traits of other wildlife species, such as deer mice (*Peromyscus maniculatus* Wagner), are also strongly influenced by seed crops (Falls *et al.* 2007), and abundance of these prey species influences population growth of their predators (Fryxell *et al.* 1999).

Unfortunately, these relationships cannot be reliably studied using the available FRI layers because of the high level of error indicated by the disagreement of the FRI and field-based measures, at a relevant classification resolution; for example, where oak- or beech-dominated stands are distinguished from other hardwood stands. This is of notable concern in Ontario because provincial habitat suitability models use information on stand-level tree species composition for assessing future forest composition impacts on 72 forest-dwelling species of birds, mammals, and amphibians (Holloway *et al.* 2004). At a landscape scale, the development of forest management guidelines has been based, in part, on habitat models for about 20 forest-dwelling animals (Elkie *et al.* 2007). Though the implications of map inaccuracies for wildlife will vary by species and depend on which tree species or habitats are misclassified, it is possible that current forest harvesting practices based on these data do not fulfill the intended goals for provision of wildlife habitat. However, Thompson *et al.* (2007) demonstrated that, at the aggregated spatial scale of whole forest management units, overall FRI species composition accuracies of 35% to 70% did not substantially affect the estimate of habitat availability for six indicator species in the boreal forest. On the other hand, it is worth noting that the species we discuss here are generalist foragers, and that map inaccuracies may have a more profound impact on habitat specialists in the Great Lakes – St. Lawrence forest.

With the advent of advanced GPS-telemetry technology, it is possible to obtain frequent, accurate, and fine-scale location and activity data on a wide variety of wild animals. A complementary suite of habitat information is generally not available without painstakingly collecting area-specific data. To appropriately apply land cover databases to forest management, and wildlife habitat provision in particular, their accuracy must improve and more rigorous evaluations should be conducted prior to their use. Though we emphasize that researchers must be aware of the accuracies of available habitat data and determine if they are suitable for their studies, resource management agencies should consider updating land cover surveys more frequently to account for successional changes in forest type and take advantage of newer technologies. Encouragingly, the Ontario Ministry of Natural Resources is currently moving toward a 10-year cycle of FRI mapping, and a new FRI, covering our study areas, is expected within the next few years. It would be wise to evaluate this, and other new FRI products, through a process similar to ours using field data contemporary with the aerial photography and confirm that classification consistency between remote and field data is improved, indicating an improvement in map accuracy.

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Appendix A. Description, sort order, and sort criteria for landscape guide forest units (LGFU) in the Great Lakes – St. Lawrence Forest region.

LGFU Name	Forest unit description	Sort order	Sort criteria ^a
PR	Red pine	1	$Pr \geq 70$ and $Pw < 30$
PWUS4	White pine 4-cut shelterwood	2	$Pw + Pr \geq 50$ and $Pw > Pr$ and $(Pw + Pr) * STK \geq 30$ and $Or + Ow < 20$
PWOR	White pine/red oak	3	$Pw + Pr + Or + Ow \geq 50$ and $Pw \geq (Or + Ow)$ and $(Pw + Pr + Or + Ow) * STK \geq 30$ and $Or + Ow \geq 20$
PWUSC	White pine/hardwood shelterwood	4	$(Pw + Pr \geq 30$ and $(Pw + Pr) * STK \geq 30)$ or $(Pw \geq He$ and $Pw \geq Sw$ and $Pw > Ce$ and $Pw + Pr \geq 30$ and $(Pw + Pr + Sw + He + Or + Pj + Ce) * STK \geq 30)$ and $(Pw + Pr + Pj + Sw + Sb + He + Bf + Ce + La \geq 80)$
PWUSH	White pine/conifer shelterwood	5	$(Pw \geq Pr$ and $Pw + Pr \geq 30$ and $(Pw + Pr) * STK \geq 30)$ or $(Pw \geq Pr$ and $Pw \geq He$ and $Pw \geq Sw$ and $Pw > Ce$ and $Pw \geq Or$ and $Pw + Pr \geq 30$ and $(Pw + Pr + Sw + He + Or + Pj + Ce) * STK \geq 30)$
PWST	White pine seed tree	6	$Pw + Pr \geq 30$ and $Pw + Pr \geq He$ and $Pw + Pr \geq Sw$ and $Pw + Pr \geq Sb$ and $Pw + Pr \geq Ce$ and $Pw + Pr \geq Or$
PJ1	Pure jack pine	7	$Pj \geq 70$ and $Mh + Ab + Aw + Bd + Be + Ch + Ew + Iw + Or + By + Ow + Po + Bw + Ms \leq 20$
PJ2	Jack pine/black spruce	8	$(Pj + Sb + Pr \geq 70)$ or $(Pj \geq 50$ and $Pj + Sb + Bf + Sw + He + Pw + Pr + Ce + La \geq 70$ and $Bf + Sw + He + Pw + Ce + La \leq 20)$
HE	Hemlock	9	$He \geq 40$
CE	Cedar	10	$Ce \geq 40$ and $Ce \geq Sb + La + Bf$ and $Ow + Ew + Iw + Ch + Mh + Ab + Aw + Bd + Be + Or + By + Po + Bw + Ms < 30$
SB	Black spruce	11	$Sb \geq 80$ and $Mh + Aw + Bd + Be + Ch + Iw + Or + Ow + By + Pr = 0$ and $Pw + Pj \leq 10$
LC	Lowland conifer	12	$Sb + Ce + La \geq 80$ and $Mh + Aw + Bd + Be + Ch + Iw + Or + Ow + By + Pr = 0$ and $Pw + Pj \leq 10$
SP1	Upland spruce	13	$Sb + Sw + Bf + Ce + La + Pw + Pj + Pr + He \geq 70$ and $(Bf + Ce + Pw + La + Sw + He \leq 20$ or $Pj \geq 30)$
SF	Spruce/fir	14	$Sw + Sb + Pw + Pr + Pj + Bf + Ce + La + He \geq 70$
BY	Yellow birch	15	$By \geq 40$
OAK	Oak	16	$Or \geq Mh + Be$ and $Or \geq 30$ and $Or + Mh + Aw + Ab + Be + Bd + By + Pw + Pr + Sw + He \geq 40$
HDSL2	Hardwood selection south	17	$Bd + Aw + Ch + Or + Ow \geq 30$ or $Be + Or + Ow \geq 30$ or $Be \geq 20$
HDSL1	Hardwood selection north	18	$Mh + Aw + Bd + Be + Ch + Ew + Iw + Or + By + Ow + He \geq 50$ and $Po + Bw + Bf \leq 30$ and $(Sc = 'X'$ or $Sc = 'I'$ or $Sc = '2')$
LWMW	Lowland mixedwood	19	$Ce + Ab + La + Sb \geq 30$ and $(Ab \geq 20$ or $Ab + Ms + By \geq 30)$
HDUS	Hardwood shelterwood	20	$Mh + Aw + Bd + Be + Ch + Ew + Iw + Or + By + Ow + He \geq 50$
PO	Poplar	21	$Po \geq 50$ and $Mh + Ab + Aw + Bd + Be + Ch + Ew + Iw + Or + By + .Ow + Po + Bw + Ms \geq 70$
BW	White birch	22	$Po + Bw \geq 50$ and $Mh + Ab + Aw + Bd + Be + Ch + Ew + Iw + Or + By + Ow + Po + Bw + Ms \geq 70$
MWUS	Mixedwood shelterwood	23	$(Sw + Pw + Pr + Ce + Mh + By + Aw + Ch + Bd + Or + Ow + Iw + Be + He) * STK \geq 30$
MWD	Mixedwood dry	24	$Pj + Pw + Pr \geq 20$
MWR	Mixedwood rich	25	Default

^a Codes: Ab – black ash; Aw – white ash; Bd – basswood; Be – American beech; Bf – balsam fir; Bw – white birch; By – yellow birch; Ce – cedar; Ch – black cherry; Ew – eastern hemlock; Iw – ironwood; La – larch; Mh – hard maple; Ms – soft maple; Or – red oak; Ow – white oak; Pj – jack pine; Po – poplar; Pr – red pine; Pw – white pine; Sb – black spruce; Sw – white spruce; Sc – species composition; Stk – stocking density.