Vermont Forest Cover Assessment

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Summary

Over the past century, Vermont's forest cover has expanded as former farmland reverted to forest. However, in recent decades, estimates from the USDA Forest Service's (USFS) Forest Inventory and Analysis (FIA) Program have indicated overall declines in forest cover across the state. These FIA estimates are based on plot-level data collected on a 7-year rotation, which introduces a high degree of uncertainty in annual change estimates and limits spatial resolution to the county level or larger. With the advent of satellite imagery and other remote sensing technologies such as LiDAR, there is growing interest in assessing how these different approaches compare in estimating forest cover change over time.

This analysis aimed to compare multiple datasets estimating forest cover in Vermont and its 14 counties over time. The goal is to improve understanding of forest cover change dynamics—particularly identifying when forest decline began after decades of gains—and to estimate approximate rates of forest loss at both state and county levels. Accurate estimates of forest cover and trends are essential for understanding rates of forest conversion to other land uses, which in turn influence Vermont's forest carbon sink, timber resources, recreational opportunities, wildlife habitat, and landscape connectivity.

Each dataset has its own strengths and limitations. Many remote sensing products rely on the same underlying imagery, and issues such as cloud cover or technical problems can affect data quality. In contrast, ground-based estimates like those from the USFS FIA Program measure actual land cover changes at long-term monitoring plots and extrapolate these to the broader landscape using expansion factors.

Key Findings

1. **Wide variation in statewide forest cover, with no clear consensus.** In 2022, statewide forest cover estimates ranged from 4,467,532 acres (75.7% of Vermont's land area) to 5,169,567 acres (87.6%).
2. **Inconsistent trends in forest cover over time.** Some datasets show increases in forest cover, others show declines, and one is stable. Correlation analysis revealed limited agreement among datasets. These trends were also inconsistent at the county level.
3. **Forest cover varies significantly by county**, with Essex and Windham Counties having the highest forest cover and Grand Isle the lowest. Three counties—Bennington, Essex, and Windham—have over 85% forest cover across all datasets.
4. **Only Addison, Lamoille, and Windham Counties show minimal or no forest loss over time** across all datasets.
5. **FIA data indicate Vermont has lost over 6,000 acres of forest annually since 2005**, with losses concentrated in Orange, Rutland, Windsor, and Caledonia Counties.
6. **Further research is needed to determine the most accurate forest cover estimates.** A more robust understanding of forest cover change is essential for assessing ecosystem service shifts—such as carbon storage and habitat connectivity—at both state and local scales.

Methods

Forest cover datasets

The datasets listed in Table 1 were included in this analysis. Other land use datasets exist, but they were either derivatives of ones included here, or did not include estimates for recent years.

All spatial data processing was conducted in ArcGIS Pro (Esri 2024). For raster datasets that categorize different types of land cover or land use (i.e., LCMS_LC, LCMS_LU, NLCD_LC), pixels corresponding to tree or forest cover were reclassified to forest, and all other area were set to null. Specifically, for LCMS_LC, pixels corresponding to trees (value = 1) were reclassified as forest. For LCMC_LU only pixels with assigned as forest (value = 3) were retained. For NLCD_LC, pixels assigned to deciduous, evergreen, and mixed forest (value = 41, 42, 43) were reclassified as forest.

For raster datasets categorizing forest cover as a percent of canopy cover (i.e., NLCD_TCC), only pixels corresponding to ≥50% canopy cover were retained; all other areas were set to null. For the SAL_TC dataset, pixels assigned to deciduous and coniferous trees (value = 1, 2) were combined for forest cover.

Once a forest cover subset was created for each raster dataset, data were converted to vector format; from this, only contiguous forest areas ≥ 1 acre were selected. This size threshold aligns with the Forest Inventory and Analysis definition of forestland (USDA Forest Service 2023b). For each dataset, forest cover was also summarized per Vermont county (US Census Bureau 2018). The FIA data were extracted from ELVAIDator (USDA Forest Service 2023a) as statewide and county-level estimates for available years. Also included with the FIA estimates are standard errors, equivalent to 67.5% confidence intervals.

To convert forest cover area estimates to the. percent of Vermont's total land area, I used land area estimates for the state and for each county provided by the US Census Bureau (2010). Land area does not include surface waters.

Analysis

All analysis was conducted in R programming language (R Core Team 2014). Temporal trends in forest cover at the state and county-level, and assessed via linear models over three time steps (2005-2022, 2010-2022, and 2015-2022). Not all datasets were able to be evaluated for all timesteps; in those cases N/A were provided in Tables 2 and 3. Correlations among datasets were tested using the corr package for R. The SAL_TC dataset was excluded from the correlation analysis because of its short timeframe.

Table 1: Forest cover datasets and associated properties. For details on data sources and access, refer to the references section.

Dataset	Dataset name	Data sources	Spatial resolution	Years available
FIA	USFS Forest Inventory and Analysis – Forest Area Estimates	Ground-based plot estimates	County-level	1983, 1993, 2005-2022
LCMS_LC	Landscape Change Monitoring System – Land Cover	Landsat and Sentinel-2 satellite imagery	30 m raster	1985-2023
LCMS_LU	Landscape Change Monitoring System – Land Use	Landsat and Sentinel-2 satellite imagery	30 m raster	1985-2023
NLCD_LC	National Land Cover Dataset – Land Cover	Landsat and Sentinel-2 satellite imagery	30 m raster	2001-2023
NLCD_TCC	National Land Cover Dataset – Tree Canopy Cover	Landsat and Sentinel-2 satellite imagery	30 m raster	2011-2021
SAL_TC	Spatial Analysis Lab – Vermont Tree Cover	LiDAR data and NAIP imagery	0.5 m raster	2016, 2022

Results

Statewide Forest Cover

There was substantial divergence among the statewide forest cover estimates (Figure 1). The lowest estimates were produced by the USFS Forest Inventory and Analysis (FIA) Program and the UVM Spatial Analysis Lab (SAL), while the highest estimates came from the two Landscape Change Monitoring System datasets—Land Cover (LCMS_LC) and Land Use (LCMS_LU) (Table 2).

Temporal trends also varied across datasets. Three datasets (LCMS_LC, LCMS_LU, and NLCD_TCC) showed increases in forest cover over time. Two datasets (FIA and SAL_TC) indicated losses, while one (NLCD_LC) remained relatively stable (Figure 1). Notably, the FIA and SAL_TC datasets were closely aligned at the statewide level, though SAL_TC only includes two years of data.

An analysis of correlations among the datasets further highlights the lack of agreement (Figure 4). Due to its limited temporal coverage, SAL_TC was excluded from the correlation analysis. The strongest correlation was between LCMS_LU and NLCD_TCC ($r = 0.83$). FIA, on the other hand, was negatively correlated with all datasets except NLCD_LU ($r = 0.56$).

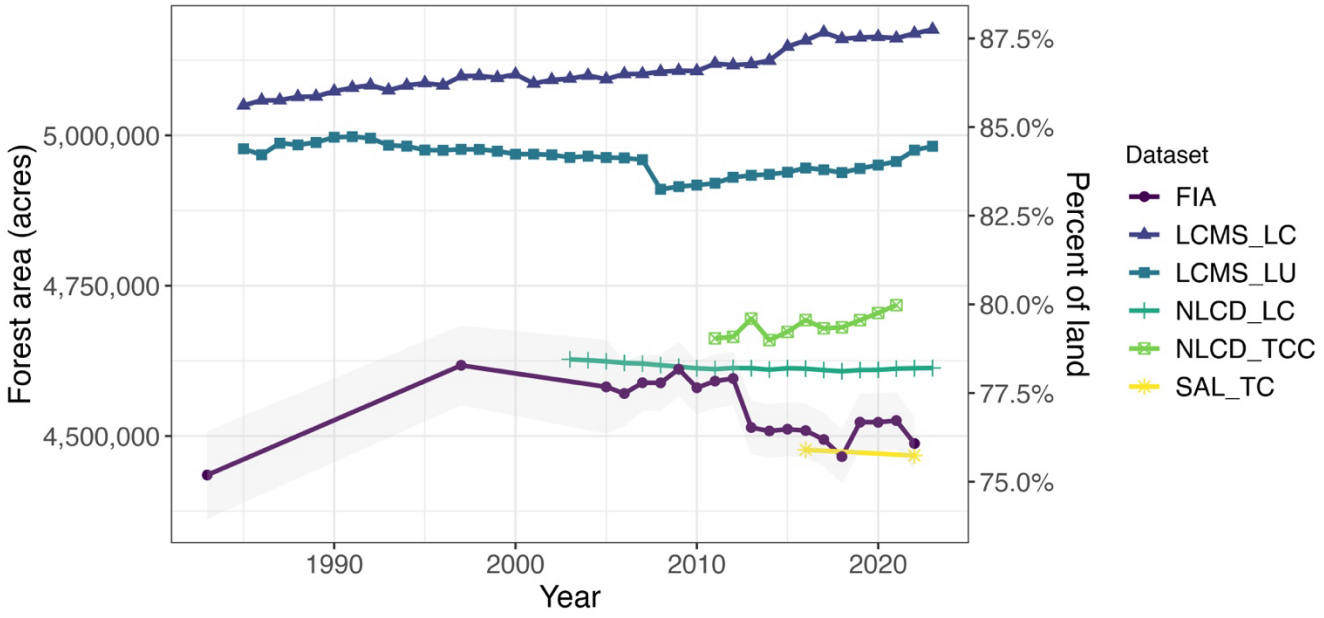


Figure 1. Statewide forest cover estimates displayed as total acres (left axis) and as the percentage of Vermont's total land area (right axis). FIA data includes standard error estimates (67.5% confidence interval, light grey shading).

Table 2. Summary and trends in statewide forest cover estimates by dataset. Mean annual change estimates (in acres per year) are derived from linear models for three different time periods. For dataset details, refer to Table 1.

Dataset	Mean annual change (acres/year)			Forest cover (acres) [percent of land area]		
	2005-2022	2010-2022	2015-2022	2005	2015	2022
FIA	-6,636	-6,875	723	4,581,767 (77.7%)	4,511,368 (76.4%)	4,487,566 (76.1%)
LCMS_LC	4,921	5,300	2,213	5,093,427 (86.3%)	5,147,657 (87.3%)	5,169,567 (87.6%)
LCMS_LU	1,456	4,051	5,033	4,963,193 (84.1%)	4,938,591 (83.7%)	4,975,414 (84.3%)
NLCD_LC	-580	-61	182	4,624,272 (78.4%)	4,612,725 (78.1%)	4,612,742 (78.2%)
NLCD_TCC	N/A	4,330	6,103	N/A	4,673,173 (79.2%)	4,717,736[b] (80.0%)
SAL_TC	N/A	N/A	-1,609	N/A	4,477,189[a] (75.9%)	4,467,532 (75.7%)

[a] SAL_TC estimate for 2016
[b] NLCD_TCC estimate for 2021

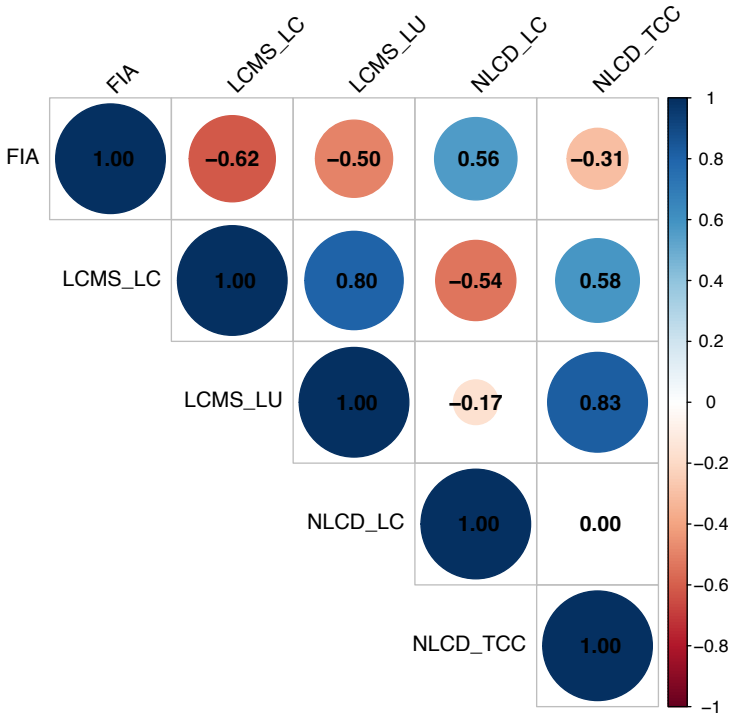


Figure 3. Correlations among the statewide forest cover datasets. SAL_TC dataset not included because of limited data. For dataset details, refer to Table 1.

County-Level Forest Cover

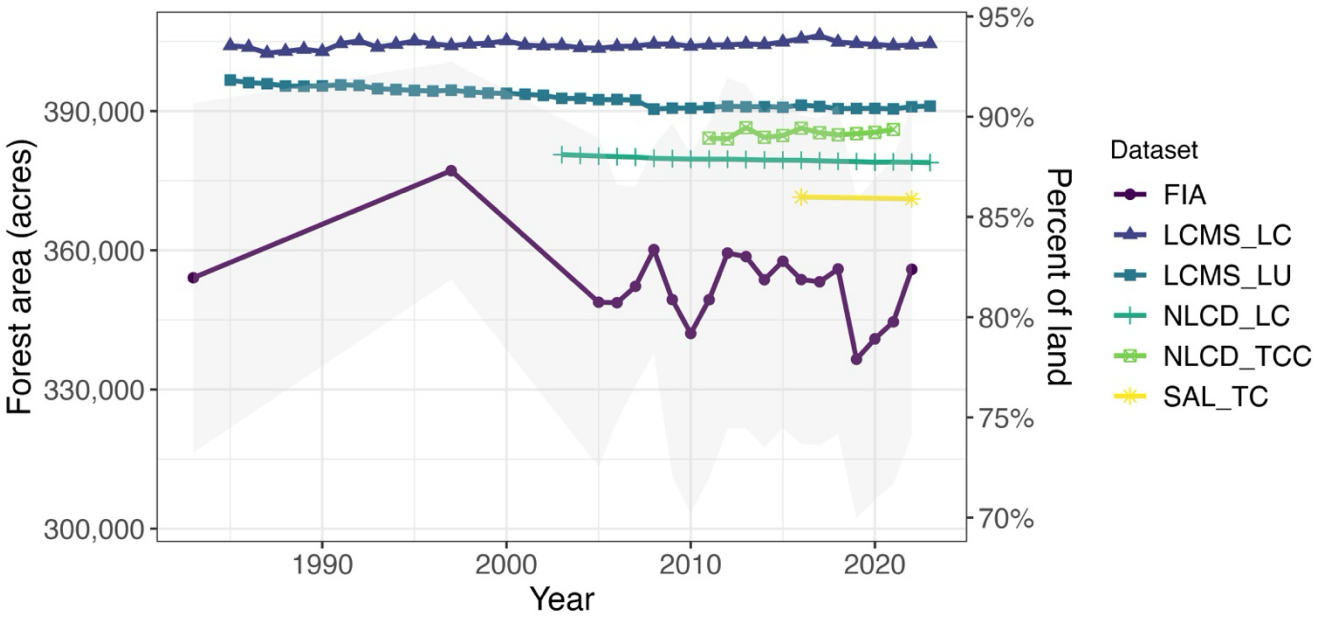
When examining forest cover trends at the county level in Vermont, similar patterns emerge as those observed at the statewide level (Figure 4). In general, the LCMS datasets report the highest forest cover estimates, while the SAL_TC and FIA datasets report the lowest. However, these patterns are not consistent across all counties. For instance, in Essex County, recent FIA estimates are comparable in magnitude to those from the LCMS dataset.

Forest cover varies both by county and by dataset within each county. Essex and Windham Counties consistently show the highest forest cover, while Grand Isle shows the least. Three counties—Bennington, Essex, and Windham—exceed 85% forest cover across all datasets.

Temporal trends also vary widely among datasets for each county, with no consistent patterns across counties (Figure 4, Table 3). Only three counties—Addison, Lamoille, and Windham—show little to no forest loss over time across all datasets. The NLCD_LC dataset indicates stable forest cover for all 14 counties. The SAL_TC dataset, which includes only two years of data (2015 and 2022), suggests recent forest loss in all counties except Chittenden and Grand Isle.

County-level FIA estimates—based on long-term plot data—indicate that Vermont has lost over 6,000 acres of forestland annually to other land uses since 2005. This loss appears to be concentrated in a few counties (Table 3): Orange and Rutland Counties each account for roughly one-third of the total estimated loss, while Windsor and Caledonia Counties each account for about one-sixth.

BENNINGTON



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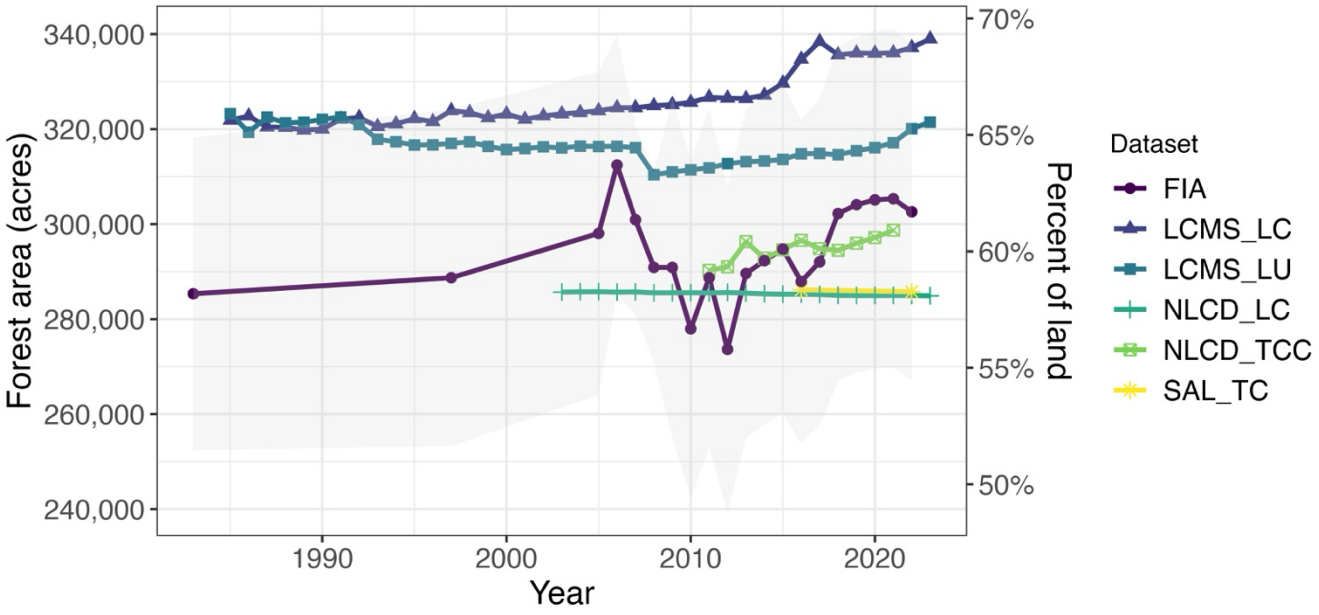

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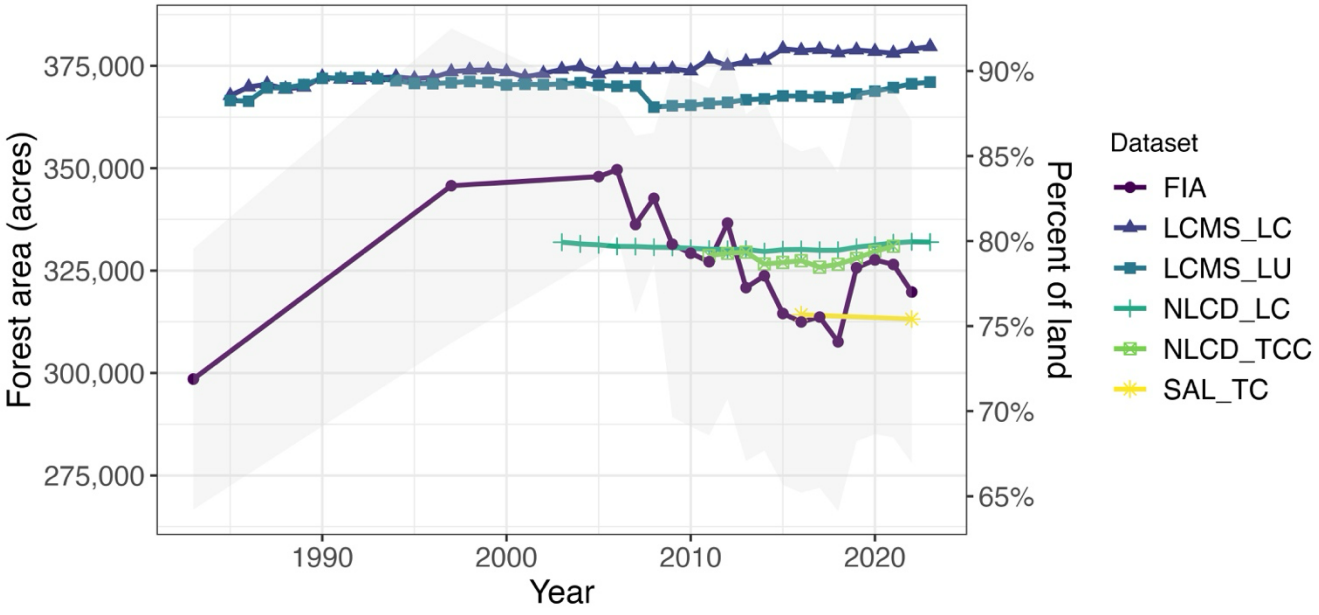

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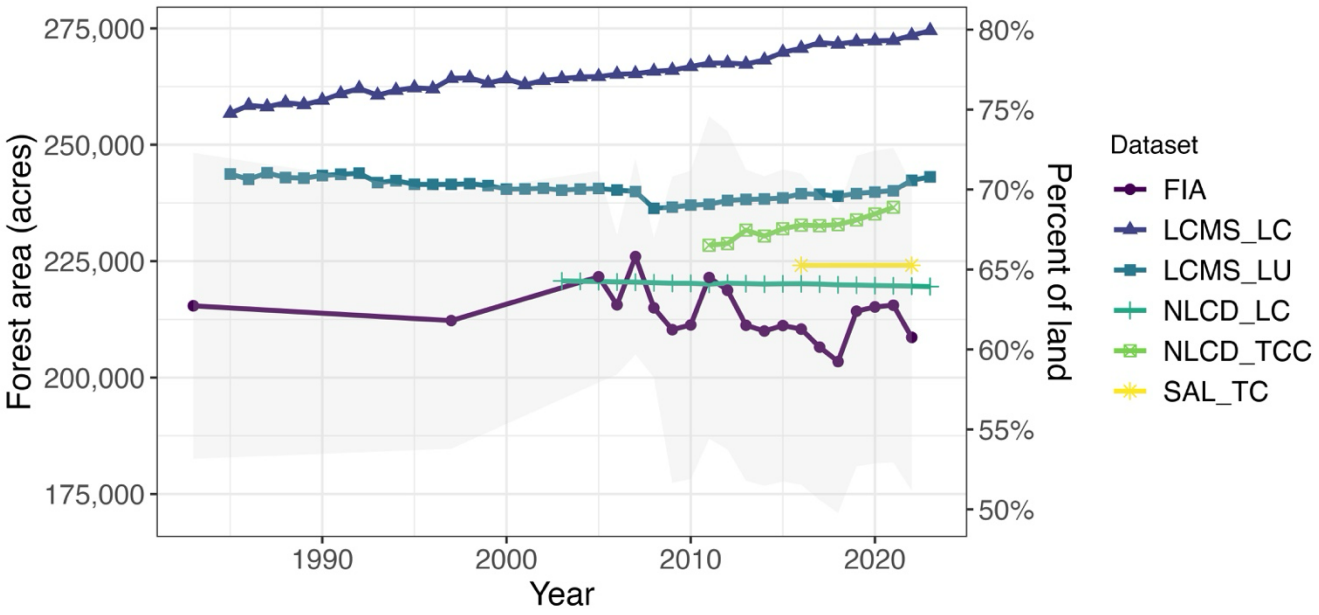

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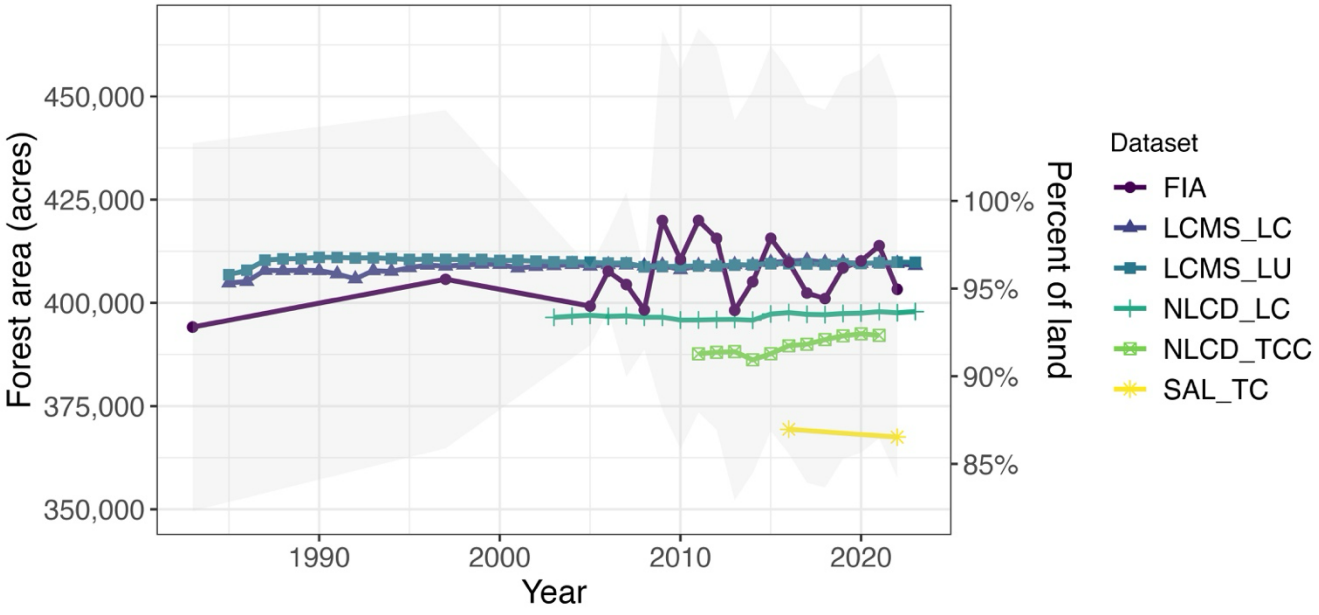

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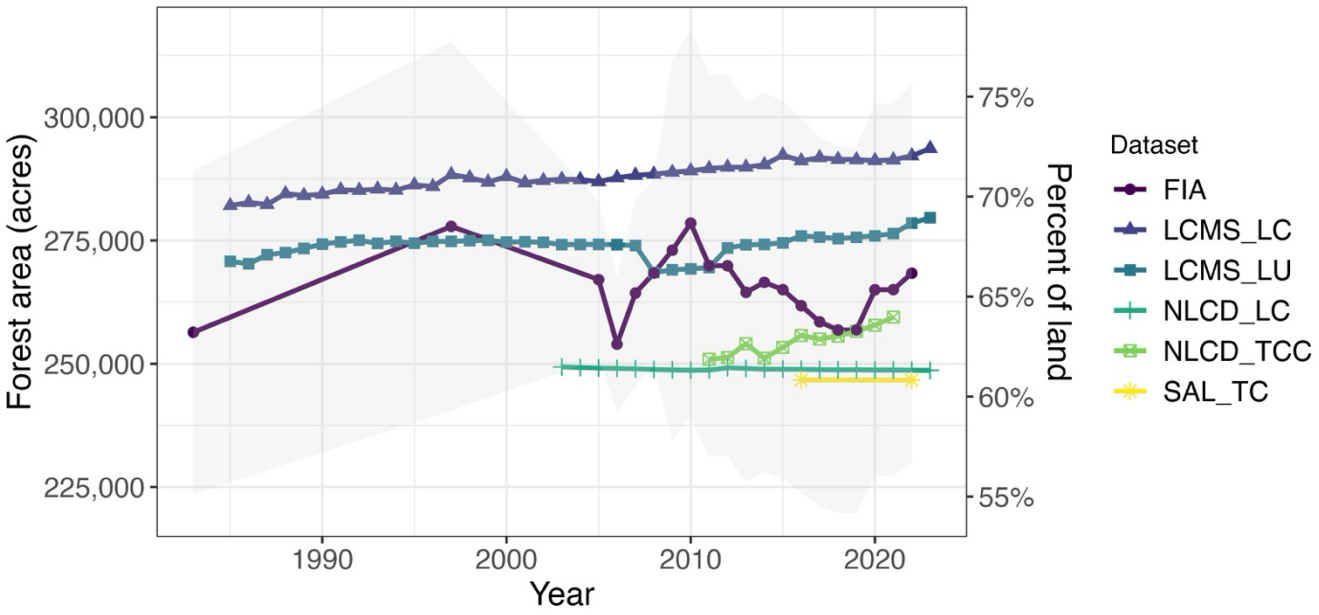

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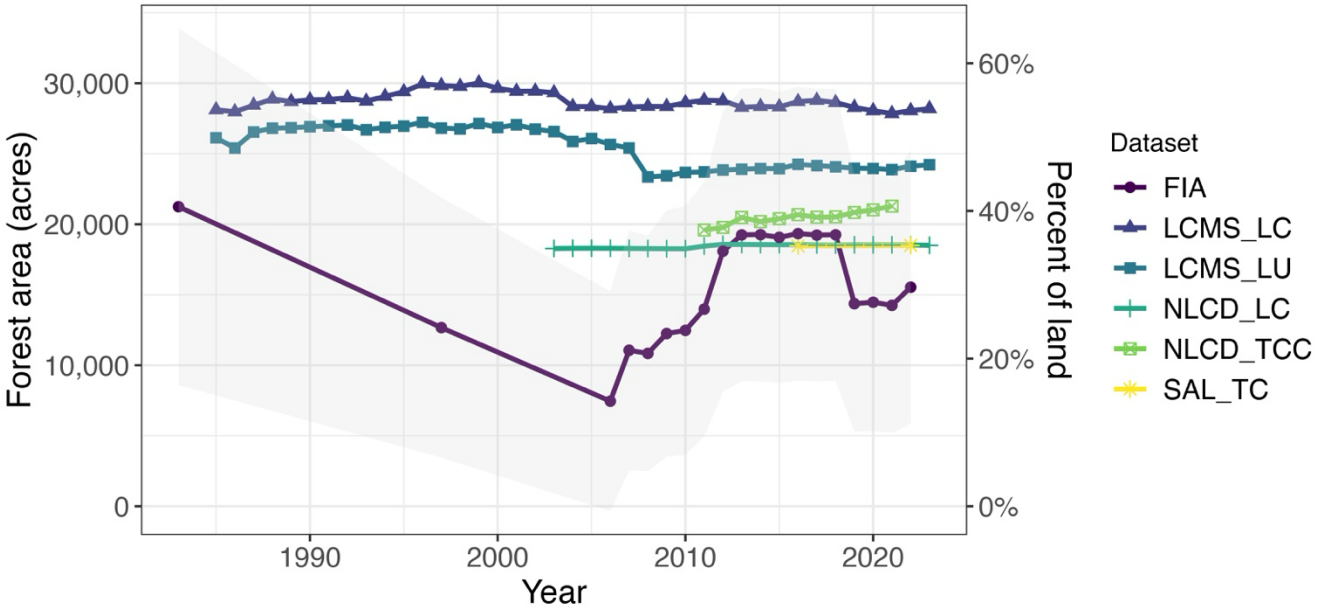
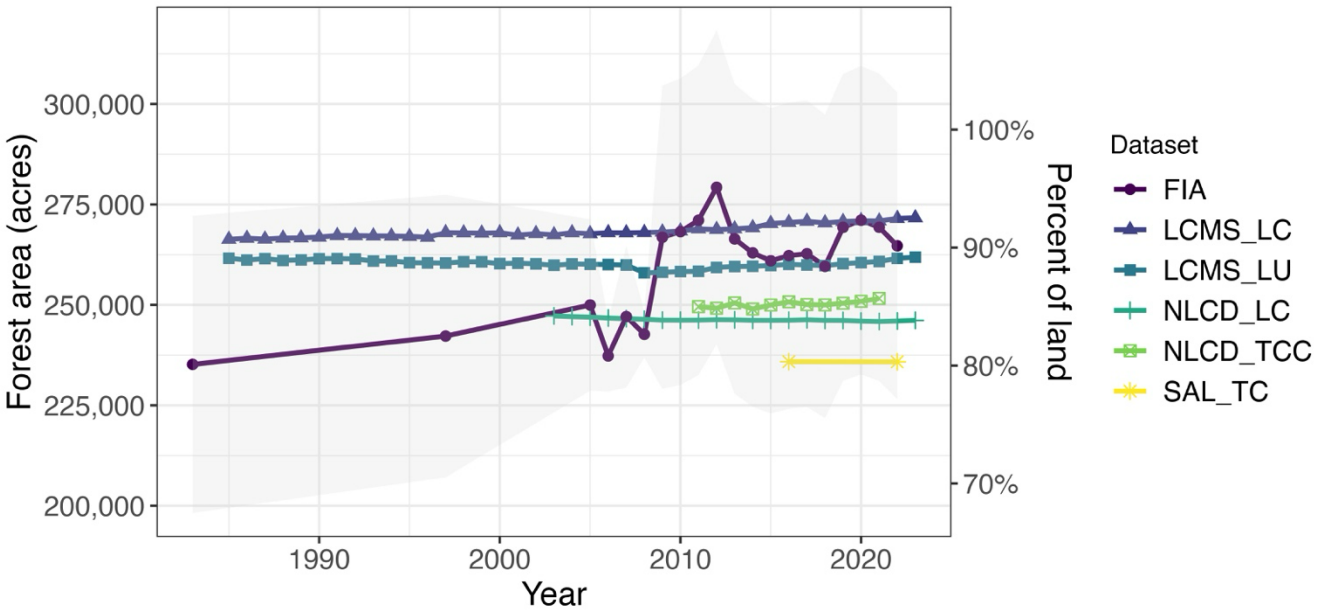
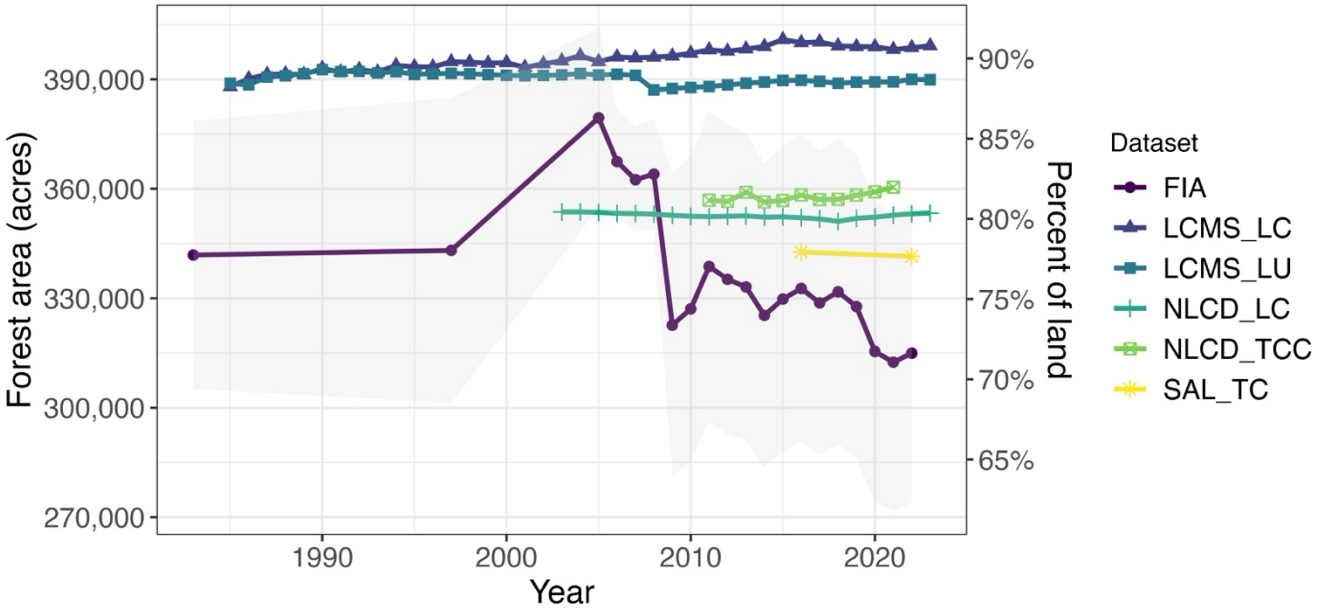


LAMOILLE



ORANGE



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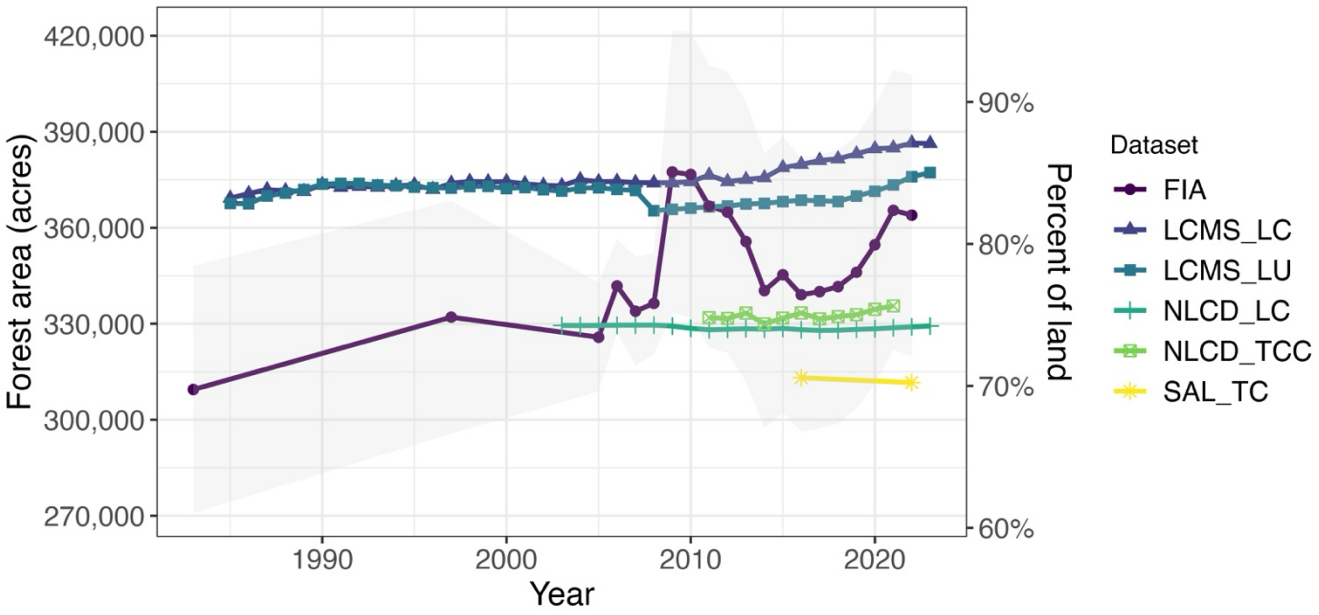

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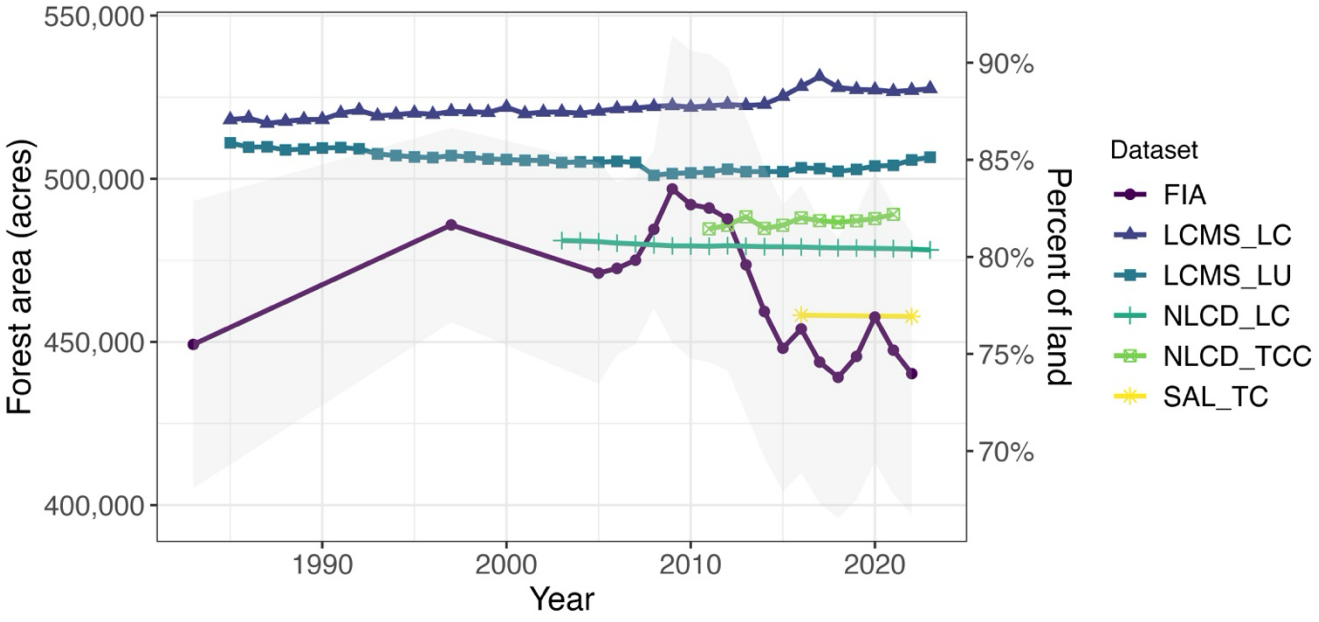
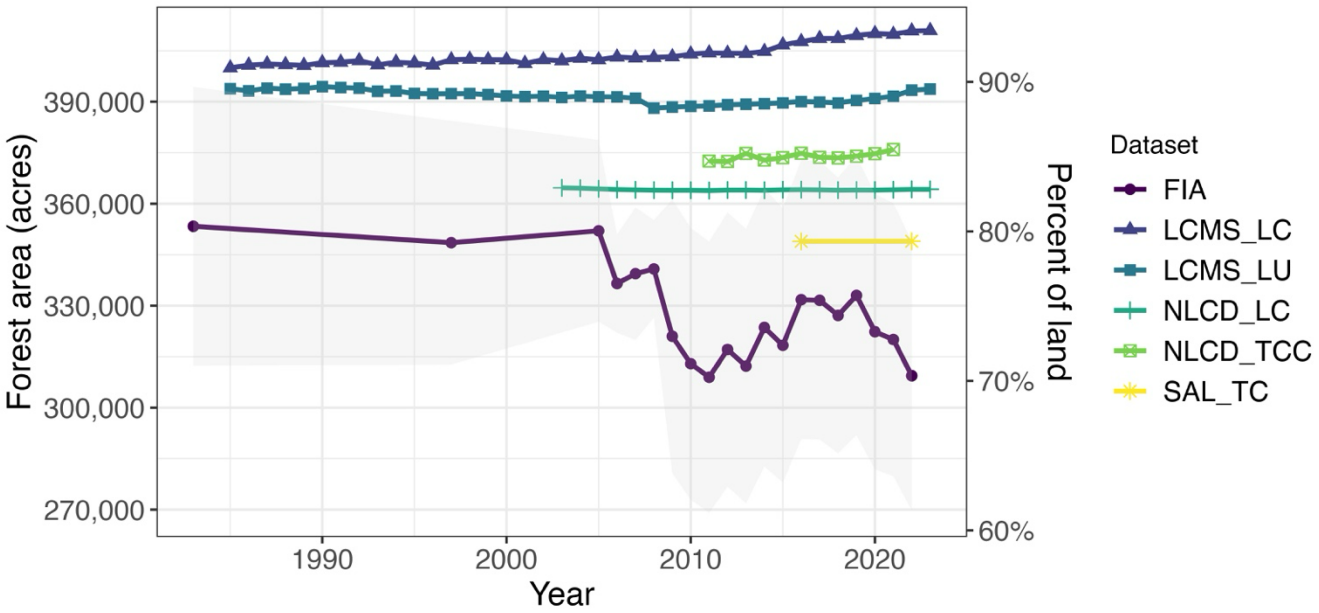


WASHINGTON



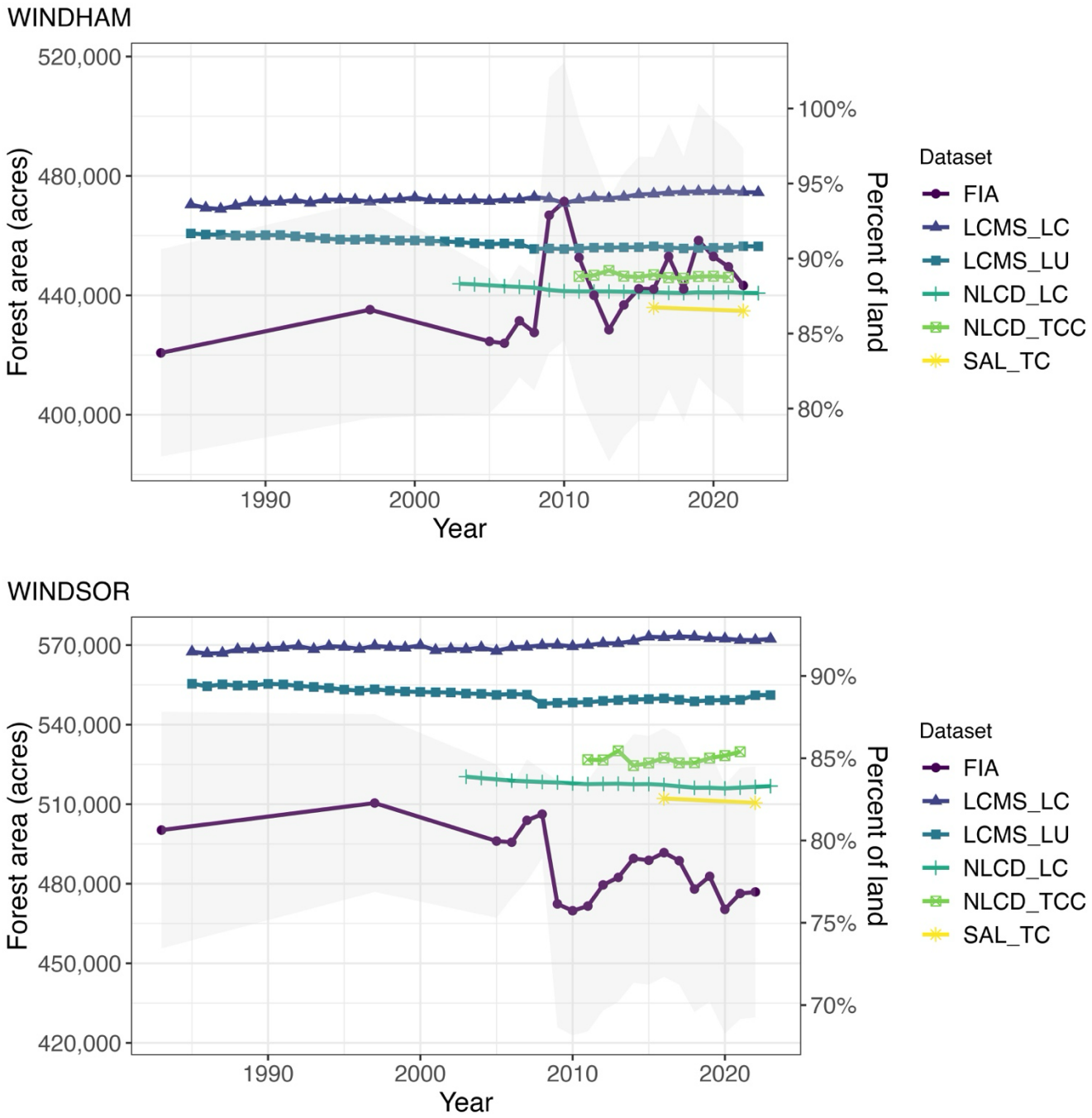


Figure 2. County-level forest cover estimates displayed as total acres (left axis) and as the percentage of the county's total land area (right axis). FIA data includes standard error estimates (67.5% confidence interval, light grey shading).

Table 3. Summary and trends in county-level forest cover estimates by dataset. For dataset abbreviations, refer to Table 1.

County	Dataset	Mean annual change (acres/year)			Forest cover (acres) [percent land area]		
		2005-2022	2010-2022	2015-2022	2005	2015	2022
ADDISON	FIA	447	2,295	2,180	298,056 (60.7%)	294,743 (60%)	302,599 (61.6%)
	LCMS_LC	937	1,115	669	323,877 (66%)	329,675 (67.2%)	337,181 (68.7%)
	LCMS_LU	291	649	887	316,345 (64.5%)	313,624 (63.9%)	320,083 (65.2%)
	NLCD_LC	-50	-56	-42	285,779 (58.2%)	285,248 (58.1%)	284,993 (58.1%)
	NLCD_TCC	N/A	631	527	N/A	294,587 (60%)	298,731[c] (60.9%)
	SAL_TC	N/A	N/A	-66	N/A	286,173[b] (58.3%)	285,777 (58.2%)
BENNINGTON	FIA	-206	-445	-1,358	348,800 (80.7%)	357,641 (82.7%)	355,896 (82.3%)
	LCMS_LC	43	15	-172	403,552 (93.4%)	404,888 (93.7%)	404,258 (93.5%)
	LCMS_LU	-65	-7	-17	392,462 (90.8%)	390,821 (90.4%)	390,931 (90.4%)
	NLCD_LC	-73	-64	-70	380,300 (88%)	379,436 (87.8%)	378,970 (87.7%)
	NLCD_TCC	N/A	115	69	N/A	384,728 (89%)	386,044[c] (89.3%)
	SAL_TC	N/A	N/A	-66	N/A	371,452[b] (85.9%)	371,053 (85.8%)
CALEDONIA	FIA	-1636	-630	1,986	347,948 (83.7%)	314,542 (75.7%)	319,782 (77%)
	LCMS_LC	374	350	30	373,045 (89.8%)	379,152 (91.3%)	379,094 (91.2%)
	LCMS_LU	111	392	475	370,268 (89.1%)	367,649 (88.5%)	370,607 (89.2%)
	NLCD_LC	39	144	297	331,282 (79.7%)	330,110 (79.4%)	332,038 (79.9%)
	NLCD_TCC	N/A	71	668	N/A	326,982 (78.7%)	330,959[c] (79.6%)
	SAL_TC	N/A	N/A	-179	N/A	314,224[b] (75.6%)	313,149 (75.4%)
CHITTENDEN	FIA	-563	-378	532	221,653 (64.5%)	211,178 (61.4%)	208,647 (60.7%)
	LCMS_LC	556	595	475	264,640 (77%)	269,863 (78.5%)	273,472 (79.6%)

	LCMS_LU	163	379	487	240,616 (70%)	238,563 (69.4%)	242,366 (70.5%)
	NLCD_LC	-52	-51	-79	220,628 (64.2%)	220,132 (64.1%)	219,643 (63.9%)
	NLCD_TCC	N/A	711	709	N/A	231,955 (67.5%)	236,566[c] (68.8%)
	SAL_TC	N/A	N/A	2	N/A	224,081[b] (65.2%)	224,091 (65.2%)
ESSEX	FIA	80	-475	-424	399,206 (93.9%)	415,621 (97.8%)	403,284 (94.9%)
	LCMS_LC	50	71	-103	408,895 (96.2%)	409,792 (96.4%)	409,549 (96.4%)
	LCMS_LU	26	73	54	409,842 (96.5%)	409,475 (96.4%)	409,861 (96.5%)
	NLCD_LC	82	177	65	396,987 (93.4%)	397,284 (93.5%)	397,603 (93.6%)
	NLCD_TCC	N/A	582	759	N/A	387,669 (91.2%)	392,142[c] (92.3%)
	SAL_TC	N/A	N/A	-317	N/A	369,371[b] (86.9%)	367,470 (86.5%)
FRANKLIN	FIA	-278	-844	705	267,066 (65.8%)	265,027 (65.3%)	268,350 (66.1%)
	LCMS_LC	295	249	122	286,941 (70.7%)	292,288 (72%)	292,167 (72%)
	LCMS_LU	397	621	503	274,211 (67.6%)	274,518 (67.6%)	278,516 (68.6%)
	NLCD_LC	-17	-18	-30	249,117 (61.4%)	248,896 (61.3%)	248,681 (61.3%)
	NLCD_TCC	N/A	793	863	N/A	253,316 (62.4%)	259,461[c] (63.9%)
	SAL_TC	N/A	N/A	-7	N/A	246,702[b] (60.8%)	246,662 (60.8%)
GRAND ISLE	FIA	403	-51	-826	7,453[a] (14.2%)	19,069 (36.4%)	15,536 (29.6%)
	LCMS_LC	-14	-50	-81	28,341 (54.1%)	28,323 (54%)	28,059 (53.5%)
	LCMS_LU	-52	28	0	26,076 (49.8%)	23,942 (45.7%)	24,115 (46%)
	NLCD_LC	17	7	-3	18,297 (34.9%)	18,548 (35.4%)	18,532 (35.3%)
	NLCD_TCC	N/A	139	132	N/A	20,391 (38.9%)	21,283[c] (40.6%)
	SAL_TC	N/A	N/A	5	N/A	18,469[b] (35.2%)	18,497 (35.3%)
LAMOILLE	FIA	1166	-324	1,145	249,972 (85.1%)	260,967 (88.8%)	264,712 (90.1%)

	LCMS_LC	235	249	155	267,710 (91.1%)	270,257 (92%)	271,510 (92.4%)
	LCMS_LU	127	231	255	260,113 (88.5%)	259,789 (88.4%)	261,587 (89%)
	NLCD_LC	-38	-20	-26	246,945 (84.1%)	246,143 (83.8%)	245,977 (83.7%)
	NLCD_TCC	N/A	174	195	N/A	249,968 (85.1%)	251,597[c] (85.6%)
	SAL_TC	N/A	N/A	-8	N/A	235,848[b] (80.3%)	235,802 (80.3%)
ORANGE	FIA	-2,986	-1,580	-2,964	379,453 (86.2%)	329,776 (75%)	314,944 (71.6%)
	LCMS_LC	225	81	-256	394,839 (89.7%)	400,905 (91.1%)	398,682 (90.6%)
	LCMS_LU	-4	123	27	391,193 (88.9%)	389,698 (88.6%)	389,992 (88.6%)
	NLCD_LC	-41	31	175	353,506 (80.3%)	352,327 (80.1%)	353,144 (80.3%)
	NLCD_TCC	N/A	250	491	N/A	356,797 (81.1%)	360,422[c] (81.9%)
	SAL_TC	N/A	N/A	-197	N/A	342,661[b] (77.9%)	341,480 (77.6%)
ORLEANS	FIA	607	-852	3,698	325,800 (73.4%)	345,320 (77.8%)	363,936 (82%)
	LCMS_LC	781	1,041	1,019	374,404 (84.3%)	378,813 (85.3%)	386,501 (87.1%)
	LCMS_LU	284	761	1,187	372,493 (83.9%)	368,187 (82.9%)	375,954 (84.7%)
	NLCD_LC	-47	45	126	329,460 (74.2%)	328,563 (74%)	329,024 (74.1%)
	NLCD_TCC	N/A	296	538	N/A	331,762 (74.7%)	335,600[c] (75.6%)
	SAL_TC	N/A	N/A	-253	N/A	313,120[b] (70.5%)	311,605 (70.2%)
RUTLAND	FIA	-2,819	-4,275	-467	471,112 (79.1%)	448,060 (75.2%)	440,288 (73.9%)
	LCMS_LC	462	504	-68	520,736 (87.5%)	525,277 (88.2%)	527,111 (88.5%)
	LCMS_LU	69	283	473	505,100 (84.8%)	502,196 (84.3%)	505,778 (84.9%)
	NLCD_LC	-109	-92	-109	480,709 (80.7%)	479,141 (80.5%)	478,463 (80.4%)
	NLCD_TCC	N/A	289	340	N/A	485,754 (81.6%)	489,090[c] (82.1%)
	SAL_TC	N/A	N/A	-62	N/A	458,150[b] (76.9%)	457,777 (76.9%)

WASHINGTON	FIA	-995	758	-1,705	352,018 (80%)	318,353 (72.3%)	309,393 (70.3%)
	LCMS_LC	529	620	503	402,338 (91.4%)	406,720 (92.4%)	410,820 (93.4%)
	LCMS_LU	136	343	517	391,426 (88.9%)	389,670 (88.5%)	393,392 (89.4%)
	NLCD_LC	1	17	13	364,378 (82.8%)	364,094 (82.7%)	364,215 (82.8%)
	NLCD_TCC	N/A	230	256	N/A	373,565 (84.9%)	375,926[c] (85.4%)
	SAL_TC	N/A	N/A	5	N/A	348,901[b] (79.3%)	348,929 (79.3%)
WINDHAM	FIA	962	-115	732	424,583 (84.4%)	442,222 (87.9%)	443,301 (88.2%)
	LCMS_LC	202	267	88	471,586 (93.8%)	473,820 (94.2%)	474,560 (94.4%)
	LCMS_LU	-30	36	22	457,099 (90.9%)	456,113 (90.7%)	456,454 (90.8%)
	NLCD_LC	-128	-47	-26	443,376 (88.2%)	441,108 (87.7%)	440,805 (87.7%)
	NLCD_TCC	N/A	-95	-29	N/A	446,108 (88.7%)	446,033[c] (88.7%)
	SAL_TC	N/A	N/A	-194	N/A	435,909[b] (86.7%)	434,746 (86.5%)
WINDSOR	FIA	-1,024	41	-2,510	496,100 (79.9%)	488,848 (78.7%)	476,898 (76.8%)
	LCMS_LC	243	189	-165	567,805 (91.5%)	573,116 (92.3%)	571,828 (92.1%)
	LCMS_LU	3	144	171	551,226 (88.8%)	549,622 (88.5%)	551,092 (88.8%)
	NLCD_LC	-164	-135	-109	519,365 (83.7%)	517,568 (83.4%)	516,518 (83.2%)
	NLCD_TCC	N/A	140	582	N/A	525,503 (84.7%)	529,772[c] (85.3%)
	SAL_TC	N/A	N/A	-272	N/A	512,120[b] (82.5%)	510,487 (82.2%)

[a] FIA estimates for Grand Isle are for 2006
[b] SAL_TC estimates for 2016
[c] NLCD_TCC estimates for 2021

Discussion

Unfortunately, the various forest cover datasets provide conflicting estimates of forest extent over time. Among the six datasets analyzed, statewide forest cover estimates for 2022 ranged widely—from a low of 4,467,532 acres (75.7% of Vermont's land area) in the SAL_TC dataset to a high of 5,169,567 acres (87.6%) in the LCMS_LC dataset. This variation makes it difficult to answer basic but important questions about how much of Vermont is forested and how forest cover has changed over time.

The datasets also failed to clearly identify when Vermont shifted from decades of net forest gain to net forest loss. In fact, several datasets still suggest that forest cover is increasing—a trend that seems inconsistent with known development patterns and land use pressures.

Where do we go from here? A better understanding of the accuracy of these datasets is needed. For remotely sensed products, it is possible to improve accuracy by ground-truthing individual pixels. However, this is not feasible for the FIA dataset, which is based on plot sampling rather than wall-to-wall mapping. Without ground validation, it is difficult to determine which dataset provides the most reliable estimate.

The FIA dataset does include estimates of standard error (67.5% confidence interval). The only dataset to have forest cover estimates consistently within this confidence interval statewide and for all counties (aside from Orleans in 2022), is the SAL_TC dataset. However, this dataset is limited by its low temporal resolution of only two collection years. One benefit of the FIA data is that only true land cover change is assessed a forest cover change as on-the-ground technicians assess the cause of canopy loss. Remote sensing datasets often incorrectly categorize logging as land use change (Potapov et al. 2022).

Preliminary indications suggest that the LCMS datasets may be overestimating forest cover. Given current rates of land development, it seems unlikely that Vermont is experiencing a net gain in forest area. Conversely, the SAL dataset, with its 0.5-meter resolution, likely offers a more precise delineation of forest edges. However, its utility is constrained by having only two years of data and by the high computational demands of processing such detailed imagery at the statewide scale.

FIA estimates are more accessible and easier to use, but their coarse spatial and temporal resolution limits their usefulness for localized decision-making. Ideally, Vermont would benefit from an easy-to-use, map-based platform that visualizes forest cover change over time, with the ability to query data by county or town. Such a tool would support municipalities and regional planners in understanding and responding to forest loss at meaningful scales.

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