Correct County Areas
with Sidebars for Virginia

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Abstract: *Historically, Forest Inventory and Analysis (FIA) has processed field inventory data at the county level and county estimates of land area were constrained to equal those reported by the Census Bureau. Currently, the Southern Research Station FIA unit processes field inventory data at the survey unit level (groups of counties with similar ecological characteristics). In short, the estimation unit has changed from an individual county to groups of counties. However, changing the estimation unit to a survey unit does not constrain the total area of each county when expansion factors are used. Here we provide a method to constrain published FIA estimates of total area at the county level to equal those of the Census Bureau. To accomplish this, we derive an expansion factor formula. Virginia serves as a case example of the techniques because of its unique geo-political boundaries.*

Keywords: *FIA, forest inventory, area control, sub-population, expansion factor*

Introduction

Forest Inventory and Analysis (FIA) is a national program of the USDA Forest Service charged with conducting and maintaining comprehensive forest resource inventories on both public and private lands in the United States. FIA inventories are design-based to provide strategic and extensive information on the quantity, status, and use of the forest resource. The sampling frame is based on a tessellation of the United States into approximate 6,000-acre hexagons derived from a larger hexagon grid developed for the Environmental Monitoring and Assessment Program (EMAP) methodology (White *et al.* 1992). Each hexagon contains one plot for the base national program. The hexagonal array is comprised of non-overlapping, interpenetrating panels.

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FIA estimates are based on a three-phase sampling scheme. The primary objective of Phase 1 is to use remote sensing to stratify land areas to increase the precision of forest resource estimates. The Phase 1 stratification assigns each Phase 2 plot to a stratum and identifies, or estimates, the area of the stratum within the estimation unit. The primary objective of Phase 2 is to obtain field observations and measurements of the traditional FIA suite of forest resource variables. Phase 3 is a subsample of the Phase 2 plots (1 in 16) on which additional forest health attributes are measured.

Bechtold and Patterson (2005) provide the compilation procedures for the national FIA program. Estimates of forest attributes are made for each population or estimation unit using these procedures. An estimation unit is typically defined as either a county or an FIA multi-county survey unit of known area (determined by the Census Bureau). The estimation procedures do not require plot level expansion factors. However, for public distribution of the FIA database (FIADB) expansion factors are used so that users can match estimates from National Information Management Systems Compilation System (NIMSCS) at the estimation unit level using the expansion factors. In addition, the expansion factors can be used to make population estimates for arbitrarily shaped areas such as wood procurement regions surrounding mills. However, when expansion factors are developed at the FIA survey unit level (groups of counties), there is no area control at finer spatial resolution than the survey unit. Therefore county-level area totals based on expansion factors will not equal the area of the county reported by the Census Bureau.

As noted above, total area estimates provided by the Census Bureau are used for area control. In Virginia, there are independent cities in no county at all (Figure 1), but reported by the Census Bureau as county-equivalents. While the Census Bureau does provide area estimates for each independent city, about 1/3 of Virginia's untabulated cities have no FIA plot at all, and thus no mechanism for area control (expansion factors).
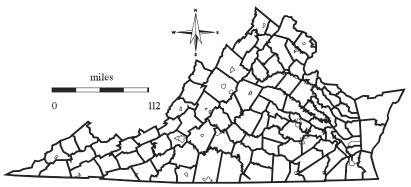

Figure 1: Virginia map showing independent cities

Since 1966, FIA has assigned each of Virginia's cities to one or more counties, as shown in Figure 1. The Tidewater cities of Chesapeake, Hampton, Newport News, Suffolk, and Virginia Beach are reported as counties. Each of those cities is reported as a county-equivalent, because they were once counties. Newport News was Warwick County, Hampton was Elizabeth City County, Virginia Beach was Princess Anne County, Chesapeake was Norfolk County, and Suffolk was Nansemond County.

The objectives of this study are 1) to document rules used by FIA for assigning independent cities to the appropriate county in Virginia and 2) to extend the formula for calculating expansion factors to address situations where the population and estimation unit are defined by FIA survey units but the subpopulation of interest has a known area that a client wants to use for area control.

Methods

Independent Cities

As noted previously, independent cities are separated from counties in Virginia. FIA combined the independent cities with certain counties, but did not outline rules for doing so. What follows are a set of formal rules.

a) A city should be tabulated with its county of origin at the time it became an independent city.
b) If a city is created from multiple counties, the historical county lines should be used.
c) If a city consolidates with a county or another city, the new jurisdiction shall inherit the lineage of the old jurisdiction. Consequently, if a city's county of origin no longer exists, the city may be tabulated under its own name.
d) With all other acquisitions short of consolidation, the new jurisdiction does not inherit lineage.

Rule (a) covers most cases. Rule (b) covers Galax and Petersburg. Rule (c) covers Richmond (tabulated with Henrico and Chesterfield Counties), and the Tidewater cities. Rule (d) covers a number of other cases. These rules capture what FIA has actually done, with two exceptions – Petersburg and Alexandria.

FIA split Petersburg between Dinwiddie and Prince George Counties. McCollum and Jacobs (2002) surmised the historical line dividing Dinwiddie and Prince George Counties to be a line northward from the point of intersection of Dinwiddie, Prince George, and the city of Petersburg. The Laws of Virginia, Chapters 19 and 31, 1752, (Hening 1823) show that this interpretation was correct south of Lieutenant Run, but otherwise the county line followed that creek, and also that Pocahontas Island was part of Chesterfield County.

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The other exception is Alexandria. Alexandria County was ceded to the District of Columbia in 1791 to form the capital city of the United States, a diamond shape that was ten miles square. The District took exclusive jurisdiction by 1801. In 1846, it was retroceded to Virginia. For the Census of 1900, the Census Office tabulated the city of Alexandria separately from Alexandria County. In 1920, Alexandria County renamed itself Arlington County. Since 1915, the city of Alexandria has spread into what was Fairfax County (DenBoer and Sinko 2005; Minnesota Population Center 2004). Since the city of Alexandria was created from Arlington County, it should be tabulated entirely with Arlington County.

Expansion Factors

The techniques used to estimate population totals do not require the use of expansion factors. In fact, Bechtold and Patterson (2005) discourage the use of expansion factors. However, expansion factors are included in the public version of the FIADB. There are two motivating factors for including expansion factors: 1) external clients can easily produce population estimates that match estimates based on stratified estimation when the estimation unit is the same (i.e. survey unit) and 2) external clients can also produce estimates for user defined subpopulations (e.g. wood procurement regions). Based on supplemental material to Bechtold and Patterson (2005) expansion factors for each stratum within an estimation unit are calculated using [1].

$$F_h = \frac{A_T W_h}{n_h}$$ [1]

where

F_h is the expansion factor for stratum h
A_T is the total area of the population (survey unit),
W_h is the weight of stratum h, and
n_h is the number of plots in stratum h.

For any subpopulation of known area within the population, the expansion factor can be defined by:

$$F_{hc} = f F_h$$ [2]

where

$$f = \frac{A_C}{\sum_{i=1}^{n} \sum_{h=1}^{H} \delta_i(c) F_h}$$ [3]

A_C is the area of the subpopulation (e.g. county),

n is the total number of plots in the population (survey unit),

H is the total number of strata,

$\delta_i(c)$ is an indicator function equal to 1 if plot i is in subpopulation C,
         0 otherwise, and all other notation is as above.

In general, f will not be equal to 1 for every county in the unit. However, on average, f will be 1. Therefore, if a survey unit consists of C counties, numbered $c = 1$ to C, then:

$$\sum_{c=1}^{C}\sum_{i=1}^{n}\sum_{h=1}^{H}\delta_i(c)\frac{A_T W_h}{n_h} = \sum_{c=1}^{C}A_c = A_T \qquad [4]$$

Case Study

We use Virginia as a case study to document how FIA combines independent cities into counties and FIA survey units. We then demonstrate how external clients can recalculate expansion factors to produce estimates for individual counties within the estimation unit (FIA survey unit in this case). The purpose of the exercise is to produce county-level estimates where the total area of the subpopulation is constrained to equal the total area of the county reported by the Census Bureau (including independent cities).

Results

Independent cities were merged into their respective counties using the decision rules presented in this paper. However because the rules for combining independent cities with counties have not been consistent overtime and the boundaries of independent cities have changed over time, the total land area for some individual counties (e.g. Arlington County) has changed (Table 1). In the Knight and McClure report (1966), the city of Alexandria was split between Arlington and Fairfax Counties, apparently along the "D.C. Diamond" line. In subsequent reports, Arlington County meant Arlington County proper. Decade by decade, estimates of land area changed to mirror the Census Bureau's. In 2005, FIA changed its methodology from using the county as area control to using the survey unit as area control.

Table 1: Estimates of land in Arlington County (FIA)

Year	Acres	Source
1966	20500	Knight and McClure 1966
1976	16640	Sheffield 1976
1986	16614	Brown 1986
1992	16614	Johnson 1992
2001	16557	Miles 2001
2005	15218	FIDO[a]
2006	17504	FIDO
2007	16943	FIDO

By definition the total area of the survey unit calculated from expansion factors using equation [1] equals the total area of the survey unit calculated from expansion factors using equation [2]. County level estimates of total area differ slightly (table 2). Data is taken from the FIA Datamart, available at *http://fiatools.fs.fed.us/fiadb-downloads/datamart.html*. For example, the total area of Accomack County was 902,292 acres based on using expansion factors from equation [1] and was 838,426 acres based on expansion factors from equation [2]. The main point here is that when using the expansion factors from equation [2], the total area estimate matches the total area from the Census Bureau for each county. Forest area estimates will also differ slightly. In absolute terms, the largest difference in forest area estimates was observed in Southampton County and the smallest difference was observed in Newport News.

Table 2: Estimates for accessible forest land and all land for each county in survey unit 1

County	Equation 1		Equation 2	
	Forest	Total Area	Forest	Total Area
		acres		
Accomack	107,858	902,292	95,926	838,426
Brunswick	269,650	366,187	266,808	364,396
Caroline	244,851	334,892	249,181	344,886
Charles City	91,566	136,533	83,158	130,698
Chesterfield	164,719	312,681	163,029	307,407
Dinwiddie	223,947	304,611	241,397	330,595
Essex	79,743	163,477	84,258	182,980
Gloucester	88,706	192,481	90,768	184,318
Greensville	122,214	166,137	142,338	194,413
Hanover	182,262	280,199	197,689	303,411
Henrico	57,868	179,261	54,572	173,913
Isle of Wight	106,279	222,418	99,897	232,166
James City	63,159	124,641	55,687	120,565
King and Queen	136,543	200,117	142,287	208,849
King George	73,695	108,444	82,773	120,186
King William	103,273	176,187	107,823	182,818
Lancaster	44,413	134,452	38,731	148,062
Mathews	24,654	175,815	29,571	161,257
Middlesex	52,581	132,173	44,922	134,882
New Kent	83,349	118,952	97,137	143,027
Northampton	25,673	574,274	20,540	509,017
Northumberland	57,096	192,872	56,894	182,825
Prince George	106,301	191,113	107,838	195,923
Richmond	78,181	149,916	74,917	138,481
Southampton	239,535	359,385	264,726	390,880
Surry	142,175	193,540	148,079	198,595
Sussex	258,098	319,428	253,765	315,411
Westmoreland	87,960	154,375	88,944	161,689
York	46,548	205,838	42,130	188,124
Chesapeake	93,003	310,663	96,909	316,047
Hampton	1,168	88,799	866	87,187
Newport News	5,879	74,395	5,710	76,192
Suffolk	175,330	272,116	179,207	274,603
Virginia Beach	35,856	341,854	31,881	318,287
Total	3,674,133	8,160,518	3,740,358	8,160,516

Discussion

Southern Research Station FIA produces FIA survey unit population estimates and does not produce county-level population estimates. However, several clients are interested in or require county-level estimates. When county-level estimates are required we suggest that clients recalculate the expansion factors so that there is area control at the county-level. Here we provide a method for adjusting expansion factors for this purpose.

Virginia provides a particular challenge for using Census Bureau estimates of total area for area control. The independent city boundaries can change over time and therefore it is important to have a set of decision rules in place for allocating the area of each independent city to the correct county. Admittedly, this is less of an issue when an FIA survey unit is used as the estimation unit. This is because independent cities are more likely to straddle multiple counties than they are to straddle multiple FIA survey units.

Here we present a technique to recalculate expansion factors that results in area control at the county level. This technique adjusts the expansion factor by dividing a known area (A_C in equation 2) by the calculated area based on expansion factors. The same technique can be used for wood procurement regions. These areas are generally used to determine wood volume estimates within some distance of, for example, a plywood mill. The total area of the region is therefore known and equation 2 can be used, provided that the procurement region is contained within one survey unit.

Our objectives were to document rules used by FIA for assigning independent cities to the appropriate county in Virginia and extend the formula for calculating expansion factors to address situations where a client requires subpopulation estimates with area control. We recommend that the formal rules described here be used by FIA for allocating the area of independent cities to the appropriate county. We also recommend that external clients who require sub-population estimates consider adjusting the expansion factors so that area control can be achieved at the sub-population level.

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