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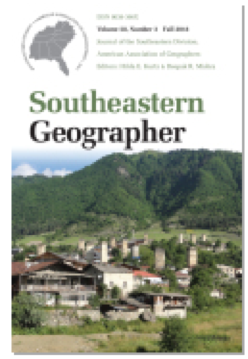

Georgianna Strode, Victor Mesev, Juliana Maantay

Southeastern Geographer, Volume 58, Number 3, Fall 2018, pp. 300-316 (Article)

Published by The University of North Carolina Press
DOI: https://doi.org/10.1353/sgo.2018.0030

Improving Dasymetric Population Estimates for Land Parcels: Data Pre-processing Steps

GEORGIANNA STRODE
Florida State University

VICTOR MESEV
Florida State University

JULIANA MAANTAY
Lehman College, City University of New York

The Cadastral-based Expert Dasymetric System (CEDS) is an established and effective areal interpolation technique for mapping populations by disaggregating census data from coarse collection units to smaller property parcels. Frequently, the boundaries of census units (whether tract, block group or block level in the United States) and the boundaries of parcels do not geometrically align completely, resulting in populations being erroneously assigned to neighboring parcels. In addition, property cadasters typically do not contain information on group living—nursing homes, college dormitories, correctional institutions, military quarters, and shelters—resulting in undercounting. As the two shortcomings are inter-related, we propose a pre-processing stage prior to implementing CEDS. The stage involves corrections for incongruent spatial geometries and cross-tabulation of census Group Quarter data with property cadastral parcels to improve estimations of group living. We test and demonstrate the merits of our research using data representing the campus of Florida State University in Tallahassee, Florida as an example of group living with college dormitories.

El sistema Experto Dasymetric basado en el catastro (CEDS) es una técnica de interpolación aérea establecida y eficaz para mapear poblaciones mediante la desagregación de datos del censo de unidades de recolección gruesa a parcelas de propiedad más pequeñas. A menudo, los límites de las unidades del censo (ya sea tracto, bloque de grupo o nivel de bloque en los EE.UU.) y los límites de las parcelas no se alinean geométricamente, lo que hace que las poblaciones se asignen erróneamente a las parcelas vecinas. A veces los catastros de propiedades no contienen información sobre la vida en grupo, como residencias de ancianos, dormitorios universitarios, instituciones correccionales, cuarteles militares y albergues, lo cual resulta en un conteo insuficiente. Como las dos deficiencias están interrelacionadas, proponemos un paso previo al procesamiento antes de implementar CEDS. Esta etapa incluye correcciones para geometrías espaciales incongruentes y tabulación cruzada de datos del trimestre del Grupo censales con parcelas catastrales de propiedades para mejorar las estimaciones de la vida en grupo. Probamos y demostramos los méritos de nuestra investigación usando datos que representan el campus de la Universidad Estatal de Florida en Tallahassee, Florida, como un ejemplo de vida grupal con dormitorios universitarios.

KEYWORDS: Aerial interpolation, Cadasters, Population census, Property parcel

PALABRAS CLAVES: Interpolación aéreo; cadastros; censo de población; parcela de propiedad

INTRODUCTION

Population estimates are important for formulating policies on socio-economic welfare, calculating access to health care, identifying crime hotspots, optimizing emergency service routing, and assessing the risks of exposure to environmental hazards and natural disasters (*inter alia.* Lirer, Petrosino, and Alberico 2010; Brantley et al. 2012; Freire and Aubrecht 2012; Freire, Aubrecht, and Wegschedier 2013). National censuses are the most commonly used source for estimating population because they are widely available, relatively inexpensive, and temporally approximate. Their major drawback is spatial aggregation: an unavoidable situation in which census returns from individual households are grouped into a single areal unit (such as a census tract) labeled with a single value that protects individual confidentiality, yet invariably conceals spatial patterns (Mennis 2003; Holt, Lo, and Hodler 2004; Langford 2012).

In addressing aggregated census units, the most common technique for estimating the underlying geography of residential patterns more precisely is to incorporate ancillary data alongside information from the census within dasymetric methodologies. Many types of ancillary data can be accessed, including aerial photographs, satellite sensor images (both daytime buildings and night lights), LiDAR, topographic land use maps, emergency response databases, street networks, electrical hookup databases, and soil impact information (*alia.* Reibel and Bufalino 2005; Deng, Wu, and Wang 2010; Dong, Ramesh, and Nepali 2010; Townsend and Bruce 2010; Azar et al., 2013; Lung et al., 2013). Another source is property parcel cadastral data, where each parcel records the physical dimensions of buildings, and is labeled with geographic information, such as type of land use, the number of residences, and the size of the living area, in addition to property and fiscal records. In the United States (US), the Federal Geographic Data Committee (FGDC) supports and presides over the standards and practices of property parcel registers (Stage and von Meyer 2006; von Meyer and Jones 2013).

The Cadastral-based Expert Dasymetric System (CEDS) is an example of an areal interpolation technique that uses ancillary data, such as property cadasters. It generates estimates of populations by disaggregating census data from relatively coarser collection units to smaller property parcel tessellations. Some examples of the applications of CEDS include environmental justice and health concerns, vulnerable populations within flood zones (Maantay, Maroko, and Herrmann 2007; Maantay and Maroko, 2009), asthma and air pollution (Maantay 2007), exposure to sea level rises (Mitsova, Esnard, and Li 2012), mapping developed land in rural areas (Leyk et al. 2014), and proximity to environmental health hazards (Chakraborty, Maantay, and Brender 2011). While CEDS performs well in cases in which input data are well formatted, it generates erroneous results when data are less complete and ambiguous. There are two distinct situations in which improper data can cause the technique to produce flawed results. One relates to spatial geometry, where the dimensions of land parcels and census boundaries do not geometrically align completely, and the other concerns group living, where cadastral databases frequently omit data on the numbers of people residing in non-traditional, multi-living properties such as nursing homes, correctional facilities, college dormitories, military units, and shelters.

Our solution is to introduce a data processing stage prior to implementing CEDS that address both spatial incongruency, and the lack of data on group living. In terms of spatial incongruency, we use geographically-weighted centroids to link census data with property parcels. Our particular focus is on linking centroids from the smallest unit of US census data, the block level, with FGDC property parcel data. This allows us to combine population data (including information on group living) from the census block with cadastral data (land use types) from the property parcels. The centroids establish consistent benchmarks as the relative areal sizes of block levels and property parcels vary interchangeably. In terms of estimating group living, the 2010 US Census reported approximately eight million people, or 2.6 percent of the population as living in non-traditional group living (or group quarters as used in the US Census). Around half resided in institutionalized quarters, defined as providing formally supervised custody of inmates in correctional institutions or care to patients, such as nursing homes. The other half resided in non-institutionalized quarters that include student housing and military barracks (Voss and Marton 2012).

Admittedly, group quarters comprise a small percentage of the US population, and their omission may not be considered significant. However, undercounting is not uniform across the US and some states have higher proportions. Leon County in northern Florida, for instance, has twice the national average living in group quarters: 14,000 of the county's 275,000 population (based on 2017 estimates). Geographic scale plays an important role in assessing the impact of group quarter data. Large geographic units can mask data patterns by averaging high and low values. Smaller geographic areas are more likely to expose data trends as high and low values have less opportunity to become obscured. Hence, group quarter data will have a greater impact in smaller geographic units such as census tracts or zip codes. Our case study in this research is a college campus that is fully comprised of group quarter living, and our population estimation results are greatly improved with the inclusion of group quarter data in a small geographic area.

We can illustrate the spatial extent of group living across the State of Florida (Figure 1), and the central area of Tallahassee—a college town and the administrative center of Leon County (Figure 2). Having around 5 percent of population as group living is large enough to consider repercussions of undercounting, which may include a lack of state and municipal awareness when handling relief operations in the event of a natural disaster or an emergency. For instance, hurricane Katrina in 2005 produced 78 deaths of people living in nursing homes across Louisiana; a more accurate estimation of their location may have informed emergency services more quickly (Brunkard, Namulanda, and Ratard 2008, Hyer et al. 2009). Group quarter residents could be considered more vulnerable than the general population, and it is important for planners, first responders, and social service agencies to be aware of their spatial locations at a resolute scale.

Figure 1. Example of group quarter data from the US 2010 Census across Florida.

Both deficiencies of CEDS–incongruent spatial geometries and a lack of data on group living–can produce results that undercount population estimates. Repercussions include populations not assigned to correct parcels, erroneously reassigned to adjacent parcels, and estimates of zero population assigned to property parcels.

CADASTRAL-BASED EXPERT DASYMETRIC SYSTEM (CEDS)

Before demonstrating our proposed pre-processing stage, a brief discussion of CEDS is necessary. The technique is designed to redistribute population from census units to property parcels using proxy measures from the property cadastral database. The proxy measures represent population and can be either the number of residential units (RU) or the square footage of residential living area (RA). Statistically, CEDS output is

$$POP_l = POP_c \left(U_l / U_c\right)$$

where, POP_c is the census population (at the census tract, block group, or block level), U_l is the number of proxy units at the cadastral parcel level (*RU* or *RA*), *and* U_c is the number of proxy units at the census level (*RU* or *RA* per census tract, block group, or block level).

Figure 3 illustrates output from CEDS where information from the property appraiser database is used to calculate the population density of residential units for the central area of Tallahassee, FL. Parcels represented by darker shading are deemed to have multiple residences, and as such are assigned high population estimates, while parcels represented by lighter shading are low density population estimates, most likely single-family homes. Parcels that do not have any reported residences are assigned zero population estimates (unpopulated).

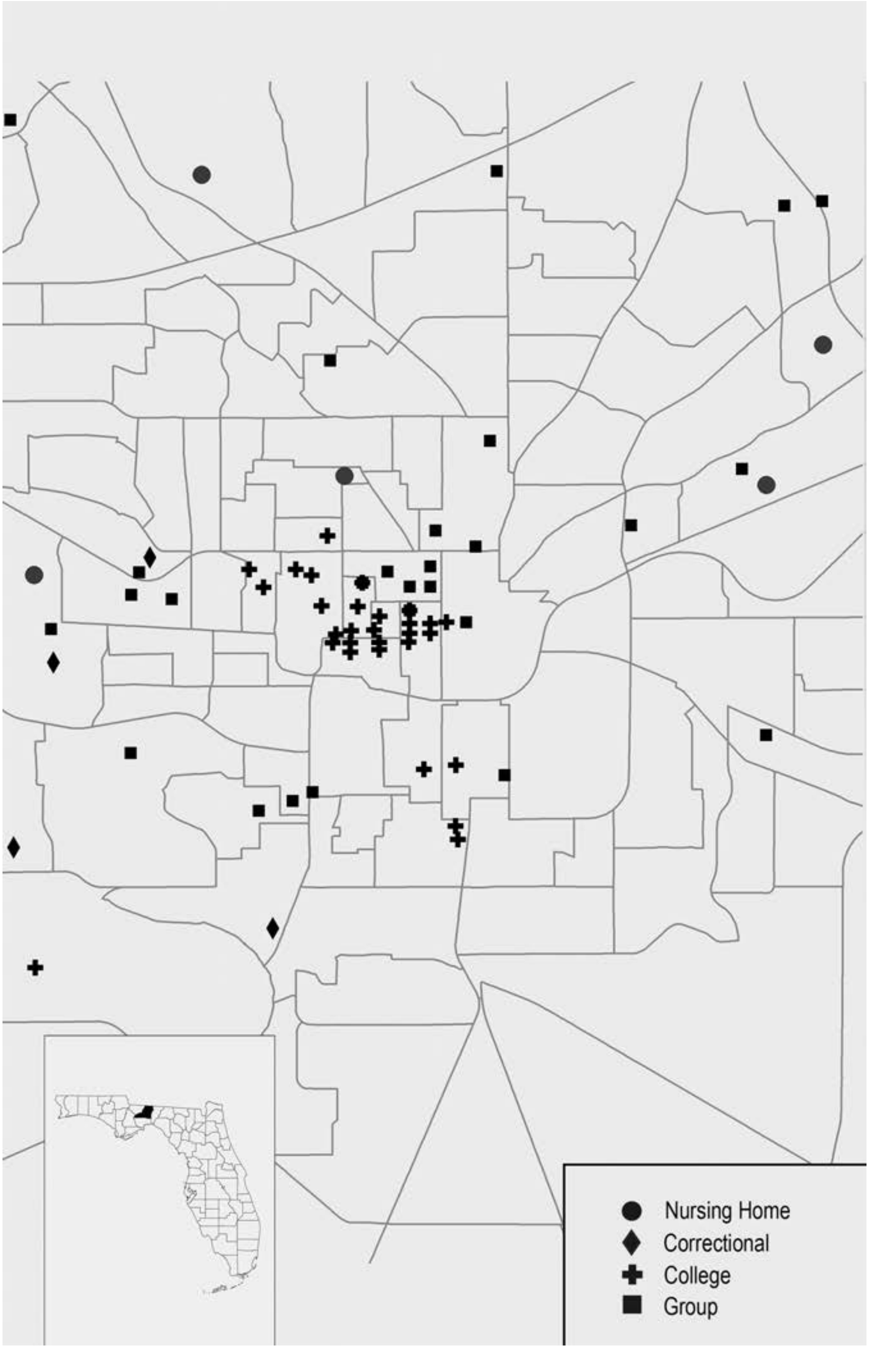

Figure 2. The distribution of group living data from the US 2010 Census across central Tallahassee, Leon County, the administrative center of Leon County.

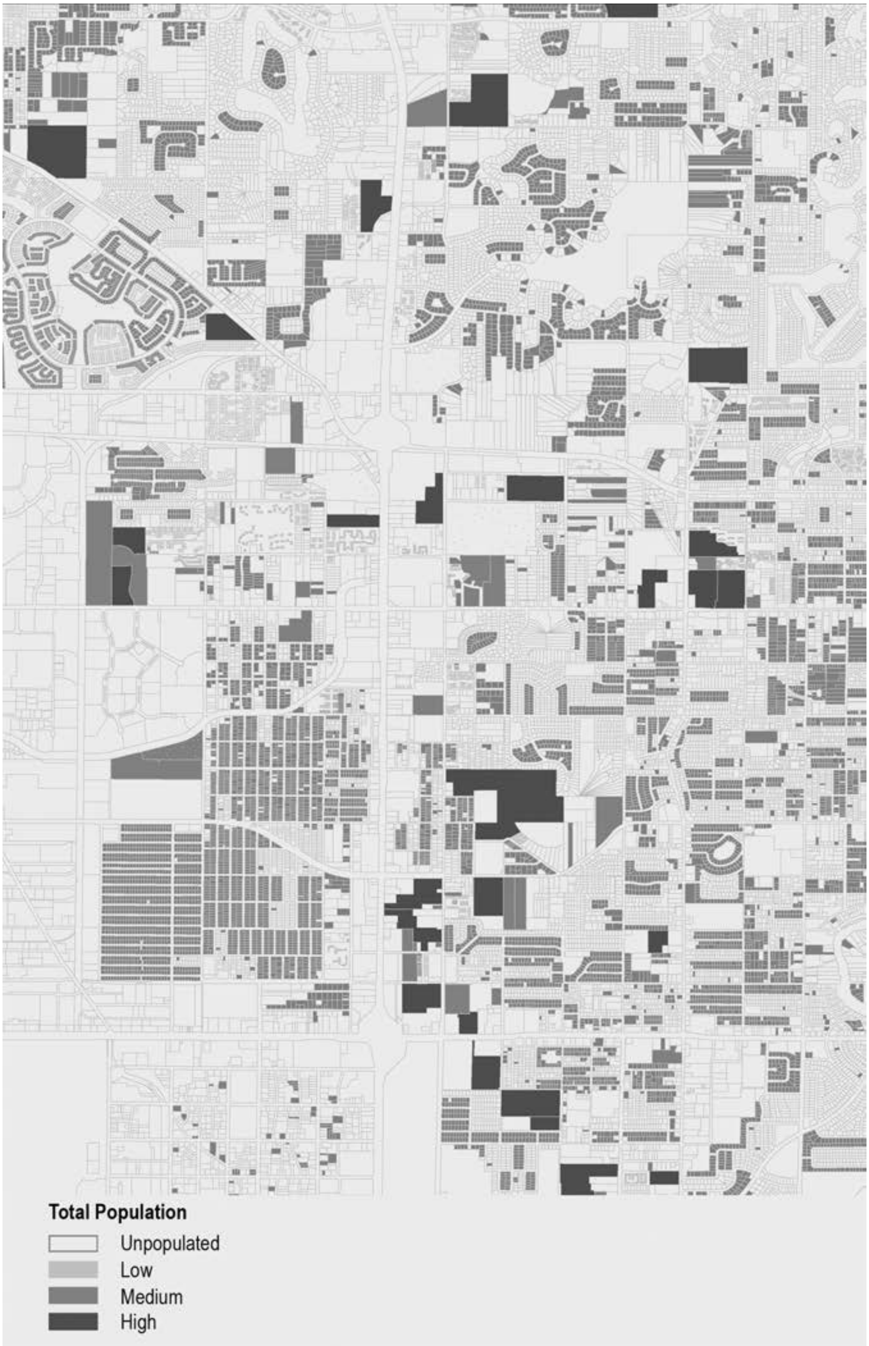

Figure 3. Example of CEDS population estimates for a central area of Tallahassee, Florida.

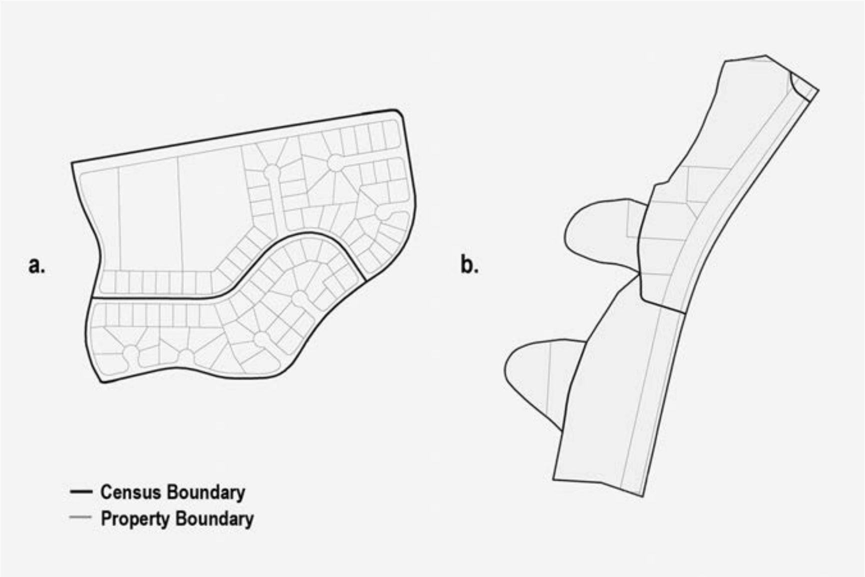

Figure 4. (a) Congruent census and cadastral geometries (b) incongruent geometries with census boundaries crossing property parcels (data for Tallahassee, Florida).

Regarding the first assumption on geometric congruence, the CEDS technique assumes that each property parcel is fully contained within a larger census unit (illustrated for an actual census unit in Tallahassee by Figure 4a). This is not always the case. Census block boundaries are assigned locally in relation to visible features such as streets or rivers. Property boundaries are not taken into consideration and thus census unit boundaries can cross property parcel boundaries, producing spatial incongruency where census units contain partial property parcels (Figure 4b).

The intersection of centroids is one way to alleviate this type of spatial incongruency (Figure 5). Property and census boundaries are overlaid using GIS *intersect* tools to create “split polygons” where boundary lines cross. Each of the new polygons is converted to a geographic centroid that retains information from its respective parent polygon—either census or property parcel. There is no need for a tolerance radius as this methodology corrects for any geographic deviation and sets the stage for population numbers from census units to be allocated proportionally to all parcels that are contained within the census unit.

In terms of the lack of data on group living, the CEDS proxies–either number of residences or square feet of living area–are not always included in property appraiser databases. One way to circumnavigate this oversight is to merge information on group living from the census directly with property parcel data. Table 1 displays sample parcel data from the Florida Department

Figure 5. Intersection of census and cadastral centroids.

Table 1. Sample data from a property appraiser database

Land use type	Number of residences Per Land Parcel
Single Family	1
Condominium	25
Supermarket	0
College	0
Institutionalized Rest Home	0
Hospital	0
Miscellaneous Residential (Migrant Camps, Boarding Homes, Etc.)	0
Military	0
Church	0

of Revenue's property database to demonstrate the potential for inaccurate population estimations. Using the number of residences as the proxy for CEDS, the *single family* and *condominium* land parcels would receive an accurate population estimate, with the *condominium* receiving more population because there are more residences. The *supermarket* parcel would receive an accurate population estimate of zero as supermarkets are not considered residential. However, the remaining would be less straightforward: *college*, *rest home*, *hospital*, and *miscellaneous residential* land use types suggest group living, and therefore should be considered residential, however zero residences are reported in the property database. The *military* and *church* land use types are uncertain, meaning military land use may or may not be used as residences, and churches may or may not double as shelters. However, data on group living is available from the census. So populating *college* from the property appraiser would involve allocating group quarter numbers from the census unit within which the property parcel is located.

PRE-PROCESSING TECHNIQUE

Our preprocessing recommendation prior to implementing CEDS would link group quarter data (from the population census) with parcel data (from the property appraiser cadaster). This involves both establishing spatial congruency, where geographically-weighted centroids identify the parcels within census units, and attribute cross-tabulation based on achieving categorical equivalencies between census group quarter categories and cadastral land use codes (Table 2). In achieving both, we advocate the following steps. First, population counts from group quarter data are spatially assigned to appropriate land parcels. Second, group living population is subtracted from the total population for that census unit. This leaves the population in traditional housing to be redistributed using CEDS. For a hypothetical census unit having 2,000

Table 2. Equivalency table examples

Census Group Quarters (from Census)	Parcel Land Use (from Property Cadaster)
Institutionalized–nursing home	Nursing homes, retirement homes
Institutionalized–other	Correctional facilities, mental hospitals
Non-institutionalized–college	College dormitories
Non-institutionalized–military	Military barracks (government)
Non-institutionalized–other	Group homes, missions, hospitals, shelters, charities, treatment centers, migrant camps, religious affiliations such as monasteries, convents, and abbeys.

people, the census group quarter data reports the *institutionalized–nursing homes* category has 250 people and the *non-institutionalized - college* category has 500 people. To address the nursing home population, we match the cadastral land use codes within the census unit for land uses suitable for nursing homes, such as *nursing homes, retirement homes* (see Table 2). Then we proportionally assign the 250 persons to the qualifying parcel(s). For the 500 in college settings, we match the cadastral data land use codes within the census unit for suitable college dormitories, such as *college dormitories* (see Table 2). Then we distribute the 500 persons to the qualifying parcel(s) proportionally. Finally, we subtract the 250 and the 500 from the total population as these have already been assigned to parcels via group living information. This method results in 750 persons listed as located in non-traditional group living, with the remaining 1,250 to be further distributed to traditional housing using standard CEDS.

To summarize, our methodology is as follows. Step 1: prepare an equivalency table to align census and cadastral categories. Review definitions of group living and cadastral land use. Develop an equivalency table similar to Table 2 except use actual land use codes from the cadastral database instead of generalized text. Investigate equivalencies between census group quarters and cadastral as this can vary by region according to cadastral data collection methods. It is possible that there could be a hierarchical ranking of land use choices depending upon the property appraiser's classification methods. Step 2: create an intersection of centroids from cadastral data and census data. This results in one or more centroids for each land parcel. Make certain that if a parcel contains more than one centroid, that only one contains census information lest this population be counted multiple times. Results should look similar to Figure 5. Step 3: assign group living populations to appropriate land parcel records. Distribute group living populations to appropriate cadastral centroids using the equivalency table (this step could be iterative if it is determined that certain land use codes carry more weight than others in the event that suitable land use codes are not found). Subtract group living population from the total population available at the census unit level. The remaining population to be distributed should be traditional housing types of apartments, condominiums, houses, and mobile homes. Step 4: run the CEDS original formula. This distributes population for traditional housing; do not assign additional people to the parcels that have already received group living data.

The results of implementing CEDS with and without the pre-processing stage are illustrated by Figure 6. Using raw (unprocessed) data in CEDS calculations results in an estimation of zero population (Figure 6e), while using pre-processed data results in an estimation of 3,432 persons calculated from the five population centroids (Figure 6f).

EMPIRICAL EXAMPLE: COLLEGE GROUP LIVING

We can further clarify the pre-processing stage with an empirical example taken for the college campus of the Florida State University in Tallahassee, Florida. The campus is approximately 5.6 km^2 in area and teaches 41,000 students. It has large land parcels, with overlapping census boundaries and dormitories that have no suitable proxies in the cadastral database to predict number of residents. We use block level data, the smallest area of the U.S. Population Census to redistribute college group living counts (*non-institutionalized–college* from Table 2) onto property appraisal parcels identified as land used as *college dormitories*. Centroids are matched and CEDS is applied. Figure 7 shows the graphic results of our CEDS estimates (with the pre-processing stage) where population estimates for each parcel summarized at the location of their geographically-weighted centroid. Residential areas surrounding the college campus are included for comparison purposes only.

We can numerate population estimates for the campus, both by using our pre-processing stage with CEDS and by using CEDS only as shown in Table 3. The campus is composed of 27 census blocks, contributing to a known 2010 population of 6,543 (some blocks are unpopulated and are consequently assigned a population value of 0). All 27 census blocks are classified as group living according to the census, and auxiliary data on group living is unavailable from the property appraiser cadaster. Because the property appraiser cadaster lacks information useful for estimating group living populations, without using the pre-processing steps outlined here, all 27 census blocks will result in a population estimation of 0. Population estimation errors are calculated as the absolute value of the known population (retrieved from the census) less the estimated population (calculated from an estimation method). Without using the pre-processing steps of this research, the estimation error using CEDS would be 6,543, or maximum error. However, by applying our pre-processing stage to CEDS—where we link block populations to property parcels—all 27 blocks are allocated group living populations. Our total estimated population is 6,542 for the 27 census blocks, resulting in an estimation error of only 1. (This error can be attributed to block 3018 where group quarter population counts do not equal census block counts.) In short, our error count of 1 is a vast improvement over the maximum estimation error. Granted this test exemplifies only one geographic area, but

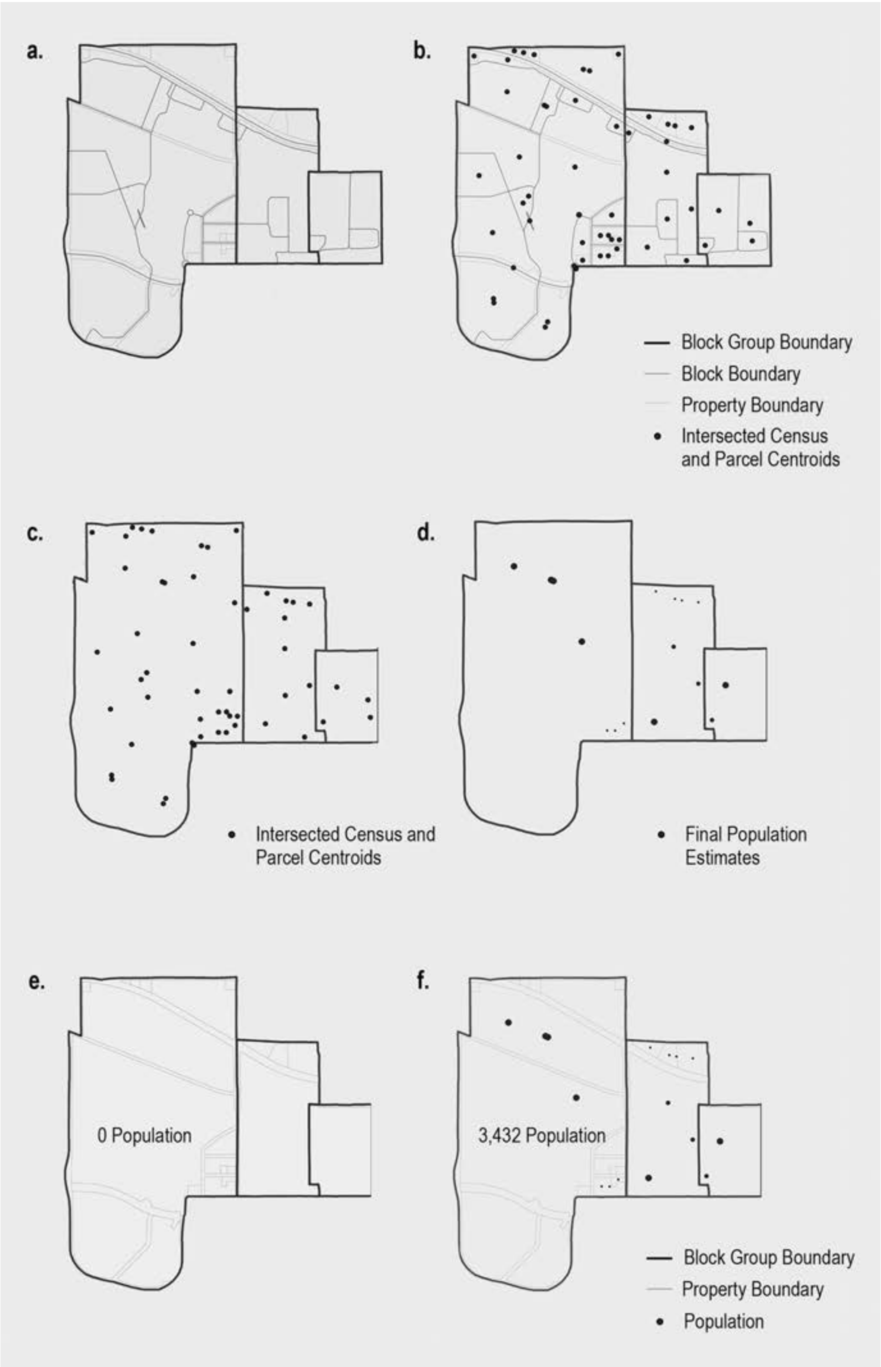

Figure 6. Illustration of the pre-processing steps: (a) visualization of the overlay of census blocks and land parcels; (b) intersected block census and cadastral centroids, (c) only the intersected centroids; (d) final population estimates used as input for CEDS calculations; (e) results from CEDS using raw data and (f) results from CEDS using pre-processed data.

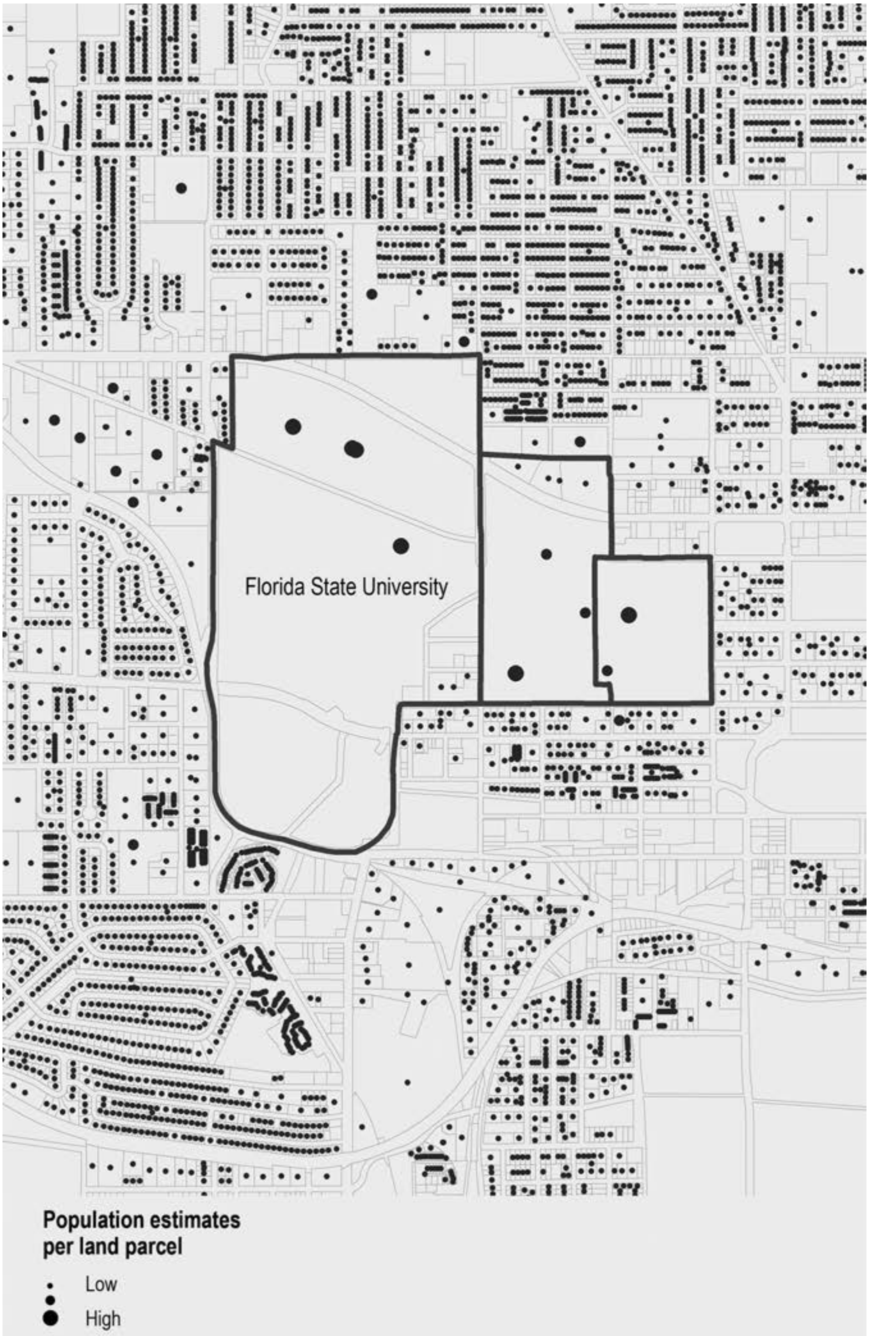

Figure 7. Population estimates for the Florida State University campus (and the surrounding area).

Table 3. Population estimates using CEDS with and without pre-processing (data for Florida State University campus)

Census Block	Known Population Counts from Census	Population Estimates Without Pre-processing	Error Without Pre-processing	Population Estimates With Pre-processing	Error With Pre-processing
1000	0	0	0	0	0
1001	0	0	0	0	0
1002	1,161	0	1,161	1,161	0
1003	231	0	231	231	0
2000	723	0	723	721	0
2001	0	0	0	0	0
2002	0	0	0	0	0
2003	406	0	406	406	0
2004	0	0	0	0	0
2005	0	0	0	0	0
2006	590	0	590	590	0
3000	0	0	0	0	0
3001	0	0	0	0	0
3002	737	0	737	737	0
3003	0	0	0	0	0
3006	0	0	0	0	0
3007	0	0	0	0	0
3009	0	0	0	0	0
3010	1,198	0	1,198	1,198	0
3011	938	0	938	938	0
3012	0	0	0	0	0
3013	0	0	0	0	0
3014	0	0	0	0	0
3015	0	0	0	0	0
3017	0	0	0	0	0
3018	559	0	559	558	1
3019	0	0	0	0	0
Total	6,543	0	6,543	6,542	**1**

we have conducted many other tests in Florida and have similarly shown very low to zero error levels.

CONCLUSIONS

We have outlined a pre-processing stage to be applied prior to implementing CEDS. The stage resolves inaccuracies in estimating group living numbers, and have reported a very low error of when estimating group living for the college campus of Florida State University in Tallahassee. We conclude that our pre-processing methodology is essential for improving not only CEDS but also all areal interpolation methods that utilize dasymetric principles when calculating populations. Generally, the trend in population mapping is to disaggregate information to the smallest available geographic unit. Usually these units do not contain complete information; some only record population counts, some only record land use types, while others contain only fiscal records. Dasymetric techniques are convenient vehicles with which to combine units from disparate sources—mostly by linking geographical centroids—to produce surfaces of population estimates that are spatially and temporally consistent. We have used US Census blocks, but our work is just as applicable to similar sized units currently used in many other countries. Cadastral data in particular is one of the more promising types of ancillary data for dasymetric mapping, simply because of their higher spatial resolutions, storage at the local level, and increasing public availability. Our research is on-going. Reducing errors when using CEDS is just one component in the search for even higher resolution population estimates for many applications dependent on demographics to map and monitor shifts in aging, transport demands, access to healthcare, crime hotspots, as well as urban encroachment on surrounding natural habitats.

ACKNOWLEDGEMENTS

Gratitude is given to Dean Jue for his insights into the potentials of group living data; Keith Sandell for his GIS automation techniques; and constructive comments from two anonymous reviewers.

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GEORGIANNA STRODE (gstrode@fsu.edu) is a PhD Candidate in the Geography Department and a GIS Application Developer/Programmer for the Florida Resources and Environmental Analysis Center (FREAC), Florida State University, Tallahassee, FL 32306. Her research interests include dasymetric population estimation, bivariate mapping techniques, and researching surface model development using the United States National Grid.

DR. VICTOR MESEV (vmesev@fsu.edu) is the Chase Distinguished Professor of Geography at Florida State University, Tallahassee FL 32306-2190. His research is on GIS/remote sensing integration, disaggregate cartography, and urban analytics.

DR. JULIANA MAANTAY (Juliana.maantay@lehman.cuny.edu) is a Professor of Urban Environmental Geography at the City University of New York, Lehman College and the CUNY Graduate Center. Her research focuses on Geographic Information Science, environmental health justice, urban environmental analysis, and demography/population science.