Divided Cities? Measuring the significance of, and relative contribution to ethnic segregation in Australia's capital cities

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1. Abstract

Determining how different communities are distributed within a city is essential to understanding the cultural and economic processes which drive community development, identity and urban growth. Segregation between ethnic and racial groups remains a popular and at times sensitive topic within the Australian urban narrative, despite little quantitative work being undertaken to examine the empirical basis of these patterns. A number of segregation indices have been developed which quantify aspects of segregation in urban centres. However, some of these are limited in their utility due to the effect of imposed administrative boundaries, or their inability to be undertaken at multiple spatial resolutions, to determine the potentially scale-dependent patterns of segregation. In this work, I use the recent introduction of a surface based segregation approach to determine the patterns of pairwise spatial segregation between 12 ethnic groups of the 2011 census across Australia's capital cities. I extend this work by introducing a novel Monte Carlo method to infer the statistical significance of the patterns, and by introducing a means to partition the relevant contribution of each of the ethnic groups towards the pairwise segregation estimates. In doing so, I address two important questions about Australia's ethno-urban fabric: (1) how spatially segregated are ethnic groups from each other in Australian cities, and (2) do certain ethnic groups display more tightly bound communities within these areas? Answering these questions is central to understanding the potentially unique cultural and identity-building processes at play within Australia's urban milieu.

2. Introduction

The interaction between ethnicity[1] and the urban environment has provided a rich subject matter for research across a number of fields, including sociology and political psychology (e.g. Gregory, 1999; Marschall & Stolle, 2004), gender studies (e.g. Brunson & Miller, 2006; Pain, 2001), public health (Harawa et al., 2004; Kataoka et al., 2002) and education (Kao & Thompson, 2003; Lopez, 2003). There is a large body of literature examining the crucial role of race and ethnicity within an urban environment as a determinant or contributing factor to specific outcomes, such as political engagement and development of community and identity structures, particularly within a North American context. These studies have consistently shown that ethnicity, and its intersection with socio-economic status, class and privilege is a central driver of the processes which ultimately shape how a city grows and develops (e.g. Briggs & Wilson, 2005; Squires & Kubrin, 2005), both socially and physically.

There has been a more limited analysis on the interaction of ethnicity, place and space within Australian cities (although see Collins, 2006; Collins & Jordan, 2009; Collins & Kunz, 2010). A notable exception to this is the function of racism and ethnic prejudice within an urban Australian context, which has received wide consideration in the last 10-15 years, in both the academic and non-academic spheres (Booth et al., 2012; Forrest & Dunn, 2007; Leigh, 2006; Nesdale, 2008; Panelli, 2008). In particular, the Cronulla riots of December 2005 galvanised ongoing public and academic attention around the role of racism, nationalism, crime and victimisation in Australia's suburbs, predominantly with respect to Middle Eastern communities (Bliuc et al., 2012; Lattas, 2007; Noble, 2009; Poynting, 2006). Subsequent global events, including ongoing military conflicts and the putative radicalisation of young Muslim Australians in Melbourne and Sydney in particular has maintained this focus on Middle Eastern and North African communities, and shifted public and media emphasis to the physical places where these populations live (e.g. Blair, 2014; Gamieldien, 2014). Additionally, wider recognition and reporting of racist behaviour in public urban

[1] "Ethnicity" and "ethnic group" in this article encompass the term "race", preferentially used in North American literature

places, such as on public transport (e.g. McNally & Collins, 2015; Pearson, 2015) has increased examination of the phenomena of cultural assimilation, prejudice and "othering" in Australia's cities.

A fundamental aspect of the discourse around ethnic identity and cultural assimilation within urban environments is the extent to which communities and groups are segregated from each other in space, and the implications of these patterns on a range of social, political and economic outcomes. The role of ethnic segregation in the etiology of urban violence (both in terms of race riots and more generalised crime), socio-economic disadvantage, health status and educational achievement and has been widely studied in both the United States (Krivo et al., 2009; Massey, 1995; Orfield & Lee, 2005; Sampson et al., 1997; Sampson & Wilson, 1995; Williams & Collins, 2001; Zenk et al., 2005) and in Britain (Burgess & Wilson, 2005; Carling, 2008; Hilmers et al., 2012; Johnston et al., 2005; Johnston et al., 2007; Nazroo & Williams, 2006; Pickett & Wilkinson, 2008; Simpson, 2004). By contrast, there is a distinct paucity of research into patterns of residential ethnic segregation in the urban Australian context, despite both the potential for fundamental insights into how ethnic communities interact with each other and place/space within the urban environment, and the preoccupation with certain ethnic communities' neighbourhoods in the wider media and public.

Considerable work has been undertaken developing means of measuring and understanding segregation, particularly residential segregation, in cities. There are a range of indices that have been implemented to quantify different components of the patterns and processes underpinning residential segregation (see Fotheringham, 1997; Massey & Denton, 1988; Morrill, 1991; Wong et al., 2007 for a comprehensive discussion of segregation measures). An emergent critique of a number of segregation methods, such as Duncan and Duncan's dissimilarity index *D* (1955) and Wong's *S* measure (Wong, 1999) is that many are global measures which are not spatially explicit, or else rely on hard administrative boundaries which may not necessarily reflect the "real world" interaction and scale-dependence between individuals and communities in space.

In response to these constraints, O'Sullivan and Wong (2007) developed a novel surface-based approach to quantifying segregation within an area. In addition to providing a global summary measure of segregation between two communities, the method developed by the authors allows for the visualisation and identification of specific areas which may contribute to the global measure of segregation. Moreover, the utilisation of kernel density methods within O'Sullivan and Wong's (2007) approach allows the procedure to be undertaken at multiple spatial scales, with minimal artefacts due to imposed administrative boundaries.

It is important to draw attention to the difference between concentration and segregation (Hamnett, 2012). The former is a description of the tendency of members of the same group (ethnic, sexual, socio-economic) to aggregate together, forming local populations which comprise large proportions of that group's overall population. The latter, by contrast, speaks to the concentration of a group *to the exclusion of others*. Ethnic concentration does not *ipso facto* necessitate the exclusion of other groups from the same areas (i.e. segregation), although there may be an exclusion effect simply due to hard limits of housing supply. The extent of this exclusion would largely be dependent on both relative overall population sizes and the total amount of people that an area can physically house. Because the O'Sullivan and Wong's *S* surface measure uses and compares the proportions of two groups' total population in an area – which are largely independent of each other - it is difficult to partition the different roles that these related but nonetheless distinct concepts play.

In this analysis, I use O'Sullivan and Wong's segregation measure to investigate the pairwise segregation between eleven ethnic groups across the eight Australian capital cities, providing the first comprehensive quantification of ethnic segregation in Australian urban areas. I also extend O'Sullivan and Wong's approach by implementing a Monte Carlo method as a potential means of inferring statistical significance for the segregation measures (a limitation of the method as indicated by the authors), as well as comparing the distribution of each ethnic group with respect to the even-ness of their spread. In doing so, I assess two fundamental questions:

(1) To what extent are different ethnic groups segregated from each other across Australia's capital cities?

(2) Do different ethnic groups have markedly different distributions within cities potentially driving high segregation indices?

(3) What is the potential relationship between these measures segregation and concentration in Australian cities

3. Methods

3.1. Study Area and Data

I performed this analysis for each of the eight capital cities in Australia (Adelaide, Brisbane, Canberra, Darwin, Hobart, Melbourne, Perth and Sydney) which allowed for a range of population sizes to be included, from 140,400 in Greater Darwin to 4,840,000 in Greater Sydney (ABS, 2015). In this instance, the Urban Centres/Localities (UCLs) for the capital cities were used as our study areas (Figure 1), which incorporate the contiguous urban areas around each city. These were selected over the Greater Capital City Statistical Areas (GCCSAs), because the latter include large areas of non-urban areas which may introduce error into the kernel density estimates. In the case of Canberra (Australian Capital Territory), the satellite New South Wales city of Queanbeyan was included, given the proximity and economic and demographic links between the two. A 20km buffer around each UCL study area was incorporated in the initial kernel density estimates in order to minimise edge effects.

Twelve ethnic groups were included in each city: *American* (including Northern and Southern American), *Australian*, *Indigenous* (Aboriginal and Torres Strait Islander), *Jewish*, *Middle Eastern and North African, Northern and Western European*, *North Eastern Asian*, *Oceanian Southern and Central Asian*, *Southeast Asian*, *Southern and Eastern European* and *Sub-Saharan African*. These represented the 9 main ethnic groups categorised by the Australian Bureau of Statistics (ABS) in the Ancestry 1st Response (ANC1P) census question, with some modifications: (1) *Oceania* in the census categorisation combines together individuals identifying as Australian, Aboriginal and Torres Strait Islander, and all other Oceanian groups (New Zealanders, Maori and Pacific Islanders). For this study, individuals identifying as either Aborginal or Torres Strait were partitioned in their own ethnic group (*Indigenous*), as were individuals who identified as Australian (*Australian*); (2) The ABS *Middle Eastern and North African* categorisation was partitioned into *Jewish* and *Middle Eastern and North African.*

Populations of different ethnic groups were taken from the 2011 Census, obtained from the ABS. These counts were obtained at Statistical Area Level 1 (SA1) aggregations, the most granular geographic level of aggregation that ethnic characteristics are available. An example of the distribution of SA1s is illustrated in Figure 2.

All spatial analyses were undertaken in *ArcGIS 10.2* (ESRI, 2011); all statistical analyses were undertaken in *R* (R Core Team, 2014)

3.2. Surface Segregation Index - *S*

Counts of individuals in each ethnic group within SA1s were converted to proportions of that ethnic group's total population within the 20km UCL buffer zone. Those proportions were then assigned to the centroid of each of SA1. The SA1 centroids were used to calculate kernel density estimates across the 20km UCL buffer zone. This was undertaken at multiple kernel bandwidths, in order to determine the potential impact of spatial scale on the results. These bandwidths were 0.5km, 1km, 1.75km 2.5km, 5km, 7.5km and 10km.

The resultant kernel density estimates were used to calculate O'Sullivan and Wong's *S* Index, calculated by Equation 1:

$$S = \frac{\sum_i \left| p_{Ai} - p_{Bi} \right|}{\sum_i \max\left(p_{Ai}, p_{Bi}\right)}$$

Where p_{Ai} and p_{Bi} represent the proportions of the total study area's ethnic groups A and B, respectively, within spatial unit i. In this instance, i represents each raster cell (125m x 125m) in the kernel density surface. The absolute differences between the proportions of the two ethnic groups are calculated, together with the maximum value. The proportion of the sums of these two variables provides the segregation index *S,* representing the proportion of total probability distribution that contains no intersection of the two populations (Figure 3).

3.3. Monte Carlo Implementation

Despite segregation patterns often being clear enough to minimize the need for significance testing, it can nonetheless be useful to be able exclude the potential role of random spatial processes in driving geographic patterns. This may be particularly important where sample populations are small. The surface-based approach developed by O'Sullivan and Wong did not incorporate a means of inferring statistical significance. Therefore, as suggested by the authors as a potential solution, a Monte Carlo process was implemented to provide an inferential significance framework. In this implementation, the total counts of residents within each SA1 were converted into individuals across each city. Individuals were then randomly assigned an ethnic group based on the total number of individuals comprising each ethnic group in the total population. The total number of individuals within each SA1 for each simulated ethnic group, within each SA1 calculated, and converted to a proportion of the total city's population for that ethnic group. New kernel density estimates were generated from these simulated populations, and *S* indexes calculated. 99 iterations were undertaken for each pairwise comparison, for each city. Due to the computational demands of the Monte Carlo process, they were only undertaken for the 1km and 2.5km kernel density bandwidths. The outputs of the Monte Carlo process were used to generate ranges of expected *S* indexes under completely spatially random conditions. Observed *S* indexes were assigned statistical significance where $P < 0.001$.

3.4. Peak Skew Calculations

The hypothetical sub-populations in Figure 3 have identically shaped distributions. A more realistic example is illustrated in Figure 4, which indicates two populations with quite different population distributions in space. As the spatial distribution or "footprint" of a population decreases, the proportion of the population living in the same area increases, represented by an increase in the height of the peak of the distribution. This is particularly so where the number of such peaks drops, that is, where a sub population lives in a single region or neighbourhood. I measured this phenomenon, by calculating the *peak skew* for each pairwise comparison, where the value of maximum peak for ethnic group A was divided by the maximum peak for ethnic group B and vice versa. Peak skew values greater than 1 can indicate fewer, higher peaks for one population (i.e. a more localized, spatially constrained population) while peak skew values lower than 1 can indicate more, flatter peaks and a flatter distribution more generally for the other population (i.e. a more widely dispersed population).

3.5. Local contribution and exclusion

O'Sullivan and Wong's method uses the proportion of a group's total population as an input, and compares it to other groups in a pairwise manner. These variables are largely independent of each other, and are potentially more reflective of both ethnic group concentration (and relative population size) rather than ethnic group segregation, which is concentration of a group to the exclusion of others. To determine the potential role of concentration versus segregation in generating the *S* index value, I calculated the extent to which the different ethnic groups dominated their local areas to the exclusion of others. To do this, I calculated the proportion that each ethnic group contributed to each SA1 population in each of the eight cities. Then, incorporating only observations where an ethnic group's contribution to the local (SA1) population was greater than zero, I determined using an ANOVA whether there were significant differences between the ethnic groups and their proportional contribution to local (SA1) populations. I used Tukey's Honest Significant Difference (HSD) to determine which of the pairwise comparisons were significantly different. I then compared groups' average proportional contribution to local (SA1) populations to groups' average *S* Index values across each of the 8 cities to determine if there was a correlation between the two, that is, if populations with high average *S* Index values also had high average proportional contributions to local (SA1) populations (thus, to the exclusion of other groups).

4. Results

4.1. Spatial Segregation

An example of the kernel density surfaces produced in the spatial segregation analyses is shown in Figure 5, illustrating the output surfaces for Sub-Saharan Africa (A) and Oceania (B) in Brisbane at a kernel bandwidth of 2.5km. The maximum value and absolute difference surfaces are also shown (C and D, respectively).

The *S* index is a single summary global statistic for the study area. However, in addition to providing a parameter component of the *S* index calculation, the absolute difference surface (Figure 5D) provides a useful and informative visualisation of the local spatial distribution of segregation between the two sample populations, where the densities of the two populations are markedly different (darker regions) or where they are similar or equal (lighter regions).

The *S* indices for all pairwise ethnic group comparisons, for all capital cities at the bandwidth of 2.5km are shown in Figure 6 (*S* index matrices for all other bandwidths are available in Supplementary Information). These exhibit a broad range of values for the pairwise ethnic group comparisons across the capital cities, from an extremely high value of 0.983 between Jewish and Indigenous communities in Hobart to an almost negligible level of segregation between Australian and North West European communities in Adelaide. The Jewish communities consistently exhibit the highest *S* index values, followed by Indigenous communities in all cities studied. Figure 7 illustrates the significant negative correlation (Pearson's $r = -0.264$, $t_{df=94} = -2.663$, $P < 0.01$) between log population size and mean *S* index values for each of the 12 ethnic categorisation, across the 8 cities suggesting that increasing *S* index values may be at least in part related to the respective population sizes of each community. There is an obvious possibility that this distribution is a statistical artefact of the varying population sizes of the different ethnic groups, where smaller population sizes can have population density surfaces which alter substantially when only a small number of individuals appear or disappear in certain areas. However, the methods deployed here are unable to distinguish between these stochastic effects, and real cultural and economic processes potentially occurring in these isolated communities.

4.2. Monte Carlo Simulation.

Most observed *S* index values for pairwise ethnic group comparisons were outside of the range of values expected by a completely spatially random (*CSR*) process, as determined by the Monte Carlo simulations undertaken in this analysis, across all cities and kernel bandwidths (Monte Carlo means, standard deviations, and upper and lower limits can be found in Supplementary Information). The exception to this pattern occurred in Darwin and Hobart, for the very small Jewish populations (10 and 9 individuals, respectively) in those cities. In these instances, the observed *S* index values for these populations were unable to be distinguished from a CSR process, for a number of pairwise comparisons with other ethnic groups. This pattern increased with increasing kernel density bandwidth.

An example of the distributions of these observed and expected values is indicated in Figure 8, for the Jewish vs. Middle Eastern and North African pairwise comparison. For all cities except Darwin and Hobart, the observed values (solid lines) are significantly higher ($P<0.001$) than the values expected by a CSR process (bands). For Darwin and Hobart, however, the observed values fall clearly within the range expected by a CSR process. This pattern, with Darwin and Hobart Jewish *S* indices often falling within the expected CSR bands, while other cities' and other ethnic groups' *S* indexes remain highly significant, is consistent across all bandwidths (Supplementary Information)

4.3. Peak Skew Calculations

The Peak skew analysis yield very large differences in the shape of population distributions between different ethnic groups in Australian cities. The Peak Skew figures for the four largest capital cities (Sydney, Melbourne, Brisbane and Perth) at a kernel bandwidth of 2.5km are shown in Figure 9. Rows indicate the ratio of that ethnic group as P_{Amax} to the column ethnic group (P_{Bmax}), with values higher than 1 indicating that the maximum peak of that ethnic group is substantially higher than the maximum peak of the comparison population.

Perhaps unsurprisingly, the Jewish communities emerge as the most skewed populations within these and the four other Australian communities (Supplementary Information), in one instance P_{Amax} for the Jewish population was more than two orders of magnitude (i.e. over 100 times) taller than a pairwise comparator. As with the *S* Index calculations, these values appear to be associated (Pearson's r = -0.378, $t_{df=94} = -3.961$, P<0.005, Kernel Bandwidth = 2.5km) with population size, shown in Figure 10. This is at least partly intuitive, given that smaller population sizes will simply tend to have a greater proportion of that population within one area. However as bandwidth increases these values shift substantially, with some ethnic groups emerging as more skewed than the Jewish populations. Moreover, as kernel bandwidth increases, the *polarisation* of the skew values increases – there are fewer peak skew values grouped around the centre, with more and more increasingly lower and higher (i.e. darker blue and red values in the table).

4.4. Local contribution and exclusion

Figure 11 illustrates the distribution of proportional contributions to local (SA1) populations for each ethnicity in Melbourne (all other cities are available in Supplementary Information). The largest mean contribution to total SA1s was observed among Northern and Western European, Australian and Southern and Eastern European ethnic groups. By contrast, the smallest mean contribution to SA1 populations was observed among the Indigenous and Oceania ethnic groups. These patterns were replicated across each of the cities, with high SA1 proportions for Northern and Western European and Australian ethnic groups, and low SA1 proportions for Indigenous, Jewish and Oceania ethnic groups. For all of the cities, mean SA1 proportions was significantly associated with ethnic groups (ANOVA results for each city can be found in Supplementary Information), and in all cities, each of the mean SA1 proportions were significantly different for most of the pairwise ethnic group comparisons (Tukey HSD results for each city can be found in Supplementary Information).

Mean S Index values for ethnic groups was significantly negatively associated with mean proportional contributions to local (SA1) populations (Pearson's r = -0.211, $t_{df=94} = -2.097$, P<0.05), as shown in Figure 12. This suggests that the *S* Index values determined by using O'Sullivan and Wong's surface method are more likely to reflect ethnic group concentration in areas, but concentration to the exclusion of other groups; groups with the highest *S* index values were concentrated in areas with other groups present (Jewish and Indigenous), while those groups with the lowest *S* Index values (Northern and Western European, Australian) dominated the local populations that they were found in, to the (partial) exclusion of others.

5. Discussion

The results presented here provide the first thorough quantitative analysis of the shape and extent of segregation between and concentration of ethnic communities in Australian cities. In doing so, they provide a much needed empirical context for ongoing political and community narratives around cultural assimilation, ghettoization and the presence of urban enclaves along ethnic lines (Veiszadeh et al., 2011). Some of these important emergent themes from this research are considered more fully below.

5.1. The *S* Index reflects concentration more than segregation

The results of the analyses undertaken here suggest that high *S* Index values produced by O'Sullivan and Wong's *S* Index method are influenced by the concentration of small populations within localised areas, but do not necessarily reflect segregation (that is, the concentration of one group to the exclusion of others) *per se*, at least within the Australian context. This suggests that the demographic and social processes driving whether groups aggregate together to develop communities of varying spatial concentration do so relatively independently of the processes intrinsic to other ethnic groups. Thus, while some small ethnic groups may be concentrated together in localised communities or enclaves, the neighbourhoods they belong to are often nonetheless diverse with respect to the presence of other ethnic groups. By contrast, the larger populations tend to dominate the neighbourhoods that they are found in to the exclusion of others. This is highly unlikely to be a deliberate process. Rather, it is likely that the large contribution to neighbourhoods by Northern and Western European and Australian ethnic groups is due to their sheer overwhelming size.

5.2. In Australia, population size matters

There is a clear indication that smaller populations in Australian cities appear to be more concentrated (but not necessarily segregated) than larger populations. The *S* index and peak skew values for the relatively small Jewish and Indigenous populations calculated here are consistently the two highest across the 8 capital cities, while the *S* index and peak skew values for the dominant North West European and Australian populations are consistently the lowest. As discussed, the methods used here rely on proportions of subpopulations in a kernel density surface as a base parameter for segregation calculations, as a result, they are influenced by changes in both the location and magnitude of those surface peaks. Smaller populations may at least in part emerge as more segregated due to stochastic effects. However, these patterns of segregation and concentration are also highly likely to be driven by contextual social and economic processes, either intrinsic to the population, such as shared cultural values and languages; extrinsic factors such as socio-economic marginalisation and prejudice, or interactions of these (Shuttleworth et al., 2014). An example of this is shown in Figure 11, which illustrates the distribution of Melbourne's Indigenous and Jewish populations (the city's two smallest). Melbourne's self-identified Jewish population largely resides in a single location in the city's southeast, while its' self-identified Indigenous population is distributed more widely (although sparingly in the more affluent inner east of the city). These populations are the most segregated from all other ethnic groups within Melbourne (and from each other), but the socio-economic and cultural processes driving their residential patterns are clearly very different.

These patterns – of smaller populations exhibiting higher S Index values than larger populations – are in stark contrast to the results of similar analyses, particularly in the United States. In developing the surface based *S* index, O'Sullivan and Wong (2007) analysed the segregation patterns of Caucasians and African Americans (the two largest population groups) in Washington DC and Philadelphia. Their results indicated high levels of segregation between these two groups: at a bandwidth of 2.5km *S* Index values between these to populations were 0.813 and 0.815, respectively. These are considerably higher than the *S* Index values for all pairwise ethnic group comparisons in all cities across Australia for that bandwidth, with the sole exception of some pairwise comparisons involving Jewish populations, This indicates that Australia's cities are overall likely to be considerably less segregated along ethnic lines, certainly for the larger population groups, than the United

States. This does not preclude delineation of Australian cities along socio-economic boundaries (which strongly interact with ethnic identity), or suggest that ethnic marginalisation does not occur, only that these patterns appear not to be as stark, or operate on as large a spatial scale as in the United States.

5.3. Jewish populations are highly concentrated, but not segregated

The clearest pattern which emerges from these analyses is the high level of spatial concentration in Jewish populations in Australia. In some cities, the very small number of individuals identifying as Jewish within the smaller cities (e.g. Darwin, Hobart) means that their spatial patterns are essentially indistinguishable from CSR processes. Nonetheless these patterns, especially in Melbourne and Sydney (where Jewish populations are well established) provide a intriguing quantitative insight into the processes operating within urban Jewish-Australian communities. In Melbourne, the Jewish population is located predominantly in the suburbs of Balaclava, St Kilda East, Ripponlea, Elsternwick and Caulfield in the city's south east, with a strong ultra-Orthodox component, including the most insular Adass community, who advocate isolation from the external community socially and spatially (Legge, 2011). Much of this area is surrounded by an *eruv*, a cable designed to delineate the area as private domain, allowing the community's Orthodox population to move freely within the area on the Sabbath. The area delineated by the *eruv* largely corresponds with the peak of Jewish population density in Melbourne in this analysis. It is possible that the isolationist views of some elements of city's Jewish community are at least in part driving this substantial singular concentration of the community in the area.

Importantly, however, the results of local contribution to populations in these areas suggest that, while Jewish populations may exhibit a preference to aggregate together in a localised community, they do not do this (at least spatially) to the exclusion of other groups. Jewish populations in both Sydney and Melbourne, whilst highly concentrated, nonetheless reside in areas with large proportions of other ethnic groups present. The high *S* Index values for the Jewish population in Australian cities are thus likely to reflect the concentration of a generally small population (i.e. high proportional peaks), in areas with large numbers of individuals from other ethnic groups, whose local populations nonetheless represent small proportions of the groups' overall population (i.e. low proportional valleys), contributing to high absolute difference and absolute maximum surfaces.

5.4. Indigenous populations are scattered, and concentrated at small spatial scales

While exhibiting high *S* index values similar to Jewish populations, Australia's urban Indigenous communities are considerably more scattered, rather than concentrated in a few neighbourhoods (e.g. Figure 13). Moreover, while Jewish populations are generally concentrated in areas of high socio-economic status (Graham, 2014), High Indigenous populations in urban areas tend to be located in either socio-economically disadvantaged suburbs, or in small socio-economically disadvantaged enclaves within rapidly gentrifying inner urban areas. (ABS, 2011). This latter component is particularly prescient, as it highlights the need to understand the scale dependent nature of investigating segregation. All of the *S* index values for all pairwise ethnic group comparisons tended to diminish with increasing kernel density bandwidth size. However, the Indigenous pairwise comparisons dropped off significantly. For example, in Sydney, the Australian – Indigenous *S* Index dropped from 0.907 at a bandwidth of 500m to 0.498 at a bandwidth of 10,000m (a drop of 45%). By contrast, the relatively high Australian – Jewish *S* index only dropped from 14.3% (from 0.918 to 0.786), while the Australian – North West European *S* index dropped 18.8% (from 0.208 to 0.169). This indicates that, unlike the Jewish community, where processes driving spatial segregation operate over relatively large spatial scales, Australia's urban Indigenous populations are segregated from other groups at relatively fine spatial scales, along micro-gradients of socio-economic disadvantage and cultural delineation. The continued gentrification of inner urban areas such as Fitzroy, Collingwood and Richmond in Melbourne, and Redfern and Newtown in Sydney is only likely to exacerbate these socio-economic gradients (if it does not result in displacement), which has implications for the measurement of socio-economic status at a fine spatial scale (Goldie et al., 2014; Tanton et al., 2015)

5.5. Middle Eastern and North African communities are neither highly concentrated nor highly segregated

Considerable media and public attention has been paid to the perceived socio-spatial segregation of Middle Eastern and North African communities in Australian cities, particularly within the context of the providing the necessary environment for the radicalisation of young Australian Muslim men (Blair, 2014; Gamieldien, 2014). The combination of both low *S* index values, and low proportions to local populations for the Middle Eastern and North African groups suggest that they do not exhibit high levels of concentration, or concentration to the exclusion of other groups. These ethnic groups are no more spatially nor segregated from the other ethnic groups in Australian cities, than would be expected for populations of their size. In Melbourne and Sydney, where much attention has been paid to the perceived role that ethnic isolationism within communities characterised by a high percentage of Muslim residents has played in radicalising some high profile individuals, the *S* Index for this community is within the same range of values as those for the Southeast Asian, and Northern and Eastern Asian communities, and only slightly higher than the *S* index values established for the Australian, and Northern and Western European communities (Figure 6, and Supplementary Information). Additionally peak skew values for the Middle Eastern and Northern African communities are similar those for Sub-Saharan African, Southeast Asian, Northern and Eastern Asian, and Southern and Central Asian communities.

Perhaps most importantly, Middle Eastern and Northern African ethnic populations are not concentrated in local areas to the exclusion of other ethnic groups; overall the mean local (SA1) proportion for the Middle Eastern and northern African groups were amongst the low values for the 12 ethnic groups examined here, indicating that members of the Middle Eastern and North African ethnic group share their neighbourhoods with individuals from other ethnic groups, in a similar way to Australia’s urban Jewish and Asian populations.

As indicated previously, these results do not imply that Middle Eastern and North African (or Sub-Saharan African communities are not segregated, isolated or marginalised with respect to wider social and urban landscape. Indeed, these two communities are predominantly located in areas of characterised by high levels of socio-economic disadvantage (ABS, 2011), which has significant implications for the ability of individuals to access material and social resources, which allow an individual's participation in society. While some of these are barriers certainly are spatially bound, the results here indicate that potential socio-economic marginalisation of Middle Eastern and North African (and Sub-Saharan African) communities is neither solely driven by, nor necessarily drives uniquely high patterns of spatial segregation or concentration.

5.6. Conclusion and Future work

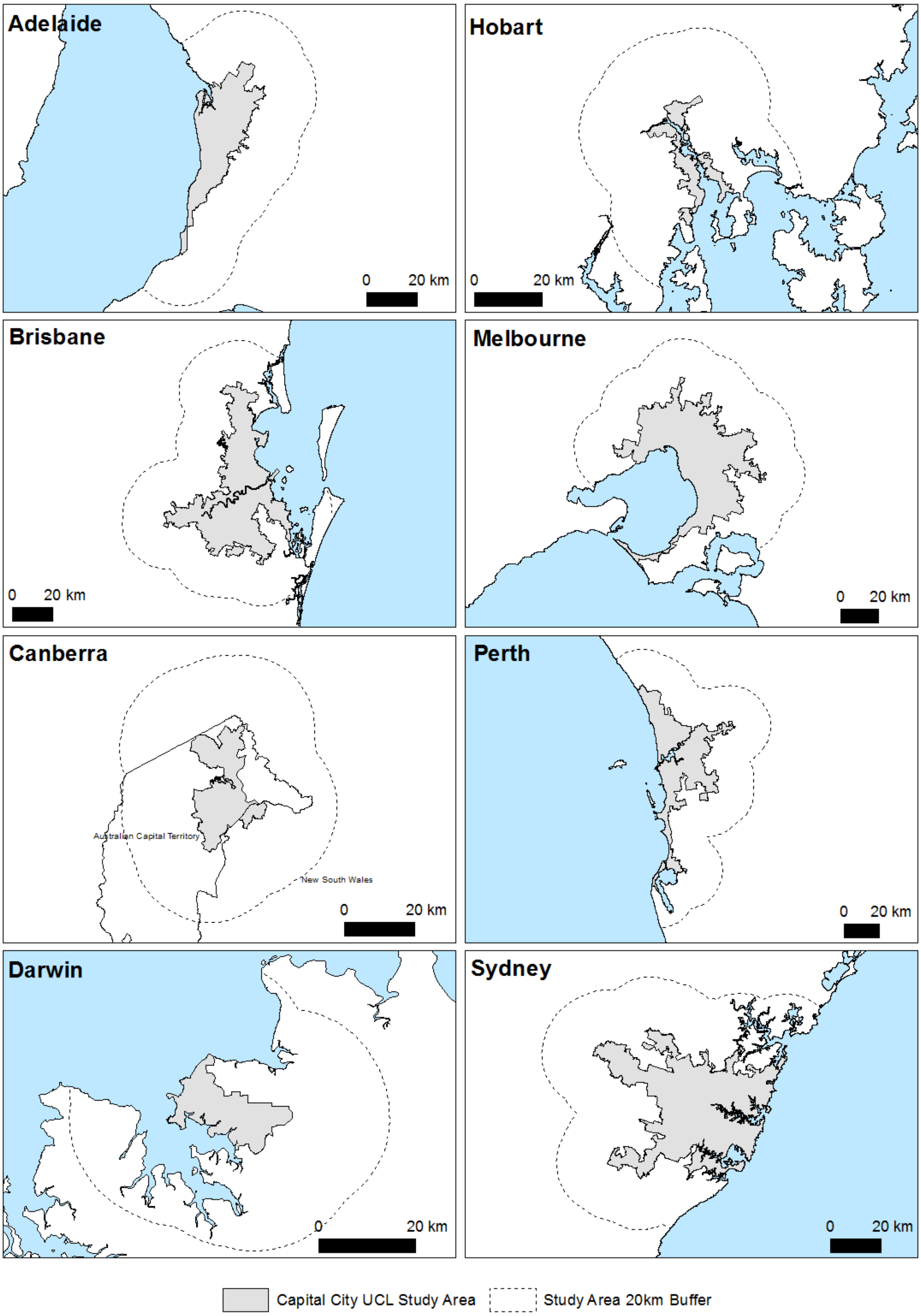
This research provided the first attempt at inferring statistical significance for the global statistic *S* Index, indicated by the original authors as the next step of extending the methods (O'Sullivan & Wong, 2007). While most of the patterns described here – particularly for the larger cities are so apparent that they do not necessarily require statistical testing, the development of a Monte Carlo has provided a useful exercise in identifying observed patterns that aren't able to be distinguished from CSR. The method employed here to simulate CSR nonetheless has some drawbacks. Individuals were used, and reshuffled randomly across each study area. This is an unrealistic model, given that family units and households are not comprised of individuals making individual choices about their place of residence (particularly individuals in partnerships/marriages, and dependent children). However, ethnic characteristics of households is not presently available from the ABS *Table Builder* database, so individuals are the only level that ethnic characteristics can be identified. Household/family level data on ethnic characteristics would provide a much greater ability to simulate a more appropriate CSR process.

Grouping distinct nationalities communities into broader ethnic groups is not ideal, and has the potential to mask segregation patterns operating at a much finer spatial and ethnic scale.

However, while efforts were made to separate out some of the more misleading “lumping” undertaken with the analysis (i.e. separating out Indigenous from Oceania, and Jewish from Middle Eastern and North African), moving to lower and lower levels has implications for the accuracy of counts at the SA1 level, due to the nature of the ABS privacy-protecting randomisation process for small counts.

The analyses undertaken allow for a greater understanding of the spatial patterns and processes which are widely perceived to be at play in Australia’s urban milieu. It is clear that the extent of spatial segregation between ethnic groups in areas studied here is related closely to the size of population, although clearly distinct processes driving ethnic segregation and concentration are operating for small populations, at varying spatial scales. Moreover, public perceptions of how certain groups are isolated spatially from the wider community are not necessarily borne out by this empirical analysis.

- **Figures**


Adelaide
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Brisbane
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Melbourne
0 20 km
Canberra
Australian Capital Territory
New South Wales
0 20 km
Perth
0 20 km
Darwin
0 20 km
Sydney
0 20 km
Capital City UCL Study Area
Study Area 20km Buffer

Figure 1: Eight Capital City Study Areas across Australia

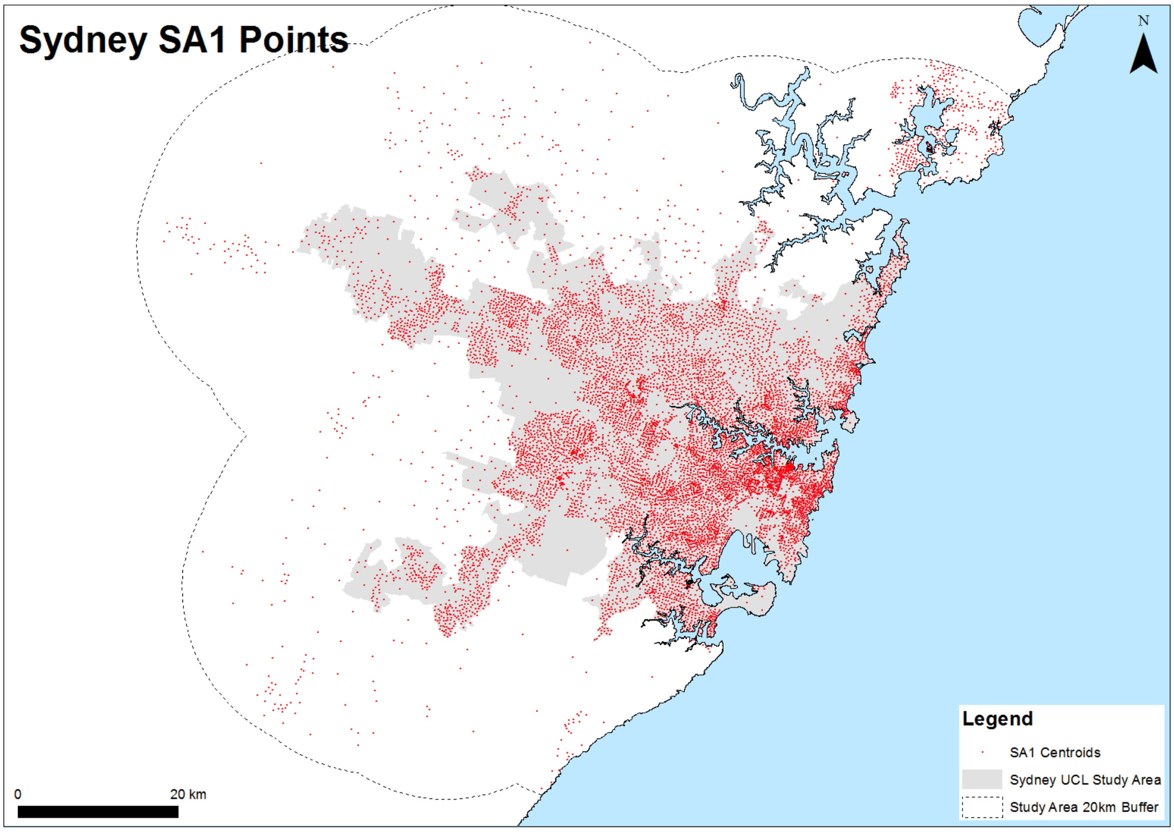


Figure 2: Example of distribution of SA1 centroids within a study area (Sydney)

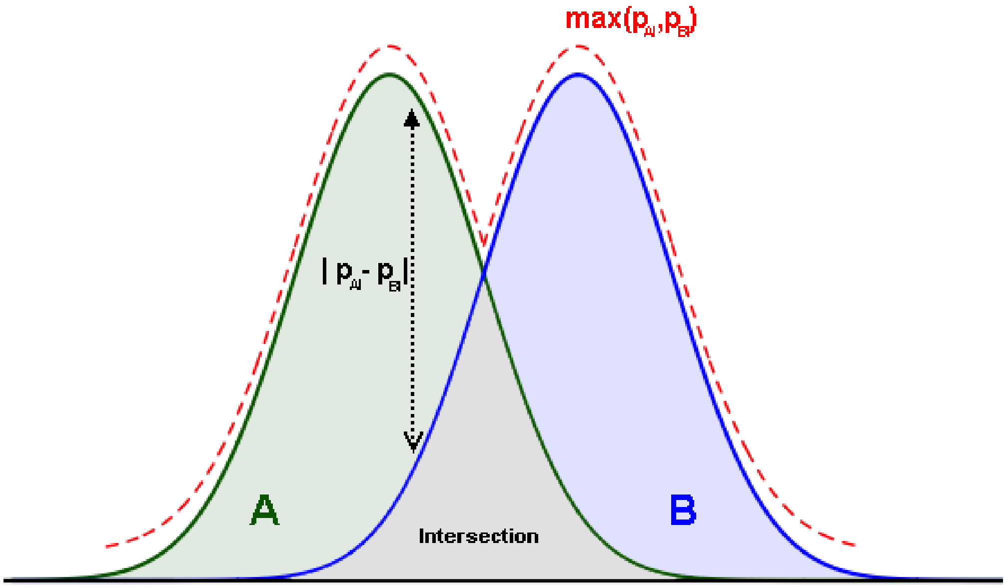


Figure 3: Example of calculation of Segregation Index *S* for two hypothetical populations *A* and *B*. *S* is equivalent to 1 – *Intersection*. Adapted from O'Sullivan and Wong (2007).

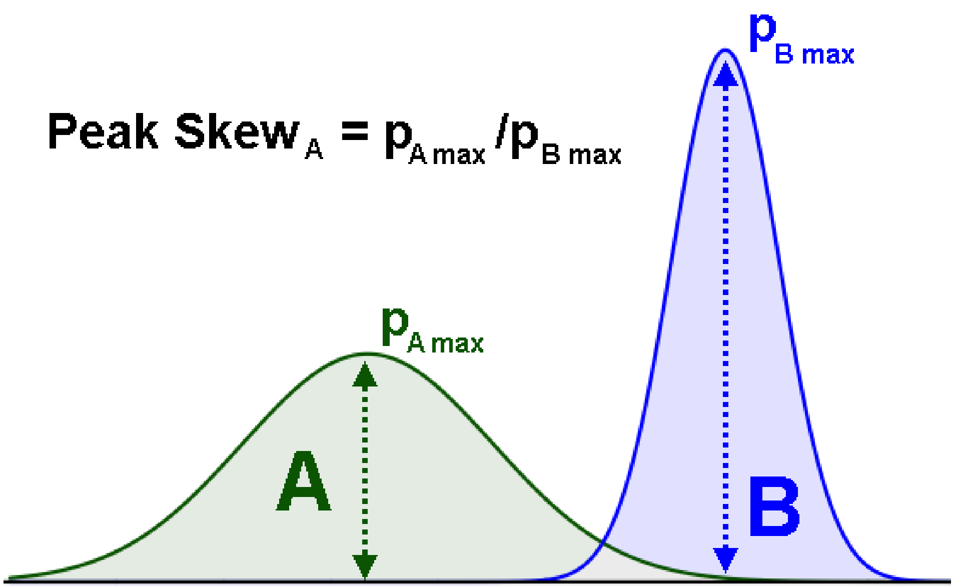


Figure 4: Illustration of Peak skew calculations for two hypothetical ethnic groups A and B. Ethnic group A has a wider geographic spread, and consequently has a flatter distribution with lower proportions of its total population in one place, compared to ethnic group B. Peak skew is calculated by determining the ratio of the values of the maximum peaks.

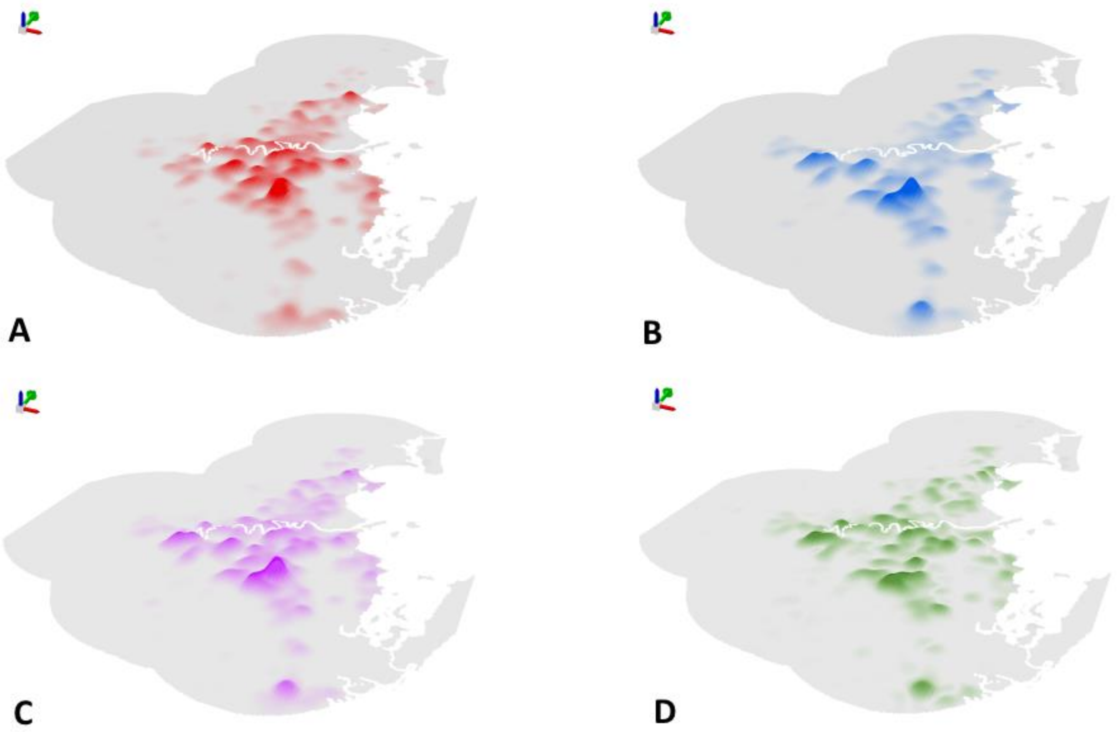


Figure 5: Example ethnic kernel density estimates for Brisbane at Bandwidth = 2.5km. (A) Sub Saharan Africa; (B) Oceanian; (C) Maximum Value for either of the two surfaces; (D) Absolute Difference between the two surfaces. The Absolute Difference surface provides a useful visualisation of the location and magnitude of segregation between the two populations.

	Oceania	S C Asian	Americas	S S African	N W Euro	S E Euro	S E Asian	N E Asian	Jewish	ME/NA	Indigenous	Australian
Oceania		0.594	0.546	0.493	0.480	0.529	0.491	0.711	0.867	0.576	0.497	0.464
S C Asian	0.529		0.446	0.449	0.525	0.388	0.429	0.424	0.785	0.350	0.635	0.542
Americas	0.417	0.469		0.449	0.417	0.348	0.486	0.533	0.761	0.410	0.623	0.448
S S African	0.433	0.442	0.433		0.454	0.409	0.481	0.593	0.801	0.429	0.578	0.459
N W Euro	0.313	0.554	0.341	0.398		0.324	0.543	0.631	0.812	0.555	0.559	0.092
S E Euro	0.498	0.406	0.453	0.433	0.466		0.464	0.532	0.783	0.423	0.598	0.351
S E Asian	0.583	0.499	0.531	0.492	0.620	0.586		0.575	0.826	0.435	0.550	0.546
N E Asian	0.572	0.369	0.483	0.527	0.589	0.437	0.604		0.815	0.455	0.745	0.647
Jewish	0.828	0.815	0.836	0.831	0.830	0.830	0.874	0.784		0.784	0.871	0.824
ME/NA	0.436	0.339	0.375	0.393	0.425	0.413	0.546	0.415	0.796		0.617	0.569
Indigenous	0.543	0.554	0.591	0.506	0.586	0.633	0.526	0.674	0.858	0.552		0.543
Australian	0.299	0.537	0.340	0.390	0.081	0.455	0.602	0.580	0.827	0.410	0.574	

BRISBANE

ADELAIDE

	Oceania	S C Asian	Americas	S S African	N W Euro	S E Euro	S E Asian	N E Asian	Jewish	ME/NA	Indigenous	Australian
Oceania		0.340	0.269	0.278	0.194	0.272	0.243	0.281	0.828	0.452	0.544	0.205
S C Asian	0.427		0.349	0.251	0.385	0.260	0.324	0.290	0.734	0.336	0.600	0.417
Americas	0.365	0.352		0.333	0.325	0.250	0.340	0.260	0.831	0.439	0.554	0.366
S S African	0.349	0.267	0.315		0.371	0.220	0.237	0.235	0.773	0.358	0.585	0.363
N W Euro	0.229	0.405	0.313	0.309		0.338	0.352	0.390	0.865	0.550	0.494	0.122
S E Euro	0.255	0.381	0.327	0.321	0.210		0.261	0.141	0.788	0.360	0.556	0.371
S E Asian	0.371	0.278	0.270	0.268	0.325	0.341		0.241	0.799	0.399	0.562	0.350
N E Asian	0.489	0.308	0.332	0.381	0.460	0.424	0.308		0.795	0.330	0.574	0.413
Jewish	0.800	0.748	0.750	0.790	0.770	0.764	0.772	0.728		0.670	0.929	0.865
ME/NA	0.420	0.329	0.342	0.313	0.347	0.358	0.276	0.363	0.759		0.672	0.555
Indigenous	0.498	0.637	0.612	0.578	0.532	0.533	0.575	0.692	0.830	0.624		0.515
Australian	0.225	0.412	0.333	0.312	0.097	0.204	0.324	0.476	0.792	0.347	0.520	

DARWIN

CANBERRA

	Oceania	S C Asian	Americas	S S African	N W Euro	S E Euro	S E Asian	N E Asian	Jewish	ME/NA	Indigenous	Australian
Oceania		0.427	0.417	0.419	0.560	0.537	0.517	0.660	0.912	0.594	0.714	0.544
S C Asian	0.503		0.435	0.410	0.578	0.483	0.502	0.526	0.909	0.571	0.725	0.553
Americas	0.380	0.439		0.371	0.439	0.423	0.483	0.560	0.868	0.596	0.719	0.443
S S African	0.484	0.336	0.473		0.536	0.507	0.519	0.579	0.885	0.629	0.718	0.517
N W Euro	0.302	0.536	0.425	0.535		0.493	0.661	0.586	0.871	0.684	0.751	0.104
S E Euro	0.341	0.351	0.390	0.405	0.338		0.560	0.574	0.889	0.476	0.693	0.464
S E Asian	0.486	0.305	0.463	0.415	0.527	0.351		0.619	0.936	0.630	0.694	0.649
N E Asian	0.562	0.508	0.492	0.639	0.597	0.557	0.479		0.895	0.698	0.765	0.594
Jewish	0.894	0.860	0.881	0.911	0.905	0.883	0.866	0.843		0.931	0.962	0.879
ME/NA	0.543	0.261	0.451	0.418	0.590	0.385	0.314	0.435	0.870		0.707	0.667
Indigenous	0.698	0.732	0.706	0.730	0.645	0.680	0.690	0.799	0.983	0.751		0.748
Australian	0.352	0.569	0.482	0.571	0.113	0.381	0.559	0.639	0.920	0.622	0.628	

MELBOURNE

HOBART

	Oceania	S C Asian	Americas	S S African	N W Euro	S E Euro	S E Asian	N E Asian	Jewish	ME/NA	Indigenous	Australian
Oceania		0.530	0.476	0.484	0.590	0.461	0.440	0.630	0.905	0.530	0.549	0.532
S C Asian	0.554		0.597	0.508	0.639	0.573	0.567	0.569	0.912	0.571	0.726	0.602
Americas	0.486	0.494		0.475	0.422	0.365	0.505	0.568	0.829	0.580	0.644	0.443
S S African	0.416	0.409	0.417		0.467	0.507	0.564	0.614	0.799	0.634	0.707	0.443
N W Euro	0.335	0.548	0.347	0.388		0.489	0.663	0.624	0.835	0.722	0.688	0.180
S E Euro	0.527	0.506	0.412	0.438	0.439		0.533	0.544	0.870	0.541	0.669	0.466
S E Asian	0.518	0.386	0.534	0.407	0.542	0.467		0.638	0.911	0.484	0.656	0.632
N E Asian	0.641	0.329	0.516	0.520	0.601	0.584	0.523		0.850	0.646	0.782	0.633
Jewish	0.898	0.863	0.851	0.868	0.880	0.824	0.851	0.864		0.937	0.910	0.863
ME/NA	0.575	0.378	0.542	0.407	0.584	0.523	0.312	0.478	0.845		0.742	0.688
Indigenous	0.582	0.634	0.689	0.620	0.653	0.669	0.544	0.710	0.915	0.601		0.661
Australian	0.326	0.531	0.358	0.395	0.110	0.416	0.520	0.592	0.882	0.578	0.634	

SYDNEY

PERTH

Figure 6: *S* Index matrices for 8 Capital City study areas in Australia between 12 Ethnic Groups, at bandwidth = 2.5km. Colours range from green (low S Index value) to red (high S Index value) within each city.

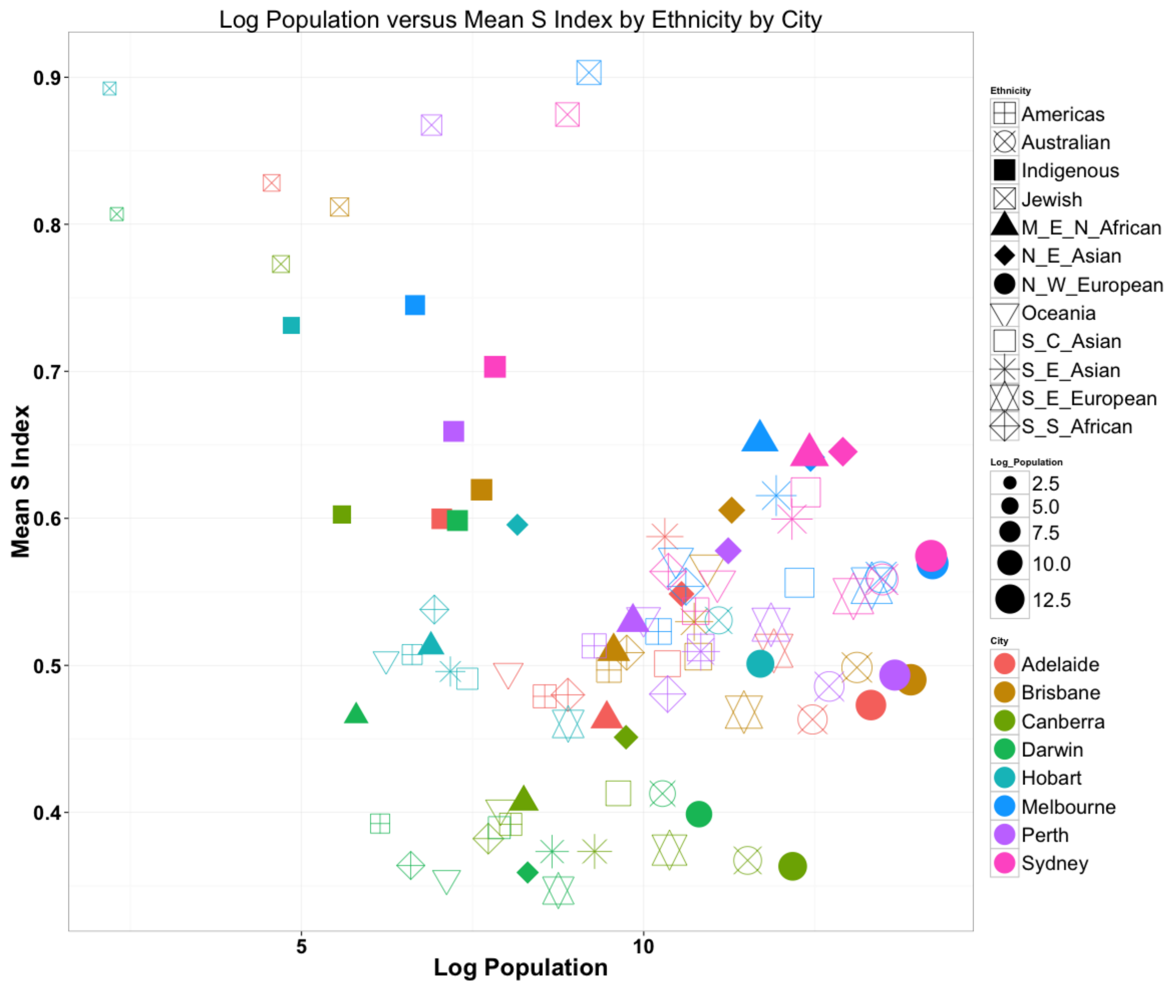


Figure 7: Plot of Log Population Size versus Mean S Index value for each of 12 ethnic groups (shape) for each capital city (colour) for bandwidth = 2.5km

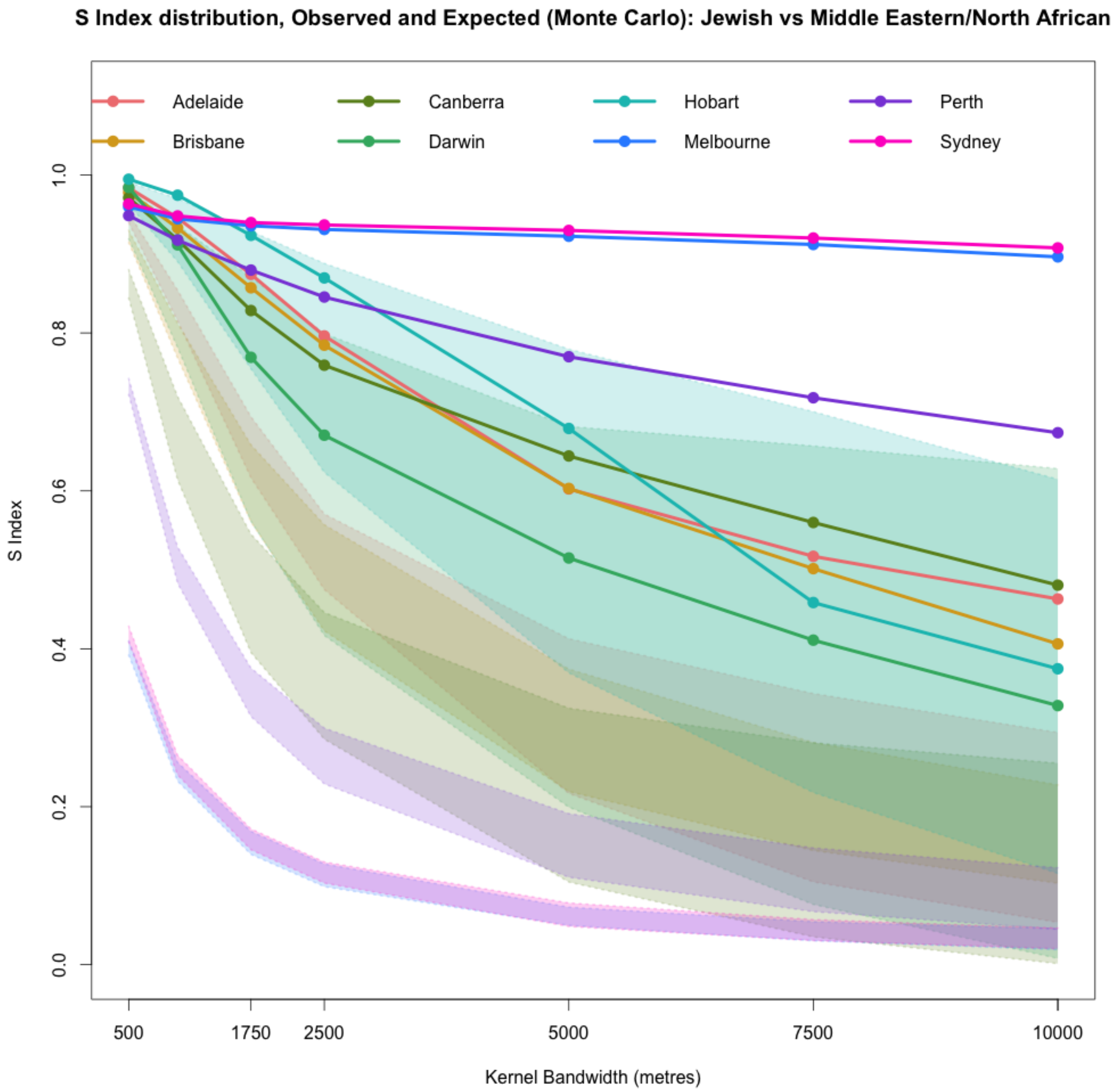


Figure 8: Observed (solid lines) and Expected (transparent bands) *S* index values for Jewish vs Middle Eastern and North African pairwise comparison across all eight capital cities for all kernel bandwidths. Only Darwin and Hobart's observed values all within the range expected by a completely spatially random process, as determined by Monte Carlo simulations

	Oceania	S(C(Asian	Americas	S(S(African	N(W(Euro	S(E(Euro	S(E(Asian	N(E(Asian	Jewish	ME/NA	Indigenous	Australian
Oceania		0.725	1.427	0.740	1.774	1.724	0.535	0.773	0.129	0.665	0.537	2.806
S(C(Asian	1.380		1.969	1.021	2.447	2.379	0.738	1.067	0.178	0.918	0.741	3.872
Americas	0.701	0.508		0.519	1.243	1.209	0.375	0.542	0.091	0.466	0.376	1.967
S(S(African	1.352	0.980	1.928		2.397	2.330	0.723	1.045	0.175	0.899	0.726	3.793
N(W(Euro	0.564	0.409	0.804	0.417		0.972	0.301	0.436	0.073	0.375	0.303	1.582
S(E(Euro	0.580	0.420	0.827	0.429	1.029		0.310	0.449	0.075	0.386	0.311	1.628
S(E(Asian	1.871	1.356	2.669	1.384	3.318	3.225		1.447	0.242	1.244	1.004	5.249
N(E(Asian	1.293	0.937	1.844	0.957	2.293	2.229	0.691		0.167	0.860	0.694	3.628
Jewish	7.745	5.613	11.049	5.730	13.737	13.353	4.140	5.991		5.151	4.159	21.734
ME/NA	1.504	1.090	2.145	1.113	2.667	2.593	0.804	1.163	0.194		0.807	4.220
Indigenous	1.862	1.350	2.657	1.378	3.303	3.211	0.996	1.441	0.240	1.238		5.226
Australian	0.356	0.258	0.508	0.264	0.632	0.614	0.190	0.276	0.046	0.237	0.191	

SYDNEY — PEAK(SKEW

	Oceania	S(C(Asian	Americas	S(S(African	N(W(Euro	S(E(Euro	S(E(Asian	N(E(Asian	Jewish	ME/NA	Indigenous	Australian
Oceania		0.864	1.036	0.514	1.695	1.648	0.546	0.419	0.084	0.348	0.538	2.259
S(C(Asian	1.157		1.199	0.595	1.961	1.907	0.631	0.484	0.097	0.402	0.623	2.613
Americas	0.965	0.834		0.496	1.636	1.590	0.527	0.404	0.081	0.336	0.519	2.180
S(S(African	1.945	1.681	2.016		3.297	3.206	1.062	0.814	0.163	0.677	1.047	4.394
N(W(Euro	0.590	0.510	0.611	0.303		0.972	0.322	0.247	0.049	0.205	0.317	1.333
S(E(Euro	0.607	0.524	0.629	0.312	1.028		0.331	0.254	0.051	0.211	0.327	1.371
S(E(Asian	1.833	1.584	1.899	0.942	3.106	3.020		0.767	0.153	0.637	0.986	4.139
N(E(Asian	2.389	2.065	2.476	1.228	4.050	3.938	1.304		0.200	0.831	1.286	5.397
Jewish	11.958	10.335	12.390	6.147	20.267	19.706	6.525	5.005		4.159	6.434	27.008
ME/NA	2.875	2.485	2.979	1.478	4.873	4.738	1.569	1.203	0.240		1.547	6.494
Indigenous	1.859	1.606	1.926	0.955	3.150	3.063	1.014	0.778	0.155	0.646		4.198
Australian	0.443	0.383	0.459	0.228	0.750	0.730	0.242	0.185	0.037	0.154	0.238	

MELBOURNE — PEAK(SKEW

	Oceania	S(C(Asian	Americas	S(S(African	N(W(Euro	S(E(Euro	S(E(Asian	N(E(Asian	Jewish	ME/NA	Indigenous	Australian
Oceania		1.189	0.677	1.189	2.641	1.589	0.451	0.540	0.329	0.952	0.798	3.638
S(C(Asian	0.841		0.569	1.000	2.221	1.337	0.379	0.455	0.277	0.801	0.671	3.060
Americas	1.477	1.756		1.755	3.900	2.347	0.666	0.798	0.486	1.406	1.179	5.373
S(S(African	0.841	1.000	0.570		2.222	1.337	0.379	0.455	0.277	0.801	0.672	3.061
N(W(Euro	0.379	0.450	0.256	0.450		0.602	0.171	0.205	0.125	0.360	0.302	1.378
S(E(Euro	0.629	0.748	0.426	0.748	1.662		0.284	0.340	0.207	0.599	0.502	2.289
S(E(Asian	2.219	2.638	1.502	2.637	5.860	3.527		1.199	0.730	2.112	1.771	8.072
N(E(Asian	1.851	2.200	1.253	2.199	4.887	2.941	0.834		0.609	1.761	1.477	6.732
Jewish	3.039	3.612	2.057	3.611	8.024	4.829	1.369	1.642		2.892	2.426	11.053
ME/NA	1.051	1.249	0.711	1.249	2.774	1.670	0.473	0.568	0.346		0.839	3.822
Indigenous	1.253	1.489	0.848	1.489	3.308	1.991	0.565	0.677	0.412	1.192		4.557
Australian	0.275	0.327	0.186	0.327	0.726	0.437	0.124	0.149	0.090	0.262	0.219	

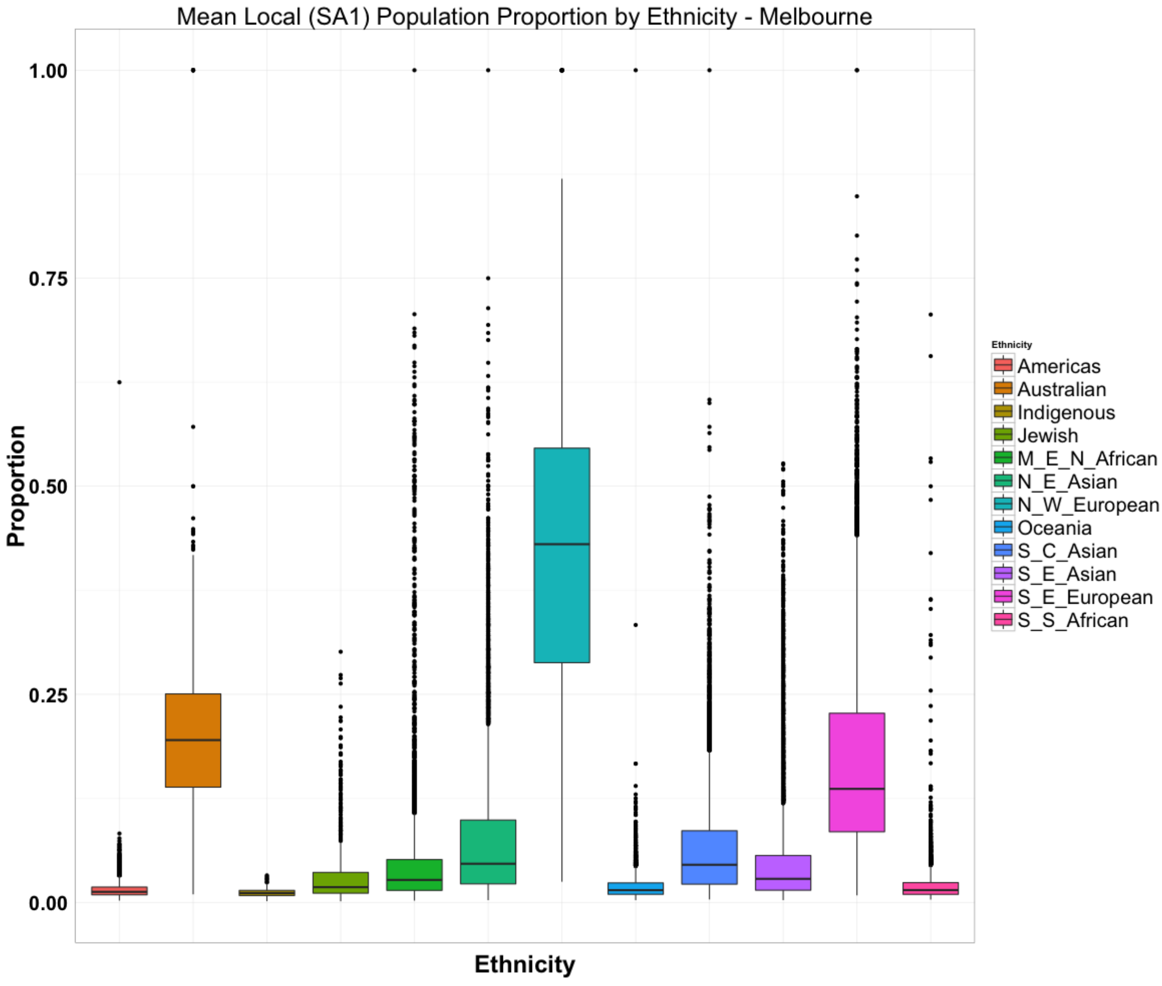
BRISBANE — PEAK(SKEW

	Oceania	S(C(Asian	Americas	S(S(African	N(W(Euro	S(E(Euro	S(E(Asian	N(E(Asian	Jewish	ME/NA	Indigenous	Australian
Oceania		0.640	0.684	0.845	1.635	0.596	0.466	0.544	0.066	0.394	0.492	1.635
S(C(Asian	1.561		1.068	1.320	2.552	0.931	0.727	0.850	0.104	0.615	0.768	2.553
Americas	1.462	0.936		1.236	2.389	0.872	0.681	0.796	0.097	0.575	0.719	2.390
S(S(African	1.183	0.758	0.809		1.933	0.705	0.551	0.644	0.079	0.466	0.582	1.934
N(W(Euro	0.612	0.392	0.419	0.517		0.365	0.285	0.333	0.041	0.241	0.301	1.000
S(E(Euro	1.677	1.074	1.147	1.418	2.741		0.781	0.913	0.111	0.660	0.824	2.742
S(E(Asian	2.147	1.375	1.469	1.815	3.510	1.281		1.169	0.143	0.845	1.056	3.511
N(E(Asian	1.837	1.176	1.256	1.553	3.002	1.095	0.855		0.122	0.723	0.903	3.003
Jewish	15.041	9.632	10.289	12.716	24.584	8.969	7.004	8.190		5.921	7.394	24.595
ME/NA	2.540	1.627	1.738	2.148	4.152	1.515	1.183	1.383	0.169		1.249	4.154
Indigenous	2.034	1.303	1.391	1.720	3.325	1.213	0.947	1.108	0.135	0.801		3.326
Australian	0.612	0.392	0.418	0.517	1.000	0.365	0.285	0.333	0.041	0.241	0.301	

PERTH — PEAK(SKEW

Figure 9 Peak Skew figures for the four largest capital cities (Sydney, Melbourne, Brisbane and Perth) Rows indicate the ratio of that ethnic group as P_{Amax}, (i.e. numerator) with row values higher than 1 indicating that ethnic group is substantially higher than P_{Bmax} (i.e. denominator)

Figure 10: Plot of Log Population Size versus Log Mean Peak Skew value for each of 12 ethnic groups (shape) for each capital city (colour) for bandwidth = 2.5km.



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533 Figure 11: Box Plots of proportional contribution to local (SA1) populations for each ethnic

534 groups across Melbourne.

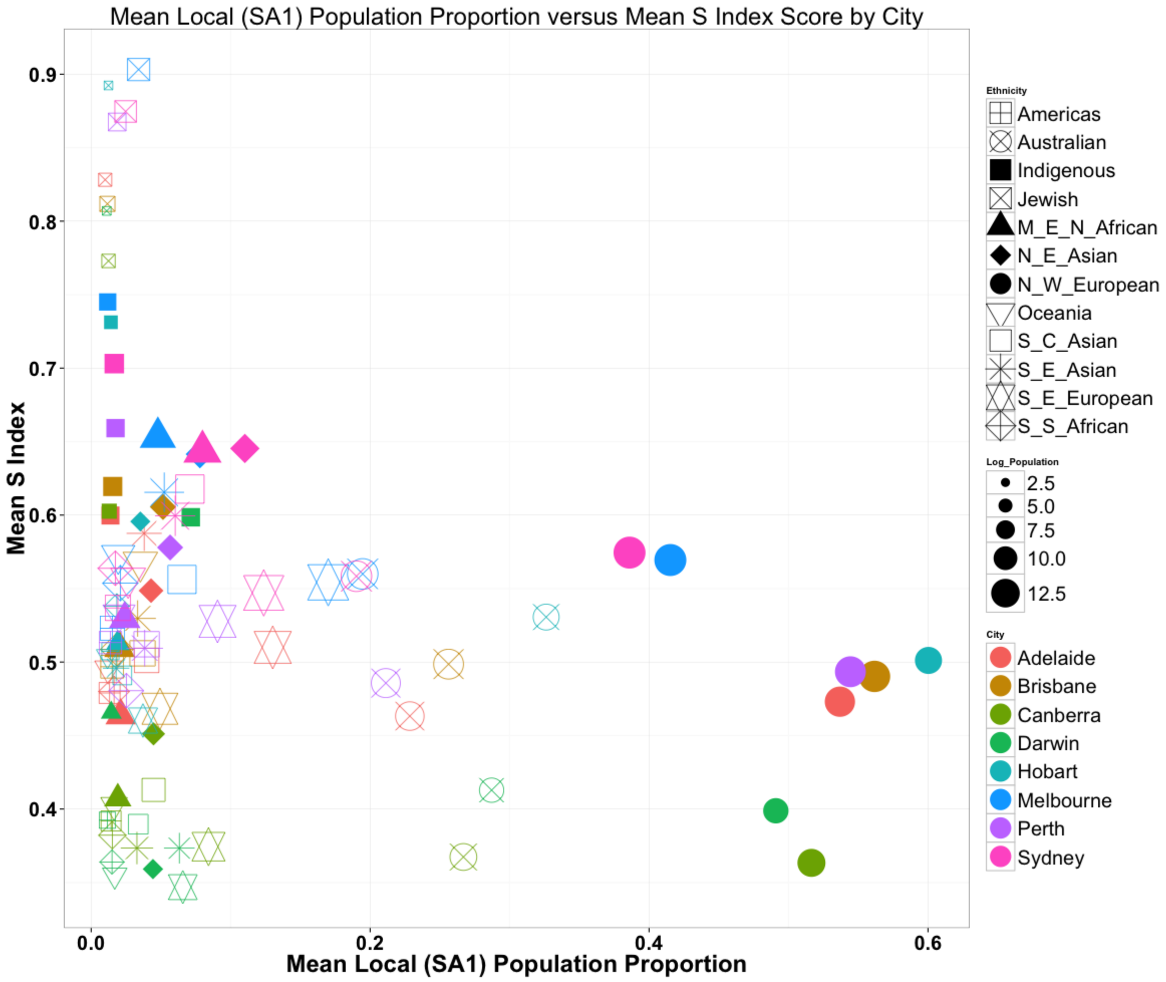

Figure 12: Plot of Mean Local (SA1) Population Proportion versus Mean S Index value for each of 12 ethnic groups (shape) for each capital city (colour).

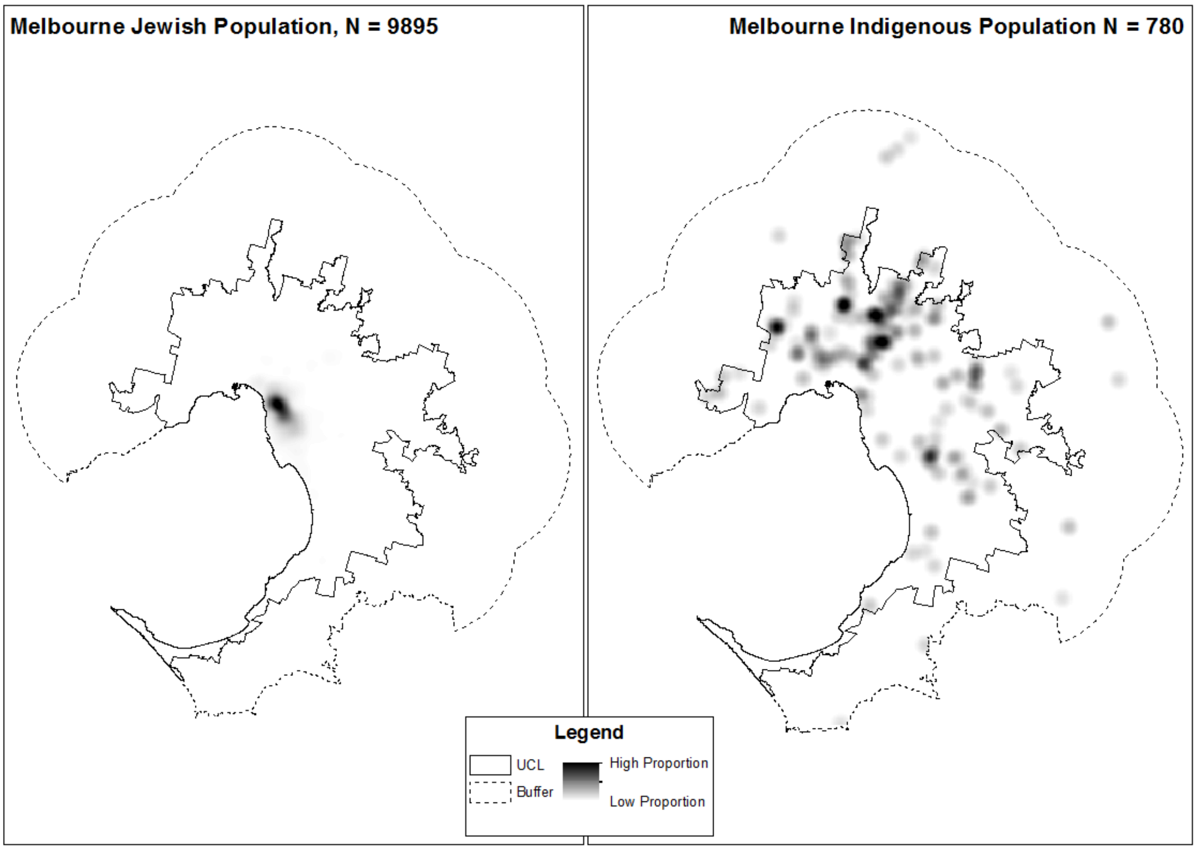

Figure 11: Comparisons of population distributions for Melbourne's Jewish (left) and Indigenous (right) populations (bandwidth = 2.5km)

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