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Measuring spatial accessibility to primary health care services: Utilising dynamic catchment sizes

Matthew R. McGrail [a], [b], [*], John S. Humphreys [a]

[a] Centre of Research Excellence in Rural and Remote Primary Health Care, School of Rural Health, Monash University, PO Box 666, Bendigo, Victoria 3552, Australia
[b] School of Rural Health, Monash University, Northways Road, Churchill, Victoria 3842, Australia

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ABSTRACT

The two-step floating catchment area (2SFCA) method continues to be a popular measure of spatial accessibility, especially in relation to primary-level health care. Despite its popularity, most applications of the 2SFCA method are limited by the utilisation of only a single catchment size within a small geographic area. This limitation is significant to health policies which are mostly applied at the state or national scale. In this paper, a five-level dynamic catchment size was trialled within the 2SFCA method to all of Australia, with a population's remoteness used to delineate increasing catchment sizes. Initial trial results highlighted two perverse outcomes which were caused by sudden changes in catchment sizes between each level. Further refinement led to trialling an additional three-level catchment sub-type to the 2SFCA method, which created a smoother transition between remoteness levels. This study has demonstrated an effective approach to dynamically apply variable and more appropriate catchment sizes into different types of rural areas, which for the first time enables the 2SFCA method to be suitable for national-level access modelling and its potential application to health policy.

Introduction

Good access to health care for all populations, regardless of geography, remains a key goal of governments and societies internationally (Dussault & Franceschini, 2006; World Health Organization, 1978, 2010). Rural communities, despite being characterised by poorer health status and increased need for health care, often experience the greatest access barriers (Australian Institute of Health and Welfare, 2008; Humphreys & Solarsh, 2008). These barriers faced by rural communities include reduced service availability, limited choice of preferred characteristics of both services and providers, and the need for greater travel to access health care (Russell et al., 2013; Wakerman & Humphreys, 2012).

Access to health care services is often modelled using catchments to define regions where utilisation of health care services occurs (Guagliardo, 2004; Luo & Whippo, 2012; McGrail, 2012). Catchment sizes delimit how far geographically services are delivering health care to patients, and, at the same time, determine how far populations are prepared to travel to access the services on offer. Catchment limits are especially important for primary health care (PHC), the key health service entry point for residents of rural communities. Generally, residents are free to choose where they access PHC services from. However, increased travel distance to access more service options often leads to a trade-off between convenience and choice. Distance and geographical isolation are foremost health care access barriers (Arcury, Gesler, Preisser, & Sherman, 2005; Chan, Hart, & Goodman, 2006; Sibley & Weiner, 2011), and most residents prefer not to travel further than required. Whilst many studies suggest that individuals in more remote settings accept lengthy travel as a routine part of their lives (Kwan & Weber, 2003; Sherman, Spencer, Preisser, Gesler, & Arcury, 2005), few have specifically investigated the variability of distance tolerance of rural residents in relation to accessing their usual PHC service (Buzza et al., 2011; Shannon, Lovett, & Bashshur, 1979; Tanser, Gijsbertsen, & Herbst, 2006).

The two-step floating catchment area (2SFCA) method has grown in prominence in the last 10 years, notably as a measure of

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[*] Corresponding author. School of Rural Health, Monash University, Northways Road, Churchill, Victoria 3842, Australia. Tel.: +61 03 51227394; fax: +61 03 51227841.

E-mail addresses: matthew.mcgrail@monash.edu (M.R. McGrail), john.humphreys@monash.edu (J.S. Humphreys).

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spatial access to PHC (Luo & Qi, 2009; Luo & Wang, 2003; McGrail & Humphreys, 2009a). A key feature of the 2SFCA method is its use of catchments that are centred on actual population and service locations (Luo & Whippo, 2012; McGrail, 2012; McGrail & Humphreys, 2009b; Wan, Zou, & Sternberg, 2012). This improvement notwithstanding, however, most applications of the 2SFCA method are limited by their utilisation of only a single catchment size. Furthermore, most demonstrations of the 2SFCA method have been contained to small geographical areas such that limitations of using a single catchment size could be ignored (Bell, Wilson, Bissonnette, & Shah, 2013; Ngui & Apparicio, 2011; Wang & Tormala, 2014). The aim of this paper is to critically appraise how dynamic catchment sizes can be employed in the 2SFCA method. Moreover, this paper aims to demonstrate that dynamic catchment sizes are a critical component of the 2SFCA method for large scale access modelling.

Background

Improved access measurement through the 2SFCA method

Access to healthcare is multidimensional, with access barriers consisting of both spatial and aspatial dimensions (Khan & Bhardwaj, 1994; Russell et al., 2013; Wang & Luo, 2005). Spatial accessibility in healthcare refers to the ease that populations can utilise health services, with an emphasis on proximity and population demand (Joseph & Bantock, 1982; Luo & Wang, 2003). Spatial accessibility measures capture both the geography separation between the population and services and the size of the population competing for limited available services. Historically, three approaches dominate measures of spatial accessibility. Firstly, travel impedance (distance or time) to the nearest service is a simple approach (Rosero-Bixby, 2004) but ignores the common behaviour in healthcare access of bypassing (Hyndman, Holman, & Pritchard, 2003) as well as not accounting for demand. Secondly, the gravity model introduces the two concepts of diminishing 'attractiveness' with increased distance, and demand from the population for limited services (Guagliardo, 2004; Joseph & Bantock, 1982; Luo & Wang, 2003), but its decay function is questionable and difficult to define.

The third approach of 'crude' provider-to-population ratios (PPRs) has long been used to differentiate access to health care between regions (Primary Health Care Research & Information Service, 2012; World Health Organization, 2013). PPRs are calculated for pre-defined regions (such as Local Government boundaries or Counties) such that residents are assumed to access services only from within their region. However, PPRs are often condemned as highly-simplistic measures lacking specificity and accuracy. In particular, PPRs are criticised because they ignore any effect of increased distance on reduced access and because they assume that population demand will only occur within their region (Guagliardo, 2004; McGrail & Humphreys, 2009b).

Elements of all three approaches are brought together in the two-step floating catchment area (2SFCA) method. A key additional feature of the 2SFCA method is that catchments used in its calculation are centred on each individual service and population location. Within Step 1 (which focuses on service catchments), the 2SFCA method calculates potential service demand by identifying all population locations with potential access to that service. These populations are identified by measuring a fixed radius (maximum time or distance) from the service location and aggregating all population locations that fall within its catchment. Similarly, Step 2 (which focuses on population catchments) calculates potential utilisation by identifying all service locations that fall within a fixed radius (maximum time or distance) from the population location. In combination, Steps 1 and 2 measure the "fit" between services and the population. However, whilst these "floating catchments" undeniably improve access methodology by using more accurate points of access origin and destination, the 2SFCA method still suffers from limited evidence as to the most appropriate catchment size(s) to apply.

Although not part of the original 2SFCA method, there is now almost universal agreement that a distance-decay function is an essential additional component of the 2SFCA method (Luo & Qi, 2009; McGrail, 2012). These additional components ($f(d_{jk})$ in Step 1 and $f(d_{ij})$ in Step 2) infer that the likelihood of access between a population and a service diminishes as distance separation increases up to the catchment border and is assumed to be zero for anywhere beyond this. A brief summary of the 2SFCA method (Steps 1 and 2), with the inclusion of a distance-decay function, is given below and its calculation follows the general process detailed elsewhere (Luo & Qi, 2009; McGrail, 2012; Wang & Luo, 2005).

Step 1. Calculate service catchments – for each provider or service location (j) of volume S_j, determine what population size (summed P_k) can potentially access that provider (up to the catchment border = d_{max}) and calculate the ratio of providers to the population (R_j).

$$R_j = S_j \Big/ \sum k \in \left[d_{jk} < d_{max}\right] P_k * f\left(d_{jk}\right)$$

Step 2. Calculate population catchments – for each population location (i), determine what services (j) can potentially be accessed by that population (up to the catchment border = d_{max}), and aggregate the PPRs for these services (R_j) as calculated in Step 1. A_i = access score for each location (i).

$$A_i = \sum j \in [d_{ij} < d_{max}] R_j * f(d_{ij})$$

Distance decay functions $f(d_{jk})$ and $f(d_{ij})$ are additionally shown here (range: between 1 = no distance decay/full access, and 0 = full distance decay/no access).

Applying dynamic catchment sizes to the 2SFCA method

Besides distance-decay, a second additional component for the 2SFCA method is the use of multiple or dynamically-defined catchment sizes – that is, different sized catchments within the same model for different regions or population subgroups. Only a few studies so far have tested the use of any dynamic catchment sizes (Luo & Whippo, 2012; McGrail, 2012) within the 2SFCA method. Unfortunately, these studies have either only split the population into two types, rural or metropolitan, or applied dynamic catchments only within metropolitan areas. Notably, these simple approaches to dynamic catchments mean that all rural populations are assumed to be one homogeneous group in their propensity to utilise health services with respect to distance barriers. This assumption of homogeneous behaviour has not been a major concern, to date, because most studies using the 2SFCA method have only investigated small geographic regions or metropolitan-only populations.

Many authors of studies utilising the 2SFCA method have concluded with recommendations their method better identifies low access areas and should be used in government health policies (Luo & Whippo, 2012; McGrail & Humphreys, 2009c; Wan et al., 2012; Wang & Luo, 2005). However, most health policies target a much broader geographic scale than “small areas” such as within these studies – that is, they are usually applied at the national level. Hence the consequences of using a single catchment size such that all rural populations are assumed to be one homogeneous group in their propensity to utilise health services with respect to distance barriers, are mostly untested at this large geographic scale.

The choice of catchment size within the 2SFCA method impacts on the resultant access score in two different ways. Firstly, an increased catchment size will increase the number of locations that can be accessed by a population when applied to Step 2. Similarly, a larger catchment size will increase the population with potential access to services when applied to Step 1. Secondly, but less obviously, an increase to the catchment size will reduce the effect of the distance-decay function. For example, if the maximum catchment is 45 min, and the distance separation is 30 min then the decay function applied (assuming simple linear decay) equals 0.33 because 30 min is 2/3 distance to the upper limit of 45 min. Therefore, if the maximum catchment was increased to 60 min then for the same location a decay function of 0.50 would apply. In this scenario, the second access score would be 50% higher solely on the basis of the choice of maximum catchment (60 min rather than 45 min) and its resultant effect on the distance decay function.

Clearly, as population dispersion increases, larger travel distances are required both within and between regions. Access to health services similarly follows this pattern, with greater travel times required to access nearby options in more dispersed areas. Rural Australia, the focus of this paper, consists of vast size and contrasting population densities with rural populations experiencing large differences in distance barriers depending on what level of “remoteness” characterises their area. Thus, it is reasonable that access catchments, when applied within the 2SFCA method, should also increase in size as remoteness increases. What follows reports the results of a study that trials the design and inclusion of dynamic catchment sizes in line with increased remoteness to a national-level application of the 2SFCA method in Australia.

Methods

Study area and data requirements

This study reported here was part of a larger research project that sought to develop a national-level Index of Access to general practitioner (GP) services in Australia (CRERRPHC, 2014). Data were collected for all of Australia from four sources. First, the number of GP services (fulltime equivalent counts) at each distinct rural community, as defined by the ABS's urban centres/localities geography (Australian Bureau of Statistics, 2011a), was collected for July 2011 to June 2012 from the Medicare Benefits Schedule (Australian Government). Secondly, metropolitan GP service counts per postcode were collected from the Australasian Medical Publishing Company as at April 2012. Thirdly, population locations and sizes were collected from the Australian Bureau of Statistics' 2011 census data, with Statistical Area level 1 (SA1) used in rural areas (each SA1 contains an average of 400 residents) and SA2 in metropolitan areas. The fourth data component was the national road network, supplied by MapData Services Australia.

Utilisation of dynamic catchment sizes within the 2SFCA method is defined by two key questions – (i) how are ‘break-points’ defined for different catchment sizes; and (ii) what size should these different catchments be set at? In Australia, the Australian Statistical Geography Standard – Remoteness Area (ASGS-RA) structure is defined by the Australian Bureau of Statistics (ABS) each census period to differentiate 5 levels of geographical remoteness nationally (Australian Bureau of Statistics, 2003, 2011b). Table 1 summarises the characteristics of the 5 levels (RA-1 to RA-5), from Major City down to Very Remote areas which decrease in accessibility and population size and increase in remoteness, area and population dispersion. These 5 levels provide an easy-to-apply and appropriate definition of break-points for different catchment sizes to apply within the 2SFCA method. A second ABS-defined geography level is SA2 (average population of about 10,000 residents) which are designed to represent “communities that interact together socially and economically” (Australian Bureau of Statistics, 2011a). Table 1 shows that a large majority of rural residents live in “inner regional” or “outer regional” catchment areas, where the average SA2 community size notably increase in size from about 26 km^2 to 54 km^2. Furthermore, only 2.3% of Australians live in remote areas which cover 86% of its land and SA2 communities increase in size to about 135 km^2 and 316 km^2 (Australian Bureau of Statistics, 2011c). These sizes provide some guidance to the relative change in catchment size that might apply to each of the 5 remoteness levels.

Using ArcView 9.1, the ‘Closest Facility’ tool of the Network Analysis module was used to determine network routes and calculate proximity between population locations and service locations. Travel time, rather than distance, was used as the measure of impedance by combining road section lengths and approximate travel speeds. Guided by the average SA2 sizes in Table 1, all national proximity data between residents and services were collected up to 60 min in metropolitan areas, 120 min in rural/regional areas and 240 min in remote areas. With the exception of the state of Tasmania, all islands were removed from access calculations. Finally, proximity data were imported into Microsoft Access 2010 to complete the 2SFCA method calculations.

Setting dynamic catchment sizes for national-level application

Empirical data on how far different population groups travel when accessing non-emergency health care are scarce. For that reason, a small study was undertaken in 2012 to test whether there were significant differences in travel behaviour of rural residents between closely settled (“inner regional”) areas compared with residents of more sparsely settled (“outer regional”) areas (see Table 1, categories ASGS-2 and ASGS-3). Parallelling Shannon et al.'s

Table 1
Geographic properties of the Australian Statistical Geography Standard – Remoteness Area (ASGS-RA) classification table.

ASGS-RA	RA label	Accessibility	Australia's population (%)	Population dispersion	Australia's area %	Density (persons per km^2)	Remoteness	Average SA2 size (km^2)
ASGS-1 (RA-1)	Major city	Most accessible	69.9%	Least dispersed	0.2%	794	Least remote	18 [4.3×4.3]
ASGS-2 (RA-2)	Inner regional	…	18.6%	…	3.2%	16.2	…	691 [26×26]
ASGS-3 (RA-3)	Outer regional	…	9.2%	…	10.2%	2.5	…	2876 [54×54]
ASGS-4 (RA-4)	Remote	…	1.4%	…	12.0%	0.3	…	18,143 [135×135]
ASGS-5 (RA-5)	Very remote	Least accessible	0.9%	Most dispersed	74.4%	0.03	Most remote	100,018 [316×316]

ASGS-RA = Australian Statistical Geography Standard – Remoteness Area.
SA2 = Statistical Area level 2.
Data aggregated from 2011 national census (Australian Bureau of Statistics, 2011c).

(1979) research, primary data on the maximum time that residents were willing to travel to see a doctor for a non-emergency from 5 small rural towns (<2500 population) in NSW and Victoria were collected. Each location was carefully selected from a sample frame on the basis of key criteria including: not being in the 'shadow' of a large rural town; having some resident health services within town, and having at least 3 nearby towns that provide alternative services from which to access health care.

The findings from this research showed a significant difference in maximum time respondents are prepared to travel to see a doctor for non-emergency health care – an average 32 min for residents of "inner regional" towns compared with 54 min for residents of "outer regional towns". Moreover, only 10% of residents of inner and outer regional towns were prepared to travel greater than 60 min and 120 min respectively. These data guided the decision for maximum catchments sizes to be 45 min for inner regional communities and 70 min for outer regional communities where populations and settlements were more dispersed. Additionally, the corresponding survival functions for these two groups confirmed that previously tested continuous distance-decay functions closely matched the observed utilisation behaviour data (McGrail, 2012; Wang, 2012).

Currently, similar empirical data for the two remote levels of Australia (RAs 4 and 5) are lacking. However, local knowledge and discussions with expert staff and remote area practitioners enabled the selection, with some confidence, of appropriate catchment sizes for these areas equal to 120 min (remote) and 200 min (very remote).

For major cities, the maximum catchment size was set at 30 min. However, an additional rule based on the number of intervening opportunities (see (McGrail & Humphreys, 2009a)) was already in place in metropolitan areas such that, in practice, major city catchments were limited to 10–15 min in most areas and the maximum catchment of 30 min only applied towards the border of this category.

Thus, in summary, primary health catchment sizes of 30, 45, 70, 120 and 200 min travel time were selected for the five ASGS-RA levels trialled in this study.

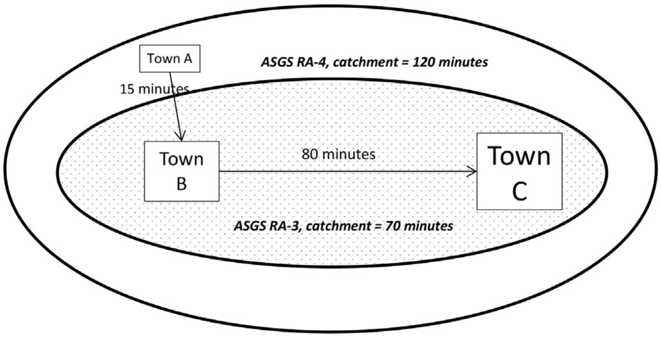
Trial dynamic catchment size results: identification of perverse outcomes

Using these 5 different catchment sizes defined by an area's "remoteness", initial testing of the 2SFCA method at both state and national level, was generally effective. During the trial phase, "effectiveness" was tested by a visual check of mapped access scores. A small number (under 5%) of results were identified as possibly incorrect, which were then further examined to determine if they fairly represented the data inputs (that is, the access score result was a true reflection of access in that area). Where results still appeared to be 'incorrect', they were further checked to see if they were an artefact of the introduced dynamic catchment sizes.

Our testing identified two types of perverse outcomes, directly caused by the introduction of dynamic catchment sizes, which are exemplified as case studies 1 and 2. Case study 1 is typical of more dispersed rural areas such as northern regions of Queensland, central New South Wales and southern regions of Western Australia, whilst Case study 2 is commonly seen in higher density rural areas such as much of Victoria and coastal regions of New South Wales.

Case study 1

In Fig. 1, residents of town B do not have access to services in town C because they are located 80 min away and the maximum catchment in their area is 70 min. However, residents of town A are located in an area with a maximum catchment of 120 min and must travel via town B to reach town C. This means that, perversely, town A's residents can access town C (95 min travel and via town B) whereas town B cannot travel to town C despite being 15 min closer than town A. Whilst town A's residents live in a more remote location and thus may be prepared to travel somewhat further than town B or C's residents, the difference is unlikely to be as large as 50 min as shown in this example. The large increase in catchment size between RA-3 and RA-4 in this example is problematic in areas close to the RA-3/RA-4 border.

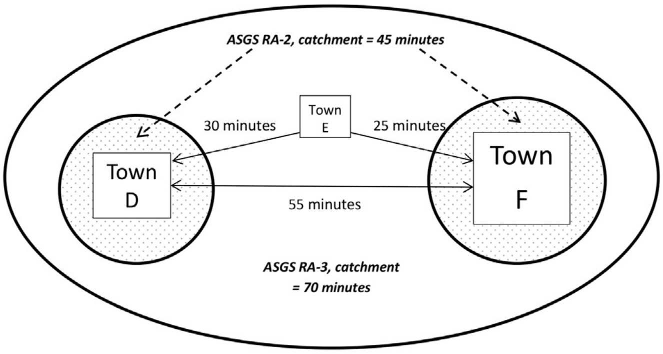


ASGS RA = Australian Statistical Geography Standard Remoteness Area;
Town box sizes are indicative of relative population size

Fig. 1. Example scenario resulting in perverse access scores for town A.

Case study 2

In Fig. 2, residents of towns D and F do not have access to services in each other's town because they are located 55 min apart, which is above the maximum catchment of 45 min in their areas. However, residents of town E are located in an area with a maximum catchment of 70 min, approximately midway between towns D and F and so they are modelled as having moderate access to both towns' services. Perversely, town E's residents are measured as having significantly higher access than either town D or F despite having no within-town services and travelling at least 25 min to reach their nearest services. The higher access score for town E is largely due to their higher maximum catchment which significantly reduces the distance-decay effect for that location. Both 25 and 30 min travel (to services in towns D and F) are less than half the maximum catchment of 70 min so that only a small distance-decay is applied and the net effect is for town E having the greatest access in this model.



ASGS RA = Australian Statistical Geography Standard Remoteness Area;
Town box sizes are indicative of relative population size

Fig. 2. Example scenario resulting in perverse access scores for town E.

The key problem within both cases (Figs. 1 and 2) is that there is a sudden increase to the higher catchment size at the edge of each remoteness category. In Fig. 1, the edge of RA-3 is located only about 10 min from the centre of town B. Town A, despite being located only 15 min from town B, is assumed to have significantly different travel behaviour (consistent with all RA-4 areas), with the maximum travel time significantly increasing to 120 min. More realistically, town A's population is likely to behave more similar to town B than to other populations within the RA-4 category. Similarly, in Fig. 2 it is likely that the town E population will have similar health utilisation behaviour to populations of the nearby towns D and F. In contrast, populations which are located well away from the remoteness level boundary are more likely to behave typically of other residents in that category. Both examples are common in rural areas of Australia and thus require a national-level adjustment. No other perverse outcomes were observed.

Redefining more appropriate dynamic catchment sizes

Case studies 1 and 2 demonstrate that, whilst it is reasonable to define catchments which increase in size with increasing remoteness to 'match' health seeking behaviour of these residents, a crude 5-level approach creates a few unintended outcomes. To address these, the most appropriate solution is to create a smoother transition between catchment sizes at remoteness level boundaries. Populations located proximal to 'less remote' boundaries (e.g. within RA-4 but nearby to RA-3, such as town A in Fig. 1) will behave similarly to the less remote population (RA-3). The proximity of a population to the catchment boundary is measured by aggregating all nearby services and measuring how many are located in the lower remoteness level. If most nearby services are located in the same remoteness level then that population must be located far from the lower RA-level boundary. In the refinement of the dynamic catchment sizes, three sub-types are defined using the following rules.

1. If most (>50%) nearby services are from the same (or higher) RA level then that location should have no reduction to its catchment size. E.g. if a population is located in RA-4 and 70% nearby services are also located in RA-4, then the catchment size is unchanged at 120 min.
2. If only some (25–50%) nearby services are from the same or higher RA level, then that location should have a moderate reduction (defined as 33% of the catchment size difference) to its catchment size. E.g. if RA-4 population and only 40% nearby services are also located in RA-4, then catchment size is moderated to: 120 (RA-4 size) − 50 (RA-4 to RA-3 difference) * 33% = 103.5 min.
3. If few (<25%) nearby services are from the same or higher RA level, then that location should have a significant reduction (defined as 66% of the catchment size difference) to its catchment size. E.g. if RA-4 population but 85% nearby services are located in RA-3 then catchment size is moderated to: 120 (RA-4 size) − 50 (RA-4 to RA-3 difference) * 66% = 87 min.

The distribution of nearby services by RA level is calculated by aggregating the volume of services for each community located within the catchment, after weighting each service by its distance separation within the catchment. Services close to the population are weighted highest whilst services close to the catchment boundary are weighted as nearly zero. For example, 8 services located at 75% distance towards the catchment boundary (e.g. 90 min if RA-4) are weighted 0.25 and contribute a score of 2 (that is, 8 * 0.25); alternatively, 5 services located only 20% distance are weighted 0.80 and contribute a score of 4.

The decisions to apply a linear reduction of catchment sizes, those being 0%, 33% and 66%, for each of the 3 sub-types, as well as to set 3 sub-types, were heuristic. There is minimal empirical evidence to guide these decisions; however, they are based on expert academic judgement. The result of applying these rules is a 5×3 level catchment size definition, shown in Table 2, which provides a smoother progression through the different remoteness levels and is more closely tied to expected travel behaviour. Also, it is seen in Table 2 that only 8–18% of areas within each RA-level are affected by this adjustment. A map of the different catchment size levels is also displayed in Fig. 3.

Updated trial dynamic catchment size results: removal of perverse outcomes

Table 3 summarises the calculated access scores for the 6 towns in Figs. 1 and 2. These access scores were calculated using 3 different catchment definitions, whilst all other elements of the 2SFCA method remained unchanged. The first column uses the original constant catchment size of 60 min; the second column uses a crude 5-level catchment size adjustment as defined in the last column of Table 2; and the third column uses the 5×3 level catchment size definition from Table 2.

The two key results are for town A and town E. In both locations, the addition of 5 catchment levels over a single 60 min catchment has seen their access score increase to be the highest of the 3 towns within their example whereas access scores in the remaining 4 towns all decreased. It is seen in Table 3 that the addition of 3 sub-types has redressed these perverse outcomes. The access score for town A is now, as expected, markedly lower than for both town B and C. Residents of town A can only access services via town B, approximately 15 min away, and so the result for town A has dropped significantly but the access scores for Towns B and C remain relatively constant. A similar correction has occurred in the second scenario, with town E seeing a significant drop in their access score whilst Towns D and F remained almost unchanged. Access in town E remains above the level of town D because, whilst its residents face a moderate distance barrier to either town D or town F, they still have some access to either town's services. Additionally, it is seen that town F has the highest access and town E, unlike town D, does have some access to these services.

Table 2
Trialled maximum primary health care catchment sizes (minutes) by remoteness (5 levels) and remoteness sub-type (3 levels).

	Type 1: few (<25%) nearby services located in same RA	Type 2: some (25–50%) nearby services located in same RA	Type 3: most (>50%) nearby services located in same RA
ASGS-1 (Major city)	N/A (default = 30)	N/A (default = 30)	30 min
ASGS-2 (Inner regional)	35.1 (4%)	40.1 (4%)	45 (92%)
ASGS-3 (Outer regional)	53.5 (10%)	61.7 (4%)	70 (86%)
ASGS-4 (Remote)	87.0 (12%)	103.5 (4%)	120 (84%)
ASGS-5 (Very remote)	147.2 (15%)	173.6 (3%)	200 (82%)

See 'Refining dynamic catchment sizes' section for further information regarding the definition of "few", "some" and "most".
Percentage values indicate how many areas are defined by each type.
ASGS-RA = Australian Statistical Geography Standard – Remoteness Area.

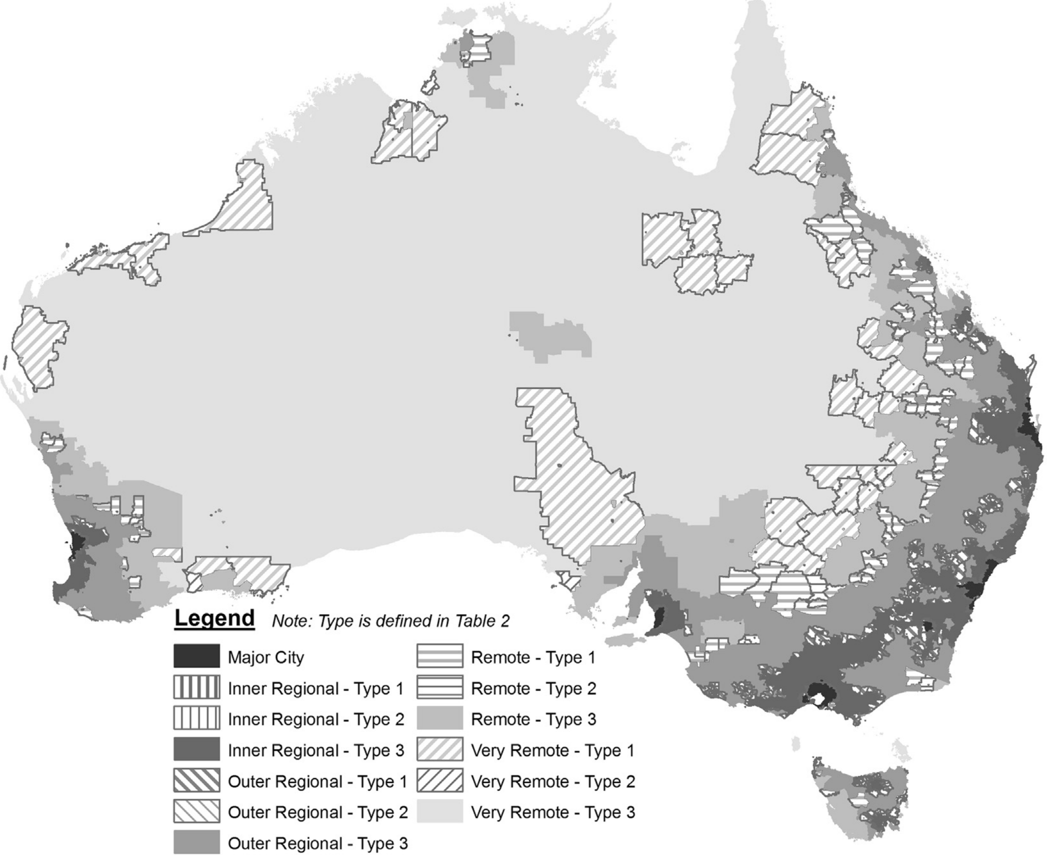


Fig. 3. Map of Australia with the 5×3 dynamic catchment size boundaries.

Conclusions

Whilst the 2SFCA method has potential to enable a much finer spatial resolution and more accurate measure of local spatial accessibility compared to other commonly used approaches, there are still some shortcomings when it is applied at a broad geographical scale. This research has trialled the application of the 2SFCA method at the national level in Australia, with the implementation of dynamic catchment sizes in different rural settings to better 'match' health care utilisation behaviour in those populations. Trial results have demonstrated the need for important smoothing adjustments in large scale applications of dynamic catchment sizes within the 2SFCA method.

Catchment size setting is an important but, to date, neglected decision point of spatial accessibility measures. Its impact in access modelling is twofold. Firstly, it determines the maximum point of access and what points are considered accessible or not. Secondly, it controls how quickly or slowly that distance-decay is applied within a catchment. Few researchers have applied the 2SFCA method at a large scale, instead focussing on much small areas where a single catchment size decision has been sufficient. Little consideration has been given to the appropriateness or impact of using the same catchment size in all geographies.

Table 3
Access scores for towns in Figs. 1 and 2 using 3 different catchment size definitions.

	1 Catchment size = 60 min	5 Catchments, defined by ASGS-RA levels	5×3 Catchment subtypes, by ASGS-RA levels
Town A	0.000904	0.001003	0.000738
Town B	0.001184	0.000932	0.000924
Town C	0.000978	0.000909	0.000929
Town D	0.000846	0.000611	0.000584
Town E	0.000990	0.001373	0.000843
Town F	0.001224	0.001138	0.001129

2SFCA method access scores (A_i) are interpreted like provider-to-population ratios, e.g. 0.000738 = 738 providers per 100,000 population.

Primary data, collected outside of this study, confirm that primary health care catchment sizes are not the same for all rural populations. Residents of densely populated areas currently do not and would not be prepared to travel as far to see a doctor as residents of sparsely populated areas. The Australian geography, like many other larger countries such as Canada and the USA, contains a huge variety of populated areas ranging from closely-settled rural towns to very isolated remote communities once outside of the main metropolitan centres. Therefore, access model catchment sizes, which represent how far residents may travel to use health services and how far health services are potentially delivering to residents, should not be the same across these settings.

Five different catchment sizes within the 2SFCA method were trialled, defined by the ASGS-RA (remoteness) classification; however, this led to two notable perverse outcomes of access scores which were both caused by the sudden increase in catchment size where ASGS-RA levels bordered each other. The behaviour of populations does not suddenly change at some line on a map; instead transitions to larger catchment sizes in more dispersed populations are much smoother. The addition of a 3-level catchment sub-type was then tested, with allocation of populations determined by the degree to which nearby services are located in less remote areas. This improved method was effective in adjusting access scores in the two affected towns to levels that are closer to what is expected, whilst having minimal effect on towns within the less remote category.

This study has demonstrated an effective approach to dynamically apply different catchment sizes into different types of rural areas – which for the first time enables the 2SFCA method to be suitable for national-level access modelling and potential implementation in health policies and health service planning. Failure to utilise catchments which accurately represent the maximum travel behaviour of that population, by remaining with the single catchment size for all geographies and all populations, means that the accuracy of 2SFCA measurements is highly questionable. This may result in mistrust of the 2SFCA method and give popularity back to simpler measures like PPRs, which implicitly use variable sized catchments, but would arguably point future health policy in the wrong direction in terms of improving access and equity to primary health care services.

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References

Arcury, T., Gesler, W., Preisser, J., & Sherman, J. (2005). The effects of geography and spatial behavior on health care utilization among the residents of a rural region. *Health Services Research, 40*(1), 135–155.

Australian Bureau of Statistics. (2003). *ASGC remoteness classification: Purpose and use*. Canberra: ABS. Report No.: Census Paper No. 03/01.

Australian Bureau of Statistics. (2011a). *Australian Statistical Geography Standard (ASGS) volume 1-main structure and greater capital city statistical areas*. Canberra: ABS. Report No.: Cat no. 1270.0.55.001.

Australian Bureau of Statistics. (2011b). *Australian Statistical Geography Standard (ASGS) volume 5-remoteness structure*. Canberra: ABS. Report No.: Cat no. 1270.0.55.005.

Australian Bureau of Statistics. (2011c). *Census of population and housing*. Retrieved May 29, 2014, from http://www.abs.gov.au/census.

Australian Institute of Health and Welfare. (2008 October). *Rural, regional and remote health: Indicators of health status and determinants of health*. Canberra: AIHW. Report No.: AIHW Cat. No. PHE 97.

Bell, S., Wilson, K., Bissonnette, L., & Shah, T. (2013). Access to primary health care: does neighborhood of residence matter? *Annals of the Association of American Geographers, 103*(1), 85–105.

Buzza, C., Ono, S. S., Turvey, C., Wittrock, S., Noble, M., Reddy, G., et al. (2011). Distance is relative: unpacking a principal barrier in rural healthcare. *Journal of General Internal Medicine, 26*(Suppl. 2), 648–654.

Chan, L., Hart, G., & Goodman, D. C. (2006). Geographic access to health care for rural medicare beneficiaries. *The Journal of Rural Health, 22*(2), 140–146.

CRERRPHC. (2014). *Centre of Research Excellence in Rural and Remote Primary Health Care*. Retrieved June 10, 2014, from https://www.crerrphc.org.au/.

Dussault, G., & Franceschini, M. C. (2006). Not enough there, too many here: understanding geographical imbalances in the distribution of the health workforce. *Human Resources for Health, 4*(12).

Guagliardo, M. F. (2004). Spatial accessibility of primary care: concepts, methods and challenges. *International Journal of Health, 3*(3).

Humphreys, J. S., & Solarsh, G. (2008). At-risk populations: rural. In H. K. Heggenhougen, & S. Quah (Eds.), *The international encyclopedia of public health*. London: Academic Press.

Hyndman, J. C., Holman, C. D., & Pritchard, D. A. (2003). The influence of attractiveness factors and distance to general practice surgeries by level of social disadvantage and global access in Perth, Western Australia. *Social Science & Medicine, 56*(2), 387–403.

Joseph, A. E., & Bantock, P. R. (1982). Measuring potential physical accessibility to general practitioners in rural areas: a method and case study. *Social Science & Medicine, 16*(1), 85–90.

Khan, A. A., & Bhardwaj, S. M. (1994). Access to health care: a conceptual framework and its relevance to health care planning. *Evaluation & the Health Professions, 17*(1), 60–76.

Kwan, M., & Weber, J. (2003). Individual accessibility revisited: implications for geographical analysis in the twenty-first century. *Geographical Analysis, 35*(4), 341–353.

Luo, W., & Qi, Y. (2009). An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health & Place, 15*(4), 1100–1107.

Luo, W., & Wang, F. (2003). Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. *Environment and Planning B Planning and Design, 30*(6), 865–884.

Luo, W., & Whippo, T. L. (2012). Variable catchment sizes for the two-step floating catchment area (2SFCA) method. *Health & Place, 18*(4), 789–795.

McGrail, M. R. (2012). Spatial accessibility of primary health care utilising the two step floating catchment area method: an assessment of recent improvements. *International Journal of Health, 11*(50).

McGrail, M. R., & Humphreys, J. S. (2009a). The index of rural access: an innovative integrated approach for measuring primary care access. *BMC Health Services Research, 9*(124).

McGrail, M. R., & Humphreys, J. S. (2009b). Measuring spatial accessibility to primary care in rural areas: improving the effectiveness of the two-step floating catchment area method. *Applied Geography, 29*(4), 533–541.

McGrail, M. R., & Humphreys, J. S. (2009c). A new index of access to primary care services in rural areas. *Australian and New Zealand Journal of Public Health, 33*(5), 418–423.

Ngui, A. N., & Apparicio, P. (2011). Optimizing the two-step floating catchment area method for measuring spatial accessibility to medical clinics in Montreal. *BMC Health Services Research, 11*(166).

Primary Health Care Research & Information Service. (2012). *PHCRIS fast facts – Access to GP services*. PHCRIS. Report No.

Rosero-Bixby, L. (2004). Spatial access to health care in Costa Rica and its equity: a GIS-based study. *Social Science & Medicine, 58*(7), 1271–1284.

Russell, D., Humphreys, J. S., Ward, B., Chisholm, M., Buykx, P., McGrail, M., et al. (2013). Helping policymakers address rural health access problems. *Australian Journal of Rural Health, 12*(1), 61–71.

Shannon, G., Lovett, J., & Bashshur, R. (1979). Travel for primary care: expectation and performance in a rural setting. *Journal of Community Health, 5*(2), 113–125.

Sherman, J., Spencer, J., Preisser, J., Gesler, W. M., & Arcury, T. (2005). A suite of methods for representing activity space in a healthcare accessibility study. *International Journal of Health Geographics, 4*(24).

Sibley, L., & Weiner, J. (2011). An evaluation of access to health care services along the rural-urban continuum in Canada. *BMC Health Services Research, 11*(20).

Tanser, F., Gijsbertsen, B., & Herbst, K. (2006). Modelling and understanding primary health care accessibility and utilization in rural South Africa: an exploration using a geographical information system. *Social Science & Medicine, 63*(3), 691–705.

Wakerman, J., & Humphreys, J. S. (2012). Sustainable workforce and sustainable health systems for rural and remote Australia. *MJA Open, 1*(Suppl. 3), 14–17.

Wan, N., Zou, B., & Sternberg, T. (2012). A 3-step floating catchment area method for analyzing spatial access to health services. *International Journal of Geographical Information Science, 26*(6), 1073–1089.

Wang, F. (2012). Measurement, optimization and impact of health care accessibility: a methodological review. *Annals of the Association of American Geographers, 102*(5), 1104–1112.

Wang, F., & Luo, W. (2005). Assessing spatial and nonspatial factors for healthcare access: towards an integrated approach to defining health professional shortage areas. *Health & Place, 11*, 131–146.

Wang, L., & Tormala, T. (2014). Integrating spatial and aspatial factors in measuring accessibility to primary health care physicians: a case study of aboriginal population in Sudbury, Canada. *ournal of Community Medicine & Health Education, 4*, 284.

World Health Organization. (1978). Declaration of Alma-Ata. *International conference on primary health care*. Alma-Ata, USSR: Geneva: WHO.

World Health Organization. (2010). *Increasing access to health workers in remote and rural locations through improved retention: Global policy recommendations*. Geneva: WHO Press.

World Health Organization. (2013). *World health statistics 2013*. Geneva: WHO Press.