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Does population density affect access to and satisfaction with urban green and open spaces?

A review for the Resilient Urban Futures programme strand on compact and dispersed development

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Summary

There has been an ongoing debate about the impacts that increased urban density has on urban green and open space availability and use. This question has current resonance in New Zealand: can urban councils and housing providers ensure the provision of enough of the right types of green amenities to support intensification without damage to residents' wellbeing and quality of life? In order to provide broader insight into such matters, this report reviews the international and New Zealand literature on availability of green and open spaces within cities, residents' satisfaction with and usage of these spaces, and to what extent these matters are associated with urban population density. This review may inform empirical study of whether intensification ("smart" or compact urban growth) will increase or decrease New Zealanders' access to green and open urban spaces.

All types of urban green space and open space (UGOS), both public and private, are included in the review. International literature establishes the existence of a wide range of different UGOS types, with varying degrees of 'greenness' that confer a wide range of important benefits for urban residents. There is abundant evidence that urban residents value UGOS in many different ways and prefer to live close to UGOS. Provision of UGOS also incurs public costs and the challenge for cities is to find an optimal/ acceptable balance between UGOS benefits and costs.

Availability of UGOS per capita and per household varies widely, within and between cities, although there are few quantitative data in the literature specifically linking population density with UGOS availability. On the whole, it seems likely that UGOS availability per capita decreases as population or household density of the urban area increases. Furthermore, several studies have shown inequalities in access opportunities to UGOS, particularly for lower access in areas of lower income or socio-economic status and higher population or household density.

Affirmative action by governments and councils is widely seen as desirable to address inequalities in UGOS availability and accessibility. Approaches need to address both the supply and the quality of UGOS. It is misleading to consider the provision and planning only with *public* UGOS. *Private* UGOS such as gardens and allotments constitute significant portions of the total green space in many cities and complement public UGOS in terms of the values they confer; but private UGOS provision is less amenable to public policy response. A key to understanding the requirements for *public* UGOS provision in the process of urban intensification is to know how to enable UGOS to be used more intensively in densely populated areas, without loss of amenity and satisfaction. Currently the evidence to answer this question is very sketchy. It is clear, however, that different UGOS users have different needs which must be taken account of and satisfied in different ways in order to maintain and enhance equitable access to and use of UGOS.

Relevance to New Zealand: Almost all New Zealand urban areas have relatively low population and household density (although increasing quite rapidly in some major cities). In addition most New Zealand urban areas are well-endowed with UGOS and most New Zealanders, regardless of socio-economic level, have good access to GOS. These factors provide a good basis for the provision of good quality UGOS to equitably satisfy the needs of all residents. A number of the above key messages are relevant to New Zealand particularly in the design of good accessible UGOS networks in New Zealand urban areas. Key gaps in understanding relevant to New Zealand are discussed.

1 Introduction

Debates about green and open space availability in relation to urban density are not new; they go right back to early town planning considerations. Urban leaders and planners even in the late nineteenth century (e.g. the Garden City movement) wished to provide healthy living spaces for workers and residents, including parks and garden allotments. As cities grew, many urban areas were able to retain private and public green and open space, but others did not, with variation sometimes even within a single metropolitan area; this now results in significant differences in the amount of public green space available per person.

There has been an ongoing debate about the impacts that increased urban density has on urban green and open space availability and use. This question has current resonance in New Zealand: can urban councils and housing providers, especially Auckland Council, with its vision of a 'compact, liveable city', ensure the provision of enough of the right types of green amenities to support intensification without damage to residents' wellbeing and quality of life? In order to provide broader insight into such matters, this report reviews the international and New Zealand literature on availability of green and open spaces within cities, residents' satisfaction with and usage of these spaces, and to what extent these matters are associated with urban population density. This review is stand-alone but may inform empirical study of whether intensification ("smart" or compact urban growth) will increase or decrease New Zealanders' access to and satisfaction with green and open urban spaces.

We use the term Urban Green and Open Space (UGOS) to include all types of green space and open space, both public and private. In this review the emphasis is on public green space such as parks, road reserves and urban forests (see section below discussing the different types), as these are usually within direct management or control of territorial authorities in most countries. However, private UGOS is also relevant to the above objectives.

There is a wide range of types of UGOS which confer a wide range of important benefits for urban residents (de Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003; Lee & Maheswaran, 2011; Maas, Verheij, Groenewegen, De Vries, & Spreeuwenberg, 2006; Tzoulas et al., 2007). Roberts et al. (2015) and Blaschke (2013) review these benefits for New Zealand. A number of benefits to health and wellbeing are among those identified (Table 1). Residing in neighbourhoods that are more walkable and with better access to green space and local transport infrastructure has been associated with increased overall physical activity, while in a recent USA study, park quantity (measured as the percentage of city area covered by public parks) has been identified among the strongest predictors of overall subjective wellbeing at a whole city level (Larson, Jennings, & Cloutier, 2016). Provision of UGOS is, of course, not without cost for cities, mainly the opportunity value of the land, but also the potential impact of providing UGOS in enlarging the city and thus increasing travel distances and costs, and associated carbon emissions. There is concern that a trend towards urban compaction may result in less area available for any type of green space or trees (Lin, Meyers, & Barnett, 2015; McPherson, Simpson, Xiao, & Wu, 2011). The challenge for cities is to find an optimal or at least acceptable balance between UGOS benefits and their costs.

Ultimately, it would be helpful to know how much more intensification could occur in New Zealand cities before availability of and access to UGOS began to approach 'congestion' levels, or even average levels typical of NZ-comparable cities, for example those of a similar size in Europe. It may be presumed that cities in North America and Australia are not as useful as benchmarks, since they are more car-oriented and much less dense, generally, and widely accepted to be less environmentally sustainable, than European cities. However, cities of comparable urban form to New Zealand cities, and whose residents lead similar lifestyles, may be useful comparators.

Table 1. Benefits from Urban Green and Open Spaces (adapted from Meurk, Blaschke, and Simcock (2013). Benefits of particular importance to urban human health and wellbeing emphasised in ***bold italics***.

Provisioning benefits	**Regulating benefits**	**Cultural benefits**
1. Crops	***8. Climate regulation***	17. Spiritual & religious values
2. Animal products including aquaculture	***9. Runoff and stormwater regulation***	***18. Aesthetic and amenity values***
3. Fibre, fuel and biomass energy	***10. Water purification, waste water and solid waste treatment***	***19. Cultural diversity and heritage values, including sense of place and social capital***
4. Other energy provision	***11. Human disease regulation***	***20. Health and wellbeing***
5. Freshwater supply	12. Pest regulation	21. Tourism
6. Genetic Resources	13. Pollination	***22. Education***
7. Physical support for structures	***14. Air quality enhancement***	23. Passive values: option, existence, bequest
	15. Natural hazard and erosion regulation	
	16. Provision of natural habitat and species niches	

2 Methods

The review takes a standard thematic approach to literature accessed using SCOPUS and Web of Science databases available at the University of Otago Wellington. The principal searches of international literature were undertaken using the search terms in SCOPUS:
"green space*" OR "greenspace" OR "open space"
AND
city OR cities OR urban
AND
"population density" OR "hous* density"
The 148 articles accessed through Scopus were prioritised and summarised in two Excel spreadsheets.

In the first part of the report dealing with the international literature, most attention is paid to cities in 'more developed', higher income countries, in particular Australia, the UK, continental Europe, and USA. Some articles from East and Southeast Asia were also relevant. In the second part of the report, the themes identified from the international literature were related to the small number of available New Zealand studies.

3 Results from international literature

3.1 Types of Urban Green and Open Spaces

There is a wide range of different UGOS types, with varying degrees of "greenness", and also an important distinction between public and private UGOS. "Accessible" or "usable" and "inaccessible" or "unusable" are sometimes used as synonyms for "public" and "private" (Richardson, Pearce, Mitchell, Day, & Kingham, 2010). In this review the emphasis is on public green space which has a significant degree of vegetation cover (not necessarily 100%) and is usually highly permeable (but may include significant impermeable areas such as roads, structures and paved areas in larger parks). These areas have the highest and largest range of ecosystem and other values (Meurk et al., 2013). Private UGOS is predominantly gardens (including paved areas that are not necessarily permeable). Public open spaces (which importantly include road reserves but do not include the road surface itself) have low vegetation cover, e.g. road reserves, reservoir tops, unvegetated road verges. Private open spaces include undeveloped land, unvegetated land around commercial buildings, and vacant lots. There is also land which is neither fully public nor private. This includes road reserves which are managed as part of adjoining private lots, leased garden allotments and communal gardens on public land.

Byrne and Sipe (2010) discuss these different types of UGOS in detail and present a typology for them (Fig.1). The typology is presented by Byrne & Sipe for parks, but appears to be suitable to apply for all types of UGOS. This typology emphasises size, facilities and naturalness of UPOS, but "more" of each of these aspects is, of course, not necessarily "better" in the urban context. "Informal UGOS" (Rupprecht & Byrne, 2014) are a further significant category of UGOS, including vacant lots, brownfields and street or railway verges.

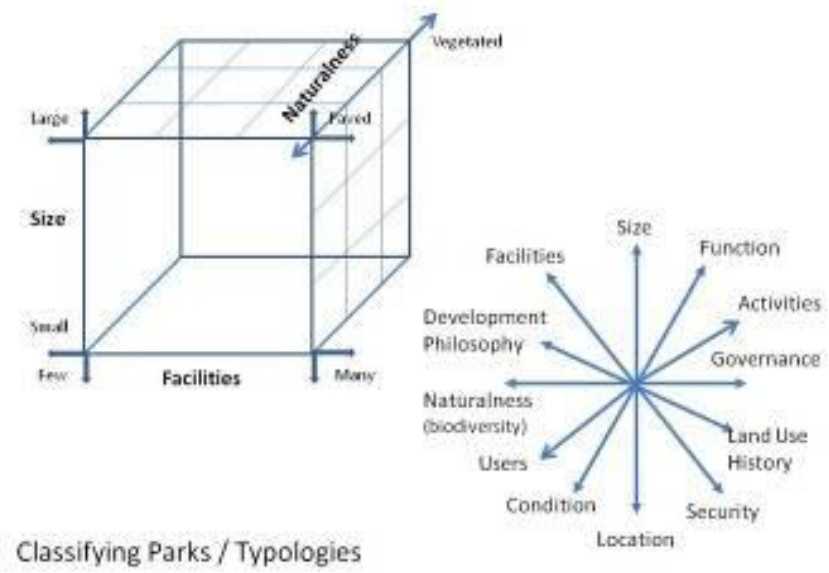

Fig 1. Typology of UGOS (from Byrne and Sipe 2010)

3.2 Population density and UGOS Interactions – availability[1]

In general there is very little in the literature specifically linking population density with UGOS availability. On the contrary, population density is sometimes taken out of studies of green space availability by adjusting for population density as a confounding effect (e.g. de Vries et al., 2003; Nutsford, Pearson, & Kingham, 2013; Shanahan, Lin, Gaston, Bush, & Fuller, 2014). The first-cited paper was an early study in the exploration of green space / health relationships, where the intent was to try and rule out "selection effects" as far as possible, by statistically controlling for relevant demographic and socioeconomic factors. This intent has been often repeated in later studies.

In interpreting any availability data it is important to remember that the apparent relationship between UGOS and density will be highly influenced by the way density is measured (Zhao, Chapman, & Howden-Chapman, 2011). A net density measure has the ability to completely or largely remove UGOS areas (by land-use type) from the equation so removing the influence of the amount of UGOS on density. Using population weighted density will reduce the influence of large areas of open space on density but not smaller areas (depending on the size of the sub-area used for weighting), while a gross density measure leaves all UGOS in, so large areas of open space (e.g. a town belt) are likely to reduce population density significantly. The choice of density measurement made by the researcher or decision maker will reflect the purposes of the study.

Availability of UGOS per capita and per household varies widely, within and between cities. This has been most clearly shown in European and Australian cities. For example, across 381 cities in 28 European countries, green space coverage (green space as % of total area of the city) varied markedly, averaging 18.6% and ranging from 1.9% to 46%. Per capita green space availability varied by two orders of magnitude, from 3-4 m^2 to more than 300 m^2 per capita. Larger European cities were no more or less densely endowed with UGOS than smaller cities (Fuller & Gaston, 2009). Similarly in the USA, a city wide comparison of urban green space availability in 44 US cities, measured as the percentage of total city area covered by parks, varied from 2% to 23% (Larson et al., 2016). These data compared whole cities. Within cities, for example, in inner and middle suburbs of Sydney, Australia, the amount of local 'open space' (*sensu* UGOS) ranged between 0.56 and 2.41 ha per 1000 residents, or 6 to 24 m^2 per capita (Searle, 2011); (Lin et al., 2015).

On the whole, looking across cities internationally, there is less UGOS available per capita, as population or household density increases. This is the case whether measured on a neighbourhood, city or regional basis (Brander & Koetse, 2011; Fuller & Gaston, 2009; Litman, 2015).

These differences arise or are accentuated when UGOS is lost as cities grow. This was well documented in 11 residential areas in Merseyside, UK, looking at the period 1975-2000 (Pauleit, Ennos, & Golding, 2005). They showed a loss of UGOS in all types of residential area, of differing socio-economic status. Over all areas, the proportion of land occupied by built structures and infrastructure in 2000 ranged from 16% to 40%, and cover of private gardens ranged between 6% and 43%. It would be expected that as cities grow, there would be a loss of UGOS both in inner areas as cities intensify and at the urban fringe as the city grows outward. However, the ratio of that loss occurring within

[1] In this report we use the term 'availability' in the sense of existential capability of being used, i.e. a simple quantitative measure of UGOS in an urban area existing per capita or per household in that urban area. By contrast, 'accessibility' is defined in the Concise Oxford Dictionary as the "ability to be reached or entered". Therefore 'accessibility' has an additional connotation (which may be expressed qualitatively or quantitatively) of an ability (physically, socially, economically and culturally) to access UGOS. In this sense, 'accessibility' can just be a synonym for 'nearby' and this is the sense in which the term is often used. However, the two terms appear to be used somewhat interchangeably and without clear distinction in much of the literature.

the city to that at the fringe would depend on the development pattern of the city. An intensification pattern would generally lead to less overall loss than in a sprawl pattern, but different types of UGOS being lost. Little literature has been found that specifically addresses the pattern of that loss.

In most of these cases, available figures relate to public UGOS, such as parks. Some studies are based on analysis of imagery with a minimum pixel size, e.g. 50 x 50m, which excludes most private green space. However, both private and informal UGOS are a critical component of UGOS availability. Private domestic gardens are known to constitute a considerable proportion of 'green space' in many cities in all parts of the world and are therefore of great potential significance for maintaining the multiple values of UGOS (Freeman, Dickinson, Porter, & van Heezik, 2012; Goddard, Dougill, & Benton, 2010; Loram, Tratalos, Warren, & Gaston, 2007). 'Informal green spaces', such as green road verges, which exclude private gardens, form a significant areal component of both Brisbane and Kyoto (6.3% and 4.8% areal coverage respectively). It is significant that this proportion is similar in both a very low density city (Brisbane) and a relatively high density city (Kyoto).

The importance of private gardens was most clearly shown in Loram et al's (2007) study of five UK cities: Edinburgh, Belfast, Leicester, Oxford, and Cardiff. In each city, with widely ranging levels of socio-economic status, the proportion of the total urban area covered by domestic gardens was at least 21%. In a random sample of at least 500 houses in each city (including semi-detached houses and terrace housing as well as detached houses), 99% had some area of associated garden. As was to be expected, areas of gardens ranged widely and their size was closely associated with housing type, but because relatively small gardens (set at <400 m^2 for this study) are much more numerous than larger gardens they contributed disproportionately to the total garden area of each city. There was no clear relationship between garden area and distance to the edge of any of the cities. The proportion of the total administrative area made up of gardens ranged from 11.3% to 24.9% and, counterintuitively, was strongly correlated with population and housing density. In other words, high population density equates to a high density of housing and therefore a high proportion of garden area. Gardens between 200 m^2 and 400 m^2 constituted the highest proportion of the total garden area of each city, ranging from 28% to 47%.

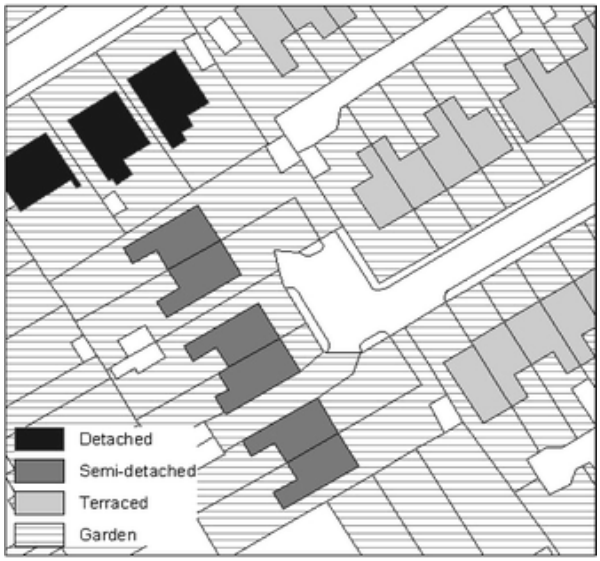

Fig 2. Examples of typical UK house types showing configuration of green space around detached, semi-detached and terraced dwellings in Cardiff. Black lines show parcel boundaries. Reproduced from Loram et al. (2007).

The widespread recognition of the multiple benefits of UGOS for urban residents (see Section 1) means that many countries and cities have **planning standards** or **guidelines** for the provision of UGOS per capita or per household. These are prominent, for example, in the UK, many continental European countries, many states in the USA and Australia. Several studies have shown that the actual per capita provision of UGOS in given cities does not match these guidelines or standards (Ambrey & Fleming, 2013; Bertram & Rehdanz, 2015; Byrne & Sipe, 2010; Chang & Chen, 2015). Even in the example of Berlin where the goal of providing 6m^2 of public green space per inhabitant is met, and research indicates that there may be an "optimal" marginal level of green space provision beyond which marginal utility decreases (see next section), most residents (75%) had less GS available in their living environment than the amount at which the positive impact on their life satisfaction would be largest (Bertram & Rehdanz, 2015). This is not surprising, given the cost of land and other costs of green space.

3.3 Access to and satisfaction with UGOS

The accessibility of UGOS, as opposed to its availability, is less well studied. Although some recent studies approached accessibility analysis by linking the distribution of UGOS to population data including socio-economic and health status (Astell-Burt, Feng, Mavoa, Badland, & Giles-Corti, 2014; Bertram & Rehdanz, 2015; Nutsford et al., 2013; Shanahan et al., 2016), most existing studies examining accessibility have needed to carry out surveys to complement studies of UGOS from land cover analysis.

There is abundant evidence that urban residents value UGOS in many ways (as discussed in the Introduction), that residents prefer to live close to UGOS and that the presence of well-known UGOS attracts migrants from other parts of the city or other cities (Wu & Plantinga, 2003). For example, Thompson (2002) referred to "many surveys of urban park use" indicating that the majority of users want to come by foot and will only do so on a regular basis if the park is within 3–5 minutes' walk of their home or workplace. There are numerous studies from many countries indicating significant monetary premiums that proximity to (or even views over) public GS confers on the owners of residential housing (McConnell & Walls, 2005; Schipperijn et al., 2010).

Recent studies have examined the influence of local public green space on the life satisfaction of residents in Australian and USA cities and Berlin (Ambrey & Fleming, 2013; Bertram & Rehdanz, 2015; Larson et al., 2016). Ambrey and Fleming (2013) found a positive relationship between the percentage of public green space in a resident's local area and their self-reported life satisfaction, which corresponded to a seemingly high implicit monetary willingness-to-pay (A$1172 in annual household income for a 1 per cent (143 m^2) increase in local public green space. These results could be due to strategic behaviour, i.e., if ratepayers or councils are considering providing more green space, it is both strategic and expected behaviour for survey respondents to put a higher perceived value on such. Their results also suggest that the value of green space increases with population density. Larson et al. (2016) used data from 44 US cities to evaluate the relationship between urban park quantity, quality, and accessibility and aggregate self-reported scores on the Gallup-Healthways Wellbeing Index. They reported that park quantity (measured as the percentage of city area covered by public parks) was among the strongest predictors of overall wellbeing, especially through parks' contributions to physical and community wellbeing. Park quality (measured as per capita spending on parks) and accessibility (measured as the overall percentage of a city's population within half a mile of parks) were also positively associated with wellbeing, though these relationships were not statistically significant.

In a Barcelona study of access to green space and subjective general health, Dadvand et al. (2016) found that residential surrounding greenness and *subjective* residential proximity to green spaces,

were associated with better subjective general health, but *objective* residential proximity did not have a statistically significant relationship to subjective health. This suggests the importance of maximising the perceived accessibility of available green space, e.g. through attractive entry points, good signage, provision of bike and car parking, etc, even if availability is not able to be increased.

Bertram and Rehdanz (2015) suggested that for Berlin residents there was an inverted U-shaped effect of urban green space on life satisfaction. The positive effect of green space was greatest at 11% area coverage of a 1-km diameter 'buffer area' around an individual's residence. These results were not directly related to population density, although a high proportion of GS will tend to reduce population density. Also, while the results may not be transferable, they do imply that when GS exceeds 10-15% of an area, its marginal benefit may start to decline. This result is interesting as it identifies a point beyond which more green space may be less valuable in terms of residents' 'life satisfaction'. The authors also derived monetary values as a marginal rate of substitution for income, indicating that the benefit of green space increases with income and begins to decline with its availability past a certain point. Monetary values attached to green spaces by Berlin residents in this study were much lower than those suggested for Australian cities by Ambrey and Fleming (2013).

Can some public UGOS in densely-populated areas become over-congested to the point that residents prefer not to visit their closest public green spaces? There is evidence to suggest that this can happen in some situations (e.g. Bertram and Rehdanz (2015); Burgess, Harrison, and Limb (1988); Byrne and Sipe (2010); Payne, Mowen, and Orsega-Smith (2002)). Some of these congestion factors relating to safety, crime and noise may especially apply to older or less abled UGOS users. But conversely, can some UGOS be used more intensively in densely populated areas, without loss of amenity and satisfaction? This is the key to understanding the requirements for UGOS provision in the process of urban intensification, but unfortunately the evidence to answer this question is very sketchy. Some research suggests population density may have minimal effects on overall wellbeing within cities (Florida, Mellander, & Rentfrow, 2013), but this research is not specific to UGOS availability or accessibility. A survey of park use in Southern California showed that neighbourhood population density was not associated with park use (Cohen et al., 2010). In this survey, the strongest correlate of park use was having a range of events organised at the park.

The key to beginning to answer this question is the two complementary principles that different types of UGOS have different uses and values, and that different UGOS users have different needs. This is a key point in the lengthy review undertaken by Byrne & Sipe (2010) in Queensland. They emphasise, in relation to more densely populated urban areas, that "there is no typical 'higher density resident'". They discuss, for example, the different needs of children for UGOS, and that increasing numbers of Australian apartment dwellers and inner city residents are children (as has been the case in Northern Hemisphere cities for a long time). They conclude that UGOS "near higher density dwellings must cater to very diverse populations".

The values of UGOS can be expressed in many different ways, and economists have recently sought to quantify these values in monetary terms, often through various hedonic pricing (HP) and contingent valuation (CV) techniques. Brander & Koetse (2011) undertook meta-analyses of the CV and HP literature to examine which physical, socio-economic, and study site characteristics determine the monetary values of open space in several countries including UK, Finland, USA, Israel, China, Australia and South Korea, and found that in both the CV and HP analyses there is a positive and significant relationship between the value of urban open space and population density. This also indicates that scarcity and crowdedness matter, although, as is obvious to anyone observing a crowded family playground, it may also suggest that being crowded may not, up to a point, necessarily diminish the 'perceived value' of UGOS significantly, or may even increase it to a point, especially if additional amenities are provided to cater to users. The nature of the UGOS may thus be an important

determinant of people's perception of and satisfaction with it. Brander & Koetse found the value of open space does not vary significantly with income. They also found important regional differences in preferences for urban open space, which suggests that the potential for transferring estimated values between regions is likely to be limited.

Does less UGOS availability in people's own residential environment mean they are more likely to visit (more distant) parks or nature reserves? If they did so, it may mean greater travel and higher carbon emissions may be associated with UGOS-scarce urban areas, especially more affluent ones. This hypothesis, known as the 'compensation hypothesis', was tested by Maat & de Vries (2006). The authors found that although people tend to make more use of green space if it is available in the vicinity, a denser urban residential environment does not result in compensation behaviour.

3.4 Effects of UGOS quality on satisfaction with UGOS

As discussed above, UGOS users' needs differ within any given city (Byrne & Sipe, 2010). Therefore residents' satisfaction with the UGOS they can access depends on how well those specific places satisfy their needs. Beer, Delshammar, and Schildwacht (2003) described how a lack of quality UGOS is an important reason why people move out of inner cities to the suburbs, thus contributing to urban sprawl. However, it is unlikely to be the key factor determining most housing choices (see section 4.1, in particular Holmes et al, 2016).

There is little systematic evidence on how well a given city's UGOS satisfies the differing needs of its users and whether the ability of specific UGOS to do so depends on definable qualities.

3.5 Inequalities in availability and accessibility of UGOS

Several studies have shown inequalities in access opportunities to UGOS, particularly in areas of lower income or socio-economic status and higher population or household density (Astell-Burt et al. (2014); Mitchell and Popham (2007); (2008); Sister, Wolch, and Wilson (2010); Wolch, Byrne, and Newell (2014); Iverson and Cook (2000); Lin et al., (2015)). Such higher density areas tend to have less availability per capita in any case, and Sister et al. (2010) showed in Los Angeles that Latinos, African-Americans, and other low-income groups were likely to live close to parks with higher actual or potential park congestion. Such findings are not, however, universal, with Ståhle (2010) showing that citizens in some dense inner city districts in Stockholm experienced higher green space accessibility than citizens in some low-density 'green' suburbs.

Inequalities can be persistent or accentuated over time. In the study of green space loss in Merseyside discussed above, Pauleit et al. (2005) also studied the distribution of UGOS loss by levels of affluence and deprivation. They showed that overall, the more affluent, low density areas lost proportionally more green space, especially of tree cover (a major cause was infill development whereby gardens were built over). However, green space was also lost in already densely built-up, deprived areas, primarily due to the reuse of derelict land. As a consequence, the models used in their study predicted negative environmental impacts for all areas.

The importance of gardens and private UGOS has been discussed in earlier sections. It is easy to assume that these private UGOS are more available to more affluent residents and therefore potentially accentuate inequalities in access to UGOS. However, the work of Loram et al. (2007) showed that private UGOS was available to almost all residents in five UK cites, regardless of deprivation levels, although in smaller amounts for lower status socio-economic areas. Opportunities for private UGOS, whether in owner-occupier or rental housing, may therefore be important in addressing inequality of access, as well as the provision of public UGOS. In Brisbane, Australia,

Shanahan et al. (2014) found in analysing both public and private UGOS, that overall tree cover was higher in more socio-economically advantaged neighbourhoods. However, higher-quality remnant native vegetation (at least from a biodiversity perspective) was much more evenly shared across the socio-economic gradient, as it predominantly occurred in public parks, as was also shown in Sydney (Lin et al., 2015).

These contrasting findings are interesting as increasing overall tree cover can be a comparatively easy public intervention in that plantings such as street and road reserve trees do not require costly land acquisition and may be contemplated even in densely populated neighbourhoods. If there are health and wellbeing benefits associated with all types of green space and not just those that are more biodiverse, then these findings suggest that increasing tree and vegetation cover in less socio-economically advantaged neighbourhoods can be a way of reducing health inequities.

3.6 Planning and design for addressing density-related inequalities in access to UGOS

Many countries and cities have planning standards or guidelines for the provision of UGOS per capita or per household, in recognition of the multiple benefits of UGOS for urban residents. In many cities, however, the actual per capita provision of UGOS in given cities does not match these guidelines or standards.

Whether through planning or design standards, or other mechanisms, affirmative action by governments and councils is widely seen as needed to address inequalities in availability and accessibility, and for private as well as public UGOS (see above). Policy approaches address both the supply and the quality of UGOS, but vary in how much is seen as desirable. In the UK the Urban Green Spaces Task Force (DETR 2000) claimed that the very objectives of the compact city model it was advocating would be compromised if more weight was not given to the good management as well as the preservation of urban green spaces.

Fuller and Gaston (2009) and Rupprecht and Byrne (2014) discussed the important role of informal GS in the ability of the full range of UGOS to fulfil the range of needs. Fuller & Gaston described how, as cities grow, interactions between people and nature depend increasingly on landscape quality outside formal public green space networks, such as street plantings, as well as the size, composition and management of backyards and gardens. As well as assisting interactions between people and nature, tree-dominated informal GS provides other important ecosystem services such as biodiversity provision, connectivity and climate moderation. It is worth noting that informal GS can be accessible to a large number of people with different needs; in both Kyoto and Brisbane more than 80% of informal green space was accessible or partly accessible (Rupprecht & Byrne, 2014)).

A key to understanding the requirements for UGOS provision in the process of urban intensification is to know how to enable UGOS to be used more intensively in densely populated areas, without loss of amenity and satisfaction. In theory, weighting crude per capita availability by population density (i.e. assuming that an inner city park can be used simultaneously by more people than the same area in outer suburbs), may give a justifiable measure of intensiveness, because we know that some of the benefits of UGOS availability in urban areas are related to social capital (e.g. Colding and Barthel (2013); Wolch et al. (2014); Fuller and Gaston (2009)); and can therefore be *enhanced* by higher numbers and densities of people using those spaces. However, this would only apply up to some threshold density where the number or congestion of users begins to adversely affect some people's enjoyment and ability to carry out activities, i.e. there are diminishing returns from more people using a space after this threshold is reached. There is very little research on what this congestion or threshold density is in urban areas (Wolch et al., 2014). By contrast, in regard to both more remote

"wilderness" areas and heritage cities, there is available research on the effect of higher visitor numbers on visitor enjoyment (McCool and Lime (2001); Russo and Van Der Borg (2002); Cessford (1997)).

In general, therefore, the quantitative or systematic evidence to answer questions about potential intensification is currently very sketchy, and much of the work being done in developing and planning UGOS is being done through documentation of programmes and case studies. A key principle is that different UGOS users have different needs and these need to be taken account of and satisfied in different ways in order to maintain and enhance equitable access to UGOS. Byrne & Sipe (2010) discussed at length the application of planning standards and best planning and design practices for public urban space and green space planning, with specific application to the needs of potential intensification in Brisbane. The purpose of their literature review was to enable a comparative analysis of the amount and quality of public urban and open space in other capital cities relative to Brisbane. For the same city, Shanahan et al (2014) discussed the important opportunities from strategies such as social marketing and incentives for enhancing nature within private spaces, particularly within more disadvantaged neighbourhoods, and considered that greening effects on private land could help promote equal access to nature. A similar analysis was applied to rapidly growing urban areas of Southeast Queensland (Byrne, Sipe, & Searle, 2010), the authors arguing that a needs-based approach, aimed at providing a variety of new types of green and open space in denser built environments, was more appropriate than one based on uniform standards of amount of green space per resident.

Many design proponents would claim that at any given use density, even in congested areas, there is some potential to maintain or even increase UGOS accessibility through conscious design and improvement of quality. This is one of the features of significant current work in many cities in the "Biophilic Cities" programme (Beatley (2010); see also http://biophiliccities.org/). There is considerable research and innovation on "good density" i.e. compact, dense areas that maintain GS values and availability through design (Byrne & Sipe, 2010; Ståhle, 2010; Wolch et al., 2014). Some of this work also addresses environmental justice issues in attempting to provide more equitable access to UGOS in more densely populated and deprived urban areas (Sister et al. (2010); Wolch et al. (2014)). However, little of this work defines thresholds or criteria for evaluating the effectiveness of such interventions. It is also clear that advancing environmental justice dimensions awaits the more general research needed on better techniques for measuring and perhaps monetising the social, wellbeing, health, and environmental benefits of urban green spaces (Orr et al 2014). These authors consider that increased urban population density will put more pressure on green spaces, world-wide. It is likely that fewer people will have private gardens and other private green spaces, and therefore, for example, smaller locally accessible 'pocket' parks will continue to be important or perhaps become more so.

It is also important to consider the potential for individual people's 'nature orientation' (i.e. how and why they interact with nature) even before specific planning for UGOS provision begins. An interesting study in Brisbane surveyed people's nature orientation as well as green space availability (Lin, Fuller, Bush, Gaston, & Shanahan, 2014). Results indicated that while both were important drivers of the amount of park visitation, nature orientation was the primary factor. The authors suggested that if we want to increase green space visits in general, measures to increase people's connection to nature could be more important than measures to simply increase UGOS availability.

4 Application to Aotearoa New Zealand

4.1 Evaluation of New Zealand studies

Almost all New Zealand urban areas have relatively low population and household density, with the arguable exception of Auckland and Wellington central cities. Using population-weighted density data, Auckland is the most dense city in New Zealand, coming after Sydney and Melbourne. Auckland and Wellington urban areas as a whole are denser than Brisbane, Perth, Adelaide and Christchurch (ordered by weighted density) (Nunns, 2014, Table 3). Despite their increasing densities, Auckland and Wellington remain, like other New Zealand urban areas, well-endowed with UGOS (Mathieu, Freeman, & Aryal, 2007; Nutsford et al., 2013; Richardson, Pearce, Mitchell, & Kingham, 2013). Most urban New Zealanders, regardless of deprivation levels, have good access to UGOS and to the coastline – another type of public green and open space very important to and highly valued by New Zealanders (Pearce, Witten, Hiscock, & Blakely, 2008; Witten, Hiscock, Pearce, & Blakely, 2008). Access is good whether measured by distance or time required to access (Witten et al., 2008). This high degree of availability and accessibility provides a good basis for the provision of good quality UGOS to equitably satisfy the needs of all residents. However a number of the key messages summarised in previous sections are relevant to New Zealand, particularly in the design of good accessible UGOS networks in New Zealand urban areas.

A small number of studies and reviews have been carried out which investigate or touch on the interactions between UGOS and health status in New Zealand (Badland, Keam, Witten, & Kearns, 2010; Freeman et al., 2012; Hand, Freeman, Seddon, Stein, & van Heezik, 2016; Ivory et al., 2015; Mathieu et al., 2007; Meurk et al., 2013; Nutsford et al., 2013; Nutsford, Pearson, Kingham, & Reitsma, 2016; Pearce et al., 2008; Richardson et al., 2010; Richardson et al., 2013; Witten et al., 2008). Few of these studies have any information specifically pertaining to population or household density, but some contain the only New Zealand current data about the spatial configuration of and use of UGOS. Witten et al. (2008) undertook one of the first national studies examining the relationship between travel time access to parks and beaches, Body Mass Index and physical activity in New Zealand neighbourhoods. The study found little evidence of an association between locational access to open spaces and physical activity, and, contrary to many results internationally, found no socio-economic gradient in this association, i.e. more deprived neighbourhoods had as good access to UGOS (and beaches) as less deprived neighbourhoods. Hand et al. (2016), examining biodiversity levels at a fine scale in three New Zealand cities, found that biodiversity across neighbourhoods was significantly related to socioeconomic class, due mainly to the greater cover of mature (private) gardens of high biodiversity value in regions of higher socio-economic status, a finding similar to that of Shanahan et al (2016) in Brisbane.

Richardson et al. (2010), using New Zealand-wide mortality data and looking specifically at urban environments, also found no association between the amount of green space in the area in which people live and mortality from either cardiovascular disease (e.g. heart attacks or strokes) or lung cancer. A more recent study led by Richardson (Richardson et al., 2013), focussing on physical activity, found that physical activity was higher in greener neighbourhoods, and that cardiovascular disease risk was reduced in all neighbourhoods with more than 15% green space availability. However, a dose-response relationship was not found and green space availability was not related to overweight or poor general health. This study also presented data, for all 1009 urban Census Area Units (CAUs) in New Zealand, on the proportion of respondents in four total green space CAU quartiles: 28.5% of respondents lived in quartile 1 CAUs (<15.69% of the CAU was green space); 30.7% of respondents lived in quartile 2 CAUs (15.69- 33.15% green space); 26.9% of respondents lived in quartile 3 CAUS (33.27-69.77% green space); and 14.0% of respondents lived in quartile 4 CAUs (>69.77 % green space).

Nutsford et al. (2013), in Auckland City[2], found that lower distance to useable green space and increased proportion of green space within the larger neighbourhood were associated with decreased anxiety/mood disorder treatment counts in the Auckland urban environment. In Wellington, however, Nutsford et al. (2016), investigating green space visibility only, detected no significant association between green space visibility and lower psychological distress scores. Nutsford et al. did not investigate population density relationships, regarding this as a confounding variable in the green space / health interaction, but provided useful data for Auckland City on public green space availability in relation to population-weighted meshblock centroids (PWCs). The average distance from PWCs to an area of public greenspace was 198 meters (about 4 minutes' walk). Just over 40% of the meshblocks had <5% greenspace within 300m of the PWC while 20% had < 1%. Three hundred metres was used to reflect the influence of green space within the immediate neighbourhood of residents. This small distance to the nearest green space reflects the high amount of green space in even New Zealand's largest and densest urban area. It is also consistent with international surveys (mentioned in section 3.3) indicating that the majority of park users want to come by foot and will only do so on a regular basis if the park is within 3–5 minutes' walk of their home or workplace.

A high proportion of many urban areas in New Zealand (especially outside the main centre CBDs) comprise private gardens (Freeman et al., 2012; Mathieu et al., 2007; Meurk et al., 2009). Sometimes these constitute the largest single land cover type (e.g. in Dunedin, approximately 36% of total urban land and 46% of the residential area[3], the largest single land use within the city (Mathieu et al., 2007)). There are many ecosystem and other values associated with these private UGOS, both gardens and other kinds of open space. Even open spaces with few natural values e.g. informal recreation, parking or private commuting routes may provide many ecosystem and other values (Meurk et al. (2013).

Many New Zealand urban parks are well-used and highly rated by users. For example, Wellington Botanic Garden was visited by more than three quarters of all 190 000 Wellington City residents per year, excluding the 600 000 visits from domestic and international tourists, and about 90% of residents think that money spent on the Wellington Botanic Garden and other city botanic gardens is good value (David Sole, Wellington Botanical Garden, pers. comm., and data from Wellington City Resident Satisfaction Survey 2011)[4]. Use of many parks is equitable across age groups, races and socio-economic groupings. Little is published on quality and accessibility although some councils gather use and satisfaction statistics.

Pearce and colleagues examined levels of geographical access to several types of community resource, including public parks and beaches in CAUs across the country and examined whether access varied between deprived and non-deprived areas of the country (Pearce et al., 2008). Their research showed that in urban areas, access is *better* in more deprived neighbourhoods (except for beaches in urban Auckland and Wellington), and the same is true of peri-urban areas although the gradient there is considerably more pronounced. This was in contrast to rural areas, where the relationship between community resource access and deprivation is more mixed, with access to the majority of resources being worse in more deprived areas. Similarly, there are regional variations in the relationship between deprivation and community resource access.

We are not aware of any research showing satisfaction or dissatisfaction with the accessibility of UGOS in New Zealand. The recent high growth of community gardening (in New Zealand and internationally) could indicate a growing desire for more accessibility and communal use of UGOS. It is, however, likely as noted above that people's choices are mainly driven by factors such as housing affordability,

[2] The former Auckland City within the current Auckland Council area of jurisdiction

[3] A reflection of New Zealand's relatively very low population density is that even with this amount of private garden space, Dunedin is NZ's third most dense city (Nunns 2014).

[4] See http://wellington.govt.nz/~/media/about-wellington/profile/files/ rss11-topline-report.pdf

and that access to green space is at best a secondary factor. A 2015 Auckland survey of housing, neighbourhood and travel preferences sheds some light on this. In rating factors important to their housing choice, Aucklanders placed 'distance to parks' as the 10th most important factor of 16 factors (after affordability, warmth and dryness, neighbourhood safety, dwelling outdoor space, parking space, attractiveness of neighbourhood, quietness of street, 'standalone home', and distance to shops', with 69% rating distance to parks as important, very important or extremely important (n=3285) (Holmes et al., 2016).

Walkability of neighbourhoods, including UGOS, is an important factor in shaping where and how residents engage with public places (Ivory et al., 2015). Walkability facilitates access to many UGOS and allows their values to be taken advantage of. New Zealand and international literature shows how residing in neighbourhoods that are more walkable and with better access to greenspace and local transport infrastructure has been associated with increased overall physical activity (Giles-Corti, Kelty, Zubrick, & Villanueva, 2009; Sallis et al., 2009; Witten et al., 2012). Wilson, Brander, Mansoor, and Pearson (2014) discuss the evidence for street-walking connectivity facilitating active urban transport in Wellington City. This is likely to be relevant for walking paths in and connecting UGOS.

However, walkability as a factor currently driving accessibility and use of UGOS in New Zealand should not be overstated, given the high level of private car use to access green spaces and natural areas. Unpublished data cited in Witten et al. (2008) stated that 72% of trips to open space recreational destinations in NZ (which would include, but not be limited to, parks and beaches) are undertaken as a car driver or passenger, while only 23% are made on foot. More recent data for the inner suburban Wellington Botanical Garden (WBG) suggest considerable variability in access mode depending on home location relative to the WBG. Here, the most common mode of transport to the WBG in 2012 was walking (38% compared with 34% in 2010, as against 32% by private car (41% in 2010) (Centre for Tourism and Leisure Management, 2012).

4.2 "Big cities" and "little cities"

Section 3 shows that, internationally, the availability of UGOS per capita and per household varies widely, within and between cities. On the whole, there is less UGOS availability per capita, as population or household density of the urban area increases. Several studies have shown inequalities in access opportunities to UGOS, particularly in areas of lower income or socio-economic status and higher population or household density. However, an important difference is that for New Zealand this relationship between lower income or socio-economic status and lower access to UGOS does not appear to hold, presumably because of the high level of access to UGOS regardless of deprivation levels, as discussed above.

To what extent is this difference also a reflection of the relatively small size of New Zealand cites? New Zealand, although highly urbanised, has one medium-sized city of 1.5 million total (spread over a large land area), two urban agglomerations each of about 0.5 million people, and of the rest of its urban areas, only two have more than 130,000 people. It has always been assumed that all New Zealand cities and urban precincts are sparsely populated, an assumption easy to make given the physical sprawl of Auckland. However, recent data has shown that the population-weighted density of Auckland has increased significantly in recent years and is approaching that of Melbourne (Nunns, 2014). In other major New Zealand cities (or parts of cities), infill has increased suburban population and household densities, with Wellington, Hamilton and Dunedin's densities growing significantly (Nunns, 2014, Table 4). It is likely that UK data showing higher percentage loss of green space in more affluent, "greener" suburbs (Pauleit et al., 2005) would also apply to these areas.

Even without taking density into account, several cities referred to in Section 3 are comparable to Auckland in size, including Brisbane (2.2m in 2014) Perth (1.9m),and Adelaide (1.26m) in Australia, Ottawa (1.1m), and Vancouver (2.15m) in Canada, Kyoto (1.8m) and Sapporo (1.8m) in Japan, and Glasgow (1.2m), Munich (1.2m), Vienna (2.2m), and Prague (1.16m) in Europe to give some examples. These cities have a range of forms, but many of them share some important characteristics of form as well as size with Auckland or other New Zealand cities. These and other international cities can provide useful points of comparison and example for New Zealand cities.

4.3 Gaps in understanding relevant to New Zealand

The most immediate gaps in current New Zealand knowledge in the area are for basic data on UGOS availability in relation to population and household density. Studies by Richardson et al (2010),(2013) and Nutsford et al. (2013), (2016) have provided a little information on UGOS spatial distribution in relation to census area units in Auckland and Wellington, but this has been related to health outcomes and not to population measures. Only when such gaps are filled can issues of accessibility and inequalities be addressed.

Basic data will allow better comparison of New Zealand UGOS availability in relation to international recommended standards and guidelines for per capita and per household UGOS availability (Box and Harrison (1993); Byrne and Sipe (2010); Harrison et al. (1995)).

As for urban areas internationally, more comprehensive direct measures of access are needed that take account of the quality and safety attributes of specific amenities and their surrounding locales, as recognised by Witten et al. (2008). Richardson et al. (2010) also comment that in New Zealand green space quality may be a better predictor of health benefits than green space quantity.

The total range of UGOS as introduced in section 3.1 is very broad. Some of these areas are much 'better' than others in terms of ecological, social, cultural and economic values and are clearly part of the accepted spectrum of urban green spaces. In a policy sense the value of others is more subjective when it comes to deciding whether they are worth keeping in their current state at the expense of infill intensification or other developments or improvements. There are then some types of open space that are clearly worth changing into more beneficial land-uses in the course of urban intensification, e.g. vacant lots and excessive surface car parking. If the scope of UGOS continues to cover all of these types then we are bound to see a reduction in UGOS as density increases, but there is a big difference between developing lower value open space for the sake of better inner-city residential dwellings compared to losing valued inner city parks and recreation areas for the same increase in density. It would be useful to split this typology in future work. Focussing on those types of UGOS that provide the greatest environmental/ecological, social and cultural benefits to cities might make future analysis of green space/density relationships more policy-relevant and enable examination of specific issues that could justify some policy conclusions.

4.4 Recommendations to address gaps in knowledge

1. Compilation of data on UGOS availability (using imagery analysis or other source) in relation to population and household density, within census units (meshblocks and CAUs), analysed within a GIS.

2. Analysis of existing land use/land cover data and census-derived population data in Auckland and Wellington Cities could be aimed at the following questions:

a. Do people living in relatively compact areas of Auckland and Wellington Cities have more or less availability and accessibility of public and total UGOS than people living in more dispersed areas of these cities?
    i. When assessed on the simplest basis of area of public/total UGOS available per capita
    ii. When public UGOS area per capita availability is weighted by population density in the areas of interest (i.e. making the assumption that publicly available OGS is equally available to all people in the area of interest)
    iii. When density-weighted area per capita is further weighted by an assumption of "diminishing returns" of UGOS satisfaction if more than the "optimal" density of people are using the same UGOS area (refer findings of Bertram and Rehdanz (2015) referred to in section 3.3).
b. To what degree is the loss of UGOS and associated values as urban areas grow and expand compensated for by continuing UGOS availability (in private and informal green space), when assessed on the basis of area of total UGOS available per capita?
c. How does UGOS availability in these compact areas In New Zealand compare with availability in European cities considered to have a high quality of life and high levels of health and well-being (e.g. Copenhagen; Stockholm)?

3. An intermediate level of analysis could be done with a simple quantity and quality census of UGOS (public and private) in high, medium and low socio-economic status CAUs, also related to population and household density in those CAUs.

4. Ultimately, it would be helpful to know how much more intensification could occur in New Zealand cities before availability and accessibility of UGOS began to approach levels which New Zealanders would consider congested.

5. Given that health and wellbeing benefits appear to be associated with all types of green space and not just those that are more biodiverse, it would be particularly useful to investigate whether and how increasing tree and vegetation cover through street and road reserve planting in denser parts of cities and in less socio-economically advantaged neighbourhoods can be a way of increasing health equity in the New Zealand context.

6. Another key policy-relevant question is how can councils maximise the value (in terms of providing the right mix and quality) of the UGOS they have, to meet the dynamic needs of current and future urban populations? This would be especially relevant to the rapidly growing populations of Auckland, Hamilton, Tauranga and Queenstown.

5 Conclusions

- There is a wide range of types of urban green and open spaces (UGOS) which confer a wide range of important benefits for urban residents.

- It is of limited value to consider the association of population density only with public UGOS. Private UGOS such as gardens and allotments complement public UGOS in terms of the values they confer, and constitute significant portions of the total green space in many cities.

- Availability of UGOS per capita and per household varies widely, within and between cities. Apparent relationships between UGOS and density will be highly influenced by the ways population density is measured.

- On the whole, internationally there is less UGOS availability per capita, as population or household density of the urban area increases. This is the case whether measured on a neighbourhood, city or regional basis.

- Several studies have shown inequalities in access opportunities to UGOS, particularly in areas of lower income or socio-economic status and higher population or household density.

- There is abundant evidence that urban residents value UGOS in many ways and prefer to live close to UGOS. Provision of UGOS also incurs public costs and the challenge for cities is to find an optimal/ acceptable balance between UGOS benefits and costs.

- Many countries and cities have planning standards or guidelines for the provision of UGOS per capita or per household, in recognition of the widespread recognition of the multiple benefits of UGOS for urban residents. In many cities, however, the actual per capita provision of UGOS in given cities does not match these guidelines or standards.

- Whether through planning or design standards, or other mechanisms, affirmative action by governments and councils is widely seen as desirable to address inequalities in availability and accessibility. Approaches need to address both the supply and the quality of UGOS. Deliberate policies such as 'green retrofitting' of open and informal space can be adopted to address loss of green spaces while cities grow.

- A key to understanding the requirements for UGOS provision in the process of urban intensification is to know how to enable UGOS to be used more intensively in densely populated areas, without loss of amenity and satisfaction. Currently the evidence to answer this question is very sketchy.

- Two key complementary principles are that different types of UGOS have different uses and values, and that different UGOS users have different needs which must be taken account of and satisfied in different ways in order to maintain and enhance equitable access to UGOS.

- Findings from international literature are relevant to NZ especially in terms of planning and design of UGOS to provide optimum benefits for all residents. Two factors require special caution in the application of international findings to NZ:

    a. Almost all NZ urban areas have relatively low population and household density, although these measures are increasing quite rapidly in Auckland and to a lesser extent in parts of Wellington, Hamilton and Dunedin.

b. Most NZ urban areas are well-endowed with UGOS and most New Zealanders, regardless of deprivation levels, have good access to GOS.

- New Zealand has a very high amount of UGOS availability to people in all socio-economic status groups, which provides a good basis for the provision of good quality UGOS to equitably satisfy the needs of all residents. However a number of the above key messages are relevant to NZ particularly in the design of good accessible UGOS networks in NZ urban areas.

- Key gaps in understanding relevant to NZ are:

    a. Basic data on UGOS availability in relation to population and household density;

    b. better comparison of New Zealand UGOS availability in relation to international recommended standards and guidelines for per capita and per household UGOS availability;

    c. more comprehensive direct measures of access are needed that take account of the quality and safety attributes of specific amenities and their surrounding locales.

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