New Zealand Population Review, 45, 46–66

Visualising and Communicating Population Diversity through Web Maps

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Abstract

An online New Zealand Atlas of Population Change (NZAPC) is being developed (http://socialatlas.waikato.ac.nz/) to communicate the interaction and associated diversity resulting from three important components of population change: migration, natural change (births minus deaths), and population ageing. A comparative evaluation is made between five prominent international population web maps that utilise automated map server technology and the NZAPC, which uses static maps designed collaboratively by a demographer and a cartographer. This evaluation combined the needs of demography, cartographic communication and human–computer interaction, as well as consideration of software. Interactive online maps and graphics are a powerful medium for communicating population distribution and associated diversity, but care needs to be taken in the choice of data and their interpretation. The NZAPC differs from the other web map sites evaluated in that it is accompanied by supporting research and narrative. The design of the NZAPC has had extensive demographic and cartographic input so that users are provided with relevant and easy-to-understand maps and graphs. This is a different approach to mainstream population web mapping sites that provide access to large data sets and allow the user to dynamically construct their own maps. We argue that the provision of research-supported maps and graphs by experienced researchers has a rising place in online mapping. We provide examples from the NZAPC with a focus on assisting New Zealanders to better understand population change and thus prepare for, respond to and celebrate the increasingly diverse population of Aotearoa New Zealand.

Keywords: population web maps, cartography, static web maps, dynamic web maps

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The use of population maps on the World Wide Web (hereafter, 'population web maps') helps people to make sense of the avalanche of population data derived from population censuses. These web maps can harness text, audio, video, animation, graphics and user interaction with the intent of improving the communication and interpretation of geographic phenomena (Fu, 2018). This paper reviews and critiques existing high-profile population web maps and argues that there is also a place for alternative web maps that have less emphasis on harnessing the latest technological advancements and more on communicating a 'narrative-based' understanding of population change. Its focus is Aotearoa New Zealand.

There are two fundamental types of web maps: static maps and dynamic maps (Fu, 2018). Static maps are map images that have been created by cartographers and then saved as an image file that is made accessible through the web. Static maps were the original form of web maps and are similar to the hardcopy atlas style of cartography, which has been used for centuries. Since around the year 2000, web server technologies have enabled the development of dynamic maps, whereby the map readers are also the map producers (Fu, 2018). Users are able to query and analyse data and then assemble maps and other visualisations themselves, enhancing their understanding of the data and their geospatial relationships (Buchroithner & Gartner, 2013; Cartwright & Peterson, 2007). The dynamic web map is usually produced by 'out of the box' server software. These maps are primarily intended to be used for data exploration, from which the user draws their own conclusions. Consequently, dynamic web maps are a powerful means of providing information, and the number of interactive web maps is growing. Over the last couple of decades, we have seen mostly dynamic population web maps. This is because dynamic maps are generally easy to create and do not require the user to have expertise in cartography or the thematic area of the map (e.g. demography in the example of a population web maps). In this paper, we compare the dynamic population web-mapping approach with the static approach used in the online NZAPC, a website currently under development.

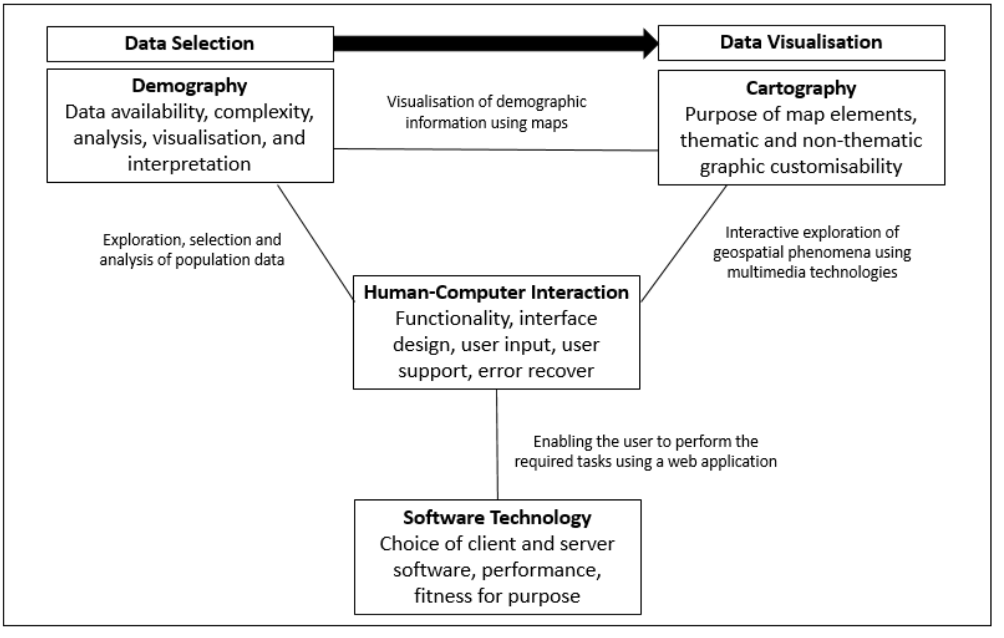
Existing research that evaluates web maps and applications has focused primarily on their usability and functionality (see, for example, Komarkova et al., 2007, 2010, 2011), and has developed very specific evaluation criteria, often regarding the inclusion or exclusion of specific computer functions. This research often overlooks the importance of the map graphics in terms of the quality of cartographic communication and the purpose of the web map (McHardie, 2016).

The assessment of population web maps is subjective, but key principles can be identified and discussed. McHardie (2016) used numerical scores to rank the performance of different web maps. Later, after review, it was realised that not only were scores unnecessary but that they were also too subjective. Instead, a more reasoned discussion is adopted in this paper based on established design principles and the expertise of the authors. Population web maps involve expertise in demography, cartography and web server software. Collectively, the authors of this paper have expertise in these key areas of knowledge. Drawing on McHardie (2016), we first discuss the design principles for web map creation. The characteristics of five major population web map sites are used to inform this discussion. Although the software technology delivering these population web maps is highly flexible and interactive, deficiencies are identified in the cartography and the absence of associated narrative. The New Zealand Atlas of Population Change (NZAPC) being developed by Jackson and Brabyn (2019) is then presented as an alternative method for visualising and communicating population diversity through web maps. Unless stated otherwise, all figures have been produced by the authors.

Population web map design principles

The design of population web map sites can be logically broken down into four considerations: the target audience (in this case, people interested in population change), cartography, human–computer interaction and server (software) technology (Fu, 2018). Design principles associated with these four components have been described by McHardie (2016) and are illustrated in Figure 1. Each of these design principles is a significant standalone subject, and this section only provides a brief overview of the principles in order to inform discussion later in this paper.

Figure 1: Population web map design principles, showing the relationships between disciplines of demography, cartography and human-computer interaction, underpinned by software technology



Population (and demographic) analysis has a range of needs, but ultimately it is to identify, interpret and project population trends and their implications, based on a range of drivers such as fertility, survival, ageing and migration. A key aspect of identifying population trends is understanding and modelling population diversity, including age, sex and ethnicity, and subnational patterns and trends. In many cases, web maps do not deliver the demographic complexity required by demographers, geographers or other users, and often their main requirement from a web map is the ability to download the underlying data, so they can analyse and interpret the data themselves (Lundquist et al., 2015). It is, therefore, encouraging that demographers and cartographers are working together so that population web maps can better serve the needs of users.

Cartography is concerned with the visualisation of spatial information using maps (Robinson et al., 1995). The underlying principle of cartography is communication (Kraak & Ormeling, 2011), and linked with this is data visualisation using symbols (mostly based on colour but also including shapes and size). Just like writing, effective cartography involves the use of established conventions (e.g. water is symbolised using blue) so that communication is efficient (Robinson et al., 1995). Quality cartography involves going through many map iterations and interactions with end users (Kraak & Ormeling, 2011). In the case of population maps, ideally there is a workflow interaction between demographers and cartographers. Demographers select and prepare the data and cartographers spatially visualise these data.

Human–computer interaction is about the interface between people (users) and computers (Dix et al., 2004; Taylor & Lauriault, 2007), and is mainly concerned with system functionality (Komarkova et al., 2007), user-interface design (Travis, 2016), user input, and user support and recovery (Nielsen, 1995). Human–computer interaction defines the interface by which computers enable the users to explore, select and analyse demographic and other data. In the case of population web maps, human–computer interaction is underpinned by the software technology powering the web applications. The computer interface to the user is crucial. Functions need to be easily seen and intuitive, and users need instant feedback on how the computer is responding.

Software technology includes both the client-side software and server-side technology. A good web map will work effectively for all the main web browsers being used by the public. Web maps that utilise server-side technology provide a customised response to user (client) requests, thereby creating a dynamic map on the fly (Fitzgerald et al., 2011). The alternative to a dynamic map is the static map, which is a map image that has been previously developed. With static maps, the server is simply delivering a pre-generated image, although it may feel uniquely generated via selecting key variables from drop-down boxes.

Characteristics of existing population web servers

Most developed countries use web maps to enable the public to view population census data. Five significant population web map systems were reviewed for this research, with the aim of identifying the characteristics of the information presented and the effectiveness of these sites in communicating population information. These sites are evaluated in the following subsections using the four design principles identified in the previous section and Figure 1. The five sites are illustrated in Figure 2 and are all regarded as significant for the country they are representing.

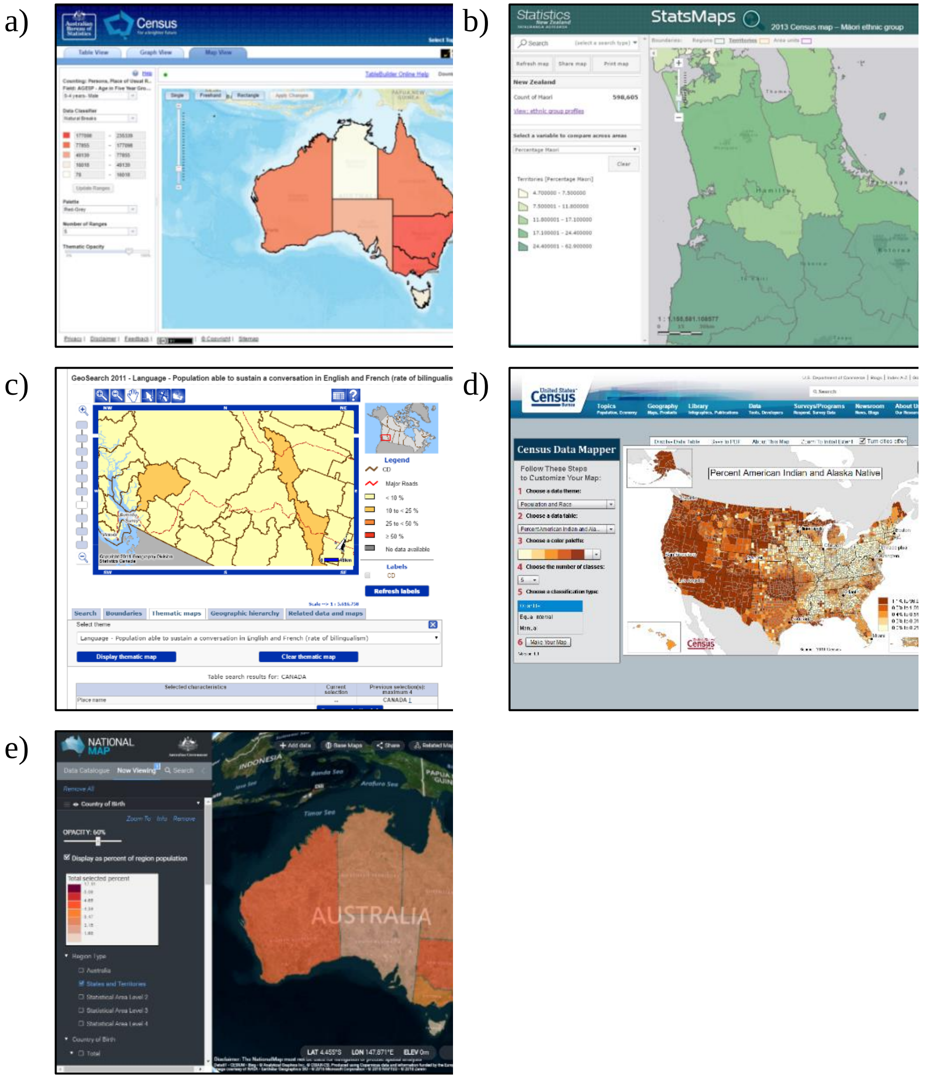
The needs of population and demographic analysis

The reviewed web maps display population census data typically based on numerical counts for different spatial unit scales. The spatial unit is typically an administration area, such as a county or region, or a small aggregation area, such as the meshblock in New Zealand. A count could be the number of people of a specified age group and/or ethnicity. These web map sites provide flexibility by enabling the user to select the spatial unit, the population theme (age, ethnicity, income, etc.) and the time period. Many are limited to displaying a single map for a given time, although some maps can be transitioned from one period to another. None of the population web maps reviewed disaggregates population change into its components, such as natural change and net migration. Only the Australian Bureau of Statistics' TableBuilder provided comprehensive statistics and allowed custom data to be exported into the maps. Government bureaus usually provide alternative sites for downloading census data rather than build this function into a web map.

Cartography

Most of the reviewed web maps provide the essential map components such as a legend, scale bar, north arrow and title. The choropleth map (predefined spatial units such as an administration area shaded with gradations of colour to represent quantity) is the dominant form of map. There are alternative map forms such as the use of points, 3-D and continuous surfaces, but these are not widely used. The choropleth map is often the only practical way to create maps automatically and dynamically for population data. Some web applications offer the ability to customise the output of the choropleths, particularly the colour palette, the number of classes and method of classification, but these options are reasonably limited.

Figure 2: Screenshots of the five evaluated web applications: a) Australian Bureau of Statistics, b) Statistics New Zealand's StatsMaps, c) Statistics Canada, d) United States Census Bureau, and e) the Australian Government's NationalMap



The major cartographic strength of the reviewed web maps is the interaction and dynamicity of the on-screen maps. Users can change the scale by zooming in and out, and often the spatial units change with the selected scale. Different regions can be easily navigated to, and in many cases, additional information can be obtained in pop-up windows by clicking on different regions.

Cartographic communication is more than symbolising choropleth maps and enabling users to navigate to different regions and scales. The choice and appropriateness of the subject matter is critical. As in a written report, if the subject is not relevant, then the communication is immaterial. Cartographers go to considerable effort to ensure that the represented data is relevant. In the case of population maps, it is useful to work closely with demographers.

Human–computer interaction

In general, the reviewed web applications performed reasonably well in terms of usability. Each site has a clear purpose and is designed appropriately for that purpose. The web applications mimic real-world workflows and use familiar language and conventional controls and layouts, which make the sites intuitive and easy to learn. Repetitive tasks are automated or made easy to perform and the amount of user input required to perform a task is kept to a minimum. Inputs are typically well labelled and have default values if appropriate. The layout of the screens is usually well proportioned so that there is appropriate space for the map, menu and function icons. The reviewed applications were free from unnecessary features to avoid confusion and distraction. Feedback is provided so that the user knows that the computer is responding and how long it will take to receive the requested map. There is also user support such as user guides and context-sensitive support. Error messages and warnings are coherent and guide the user to solutions. There are undo and redo controls, and a user's work is recoverable in the event of a user or system error.

Software technology

All five reviewed web map sites utilised dynamic map technology that relies on both server-side and client-side software. This meant that maps were created on demand in the cloud and then served to the user. The advantages of dynamic maps are that an unlimited number of map themes and extents are available to the user. In addition, if the underlying data are updated, the maps being served through the internet will also be updated. Dynamic web maps generally use expensive software for serving the maps, although there are open-source solutions. ESRI's Arc Internet Map Server (ArcIMS) is mostly used, while the Australian Government's NationalMap uses open-source software. Dynamic web maps also require a high level of IT expertise to develop the underlying programme, but increasingly there are 'out of the box' solutions such as ESRI's ArcIMS . When large data sets are being served and there are many clients, powerful server platforms are required. None of the reviewed web maps used a static map approach.

The need for web mapping to have a narrative

The main advantage of the dynamic web maps reviewed in the previous section is their high levels of flexibility and user interaction, so that the user can produce maps that suit their needs. The growth of dynamic population web maps during the last two decades parallels advances in web map technology, and many governments are seeing these web map tools as an efficient method for improving both policymaker and public access to population census data. These automated population web maps enable people not trained in cartography or demography to produce a wide range of population maps, especially for reporting purposes. These population web maps have been successful in improving access to population data, but what cannot be so readily provided is insight into what story the information is actually telling.

Population web mapping often requires the user to be able to select appropriate statistics to enable valid comparison between areas or sub-populations. As identified in the above review, population data available on web maps generally consist of population counts (by age, gender, ethnicity, income bands, etc), not more complex derived statistics. Derived statistics usually involve the selection and combination of numerators (the variable of interest) and denominators (the population 'at risk'). Often these data are not available from the same database, and can generate misleading analyses if inappropriately specified. As will be demonstrated in the following discussion of the online NZAPC, a deeper understanding of population change may, for example, be enhanced by knowing how natural change, migration and age interact. Ultimately, a more nuanced understanding engenders more accurate interpretation. It is not possible to interpret population change from population count data alone.

Cartography is about communicating effectively, and in many cases telling a story, or having a clear message. Cartographers prudently choose the data and deliberate carefully on the design of the map. Just like writing an essay, cartographers will produce many iterations until they are satisfied. Adding to the difficulty of cartography is knowing the subject area, such as demography. There is considerable advantage when experts in cartography and demography (or any other specialty area) work together.

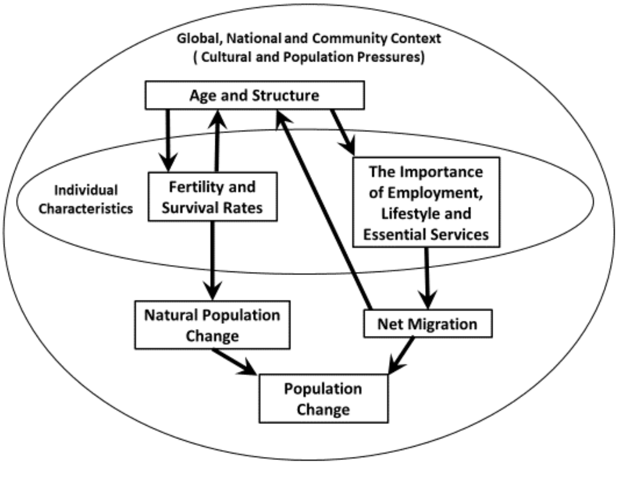
Story maps (maps with a narrative) are becoming increasingly popular because they provide a context for the maps (for examples of story maps, see ESRI StoryMaps at http://storymaps.arcgis.com). Maps combined with narrative text, images and multimedia make it easier to tell and understand stories (Caquard & Cartwright, 2014). Story maps are used for illustrating fictional stories as well as presenting factual content. It is the latter that can be important for providing a narrative around the spatial aspects of population. Maps as a narrative become more than simply an expression of cartography – they can convey and educate about key concepts of population change, so that the users develop a deeper understanding.

Cartographic design of maps involving accompanying narrative requires careful consideration of many different map elements, and there are many cartography textbooks that elaborate on this. As discussed previously, web maps typically default to simple colour shading of choropleth polygons, while carefully designed maps, using dedicated mapping software, can use a range of symbol types and even combine symbols to present more than one theme simultaneously (such as size and growth rate). Cartographers also create maps side by side to show two themes or variables at once, or a sequence over time. Many cartographic techniques can be used to increase the richness of the map and ultimately improve the communication. These techniques are illustrated below for the New Zealand Atlas of Population Change.

New Zealand Atlas of Population Change (NZAPC) – An alternative approach

The online NZAPC (http://socialatlas.waikato.ac.nz/) demonstrates an alternative approach to automated population web maps. The emphasis with the NZAPC is to use quality cartography combined with text to provide educational narrative. These narratives are further accompanied by supporting research. In essence, the NZAPC is not just providing data and information on population change, but is 'talking' end users through it and 'teaching' them about it. As indicated above, one example is the interaction and associated population diversity resulting from the three main components of population change: migration, natural change (births minus deaths) and population ageing. This interaction is summarised by Figure 3, which is similar to a number of general population change diagrams (for example, see Myrdal in Hagget, 1983). Population change is simply the sum of natural change (births minus deaths) and net migration (internal and international combined) between census periods. Feeding into that change, demographically, are fertility and survival rates and their interactions with age structure. Age interacts with both natural population change and net migration but is often ignored or missing in population change diagrams.

Figure 3: Conceptual diagram showing the general determinates of population change

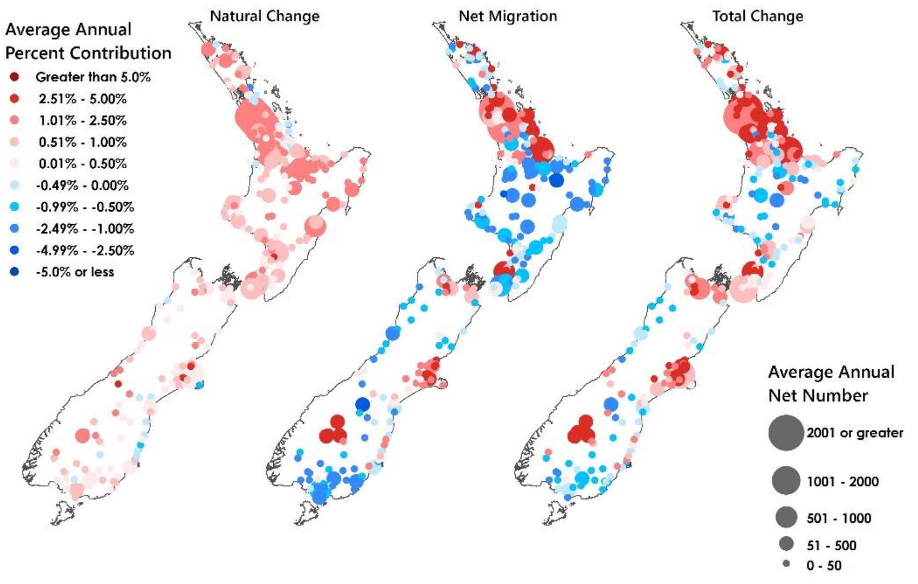


The maps shown in Figure 4 show how overall population change across 275 New Zealand urban places results from natural change and net migration (the maps are downloadable from the NZAPC). They have been chosen because they show some clear themes that are linked to the conceptual diagram in Figure 3:

- Natural change has been positive for most urban places across the period 1976–2013 and is relatively homogeneous across New Zealand.
- Net migration is much more variable and there are many towns that have experienced positive migration and many that have experienced negative migration.
- Together, the maps show that the spatial variation in total population change is primarily driven by net migration.

The cartography associated with these maps has qualities that cannot be easily replicated with dynamic cartography (i.e. maps generated 'on the fly' presented in the web maps that were reviewed). Firstly, the maps simultaneously convey two statistics: percentage change and absolute change (net number). Two different types of symbolisation are used: colour for percentage change and circle size for absolute change. The legend intervals used for these two statistics have been carefully chosen to represent the spread of the data, and the colours are those typically used for population data – red for positive growth and blue for negative (hot and cold colours, respectively). The use of symbols (in this case, colour) that people associate with different themes is an important principle of cartographic convention and improves the efficiency of map communication (Robinson et al., 1995; Jones, 1997). Automated web maps do not often select the best symbols and data classes for generating maps.

Figure 4: Comparison of natural change, net migration, and total change for New Zealand urban places between 1976 and 2013



The data to produce the natural change and net migration maps in Figure 4 are also not raw census data. The generation of these data involved a considerable amount of methodological conceptualisation, compilation and analysis, and was done as part of a much larger project (see Jackson and Brabyn, 2017 for more detail). Time-series components of change data at the urban place level (cities, towns and remote settlements) over the period shown are not available directly from the New Zealand population census data. These data needed to be statistically derived, and a description of the methodology is included on the website. The urban place level ($n = 275$) was chosen because many people can relate to an urban place, as it represents a recognised spatially clustered community of people. The population density of a given place is relatively homogenous compared with spatial units such as counties or district council areas that are typically used by automated web maps. Within many district council areas, there are both rural and urban areas; therefore, while the population density is actually heterogeneous, it is represented cartographically as homogeneous. This is an example of a well-known cartographic representation issue called the 'ecological fallacy' in which inferences are made for disaggregated data based on an aggregated form of the data. The use of urban places as the spatial unit reduces this well-known error.

Having identified that the spatial variation in net migration has been driving the spatial variation in total population over the past 37 years, the NZAPC continues the narrative by showing how net migration patterns vary by age. Figure 5 and Figure 6 show net migration by decade across the period 1976–2013 for the 15–24 and 65+ age groups, respectively. The main themes are that:

- The 15–24-year age group have completely different net migration patterns to the 65+ year age group.
- The 15–24-year age group are moving to the larger cities and tourist towns and the 65+ year age group are moving out of the large cities to small lifestyle towns
- The spatial patterns of net migration for both these age groups are relatively consistent over time, although the period 1996–2006 shows net migration loss for those aged 65+ years was more widespread than across other decades.

The narrations accompanying these maps embedded in the NZAPC cover many different topics to help the viewer/user understand how New Zealand's population has been changing. The narrations are not limited only to maps. There are also graphs for each urban place showing how natural change and net migration have interacted between 1976 and 2013 to produce total population change. Figure 7 shows these data for Tauranga. By enabling viewers to observe past trends, they are in a better position to understand how the population may change in the future. The narrations have reference to the demographic transition, which is an important consideration that helps viewers understand population change.

As shown earlier in Figure 4, the NZAPC maps show how natural change has been, and currently is, positive for most urban places. Demographers know that with an ageing population, New Zealand will follow what is already happening in countries such as Japan and much of Europe (for example, Matanle and Rausch (2011), among many others); that is, natural change will become increasingly negative as deaths come to outnumber births. The NZAPC has maps based on StatsNZ's projections to show this progression (see Figure 8); like other projection maps in the NZAPC, they are also provided with projection variants (high, medium and low assumptions).

Figure 5: Average annual net migration at 15–24 years (% of age group) by decade, 1976–2013

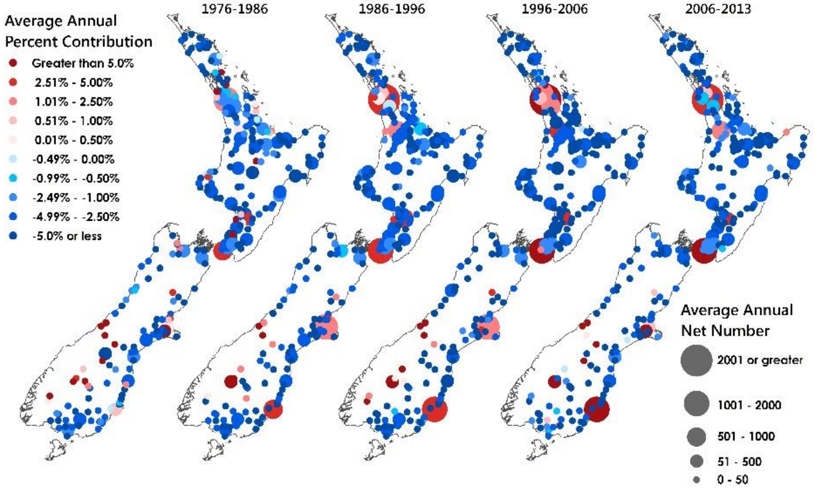
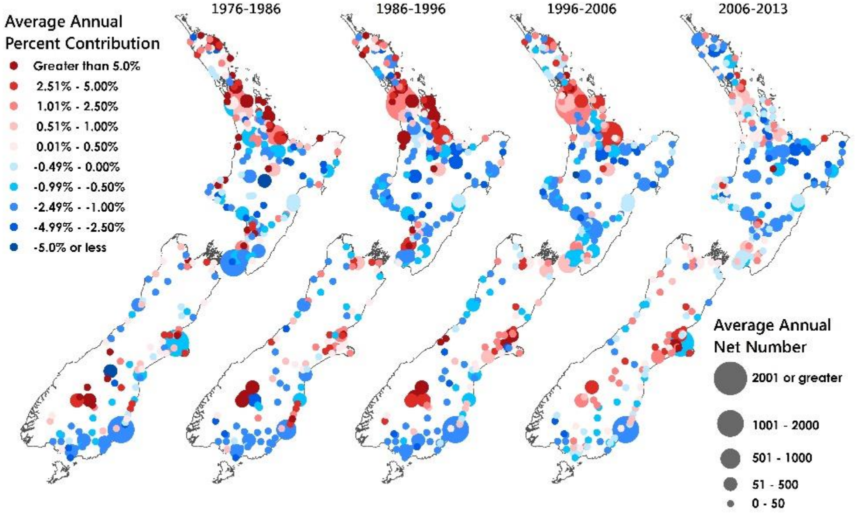


Figure 6: Average annual net migration at 65+ years (% of age group) by decade, 1976–2013



With the NZAPC, the maps were generated using cartography software (in this case, ArcMap 10.6) by the developer. Each map was produced and stored as an image file and is accessed like any other file-based html-coded website. One drawback to this approach is that each map has to be a priori produced by the developers, and when new data sets become available, such as with a new population census, the maps have to be reproduced or added to. A solution to this issue is to use scripts that automate both the data set-up and the development of maps and graphs. Maps and graphs created in the NZAPC were mostly developed using Python scripts (in this case, using the ArcPy library). A map produced in ArcMap can be saved as a map document, and this document can be used as a template and manipulated using Python. There are other Python libraries, such as Matplotlib, for automating graph production. The use of Python scripts to automate the production of maps and graphs means that the static map approach involves technical expertise, even if the website itself is simple.

McHardie's (2016) review of dynamic population web maps did not calculate costs, but it is worth comparing dynamic and static population web map solutions with regards to the effort and expertise required. The NZAPC has involved a demographer, cartographer (with programming skills), and a web developer. These professional services are expensive because the process of developing the NZAPC has required ongoing iteration, analysis, and careful consideration and development of content. The development of dynamic map solutions similarly requires IT professional skills and time. The dynamic map technology generally involves 'out of the box' solutions, which makes set-up easier and quicker. However, the more complex server technology used for dynamic sites means that an IT specialist is required for regular monitoring and maintenance. There is also considerable cost associated with the internet map server software and the server hardware that hosts the site. Both types of websites require ongoing monitoring and maintenance, and this is typical of all websites.

Figure 7: Contribution of natural change and net migration to total change, Tauranga City, 1976–2013

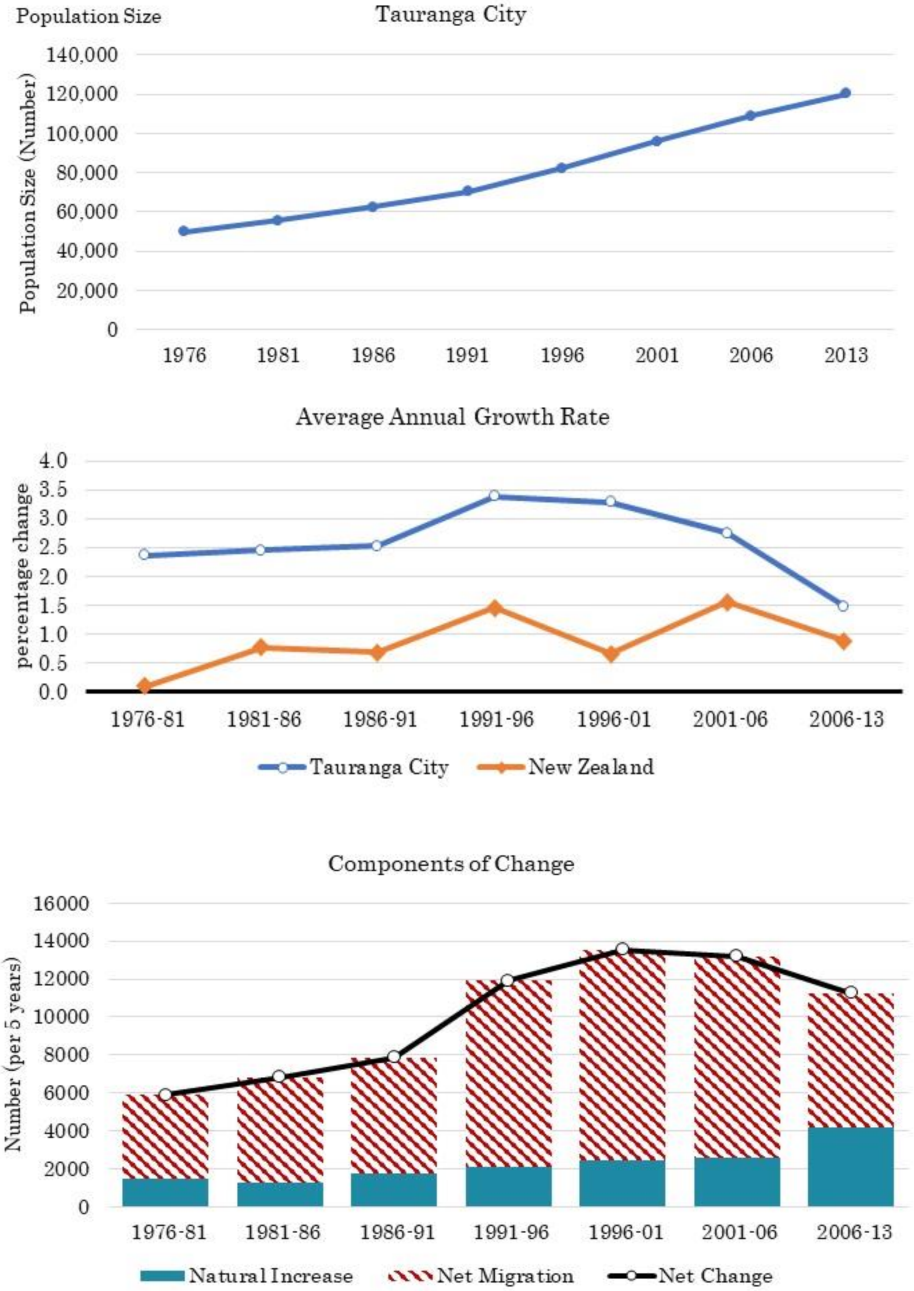
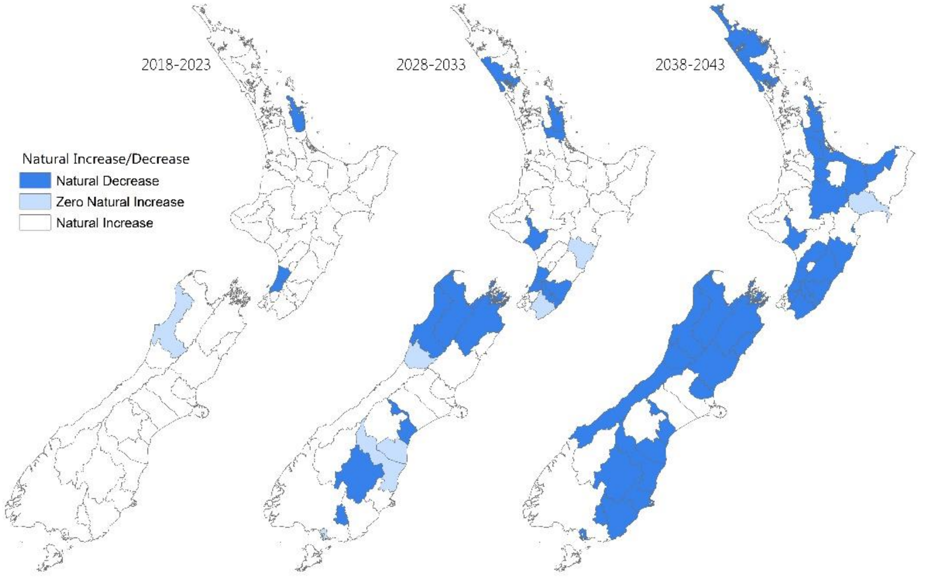


Figure 8: Projected natural increase/decrease by territorial authority area 2018–2043, medium variant



Conclusion

This paper has compared population web maps created using internet map server technology to produce on-demand dynamic maps with the NZAPC which uses static maps developed with the combined efforts of a demographer, cartographer and web developer. Both forms of web maps (dynamic and static) have their place although the dominant form is currently the automated dynamic web map. The dynamic web map serves the purpose of making census population data accessible to the public. However, the static web approach to population maps has several advantages over dynamic web maps primarily because the static map with accompanying narrative can guide the map reader through a better understanding of the information provided in the maps.

Compared with the current mainstream approaches that have been discussed in this paper, the NZAPC demonstrates an alternative form of mapping population data. The NZAPC involves careful consideration of the needs of both demographic and cartographic communication principles, and end usage. Using the NZAPC as an example, this paper has shown that there is both art and science involved in producing maps of high cartographic quality, and that this cannot be easily automated by dynamic web maps. Through carefully selected themes, data, maps and graphs relating to New Zealand's population change, the NZAPC provides a series of narratives that lead the viewer on a journey to deeper understanding.

The NZAPC promotes the importance of having narrative accompany the maps in order to assist users to understand the story the data are telling. Understanding can be further enhanced by reading the accompanying methodological notes, which explain how the data, especially derived statistics, were created. Population change is no different in this regard to any other subject, but the provision of derived statistics such as components of change, rates and ratios on the NZAPC, rather than simple population counts, allows users to make more nuanced comparison between areas. The population census data being visualised by many automated population web maps is typically based on simple population counts, and although these can be accessed at a range of spatial scales, the resulting information is context-free.

The well-established notion that data lead to information which leads to knowledge which leads to wisdom was first specified in detail by Ackoff (1989). Consideration of this hierarchical process is becoming more important than ever, as the amount of data being produced is increasing exponentially, and tools and artificial intelligence are being used to make sense of these data. This hierarchical process is based on filtration, reduction and transformation, as well as increasing understanding of relations, patterns and principles. Making sense of population data often requires social and historical context, which cannot be so readily auto-manufactured. This is where accompanying narrative is useful. This paper supports a growing move towards online story maps (see Caquard and Cartwright, 2014) that are not meant purely for data exploration, but for conveying a more directed message. This is particularly important for helping people to understand changes in population diversity and to anticipate or predict demographic changes to their communities. It is our hope that the relations, patterns and principles conveyed by the NZAPC will contribute to developing this outcome for users.

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