Spatial Differentiation of Landscape Values in the Murray River Region of Victoria, Australia

Xuan Zhu · Sharron Pfueller · Paul Whitelaw · Caroline Winter

Abstract This research advances the understanding of the location of perceived landscape values through a statistically based approach to spatial analysis of value densities. Survey data were obtained from a sample of people living in and using the Murray River region, Australia, where declining environmental quality prompted a reevaluation of its conservation status. When densities of 12 perceived landscape values were mapped using geographic information systems (GIS), valued places clustered along the entire river bank and in associated National/State Parks and reserves. While simple density mapping revealed high value densities in various locations, it did not indicate what density of a landscape value could be regarded as a statistically significant hotspot or distinguish whether overlapping areas of high density for different values indicate identical or adjacent locations. A spatial statistic Getis–Ord Gi* was used to indicate statistically significant spatial clusters of high value densities or "hotspots". Of 251 hotspots, 40% were for single non-use values, primarily spiritual, therapeutic or intrinsic. Four hotspots had 11 landscape values. Two, lacking economic value, were located in ecologically important river red gum forests and two, lacking wilderness value, were near the major towns of Echuca-Moama and Albury-Wodonga. Hotspots for eight values showed statistically significant associations with another value. There were high associations between learning and heritage values while economic and biological diversity values showed moderate associations with several other direct and indirect use values. This approach may improve confidence in the interpretation of spatial analysis of landscape values by enhancing understanding of value relationships.

Keywords Landscape value · Hotspot · Spatial analysis · GIS · Place

Introduction

Understanding how people perceive places and, as a consequence, invest them with value is gaining recognition as an important component of decision making to determine appropriate land use and management (Williams and Stewart 1998; White and Lovett 1999; Williams 2000; Calheiros and others 2000; Priskin 2003; White 2007; Moore and Polley 2007; Raymond and Brown 2006). Since people and place are inextricably linked in socio-ecological systems, natural resource management needs to address perceived values as well as objectively measured ecological qualities of the landscape (Alessa and others 2008). This is especially so in regions which include protected areas as well as possessing natural resources which support a range of agricultural, commercial, residential and tourism activities (Williams and Stewart 1998). Landuse decisions which neglect local knowledge and deeply embedded moral and ethical values may threaten individuals and their assets and undermine attempts by government agencies to

X. Zhu (✉) · S. Pfueller
School of Geography and Environmental Science, Monash University, Clayton Campus, Wellington Road, Clayton, Melbourne, VIC 3800, Australia
e-mail: xuan.zhu@arts.monash.edu.au

P. Whitelaw
Centre for Hospitality and Tourism Research, Victoria University, Melbourne, VIC 8100, Australia

C. Winter
School of Business, University of Ballarat, Ballarat, VIC 3350, Australia

obtain binding agreements between regional stakeholder groups or to manage conflicts (Zhu and Dale 2000).

Many approaches to gaining insight into perceptions of places and their associated meaning have relied on the use of interviews, focus groups or attitudinal questionnaires (e.g., Henwood and Pidgeon 2001; O'Brien 2006; Collier and Scott 2008). Such methods have also been used to map associated cultural and institutional assets (Fuller and others 2002; Kretzmann and McKnight 1996) and to plan local area management (Schusler and Decker 2002). These latter methods, involving face-to-face discussion, have an advantage in providing participants with the opportunity to define the direction of research and to nominate what they perceive to be of value. They do not, however, simultaneously provide high levels of quantitative information on both location and importance of places (Dredge 1999; McGuirk 2001).

Quantitative spatial methods have been developed to relate measurable physical characteristics of landscapes to people's preferences. In one study, respondents completed surveys in which they linked landscape qualities to numbered areas on maps (Tyravainen and others 2007). In another, in order to understand the suitability of landscapes for recreational use, Kliskey (2000) asked survey respondents to nominate preferred landscape qualities, such as steepness or remoteness, and then defined locations on topographic maps. To capture spatially the subtleties of the meanings that people associate with landscape, Reed and Brown (2003) developed a method called Values Suitability Analysis (VSA). VSA involves measuring an inventory of place-specific social perceptions of landscape values which are defined as the "values people associate with the places where they live, work, visit, or otherwise attach meaning" (Alessa and others 2008) and include aesthetic, wilderness, spiritual, life sustaining, intrinsic, and economic values. The VSA method uses landscape values as operational measures of sense of place to identify land use opportunities that are consistent with the values, perceptions and preferences of the public from environmental, social and economic perspectives. Perceived landscape values are measured and mapped through public surveys and GIS-based density mapping techniques are then utilised to aggregate valuations and to identify places with high densities. This approach has been used in a number of resource management contexts. In Alaska, USA, it was applied in the Chugach National Forest planning process (Reed and Brown 2003; Brown 2005). In Australia it has been used in the Otways region of Victoria to explore the relationship between place attachment and landscape values (Brown and Raymond 2007) and visitor attitudes towards tourism growth and development (Raymond and Brown 2007). The results of its use show good agreement between perceived values and scientific assessment of

geographic features (Brown and others 2004) and of conservation priorities (Raymond and Brown 2006). In the Kenai Peninsula, Alaska, its use revealed areas of high levels of perceived values which correlated well with measured ecological richness (Alessa and others 2008). It has, therefore, proven useful in providing better understandings of multiple perceptions of place and of their relationships to scientifically observable characteristics.

Value density mapping, therefore, appeared to provide an appropriate approach to assessing broad perceptions of values associated with the Victorian bank of the Murray River. The region surrounding the river has been valued highly for its natural resources as well as for its environmental and cultural qualities. The river provides a variety of unique wildlife, riparian habitats, historic towns and magnificent scenery as well as water for a variety of agricultural and horticultural industries, forestry and recreation activities. These features have led to growing urban development, an extensive tourism industry and increasing pressure on natural resources. As a consequence, the health of the river and the environmental quality of the region have declined significantly since European settlement. In order to reconcile the conflicting needs of the environment and of agricultural and commercial development, it became necessary in 2006 for the Victorian Environment Assessment Council (VEAC) to assess whether the levels of protection of natural areas in the region should be changed to aid the conservation of important species, habitats and cultural assets.

This study seeks to provide input into deliberations on the conservation status of the Murray River region by revealing key insights into landscape values held by those for whom the region is important as a place to live, work or engage in recreational activities. It applies density mapping of landscape values as developed by Brown (2005) but also attempts to overcome some limitations of this approach. As Brown (2005) pointed out, the density mapping technique does not indicate at what density an aggregation of a landscape value can be regarded as a statistically significant hotspot. It is not easy to determine subjectively a density threshold for delineating such hotspots and, even if it could be done, it would be difficult to establish or statistically test the significance of individual hotspots identified from density maps. Alessa and others (2008) used a standardized density value of 0.67 as a threshold to define the boundary of a hotspot in a landscape density map for social-ecological hotspot mapping. However, they acknowledged that using a density threshold could generate a false sense of precision about the hotspot boundaries, because a slight change of the threshold value (for example from 0.66 to 0.6) would alter the size, shape and even the number of hotspots. It is also difficult to distinguish whether areas of high density for different values which

overlap are indicating identical or adjacent locations and, therefore, to determine if there are any relationships between different landscape values.

A study by Winter and Lockwood (2004) employing a questionnaire rather than a mapping task has indicated the existence of 4 distinct categories of values: intrinsic, non-use, use (non-recreation) and recreation. However, density mapping techniques described above have not explored whether the landscape values studied were actually distinct in people's minds or whether they represented different facets of particular places. Therefore, this study extends density mapping with spatial statistical analysis for identification of hotspots, and for examination of associations between landscape values. The article presents the extended method and its application in the Murray River region.

Study Area

The Murray River Region of Victoria

The Murray River is Australia's second longest river stretching over 1,500 km from its headwaters in the Great Dividing Range in the north east of Victoria to its mouth in South Australia. It is one of the world's longest navigable rivers and a major source of water for much of southeastern Australia. Together with the Darling River, it forms part of the river system in the Murray-Darling Basin, which drains most of inland Victoria, New South Wales, and southern Queensland (Murray-Darling Basin Commission (MDBC) 2006).

Since the 1880s, the Murray River has been a source of irrigation for agriculture (Sinclair 2001). In 1915, three states, Victoria, New South Wales and South Australia signed the Murray River Waters Agreement, which provided for a number of river entitlements, navigation, infrastructure and irrigation needs and proposed to construct infrastructure of dams and locks to support both navigation and irrigation (Conacher and Conacher 2000). Since then, a series of locks, weirs and reservoirs have been built along the river. The infrastructure has ensured the availability of water for farming and made the Murray River region the most productive agricultural area in Australia relying mainly on broadacre dryland pasture and cropping, on irrigated orchards and vineyards and on forestry in the Central and Eastern segments (Department of Primary Industries 2007). However, irrigation has led to rising river salinity that now threatens agriculture (Murray-Darling Basin Commission (MDBC) 1999).

The Murray River is also home to a number of unique species including the Murray cod (*Maccullochella peelii peelii*), Macquarie perch (*Macquaria australasica*), eel-tailed catfish (*Tandanus tandanus*), Australian smelt (*Retropinna semoni*), Murray short-necked turtle (*Emydura macquarii*) and Murray River crayfish (*Euastacus armatus*) (Murray-Darling Basin Commission (MDBC) 2004). It also supports river red gum (*Eucaluptus camaldulensis, Denhardt*) forests and their associated fauna and flora. Irrigation infrastructure, including dams and locks has, however, seriously disrupted the life cycles of many ecosystems both inside and outside the river. Recent extreme droughts from 2000 to 2009 have also put significant stress on river red gum forests, such as those at Barmah, such that there is mounting concern over their long term survival.

Along the river, there are magnificent scenic landscapes, historic towns and many other sites of cultural and heritage interest, with significant areas of public land including National and State Parks, Forests and nature reserves. Consequently, the region is a major attraction for tourism and recreation. Visit and recreation are based on sightseeing, bushwalking, bird watching, water sports, visiting friends and relatives, opportunities to taste fine wines and fruits and, particularly in Echuca, Mildura and Wodonga, heritage trails and festivals, paddleboats and houseboats. It is the most popular regional area for tourism in the state of Victoria. For example, for the year ending March 2006, there were 2.1 million domestic overnight visitors, 2.6 million daytrip visitors (Tourism Victoria 2009a) and 39,022 international overnight visitors (Tourism Victoria 2009b). Seventy-eight percent of domestic visitors stay in the region for 1–3 nights while 53% of international visitors spend 1–3 nights in the region with 18% staying for 15 nights or more (Tourism Victoria 2008). Because the area is only approximately half a day's drive from the state capital city, Melbourne, it is popular for weekend trips and many people return to it frequently, especially on holiday weekends for particular sporting and cultural events. For example, in 2008 in Swan Hill, 63% were repeat visitors and a further 33% were likely to visit again in the next 12 months (Tourism Research Australia 2009). The length of the region from east to west means that people who live in one part of the region may visit other parts of it for recreational activities. These levels of visit have necessitated the extensive provision of motels, hotels in towns and camping areas in towns, National Parks and many other locations on the river bank.

The portion of the Murray River region studied includes the land lying approximately 50 km south of the river between its headwaters and the border between Victoria and South Australia (Fig. 1). It includes the major regional centres of Mildura, Swan Hill, Tocumwal, Echuca, Yarrawonga and Wodonga. The last three extend across the river to the towns of Moama, Mulwala and Albury respectively which are regarded as "twins" on the northern banks in New South Wales and are included in this study.
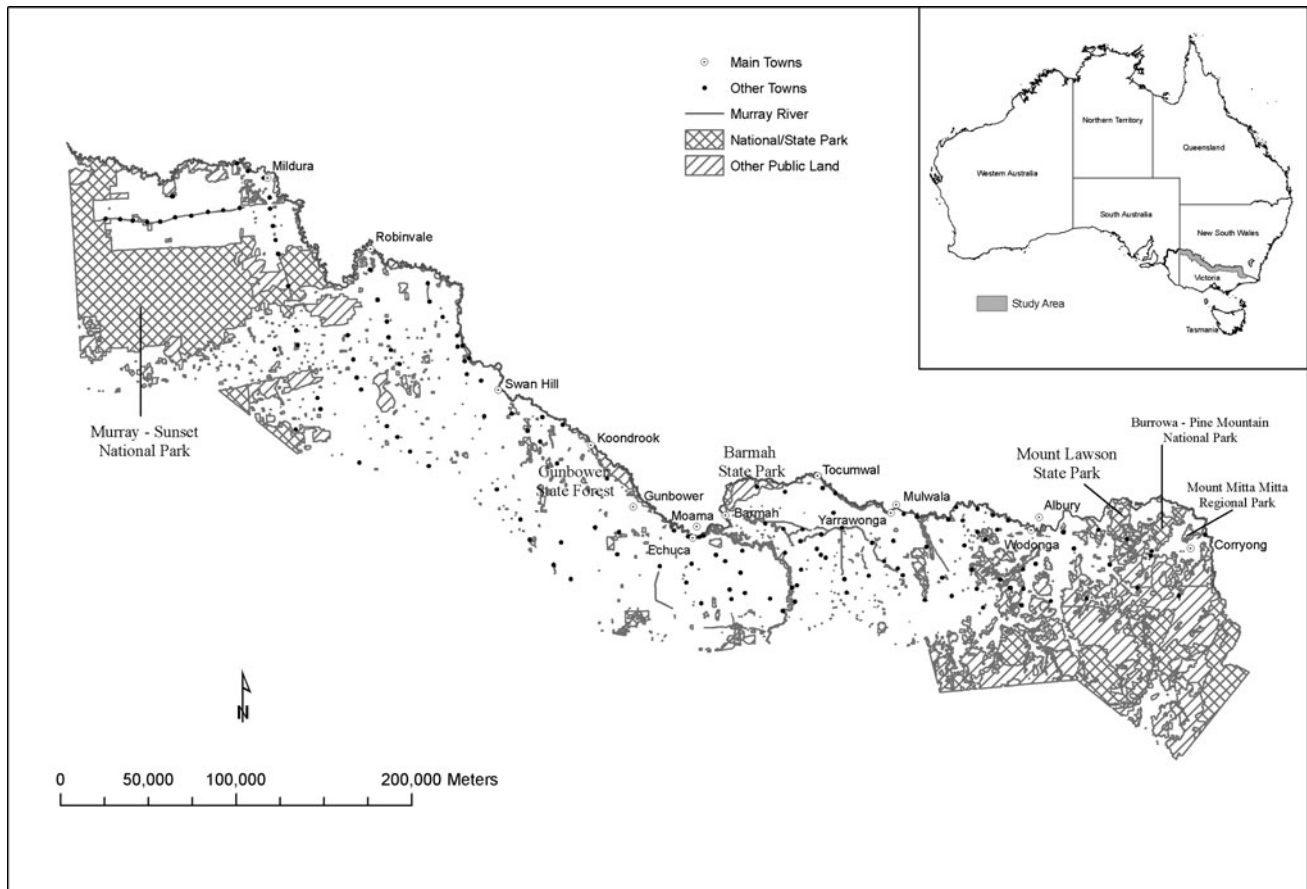
Fig. 1 Study area

Methods

Landscape Values

There are many different types of landscape values, ranging from instrumental values (for places that may provide sustenance) to symbolic values (for places that may represent abstract ideas) (Brown 2005). This study adopts the landscape value typology developed by Raymond and Brown (2006) for their study in the Otways region of Victoria. It includes 12 landscape values: aesthetic/scenic, biological diversity, economic, future, heritage, intrinsic, learning, life sustaining, recreation, spiritual, therapeutic and wilderness. Their definitions are listed in Table 1.

Data Collection

Place valuation was implemented through surveys modified from those of Raymond and Brown (2006). In developing a sampling strategy, it was necessary to take account of the full range of people with local knowledge of the study area. People engaged in tourism and recreation would be expected to have considerable knowledge of the region

particularly because of the high percentage of repeat visitors and because people from one part of the region engage in recreation in other parts. Therefore, such people were included in the study as well as a sample of people contacted directly through their residential addresses. The former are termed "visitors" and the latter "residents".

The study area contained 76 postcodes with a total number of households of 71,870 according to the Australian Bureau of Statistics (2001) which was the most recently available at the commencement of study (Australian Bureau of Statistics 2007). The total number of residents was 259,525. To obtain a minimum of 350 responses from residents which would permit multivariate analysis with a 95% confidence interval and a sampling error of ±5% (Salant and Dillman 1994), we aimed for a random sample of 1400. Residents were randomly selected from the 76 postcodes from the electronic White Pages in proportion to the total population in each postcode. To obtain the desired sample of 1400, a total of 1615 names associated with households were obtained on the assumption that 15% of the phone numbers and, therefore household addresses, might be out-of-date. This strategy excluded residents without land line phone connections or

Table 1 Typology of landscape values (adapted from Raymond and Brown 2006)

Value	Definition
Aesthetic	Places with attractive scenery, sights, smells or sounds
Economic	Places with economic benefits or potentials, such as tourism, forestry, agriculture or other economic activities
Recreational	Places with outdoor recreation opportunities
Life sustaining	Places that may help produce, preserve and renew air, soil and water
Learning	Places with opportunities for learning about the environment
Biological diversity	Places with a variety of plants, wildlife, aquatic life or other living organisms
Spiritual	Places that are spiritually special
Intrinsic	Places with special values for their own sake
Heritage	Places with natural and human history
Future	Places allowing future generations to know and experience them as they are now
Therapeutic	Places making people feel better physically and/or mentally
Wilderness	Places that are wild

silent numbers. It also did not seek to ensure inclusion of minority groups. Therefore, since no data on racial background of respondents were collected, it is not clear how many of the respondents came from the indigenous population which represents 1.4% of the total.

There was no simple way to define a balance between residents and people engaged in tourism and recreation to be surveyed because of the large number of people who visited annually (around 4.7 million) and the heterogeneity of visitor length of stay in relation to numbers of residents. Therefore, an arbitrary decision was made to aim for a sample 500 visitors. In order to obtain a sample of this size across a range of categories of tourism and recreation attractions, the Easter long weekend, 2006, which is one of the peak periods for tourism and recreation, was chosen as the sampling period. Research assistants were assigned to each of 3 stretches of the Murray River which attract approximately equal numbers of visitors according to past reports (Tourism Research Australia 2005). Each assistant traveled through their area over the 4 day period, focusing on Parks and reserves selected on the advice of Park Rangers in the region and on other major tourism attractions. They collected contact details of approximately equal numbers of people engaged in tourism or recreation activities in each segment in a convenience sampling process yielding a total of 508. We also contacted 32 tour operators licensed by Parks Victoria for this region. The postal addresses of all but 4 of these operators were located

outside the study area, and, therefore, the tour operators are best considered as part of the visitor group.

Surveys were sent by post to all potential respondents. Responses were received from 346 residents (25% response rate), 198 visitors (39%) and 9 tourism operators (28%). This gave an overall response rate of 30% after adjusting for non-deliverable surveys to both resident and visitor groups. Because the number of surveys completed by tourism operators was so small and because the majority of operators were visitors to the region, they were combined with the visitor sample.

Surveys also involved a mapping task to identify the locations or places perceived to possess landscape values. Respondents were asked to nominate up to six locations for each of the 12 landscape values. This was done by placing coded sticker dots on a 1:294,000 grey-scale map of the study area. The area covered by dots was limited by the maximum size at which maps could be printed which was 610 mm × 870 mm. To make dots represent the smallest area possible, the study area was split into 3 sections, east to west, and printed separately. This meant that each dot was equivalent to an area of 1.76 km in diameter. Each dot had a code indicating the type of landscape value for places, e.g. 'a' stands for aesthetic/scenic value, 'e' for economic value, 'r' for recreation value, etc. Each dot also had an importance rating or weight so that for each value respondents could place up to 2 dots weighted at 5, 2 at 10, and one each at 20 or 50. This allowed respondents to place highly weighted dots at locations which they thought possessed highest levels of that landscape value. It also allowed respondents to choose to place dots at widely different locations, even within a National or State Park, or to cluster them in different configurations to denote larger areas. All dots placed on the returned maps were digitized by recording the geographic coordinates of their centroids and, together with their associated landscape values and weights and corresponding respondents' ID numbers, stored as a digital map data layer in a GIS. After eliminating outliers, a total of 15,517 dot or point locations were obtained, each representing a place with a weighted landscape value (Fig. 2). Among them, 10,134 places were nominated by resident and 5383 places were proposed by visitors and tourism operators. They were combined to represent the places in the region with landscape values perceived by a broad spectrum of people who had knowledge of the region.

As the placement of a dot relies on respondents' visual judgement, all value locations are prone to locational error. This type of error may result from misreading of a location on the map, inability to demarcate accurately the centroid of an area with a landscape value or inaccuracy in locating a point during the digitising process. According to Brown (2005) and Raymond and Brown (2006) in their studies
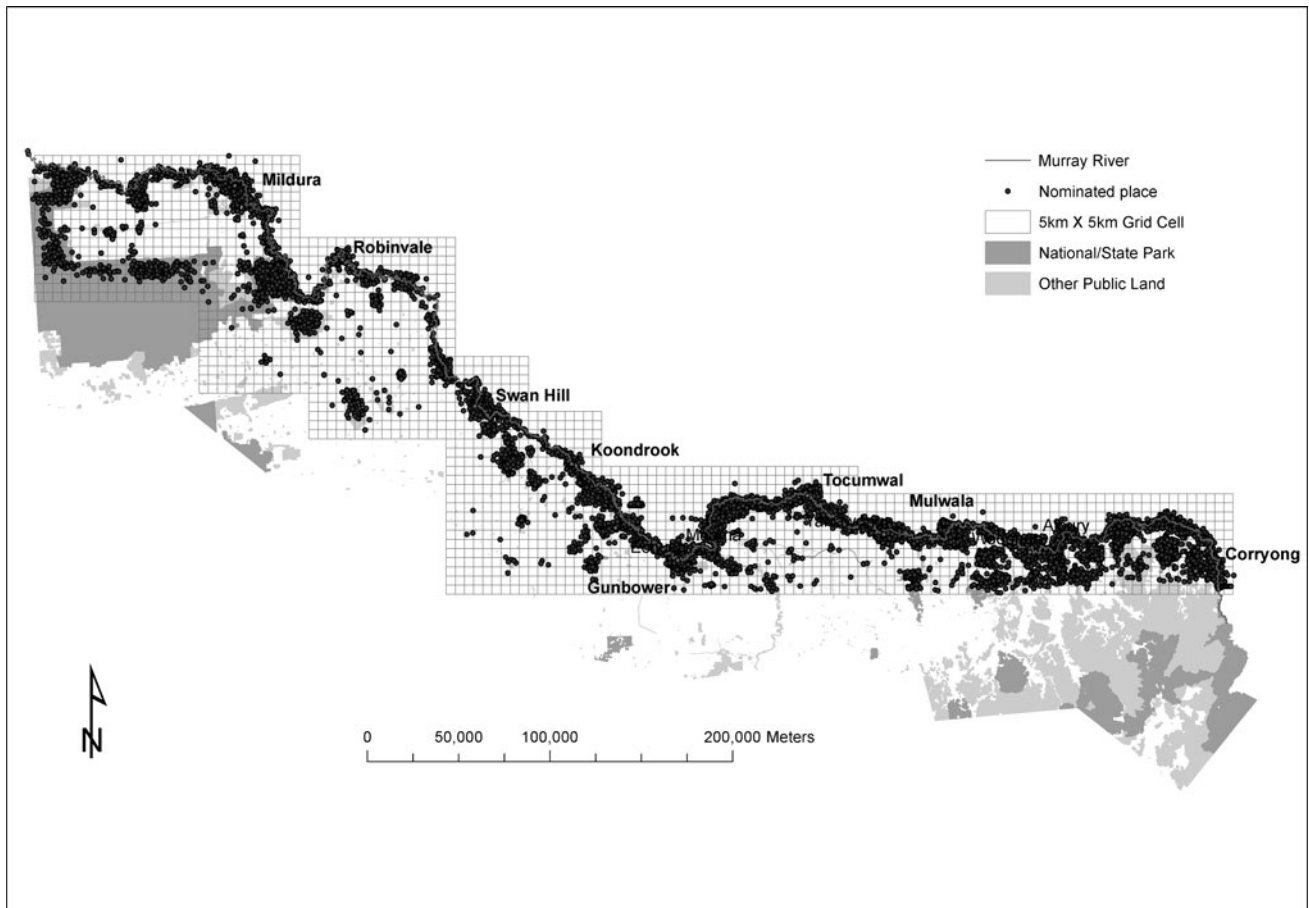
Fig. 2 Distribution of places with weighted landscape values as nominated by survey respondents. The grid cells used for hotspot mapping are also shown

that use the same size sticker dots on maps of similar scales, respondent error in dot placement is within 2.5 km, and there is also the potential for up to a 2.5 km error in digitizing the dot locations. Their error estimates are consistent with this study. The size of these errors is largely determined by both the limits to the size of maps and the use of the stickers.

Density Mapping

Based on the weights of each landscape value at every nominated location, density maps of the 12 landscape values were produced using ArcGIS software. Landscape value densities were measured using kernel estimation (Silverman 1986; Reed and Brown 2003; Alessa and others 2008). This method yields more reliable results than point interpolation methods for estimating densities at unsampled locations (Alessa and others 2008). Conceptually, a circular neighbourhood area is defined around each nominated location with a weighted landscape value. A smoothly curved surface is fitted over each nominated location, which is called a kernel surface. The surface value

is highest at the nominated location and diminishes with increasing distance from it, reaching 0 at the edge of the neighbourhood area. The volume under the surface equals the weight of the landscape value for the nominated location. The density of the landscape value at a certain location is calculated by adding the values of all the kernel surfaces where they overlay the location. In ArcGIS, density mapping is implemented over a grid of locations, represented as raster cells. Each density map is a raster data layer with a grid resolution of 500 m, which shows how the intensity of a landscape value changes continuously over the study area.

Hotspot Analysis

Mapping of each landscape value resulted in a number of density maps. The areas with especially high densities of a landscape value have been referred to by Brown and others (2004), Brown (2005), and Alessa and others (2008) as "hotspots". However, in this study, a spatial statistic namely Getis–Ord Gi* or simply Gi* statistic (Getis and Ord 1992) was applied to identify statistically significant

spatial clusters or concentrations of high densities of a landscape value. These authors also refer to these statistical significant clusters as "hotspots" and their definition of hotspots is used here. A hotspot is not necessarily a single point. Rather it is an area of a certain size representing a spatial cluster of points with landscape values higher in magnitude than you might expect to find by random chance. The Gi* statistic measures the degree of association that results from the concentration of all weighted points within a radius of a certain distance from the original weighted point (Getis and Ord 1992). In this study, the study area was divided into 2171 grid cells, as shown in Fig. 2. Each cell covers an area of 5 km × 5 km. This size is compatible with the size of sticker dots and in errors associated with their placement as described above. Each cell is identified with its centroid whose Cartesian map coordinates are known. In addition, each cell has associated with it a density value of every landscape value. For a particular landscape value, the statistic for grid cell i is

$$Gi^* = \frac{\sum\limits_{j=1}^{n} w_{ij}(d)x_j}{\sum\limits_{j=1}^{n} x_j}$$

where $\{w_{ij}\}$ is a symmetric 1 or 0 spatial weight matrix with 1 s for all grid cells within distance d of cell i, including cell i itself, and 0 s for all other grid cells; x_j is the density of the landscape value associated with cell j. The numerator is the sum of all density values of the landscape value associated with the grid cells within d of cell i, while the denominator is the sum of the density values of the landscape value associated with all grid cells (2171 cells in this case).

Therefore, the Gi* statistic measures the concentration of the sum of density values of a particular landscape value in the study area covered by the grid. It indicates whether high density values or low density values (but not both) tend to cluster in the area. A high value for the Gi* statistic indicates that high density values—that is, densities higher than the mean density for the study area—tend to be found near each other. A low value indicates that densities lower than the mean density tend to be found together. Given the set of grid cells with density values, the Gi* statistic identifies those clusters of cells with density values of a particular landscape value higher in magnitude than it might be expected to find by random chance. These clusters of cells are hotspots.

The Getis-Ord Gi* hotspot analysis tool available in ArcGIS was used for each of the 12 landscape values. The output of this function is not a Gi* value for each grid cell, but a z score for each grid cell. The z score represents the statistical significance of clustering or hotspots identified

by the Gi* statistic. A high positive z score for a grid cell indicates there is an apparent concentration of high density values within its neighbourhood of a certain distance, and vice versa. A z score near zero indicates no apparent concentration (i.e. neighbouring grid cells have a range of density values). To determine if the z score is statistically significant, it was compared to the range of values for a particular confidence level. For example, at a significance level of 0.05, a z score would have to be less than -1.96 or greater than 1.96 to be statistically significant. In this analysis, those grid cells with a z score of greater than 1.96 were identified as hotspots of a particular landscape value at a significance level of 0.05 and the hotspots of each of the 12 landscape values were mapped. The grid cells with a z score of less than -1.96 are clusters of low values, which were not mapped.

Spatial Associations between Landscape Values

The analysis of spatial associations between landscape values focused on relationships between the distributions of high landscape values. It was performed through correlation analysis of each pair of landscape values associated with the identified hotspots. The correlation analysis was carried out using the phi correlation coefficient (φ). φ measures the extent and strength of any relationship between two dichotomous attributes. It can provide statistical evidence for determining whether there is a relationship between a pair of landscape values associated with the hotspots, and how strongly the two landscape values are associated with each other.

The φ coefficient is calculated based on 2×2 contingency tables (Walford 1995). This study used the contingency table listed in Table 2 for the analysis of spatial associations between landscape values. With the contingency table, the φ coefficient is calculated as

$$\varphi = \frac{C1C4 - C2C3}{\sqrt{[(C1 + C2)(C3 + C4)(C1 + C3)(C2 + C4)]}}$$

The φ value is within the range of -1.0 and 1.0. The closer the value approaches to either of the extremes, the stronger the relationship. The significance of φ is determined by χ^2 test statistic, which is calculated as

$$\chi^2 = \varphi^2 n,$$

Table 2 Contingency table for the φ coefficient

		Landscape value A	
		Absent	Present
Landscape value B	Absent	C1	C2
	Present	C3	C4

where n is the total number of hotspots. If the calculated φ value failed the χ^2 test at a specified significance level, it would suggest that there is no relationship between the two landscape values with the nature and magnitude indicated by the φ value. In other words, there is insufficient evidence to conclude that they are associated with each other.

Results

The mean age (± 1 SD) of respondents was 51.62 ± 14.92 years. The majority had only secondary school qualifications (35.9%), 22.3% had completed tertiary education, 11.8% postgraduate education, 16.1% vocational education and 11.6% had only completed primary education. Respondents were employed in a range of areas with the largest proportion being retired (21%), 23% in professional services and 11% in agriculture. The smallest employment category was tourism (3%).

Density Distribution of Landscape Values

Density maps were produced for each of the 12 landscape values. Through visual inspection, the areas where high landscape values appear concentrated can be identified. When separate density maps for residents and visitors were compared to the maps for combined data, they were found to be almost identical with only some small differences relating to areas with low value densities. Figure 3 shows the density map of wilderness value for the whole sample. It can be seen that, as might be expected, high wilderness values are mainly concentrated in specific areas of National/State Parks, but that they also appear in State Forests near Barmah and Gunbower, and in Regional Parks at Mt. Mitta Mitta and in other public land along the river towards the headwaters in the east. Therefore, the areas in the study area with high wilderness values are not confined to locations within National or State Parks.

Hotspots of Landscape Values

Hotspots of Individual Landscape Values

Hotspot maps were produced for each individual landscape value according to respondents' place valuation. The maps generally confirm the corresponding density maps, i.e. the sites identified correspond to the areas with medium to high densities on the density maps. However, the hotspot map precisely separates hotspots from density areas where, although the aggregation of density is moderate, it is not significant enough to be recognized as a statistically significant valued location. For example, the hotspot map of

wilderness value (Fig. 4) shows similarities to the density map shown in Fig. 3 such as between Koondrook and Gunbower and at Barmah. However, some areas of moderate density west of Mildura do not appear as hotspots while others do. It also shows that statistically significant hotspots occur at locations where the density relative to other areas of high density might not appear to indicate a location of significant landscape value. This is apparent near Gunbower and Tocumwal, south and south-east of Mulwala and between Albury-Wodonga and Corryong (shown by arrows in Figs. 3 and 4).

Overall Distribution of Hotspots

A total of 251 hotspots (counted as the number of grid cells) with one or more landscape value were identified. As shown in Fig. 5, the hotspots are mainly distributed close to the Murray River, in National and State Parks, State Forests and other public land, and near major towns. Figure 5 also shows the distributions of the hotspots with a single landscape value and those with multiple landscape values. Locations of single values can be differentiated from closely located sites where hotspots for two or more values occur. For example, to the north-west of Mildura there is a single value hotspot which is spiritual, and just to the south-east of Mildura, spiritual value co-locates with recreation, but in the adjacent area it co-locates with aesthetic value. Then just north of that area, hotspots for recreation, spiritual, life sustaining, therapeutic, biological diversity and learning values co-locate in the same grid cell. These areas all represent different parts of King's Billabong Nature Reserve. The single value hotspot to the north of that area is for aesthetic value alone.

Figure 6 shows the number of hotspots plotted against the number of associated landscape values. About 40% of the hotspots are for a single value. The hotspots with a single landscape value are mostly linked with spiritual (40 hotspots), intrinsic (20 hotspots) and therapeutic (12 hotspots) values. There are no hotspots with all 12 values. Four hotspots have 11 landscape values, of which two do not possess wilderness value and the other two do not have economic value. Two of the four hotspots with 11 landscape values are located in Barmah State Park, the remaining two are near the major towns of Echuca-Moama and Albury-Wodonga. Less than 40% of the hotspots have three or more landscape values.

Results of further analysis of the hotspot maps for each individual landscape value are shown in Table 3. Spiritual value shows the greatest number of hotspots (120) which are almost evenly distributed across the region, with 24% of them located in National/State Parks. There are 97 hotspots with intrinsic value and the majority of them are located along the river with only 40% in National/State Parks. The 73 learning value hotspots are mainly
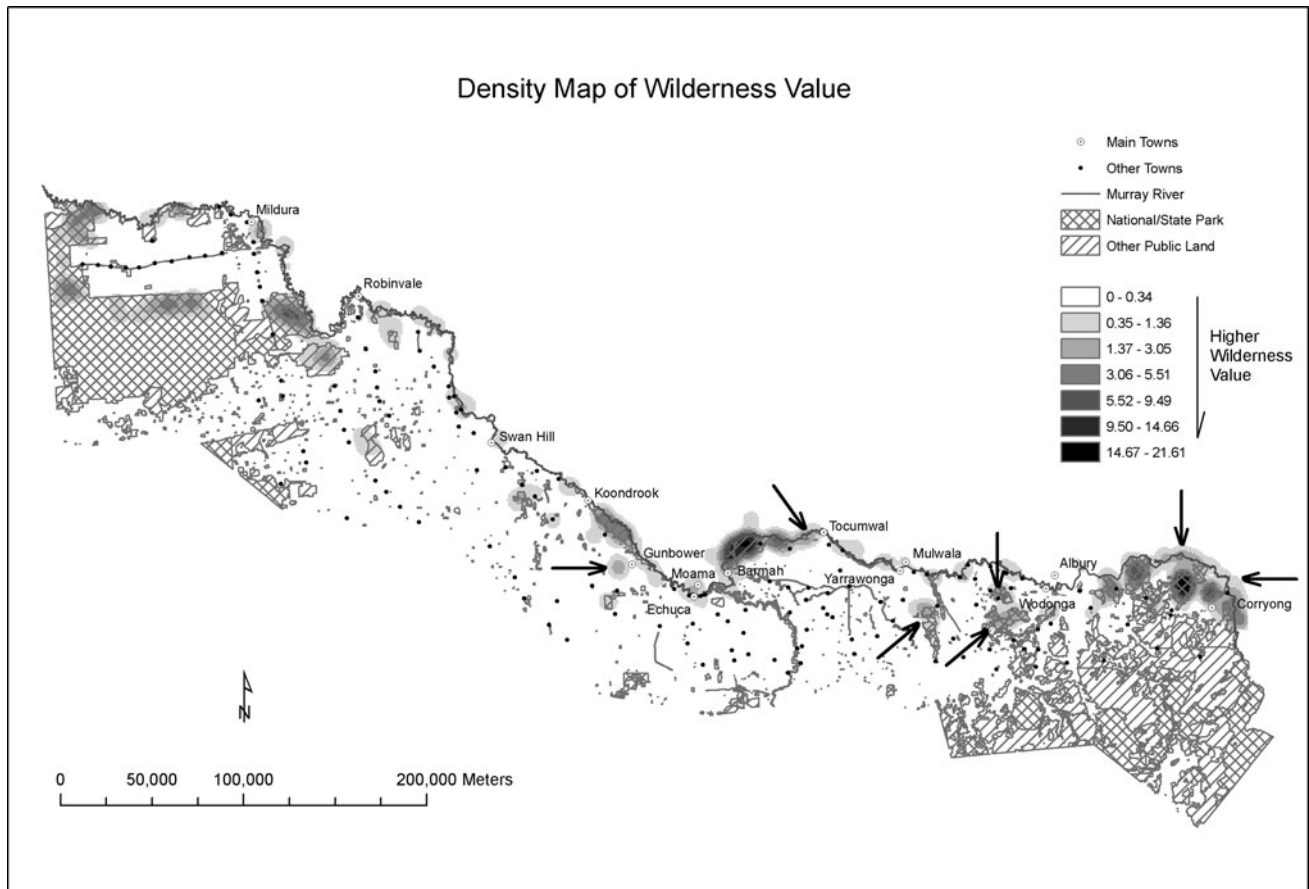
Fig. 3 Density map of wilderness value. *Arrows* indicate areas of moderate density which were shown to be hotspots for this value (see Fig. 4)

distributed across all land classifications with many near major towns. The 72 hotspots with therapeutic value are mostly distributed close to the river bank with the majority located in land other than National/State Parks. Both future and biological diversity value hotspots are almost equally distributed in National/State Parks and other land. There are 68 hotspots with biological diversity value with slightly more than half located in land other than National/State Parks, particularly in Gunbower and Barmah State Forests, river reserves and other areas close to the river bank in the east. The distribution of 60 hotspots with wilderness value is most closely associated with National/State Parks and State Forests with 62% within them. The 59 hotspots with aesthetic value are spread across the region on or near the river bank, mainly concentrated around the towns of Mildura, Swan Hill, Echuca-Moama, and Yarrawonga-Mulwala and the State Park and Forests at Gunbower and Barmah. Among them, only 13 are within National/State Parks. Of the 51 hotspots with life sustaining value, most are located in the areas near Mildura, Yarrawonga-Mulwala and in the public land near the middle and eastern sections of the river. There are 45 hotspots possessing recreation value scattered along the river with only 18% of

them located in National/State Parks. The 33 hotspots with heritage value are scattered around Mildura, Swan Hill, Echuca-Moama, Yarrawonga-Mulwala, Albury-Wodonga and Corryong in a variety of different land classifications with only 7 located within National/State Parks. Out of the 19 hotspots with economic value 17 are found around major towns including Mildura, Robinvale, Swan Hill, Echuca-Moama, Yarrawonga-Mulwala and Albury-Wodonga. None of them is within National/State Parks.

Associations between hotspots of landscape values

According to Figs. 5 and 6, more than 60% of the hotspots hold two or more landscape values. Therefore, some may be associated with each other. Table 4 lists the results of φ correlation coefficient analysis for each pair of the 12 landscape values associated with the hotspots. χ^2 values were calculated for testing their statistical significance, but not listed in the table. The *P*-value is the exact probability of getting a value of the χ^2 test statistic of a given magnitude if the null hypothesis is true. It determines whether the calculated correlation value is statistically significant, but not the strength of the correlation relationship. Here,
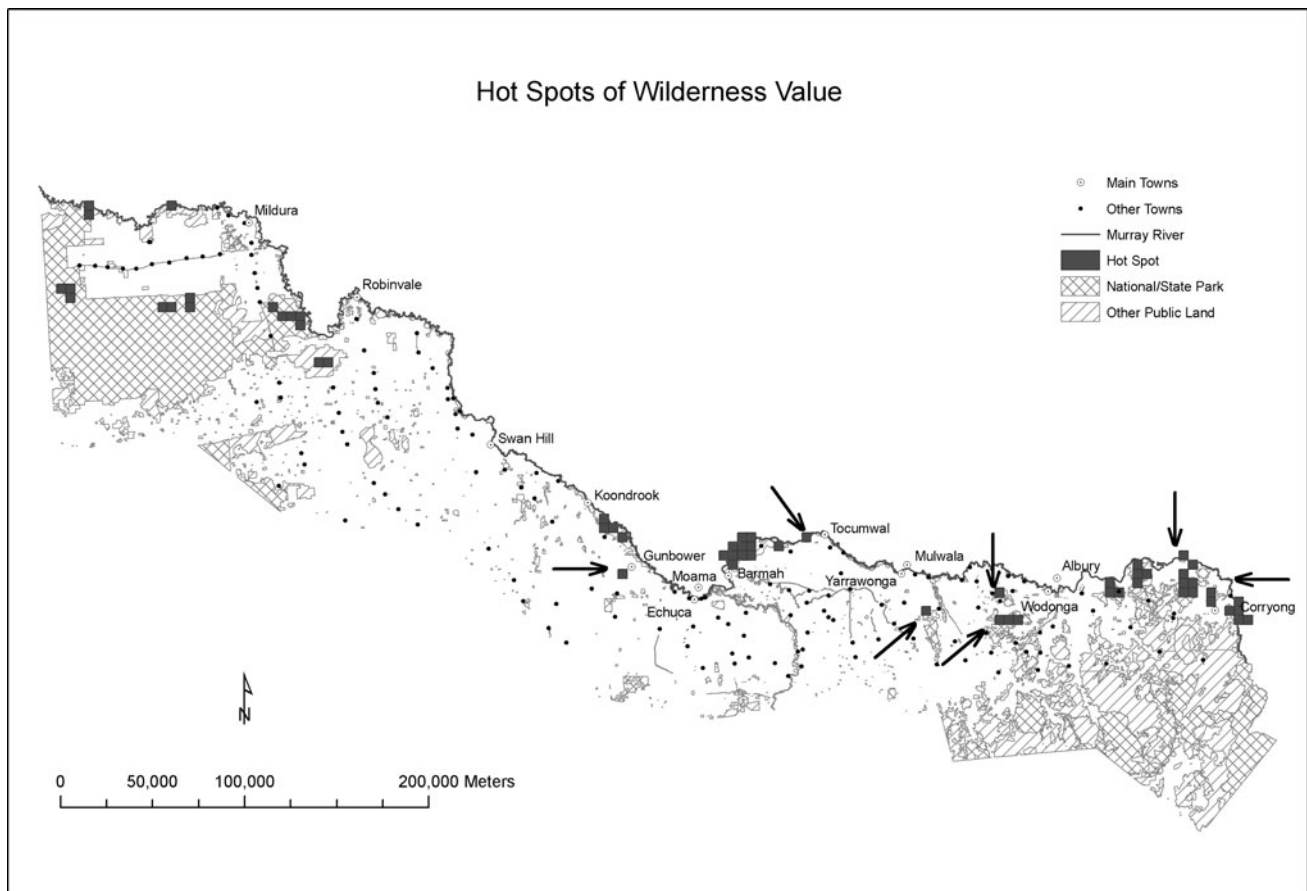
Fig. 4 Map of wilderness value hotspots

the null hypothesis H_0 is that the calculated φ value has occurred through chance, and there is no association or relationship between the pair of landscape values. A significance level of 0.05 was used in the analysis. H_0 is rejected if the P-value is 0.05 or less.

There is no scientific rule for determining what value of a correlation coefficient is considered strong, moderate or weak. Here we use the range of possible correlations and their usual interpretations proposed by Fitz-Gibbon and Morris (1987) to group the relationships between landscape values into four categories according to the φ value: $|\varphi| < 0.2$—little or no association, $0.2 \leq |\varphi| < 0.4$—weak association, $0.4 \leq |\varphi| < 0.6$—moderate association, and $|\varphi| \geq 0.6$—strong association. In Table 4, eight of the correlations showed statistically significant strong or moderate associations at a significance level of 0.05. The remaining statistically significant associations are for pairs of values where the associations are weak or extremely low. This indicates that there are very few hotspots where association of those values is statistically significant and that in considering the overall results, these low associations have little meaning. The distributions of hotspots for values with statistically significant strong and moderate associations are shown in Table 5.

The strongest association is between high learning values and high heritage values ($\varphi = 0.67$) in and around the three largest towns in the region. These are among the oldest and contain many historic buildings and monuments. These values are also associated around Lake Hume where the Hume Weir created the largest dam in Australia when it was constructed in 1936 and has a variety of historical features (New South Wales Government 2009). The river red gum forests on its banks together with those in the Barmah State Park and Forest comprise the largest and oldest such forests in the world and their associated wetlands are protected under international migratory bird agreements (Chong and Ladson 2003). These features are, therefore, rich in natural and cultural heritage.

There are moderate associations of high values for 7 pairs of landscape values (Table 5).

High recreation values associate moderately with both aesthetic and economic values. They cluster around Lake Hume and major towns of the region where river and forest scenery and possibilities for a variety of water and land-based tourism activities have stimulated provision of tourism accommodation and services. These towns are also hubs of commercial activity and are major sources of
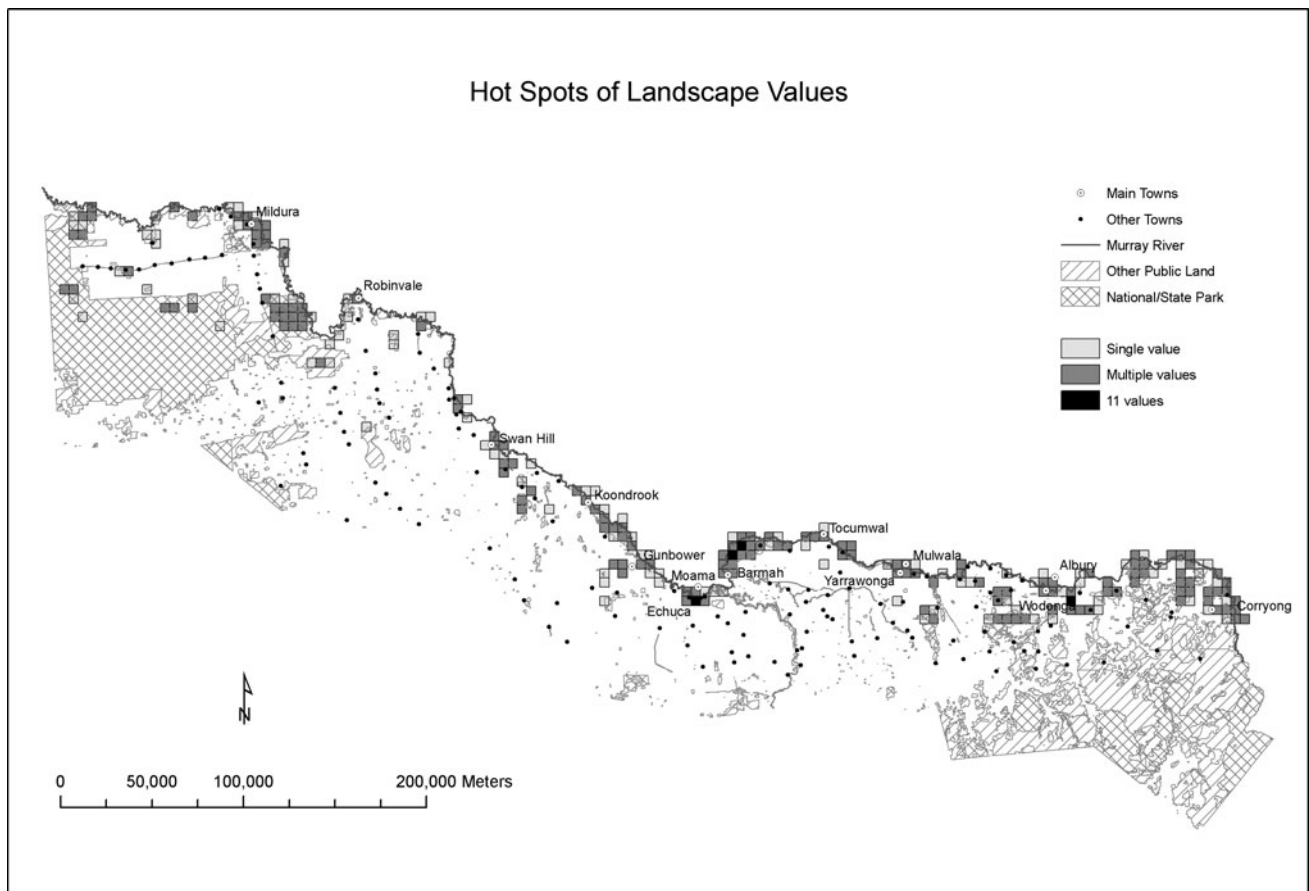
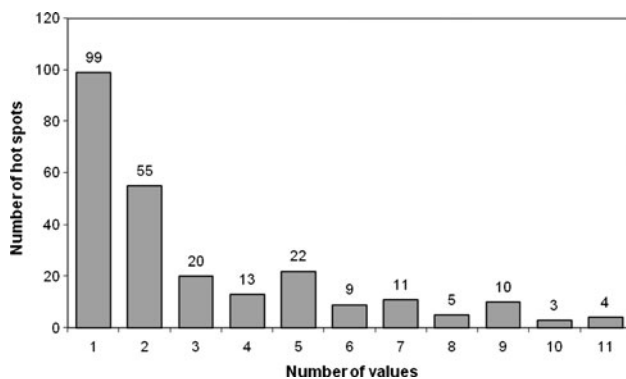**Fig. 5** Distribution of hotspots with one or more landscape values

Fig. 6 The number of hotspots sharing different numbers of landscape values

income for the region. Recreation, aesthetic and economic values are also associated around Barmah and Gunbower State Forests and nearby river banks. The State Forests at Barmah, Gunbower and Cobram are sources of timber as well as tourism attractions.

As well as a moderate association with recreation values, high economic values are associated with heritage and aesthetic values. However, the association with aesthetic values is less and found around fewer towns than heritage values and not around Lake Hume.

High values for biological diversity show moderate association with life-sustaining and future values. These are predominantly in nature reserves, around Lake Hume and in National and State Parks and State Forests while the association with future values occurs around three of the major towns. The association between learning and future values is found relatively broadly across the region in towns, forests, Parks and around Lake Hume.

High levels of wilderness, therapeutic, spiritual and intrinsic values show only very weak or no associations with other values. In Table 4, there are 39 other associations which are statistically significant at the 0.05 level, but the φ values indicate that the level of these associations is weak or extremely low.

Discussion

In this study, spatial analysis of landscape values yielding density maps has been extended through use of the Getis-Ord Gi* analysis tool to allow identification of areas with

Table 3 The distribution of hotspots of each landscape value and their distribution in different land categories

Value	Number of hotspots	Land use			
		National/state park		Other land including state forests	
		Number of hotspots	%	Number of hotspots	%
Spiritual	120	29	24	91	76
Intrinsic	97	39	40	58	60
Learning	73	26	36	47	64
Therapeutic	72	19	26	53	74
Future	69	28	41	41	59
Biological diversity	68	28	41	40	59
Wilderness	60	37	62	23	38
Aesthetic	59	13	22	46	78
Life sustaining	51	22	43	29	57
Recreational	45	8	18	37	82
Heritage	33	7	21	26	79
Economic	19	0	0	19	100

statistically significant concentrations of high landscape values i.e. hotspots. This tool also provides a means for analyzing the extent to which these values are related to one another. Boundaries between areas of high landscape values on density maps are not clear because the data are based on perceptions (Harries 1999). However, hotspots defined using the Getis-Ord Gi* tool define only those areas where there is a statistically significant cluster of high density values and that are not subject to arbitrary setting of a density threshold for class boundary definition as in the study of Alessa and others (2008). This tool also identifies areas where the spatial association of locations nominated by respondents is high, but where the overall density might be only moderate. Therefore, this type of analysis appears effective in associating significant landscape values with specific locations and improves insight into people's sense of place. Such analysis also allows quantification of the associations between high densities of different landscape values, revealing some in this study, such as learning and heritage values, which are strongly associated, and others such as wilderness and spiritual, which appear to be largely distinct.

In interpreting the results of hotspot analysis, it has to be recognised that place valuation using predefined landscape values is based on subjective judgements and personal values, which are heavily influenced by respondents' understanding of what is meant by the description of the values, their knowledge and past experiences, their familiarity with the study area, the diversity of their activities, their map literacy and the intrinsic appeal of the places themselves. Further limitations of landscape values mapping have been pointed out by Brown (2005), some of which are equally applicable to this study. These include

ambiguous dot placement where the location being mapped is actually smaller than the 1.76 km dot diameter and erroneous placement and incomplete mapping by respondents who are less familiar with the region. This means that hotspots represent areas of 5 km × 5 km and that, in some cases, what is being identified by respondents is a much smaller location. Web-based mapping technologies may alleviate these problems. Respondents can zoom into the area of interest and place a small valued (coloured) dot (rather than a coded sticker dot covering an area of 1.76 km in diameter). This approach identifies a smaller area, reduces the chance of erroneous placement and avoids errors associated with the digitising process.

Another potential problem with this study is that some areas perceived to be of high landscape value may be better represented by lines or polygons, rather than points at the centres of dots placed on the maps. However, respondents were able to place multiple dots of the same or different weights for each landscape value close to one another if they wished to nominate more extended areas. In fact, as seen in Fig. 4, as well as single grid cells identified as hotspots for wilderness value there were groupings of grid cells which formed different shapes. It is clear from the existence of multiple, well-separated hotspots in some National and State Parks that respondents were indicating separate locations within these entities.

Hotspots can be seen as a specific group of areas in the region which are perceived to possess one or more of 12 landscape values. Less than one-third of these hotspots were for direct use values i.e. 19 for economic value, 33 for heritage value and 45 for recreation value. Thus, non-use or indirect use values (including aesthetic/scenic, biological diversity, intrinsic, learning, life sustaining, spiritual,

Table 4 Magnitude and significance of associations between landscape values

	Aesthetic	Biological diversity	Economic	Future	Heritage	Intrinsic	Learning	Life sustaining	Recreation	Spiritual	Therapeutic
Biological diversity	φ = 0.212										
	P-value = 0.001										
Economic	φ = 0.410	0.097									
	P-value = 0.000	0.126									
Future	φ = 0.185	0.428	0.296								
	P-value = 0.003	0.000	0.000								
Heritage	φ = 0.229	0.161	0.424	0.368							
	P-value = 0.000	0.011	0.000	0.000							
Intrinsic	φ = 0.100	0.197	0.082	0.134	0.175						
	P-value = 0.112	0.002	0.193	0.033	0.005						
Learning	φ = 0.348	0.379	0.314	0.431	0.670	0.158					
	P-value = 0.000	0.000	0.000	0.000	0.000	0.012					
Life sustaining	φ = 0.257	0.450	0.043	0.310	0.214	0.230	0.352				
	P-value = 0.000	0.000	0.499	0.000	0.001	0.000	0.000				
Recreation	φ = 0.574	0.276	0.455	0.317	0.310	0.077	0.318	0.177			
	P-value = 0.000	0.000	0.000	0.000	0.000	0.223	0.000	0.005			
Spiritual	φ = 0.222	0.063	0.118	0.054	0.076	−0.137	0.019	0.032	0.176		
	P-value = 0.000	0.321	0.061	0.394	0.228	0.030	0.760	0.611	0.005		
Therapeutic	φ = 0.272	0.343	0.185	0.221	0.222	0.112	0.292	0.271	0.255	−0.007	
	P-value = 0.000	0.000	0.003	0.000	0.000	0.077	0.000	0.000	0.000	0.906	
Wilderness	φ = 0.086	0.226	−0.125	0.136	0.003	0.246	0.114	0.321	−0.018	0.006	0.099
	P-value = 0.174	0.000	0.048	0.031	0.961	0.000	0.071	0.000	0.770	0.926	0.117

Table 5 Distribution of hotspots for landscape values with strong and moderate associations

Landscape values	φ	Location						National Parks	State Parks	State Forests	Other public land
		In and/or around									
		Mildura	Swan Hill	Echuca-Moama	Yarrawonga-Mulwala	Albury-Wodonga	Lake Hume				
Learning/heritage	0.67	x		x		x	x		Barmah	Barmah	
Recreation/aesthetic	0.574	x	x	x	x	x	x		Barmah	Barmah Gunbower	Lake Boga, Camp site in east
Recreation/economic	0.455	x		x		x	x				Barmah, Cobram
Heritage/economic	0.424	x	x	x	x	x				Barmah	Barmah
Aesthetic/economic	0.41	x	x	x							Cobram
Life-sustaining/biological diversity	0.45			x			x		In east, Hattah-Kulkyne	Barmah, several in east	Gunbower	Kings Billabong Nature Reserve
Future/biological diversity	0.428	x		x	x	x	x		In east, Hattah-Kulkyne, Murray-Sunset	Barmah	Barmah Gunbower	
Learning/future	0.431	x		x	x	x	x		Hattah-Kulkyne	Barmah	Barmah, Gunbower,	Kings Billabong Nature Reserve

therapeutic and wilderness) dominate the Murray River Region. National and State Parks were the sites for the majority of wilderness, life sustaining, biological diversity, future and intrinsic values.

Around 60% of the areas delineated as hotspots, in both various categories of public land and near major towns, have 2 or more landscape values. Analysis of the 66 possible associations between the landscape values indicates that, in general, the overall level of association between them is quite low, with 29 of the φ values being less than 0.20. Wilderness, therapeutic, spiritual and intrinsic values fall entirely into this category suggesting that they have a high level of independence and a low level of multicollinearity. Of the values studied, these are some of the most personal, depending on people's individual sense of place. They are also some of the values for which there is the greatest number of distinct hotspots. This finding confirms that of Alessa and others (2008) in their study of the Kenai Peninsula, Alaska. It suggests that while wilderness can provide spiritual inspiration (Fredrickson and Anderson 1999) and has therapeutic value (Pohl and others 2000) it is only one of many sources of such benefits. It could also indicate that respondents consider these values are somehow different in character from the other values, and that more sophisticated instruments may be required for their measurement.

Only 8 landscape values show a moderate degree of association with at least one other value with φ values between 0.40 and 0.60. These are largely direct or indirect use values. In particular, recreation and aesthetic values show association with economic values and with each other reflecting the importance of the tourism industry in the region. Association between heritage and economic values is not surprising given the importance of historical sites for tourism. The existence of 4 hotspots with 11 landscape values indicates places which are clearly perceived to be very important. Two of these, at and around Echuca-Moama and Albury-Wodonga, have economic but not wilderness value, suggesting that here both natural and cultural assets can coexist. This raises the possibility that their economic value may actually result from the close location of places that are valued in multiple ways. The other two sites with 11 values were in the Barmah State Park and held wilderness but not economic value. It would be useful to repeat this study using maps of smaller areas at a larger scale for specific locations so that more precise spatial information might allow separation of hotspots for different values.

Associations between hotspots might be a result of people's understandings of what contributes to particular values, for example, that a place for recreation should be aesthetically pleasing or that areas of biological diversity

should persist in the longer term, allowing future generations to know what they are currently like. Alternatively, co-location of different values might represent multiple distinct aspects of particular places. Our findings that only some hotspots for particular values are associated with others and that there are some locations where hotspots for many values are found lend support to the latter interpretation. This is supported by the findings of Brown and Reed (2000) that the 12 landscape values represent distinct variables. However, it might be expected that values shown to be strongly and moderately associated in this study would show similar association in other regions where a similar mix of land use occurs.

The findings reported here are based on the combined survey responses from residents, visitors and tour operators in order to address the spectrum of people with experience and knowledge of the Murray River region. Further research is needed to explore any differences in the spatial pattern of hotspots and their associations between these groups. However, identification of statistically significant hotspots from such a diverse group suggests that their locations represent perceptions of a broad cross-section of the population associated with the region. The results of our study are compatible with those of VEAC which used biophysical assessment, advisory groups, consultation with groups and individuals and submissions from the public (Victorian Environment Assessment Council 2008). Barmah State Park and Forest, which our study has found to be the site of 2 hotspots with 11 values, including wilderness value, has recently been upgraded to that of a National Park so that its diversity of values can be better protected (Victorian Environment Assessment Council 2008).

The results of this type of analysis provide a useful starting point for understanding social ecological systems and for identifying opportunities and prioritising activities for conservation and development for the sites identified as hotspots. This approach can be a useful adjunct to qualitative methods involving interviews and/or focus groups which provide participants more freedom in generating ideas about what is of value and also make it easier to include minority groups who might not be willing to participate in a mapping survey. However, hotspot mapping might not be an appropriate way of gaining participation of people whose educational and cultural backgrounds mean that they have difficulties with language and map reading.

Nevertheless, this approach can complement other quantitative information derived from biophysical assessment (e.g. biological diversity, biophysical land covers, wildlife records, wildlife habitat distributions, etc.). All these approaches provide different types of information and their integration can provide the basis for future planning that is both scientifically based and socially acceptable.

Conclusion

The technique of hotspot mapping using the spatial statistic Getis–Ord Gi* allows areas holding particular landscape values to be identified better than by analysis using density mapping alone. It reveals statistically significant locations where interpretation of simple map density is difficult and limits hotspots to densities that are statistically significant. It also provides a means for examining whether the apparent co-location of high densities for different values is of statistical significance. For the Murray River region, many places have been identified as hotspots with the majority of hotspots sharing two or more values. Hotspots having the greatest degree of co-location were for direct use values while non-use values like wilderness, intrinsic and spiritual were more broadly scattered across the region. Only four hotspots represented 11 of the 12 values studied and are, therefore, clearly of major importance requiring careful consideration in planning for the future.

The capacity of this approach to reveal which values are linked and where they are located indicates that it can be a tool for gaining a more thorough understanding of the characteristics of particular areas and places in a wide range of contexts. Because the results show good agreement with an independent study based on scientific ecological and economic assessments and qualitative methods, hotspot analysis would appear to be a useful adjunct to such approaches in defining areas which should be given high priority in land management decisions.

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