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Biocultural mapping: unpacking the myth of an unsuitable Country in the arid zone, Willandra Lakes Region World Heritage Area, Australia

Katherine Thomas[1,2*]

Abstract

Defining spaces and places in retrojective Geographical Information Systems (GIS) of land use and occupancy is not an easy task. Research into the areas described as suitable for land use and occupancy need to incorporate multiple perspectives of what makes a land use patch useful or salient ecologically. The effect of the concept of 'Terra Nullius' and European colonisation is deeply apparent in the current GIS models of historical land use and occupancy of Aboriginal communities within arid zones in Australia. Biocultural zones of land use and occupancy zones omit spaces and places of habitation due to European bias of what a suitable ecological or hydrological land use zone should look like. This article employs Exploratory GIS methods to interrogate the data layers within the Willandra Lakes Region World Heritage Area, NSW, Australia. This work conclusively demonstrates that there are ranges of areas and land suitability zones prior to colonisation in the nineteenth century. In turn, these Exploratory GIS models of an active Country comprehensively address the question of why visually salient areas of hydrological and ecological Indigenous land use and occupancy continue to be ignored, destroyed, and damaged by settlements in semi-arid regions. Biocultural GIS mapping unpacks the myth that areas were empty or uninhabited by Aboriginal communities and underlines the need for biocultural GIS mapping tools to understand the habitable spaces and places of the arid zone.

Keywords Exploratory, GIS, Land suitability, Raster

Introduction

Exploratory biocultural GIS models are the best way to understand land suitability classifications. Understanding what makes an area of land suitable for habitation is the key to understanding where an archaeological site might be located, even in the absence of material remains. This work forms part of a larger research project in the Willandra Lakes which incorporated oral testimonies of the Mutthi Mutthi, Paakantji/Barkindji, and Ngiyampaa communities into framing the biocultural GIS mapping. These are GIS models of visual salience of what makes an area significant ecologically or hydrologically. Exploratory GIS describe land use zones as a range of possibilities and erodes the idea of a single place or vegetation patch as the only suitable patch. European settlement and exploration changed the vegetation and hydrological zones by degrees and by catastrophic change. Exploratory GIScience methods are important because they show a range of suitable land use zones and show how and why having an understanding what makes an active or occupiedCountry would have prevented the cataclysmic

*Correspondence:
Katherine Thomas
thomas.k@unimelb.edu.au
[1] Honorary Research Fellow, Faculty of Engineering and IT, University of Melbourne, Melbourne Connect, 700 Swanston St., Carlton, Melbourne, Australia
[2] Adjunct Research Fellow, Department of Archaeology and History, La Trobe University, Melbourne, Australia

Fig. 1 Location of the Willandra Lakes Region World Heritage Area, NSW

assault on an Indigenous vibrant arid land in the nineteenth century and now. The land was not *terra nullius* at European settlement and the gaps on the current GIS models of water and suitable plants are not voids and 'nothing' spaces. This study demonstrates that Exploratory biocultural GIS models of land suitability are the key to unpacking the settler biases around classification of hydrology and vegetation zones within the arid zone. Not all activities on the landscape left traces in the material record of land use and occupancy. Biocultural GIS mapping calls for protection of areas that are currently classified as *terra nullius* or not suitable for occupancy.

A vibrant Country in the arid zone

The WLRWHA is situated in an arid zone, but the environment is far from sterile. The boundaries of this project originate from a centroid set on Lake Mungo which overlaps the Mutthi Mutthi, Paakantji and Ngiyampaa areas (Hercus 1969; NSW National Parks and Wildlife Service 2006; Tindale 1974). These three communities form the WLRWHA Aboriginal Advisory Group. *Terra Nullius* is an often utilised term to describe empty areas of the landscape (Coleman 2017; Miller 1995; Sandom et al. 2013; Walton and Bailey 2005). Often unconsciously, and following on from the initial settler ideologies, landscape archaeology with associated GIS analyses have framed remote areas as natural and uninhabited. This form of landscape archaeology of the site and the non-site is deeply connected to the framing of *terra nullius* and the concept of the desert without a garden (Coleman 2017; Gammage 2005). Furthermore, in early Australian court cases, such as Cooper v. Stuart (1889), the Privy Council held that settlers could start to occupy new areas if the land was only inhabited by Aboriginal communities (Simpson 1993, p. 202). *Terra nullius* in practice was a way to justify colonial settlement and it was underpinned by a dismissal of the land suitability of arid lands and the Traditional Owners within them (Fig. 1).

For the WLRWHA, set on the Lower Darling run, this interpretation of *terra nullius* was particularly fitting as the area was and is a semi-arid region with low density community groups (Borch 2001; Frost 1981; Wolfe 2006). The *terra nullius* precepts for occupation, settlement, and acquisition of the WLRWHA were supported by the biogeography and the movement patterns of the Traditional Owners. Although the *terra nullius* concept was overturned legally with the 1992 Mabo court decision (Vincent 2015, p. 16), the idea of this empty natural

space exists within the GIScience applications of landscape archaeology frameworks. Furthermore, it is important to note that these concepts unwittingly have crept into the more focussed perspectives for assessing an area or a land use zone as suitable or unsuitable. This artificial land use division of empty versus occupied, with the conception of the natural, permeates into all aspects of GIS applications of landscape archaeology approaches, methods, and objectives.

Within the archaeological discipline, the approach to land use and occupancy mapping has focussed very much on the site or activity areas and contrasting those areas to the non-site or non-activity areas (Binford 1982; Hodder & Orton 1989). However, as Dunnell points out in the discussion on the 'notion site', these places are what the archaeologists are looking for in the landscape (Dunnell 1992, p. 21). In looking for definitive sites, archaeologists are searching in the archaeological record to find the blank spaces to encircle the sites. This is why *terra nullius* is an importance concept for GIS mapping. Archaeologists are searching the natural versus the site and have defined ways of identifying areas of habitation. Biocultural GIS mapping has changed the concepts of what a land-use zone might look like. The definitions of the site versus the non-site are more complex when the material archaeological record is considered within its ecological context. Uninhabited or natural landscapes may be occupied, suitable and useful. Furthermore, areas where the occupants were more highly mobile, left little or no traces for their activities, or are conceptually linked to the concepts of 'wilderness' and do not conform to modern agrarian or urban land-use zones are often hard to identify. Not all landscapes of activity conform to the standard metrics that are applied to define an archaeological place or a site. Arid lands, like the WLRWHA, fall into the category of areas that are often classified as 'natural'. Exploratory GIS resets biases about *terra nullius* and suitability by showing the range of areas that provide life on in a vibrant Country.

Hydrology

Tying into this discussion is the perception that water, particularly a large body of water, is necessary to support life in a daily accessible way. This concept is especially resonant for European colonists looking for water features, such as lakes and ponds, that resembled their home country (Harris 2014, p. 45). There is no doubt that water transforms the arid landscape to a far greater degrees due to its scarcity (Burmil et al. 1999). However, in the arid zone the water features and water sources are harder to locate on a GIS model. Arid areas are viewed as uninhabited 'natural' places because locations of waterholes, palustrine features, and ephemeral wetlands, or floodplains may be perceived as *terra nullius* or areas without life or land use and occupancy features. The issues surrounding this failure to identify suitable areas of arid zone land-use are due to not being able to identify land-use and occupancy zones or water sources that differ from the European perceptions of what a land-use or a water source looks like. This is an absorption of this concept of *terra nullius* into identification of land use and occupancy areas. Alternative approaches and methods to find water and land use or occupancy zones within an arid environment and within a landscape archaeology framework must come through consultation with Traditional Owners, Exploratory GIS frameworks and/or Participatory GIS (pGIS).

Background

Modelling potential vegetation resources and water availability on the landscape has been the cornerstone of many conceptual models of past human behaviour and subsequently the GIS predictive models within archaeology (Kelly 2013; Kvamme 1985). Water, a critical limiting feature for life and habitation, has been used to create predictive models of where archaeological sites exist in all probability on the landscape (Brandt et al. 1992; Cooper 2010). Watercourses are used to define occupation areas of different communities because they are interpreted as the natural landscape boundaries within GIS modelling. In addition to this, watercourses are also used to map potential migration routes into, and out of, arid zones (Bird et al. 2016; Davies et al. 2015; Harrower 2010). Resource locations and water availability can be limiting factors for behaviour, but they also can be completely subsidiary to other reasons for habitation and occupancy. Hence, the issues of inappropriately assessing importance of the resource, coupled with the inaccuracy of the location of the resource, results in poor predictive modelling of culturally or archaeologically sensitive areas. The assessment of critical resources, particularly water availability, on Country has several theoretical flaws which are amplified within any standard GIS model that is created without Exploratory design. This is part of the general criticism of environmentally determined modelling of presence only data sets (Wheatley 2004; Whitley 2004).

Focussing in upon hydrological modelling, there are several issues inherent in such an approach. Raster or vector hydrology data is a representation and amalgamation of either known water locations or indices of water availability/vegetation greenness (FAPAR/NDVI)[1] and this information is often completely inappropriate for

[1] FAPAR = The Fraction of Absorbed Photosynthetically Active Radiation; NDVI = normalized difference vegetation index.

modelling the past landscape. These classification procedures all require averaging on some level of the measured water locations by computer or human classification methods, and the accuracy of the averaging is impacted by the methods (Chen et al. 2009). Human gestalt or automated machine judgements on the crucial aspects of proximity, barriers, similarity, and separateness of a potential inundation zone creates images of where the water locations might be, but these are in relation to imperfect classification systems. In addition, the important water sources for the Traditional Owners on Country are often too small to be seen in these raster-based classifications of water availability because ground water soaks have constrainedsmall surface areas that are not an easily visible resource (Silcock 2009, p. 4). Furthermore, the issue of water as a permanent or an ephemeral source due to the changeable nature of the ground water sources due to anthropogenic impacts is another concern in adopting a purely inductive based hydrology mapping GIS model (Chapman 2000; Graz et al. 2012). Watercourses are not static features and have changed considerably in the last 200 years, let alone the last 20,000 ka. Within western NSW, this has also been illustrated by Kemp and Rhodes in their work on the paleochannels in the nearby Lachlan river (Kemp 2010). Water locations and resources, even if they are conclusively proved to exist as a continuous source, are pivotal to varying degrees in different climates, seasons, and periods of time. Conclusively, a weak signal of a soak nestled in linear dunes may be more important due to its rarity. This is exactly the type of transient and ephemeral data that a standard GIS model will fail to locate, predict, or map without an Exploratory GIS design.

Hydrological modelling feeds into the 'scientific' modelling of areas deemed suitable for habitation. Variables used in GIS models are interdependent, collinear, and have multi-scalar and multi-phasic effects. The variables within a standard object-based GIS model of the landscape are the potential plant locations, vegetation zones, the known material cultural remains, the elevation of the land, and potential views from the located archaeological sites (Kvamme 1989; Lake and Woodman 2003; Pardoe 2003; Taliaferro et al. 2010). Akin to the hydrological modelling of the points of water access or inundation zones, the other resource variables within GIS models are affected by the imperfect classification systems, the lack of stasis in the variable, and the varying degrees of importance of the variable on the composite GIS model.

This article is focussing on the hydrology, potential plant resources and vegetation zones (Haslem et al. 2010; Head and Atchison 2009). However, it is not within the scope of this project to model viewsheds from potential sites affecting site location, perform elevation level modelling, or determine the relationship between the known archaeological record and the GIS predictive model. Utilising these variables with GIS modelling would be flawed on the fundamental theoretical levels that: (1) viewsheds and lines of sight of the Traditional Owners cannot be assessed in the same ways that they are perceived by the settler perspectives (White 2003), (2) the elevation surface changes are not relevant to establishing relative land suitability in the WLRWHA because the gradient changes are unlikely to be the main determinant of land use and occupancy in an arid zone (Bowler et al. 2012) and, finally, (3) material cultural remains do not represent the full gamut of activity and occupation within the WLRWHA and are often representative of erosional areas and areas of survey (Stern 2015). On the other hand, looking at the plant resources and the potential vegetation zones coupled with the areas of water availability to map land suitability on Country has a clear theoretical basis for using these symbols as places for niche construction within land use and occupancy and thus the complex shifting cultural record and contexts (Bowdler 1981; Ens et al. 2015; Hercus and Gott 2005; Hynes and Chase 1982; White 2003; Yibarbuk et al. 2001).

Methods

Land suitability versus a vibrant Country

Standard GIS mapping of land suitability has customarily taken the form of map algebra techniques with raster data sets (Angel 2014; Carr and Zwick 2007; Ciolli et al. 2017). Map algebra techniques of land suitability are only as good as the classifications, averages or scaling of the base elements of the model. This research project assessed classifications of water and vegetation for land use zones in the WLRWHA. The first issue influencing the mapping of Country is whether the variables affecting the land use and occupancy zones represent discrete categories (e.g. Deep sand mallee or Belah/Rosewood woodland) or whether there is overlap between these categories. The next issue to consider is whether each variable or zone will exert the same influence on the GIS model. Although there are other issues, the last main consideration affecting the accuracy of the mapping outputs is whether, given these issues, the relationship between the attributes is fixed and therefore can be expressed in a mathematical format.

Unpacking these concerns allows some interrogation into the composite land suitability model. Land suitability modelling attempts to quantify areas into binary yes/no assessments of whether an area of land is suitable for land use or occupancy. GIS models, either the identification of zones or the connections between them, are

dependent upon the available thematically grouped data and the methods employed to develop the articulation of space.

Technical details

To perform any of the above operations of map algebra, it was necessary to transform the data to raster. It is exceedingly difficult to have confidence in whether the areas mapped accurately represent the delineation of a vegetation polygon, hydrological area or occurrences of cultural material. In a simple ordinal method priority rankings would be ascribed to certain habitats or to land use and occupancy zones. These numerical values would then be applied to attributes and multiple map overlays would be created and added together. This would not be appropriate as the data sets are neither complete or nor independent. Therefore, any composite overlay map would be an expression of these errors rather than a predictive model for areas of land use and occupancy. The next phase is typically to employ weighting to certain variables in the linear combination methods. There are many articles that cover different approaches of weighting the variables to balance the differing effects of certain variables (Adamopoulos and Rinaudo 2021; Attaway et al. 2016). Unfortunately, ascribing appropriate weighting to variables is fundamentally influenced by the initial scales that the nominal variables were translated into (i.e. is the scale for management option prioritisation comparative or compatible with the scale for vegetation option prioritisation). Often this is not the case, resulting in the composite GIS predictive modellingoutputs become magnified versions of the errors made in scalar judgements at the initial classificatory level.

Results

Visual salience is the uncited mainstay of object-based predictive GIS models of key zones within the cultural landscape(Caduff and Timpf 2008; Götze and Boye 2016; Kattenbeck 2017; Klippel et al. 2005; Röser et al. 2013). Assessing visual salience means focussing on proximity, similarity, continuity, and closed sets for our geometric primitives. Our geometric primitives for a basic land suitability map of ecological zones includes hydrology, vegetation, geomorphology, and land system layers. For each of the ecological zones, alternative views of the data will highlight the 3 key effects of: categorisation, thresholding, and scale.

In addition, most of the GIS models focus on presence only data and looking for presence of a resource. A far more useful approach is mapping the areas of absence within a GIS model and to assessing the land from this vantage point. Areas where accessing water or vegetation zones appears to be very difficult, coupled with an absence of material traces, are far more interesting to discuss because they appear as voids in the record of land use and occupancy. Thus, with the basic maps of the land, a better way to do the modelling is to model the converse of suitability and map the voids where no water or no vegetation is accessible and then assess whether there is a case for that area to be culturally significant. In this approach, the economic rationality of resource mapping is flipped around, and Country is all significant.

Hydrology

Mapping hydrology is presented by GIS experts and land managers as straightforward. It is not. The Willandra Lakes in far western NSW is empirically a place of great dryness and frequent drought. The Bureau of Meteorology has a several ways of presenting this, from precipitation estimates to assessments of deep soil drainage and soil moisture. In all years and at all times, this area is an area of low soil moisture and precipitation, comparative with the rest of Australia, (Frost et al. 2015).

Access to water is key to survival and habitation. With the aim of establishing areas that had access to water within the WLRWHA, several single land suitability maps of were created. This illustrates the issues attached to classification and the reliance on inappropriate or incomplete hydrological data sets. All the information recording the inaccuracies for a hydrological data set is detailed in the supplied metadata. Within archaeological GIS modelling, metadata documents appear to be ignored or discounted as irrelevant and the hydrology layers are fed into the suitability maps without reference to the errors. This study compiled many ways of presenting the mapped or captured hydrological information for the Willandra Lakes (Additional file 1: Table S1).

Categorisation of water zones

Water, the most critical limiting feature for land use and occupancy, is often used as a baseline for GIS models of land use suitability. Water illustrates the concept of flow and flux on the landscape through the changing water signatures connected to rainfall and river pulse changing. In addition, there are obviously many ways to record and map water layers. As illustrated in Additional file 2: Fig. S1 there are several ways to access hydrological data for a GIS model of hydro-suitability. Each hydrological data set that is available for the Willandra has limitations that are summarised in the Additional file 1: Table S1.

In an Exploratory GIS design, it is important to note how changing the base data affects the outcome of the hydro-suitability model. The hydrological data comes from the Geoscience Australia *srtm_water*, the Department of Primary Industries 1:250,000 hydrological data sets, and the Water Observations from Space (WOfS)

data set. Quite apart from a discussion on whether these are accurate water features for the late nineteenth century Lower Darling region, is the non-subtle and very glaring issue of how thresholding, buffering, and perception of visual salience results in different regions for hydro-suitability (Gallant et al. 2011; Symons and Chapman 2015).

To illustrate the importance of Exploratory design in GIS inputs for hydrology, there are four examples below. In Additional file 2: Fig. S1 it is possible to immediately see main points of conflict with these two hydrology layers. The DPI supplied hydrology layers differ greatly from the mapped WOfS layers of standing water. Referring to Additional file 2: Fig. S1 it is possible to see the main issues in the DPI data set are that it: (1) includes areas as water features that are devoid of water and (2) ignores ground water. A visual inspection of the data shows that the DPI data set, in comparison to the WOfS data, is not representative of the current water features, let alone being suitable for mapping hydro-suitability mapping of the past landscape. The categorisation of where the water might be fails at the most basic first hurdle of the GIS objective model of the past landscape.

The next example of applying different thresholding values to the GIS hydrology data illustrates that changing the histogram for the input values of hydrology dramatically changes the perceived availability water for an area. Again, these base layers are being employed in GIS predictive models, within planning and cultural heritage management, with no consideration of set theory or the issues with changing the base histogram for displaying water values. In the figures below, different areas are displayed for hydro-suitability in relation to either thresholding the base data by standard deviations or by natural breaks (Additional file 3: Fig. S2, Additional file 4: Fig. S3, Additional file 5: Fig. S4). It is possible to see great changes here in the base data in these figures. Subtle alterations in the histogram for displaying zonal areas for hydrology can result in vastly different maps.

Visual salience

Referring to the images of the bases for hydro-suitability in the areas around Lake Garnpung, it is important to note the effects of the single snapshot image approach of GIS. The concept of flow on the landscape is best demonstrated by water and these models of hydro-suitability are at best averages of the appearance of water on the landscape. This means that the maps are ultimately meaningless when applied to the more complex issues of mapping the cultural landscape as this is a lived and personal experience for both people today and for previous Aboriginal communities. In addition, from a technical level, the human eye tends to see patterns and edges to areas where a real boundary does not exist. This is substantiated by studies in comparative GIS mapping of mangrove stands by computers versus expert classifications (Neukermans et al. 2008).

Land unsuitability

Rather than mapping the areas that water might affect the landscape, a more useful GIS model of land dryness and of where accessing a water source would be unlikely present more meaningful models for the Willandra Lakes. After modelling many versions of hydro-suitability for the Willandra Lakes with Exploratory GIS using the WOfS data set at various thresholds of distance to water, size of water feature, the below map of land unsuitability was developed (Fig. 2). Here in this model, the areas of dryness in the Willandra are presented as graduations of levels of dryness. There are areas to the west and to the east of the Willandra lake beds that are less likely to yield water.

Vegetation zones

Mapping the vegetation zones within the Willandra is as complex as mapping the hydrology zones. The same concerns over the base data exist, including vegetation specific concerns over categorisation, salience, averaging, optimisation, and validation of the vegetation thematic layers. Additional file 1: Table S2 is a collection of the different vegetation data sets that were placed within these Exploratory GIS models. The data sets were collected with different criteria, at different scales, and for different purposes. Like the hydrology layers, none of the vegetation layers should be used in isolation to assess the potential resource zones in a GIS model of the past ecological zones. Akin to the hydrology layers, they are often used with reference to the data context, metadata, or critical limitations of their appropriateness for modelling the land suitability of the pre-European landscape of the Willandra Lakes. This section is centred on the categorisation mismatches of the vegetation layers, the concepts of visual salience as it applies to discrete vegetation polygons, and the importance of ecotonal areas.

Categorisation of vegetation

The categorisation issues with the vegetation polygon mapping themes that exist for the WLRWHA are manifold. There are the standard errors of scale, thresholding, and categorisation combined with more nuanced issues attached to set theory judgements about vegetation classes. The practical applications of gestalt judgments in defining what classifies a vegetation community differ across the various products. This section will consider

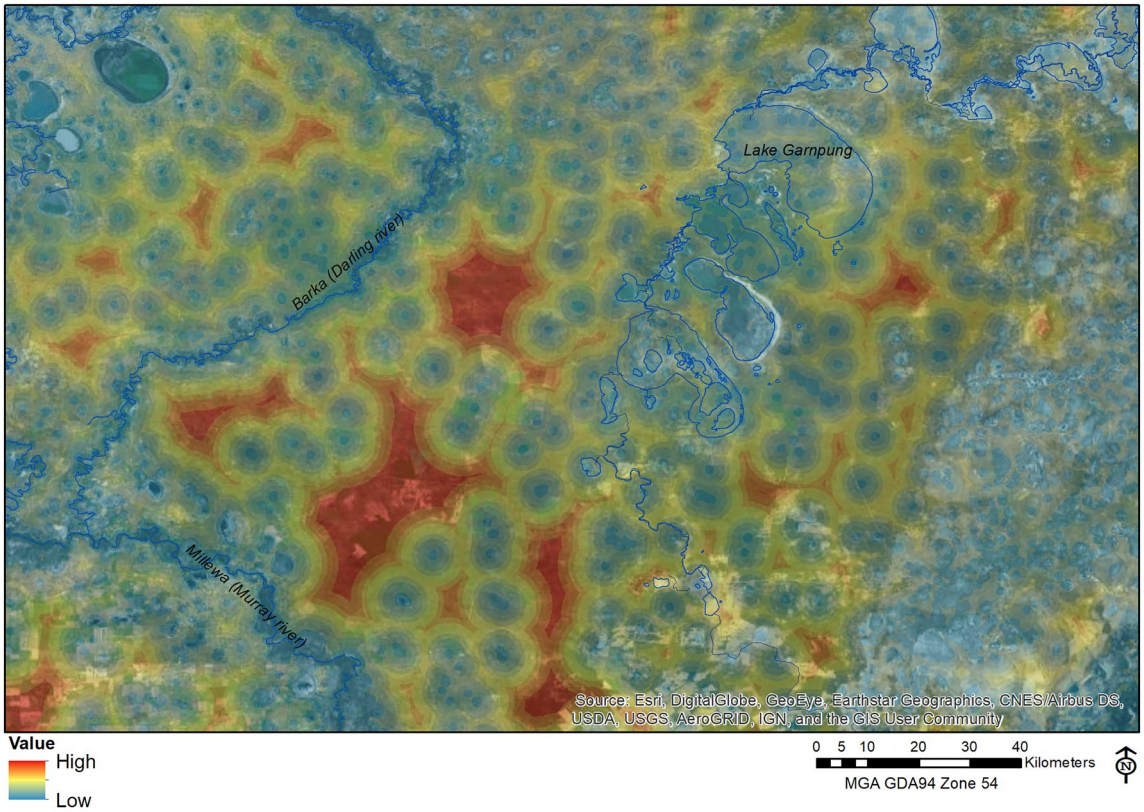

Fig. 2 Land unsuitable based on water availability, WLRWHA

these discrepancies across the vegetation thematic layers. This will be illustrated with comparative mapping of the same location with different vegetation community classifications, mapping of indicator species rather than an entire community, and suitability mapping from one vegetation community versus mapping of ecotonal areas.

Vegetation community classifications: now and then

It should be apparent from the below two figures that quite different vegetation classifications were used to define the previous vegetation community areas. However, in both the Southern Mallee layer and the NVIS layer, the lakebed floors are described as Chenopod shrublands (Additional file 6: Fig. S5, Additional file 7: Fig. S6). These low-lying Chenopod areas are flanked with Mallee (of differing types) to the west and to the east. There are pockets of Belah, Rosewood, and White Cypress Pine that are retrofitted back onto the hinterland of the WLRWHA (Additional file 6: Fig. S5). In addition, there are areas of Lignum shrubland that can be employed as indicators of areas of flooding and standing water.

To understand these retrofitted models of the past vegetation, it is necessary to look at the currently mapped vegetation for the region (Additional file 8: Fig. S7). In this layer, it is possible to see a similar classification system to the Southern Mallee base data set, but there is the additional information of the areas of clearing on the lakebed floors. However, all these products are not suitable for analysis. This is due to the broad brush of the mapping of the communities, the reliance on a single indicator species for the community, and arbitrary lines between the community areas. Haslem et al. have created an alternative layer for the study area which attempts to redress these issues by proposing instead a neural network based map of the current vegetation in the area, ground-truthed by site survey (Haslem et al. 2010) (Fig. 3). This is the only layer that is suitable for analysis in an Exploratory GIS model because it is a ground-truthed composite layer of all the previous surveys and GIS outputs. The other layers are only suitable for cartographic GIS display and this is the type of value judgement that needs to come into the building of an Exploratory GIS modeling.

Mapping of indicator species

To continue, most of the GIS resource modelling has been attempting to find areas that are habitable or

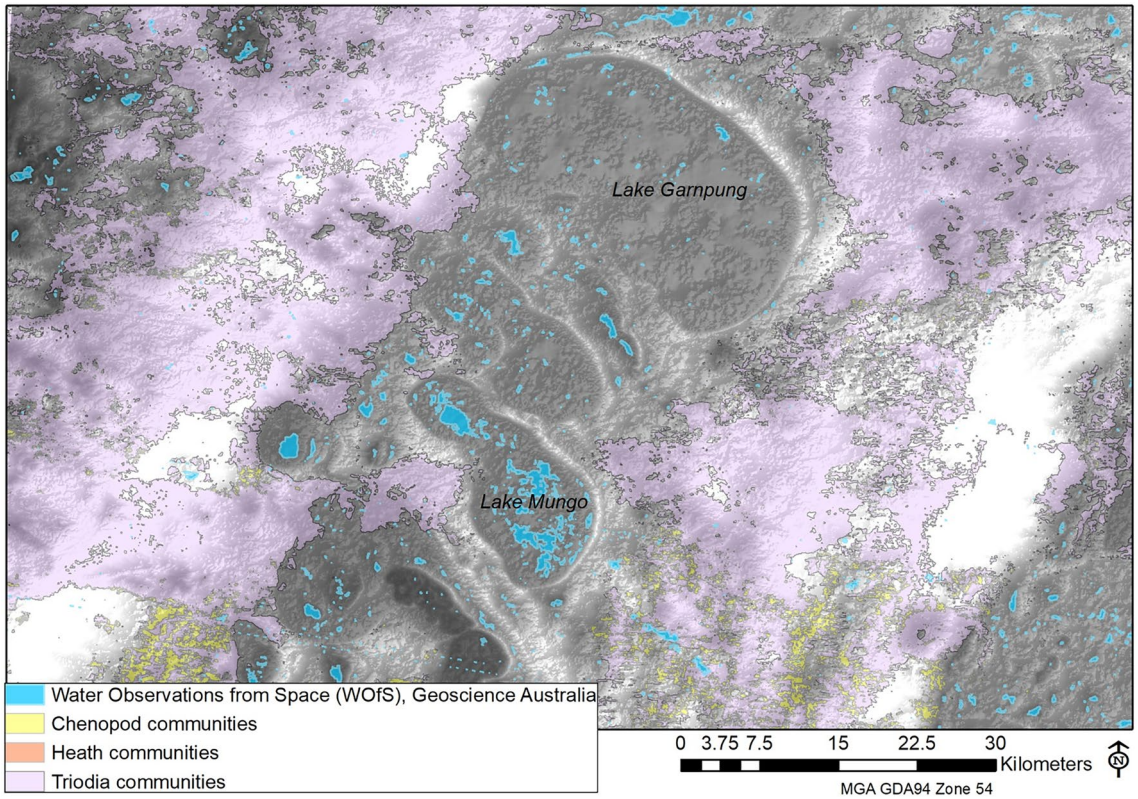

Fig. 3 Neural network mapping (Haslem et al. 2010)

have resources by creating land suitability maps for the archaeological record from identifying attractive resource pockets. This concept follows Zubrow's early work on developing 'attractors' on the landscape and modelling around those attractors (Zubrow 1994). However, the chosen indicator species for the vegetation communities might not be the desired resource for an Aboriginal community and the indicator species might not be a visible part of any averaged representation of a vegetation community.

Trees are arguably a highly visible indicator species, but there are also issues if one models the suitability of the land based on these construction resources. Much of this landscape has been affected by clearing as per the discussion in the pastoral lease files and research into the effects of fencing (Brown 2011; Pickard 1997). Therefore, although it is theoretically possible to utilise the areas of extant White Cypress Pine, Belah, and Rosewood to create areas of potential resource salience in the landscape, it does not work in practice. In the figure below, it is possible to see the visualisation from the data sets of the tree stands affected by clearing (Fig. 4). This issue of clearing is in addition to the previously cited issues with these data sets. Thus, this type of land suitability map is only appropriate at a small scale, i.e. mapping the trees around an already identified potential land use or occupancy site. The scale of the model is key and mapping indicator species for past vegetation resources within the Willandra Lakes is only appropriate in small local area surveys and not at a regional scale, as neither the data sets nor the effects of pastoral occupation allow for such a GIS model.

Composite ecotonal areas as suitable land use areas

A much clearer basis for a land suitability map in the Willandra is to employ an object-based model of the ecotones at the current intersection of Chenopod, Mallee, and Triodia areas from the neural network GIS mapping work of Haslem et al. because their work has already tackled the issues of developing an integrated map and data set for vegetation across a broad spatial extent (Haslem et al. 2010). This can be modelled against the available hydrological WOfS dataset with different thresholds. The case for using ecotones and edges of vegetation communities as key areas for land use and occupancy has a solid basis in logic because it supposes that access to many different resources should result in an area being more suitable for land use and occupancy. Studies such as Epp's early work in Canada were structured to find more sites in ecotonal areas (Epp 1985) and, thus, arguing that the sites were

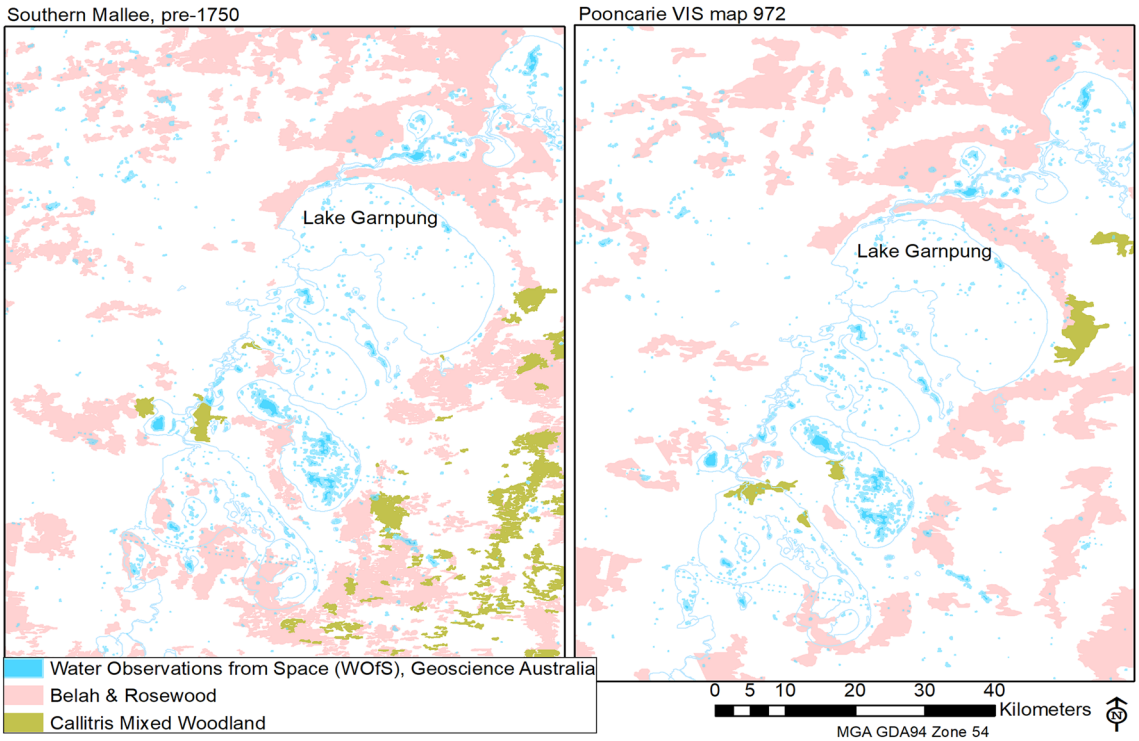

Fig. 4 Mapping of trees as indicator species, comparative mapping 1750 to present day

caused by their proximity to an ecotonal area. Recent work by Foley on the Mungo lunette on extracted flora and fauna remains from multiple hearth excavations indicate that the lunette was potentially frequented because the Aboriginal communities had to access to a wide range of resource types (Foley 2020). Essentially, this also substantiates the GIS model that these lunettes are also ecotonal areas (as shown in the below figures) and, ultimately, that the current definitions for ecotonal areas fail in describing the complexity of biome intersections. GIS modelling these ecotonal intersections at different scales and different thresholds creates an important visualisation tool for the Exploratory GIS in the Willandra.

Clearly, in practice, this type of Exploratory GIS modelling illustrates the issues with averaging, optimisation, categorisation, and salience identification techniques. Borrowing from behavioural ecology the concept of the ecotone and the extension of this concept into variants of optimal land use and occupancy with the advent of NCT (Niche Construction Theory) and Human Behavioural Ecology (HBE) ignores the basic issues of the inability to define an ecotonal community (Banks et al. 2006; Warren & Seifert 2011; Zarnetske et al. 2007). Rhoades' early paper on the misuse of the ecotone in archaeology neatly summarises the concepts of the failure to identify the shape of the ecotonal areas (corridor, graduated polygon, or irregular polygon), the presence or absence of indicator species, and the issues connected to edges (Rhoades 1978). To reiterate, this is not a reason avoid GIS modelling or concepts from behavioural ecology, but a reason as to why GIS modelling should be done in a plural and Exploratory fashion.

Identifying a problem in data classification and visualisation is the first step. The next stage is to model the available data in a variety of ways to create multiple outputs and discussion points as to how the land might have been used or occupied. In Figs. 5 and 6, the dark green areas represent visualisations of ecotonal areas in the WLRWHA. In these two visualisations, the ecotonal areas have two different thresholds of distance from ecotonal areas (200 m and 1000 m from the point of intersection between vegetation communities). Figure 6 illustrates the change with to a 1000 m threshold within the Exploratory GIS. These ecotonal areas of different thresholds were placed into the iterative model for places of land suitability for a variety of increments and raster cell sizes. This was the basis for the composite maps of land unsuitability derived from ecotonal distances (e.g. Fig. 7).

Thus, in building the land use and occupancy models of the Willandra Lakes, these two options of limiting assessing the land based on distances to ecotones or distances to water were merged into composite outputs of land unsuitability from generalised additive models with

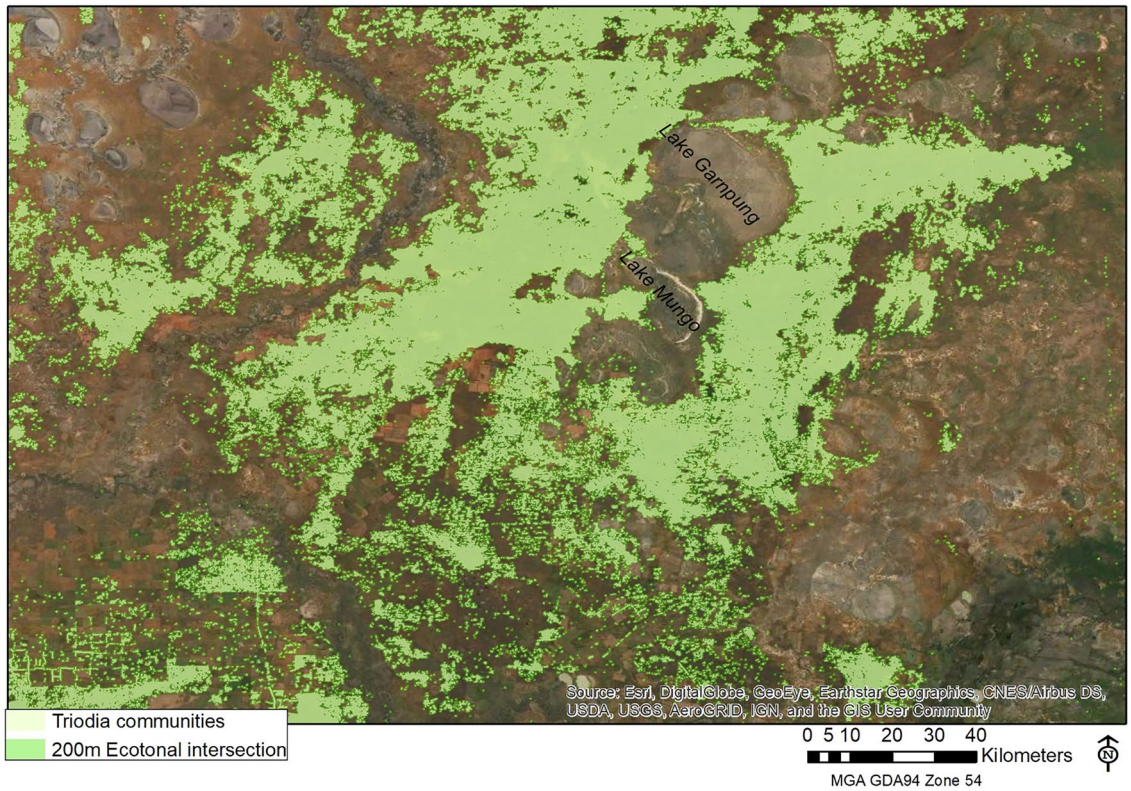

Fig. 5 200 m intersections, ecotonal areas

different weights ascribed to the overlays. Here again, it is apparent that there are decisions made at each stage of the post processing of the base layers with respect to thresholding, categorisation, averaging and display. In the below outputs, changing the input values for the weights of the land suitability maps alters again the visualisation of the past landscape. This reemphasises the point that GIS need to be employed in a plural and Exploratory fashion. Please refer to the completely opposite visions of the land unsuitability by comparing the figures below. In the first figure (Fig. 8), the opposing ratios of water Euclidean distance raster 10%: ecotonal Euclidean distance raster 90% is contrasted with the second figure where the ratio is reversed. In the second figure (Fig. 9), equal weights are ascribed to the importance of water and ecotonal resources and it is obvious that altering the input values substantially impacts the output values. A single view of the resource modelling of the past is not suitable.

Geomorphology, geology and land systems

Vegetation modelling is underpinned by models of geomorphology, geology, and land systems but these are difficult to incorporate at a regional scale. Regional mapping does not account for complex microtopographic changes. Changes in soil pH and elevation coupled with variable wind exposure, sun/shade, and water availability result in complex variable environmental states that are almost impossible to translate into an additive weighted GIS model. Akin to mapping vegetation or hydrology mapping, these GIS models fail at the point of categorisation, thresholding, averaging, and assessments of salient attributes or places. However, it is fair to state that vegetation zones are predominately tied to the land system that they fall in and that these layers were employed as a powerful cross- check for the stated vegetation zones for the region (Additional file 9: Fig. S8). Additional file 1: Table S3 presents a list of the available data sets and their associated limitations.

Activity zones

The last component of this GIS model of the past landscape is of the activity zones and the relationship of these material culture layers to the concept of suitable zones of land use and occupancy. Activity zones are displayed cartographically from the following areas: the archaeological record, the pastoral impacts, the areas of research focus, and the erosional areas. This section will focus on these areas in the Willandra Lakes region from the existing

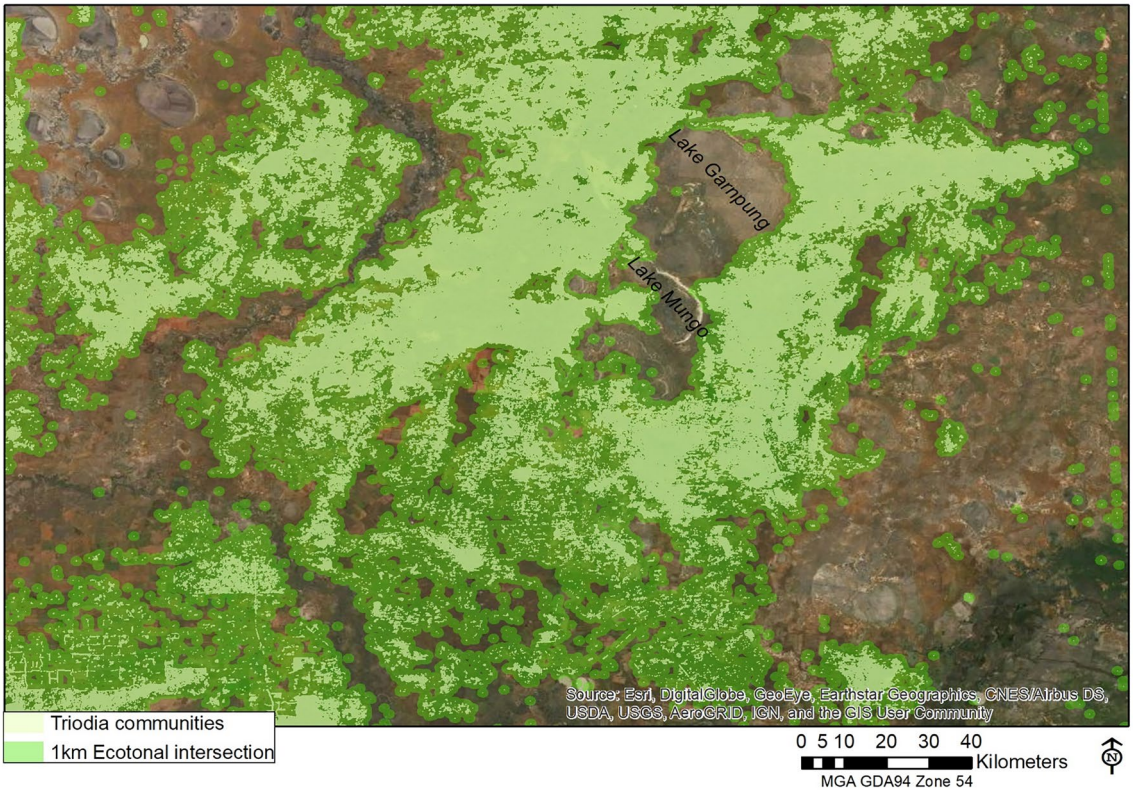

Fig. 6 1 km intersections, ecotonal areas

legacy data sets from the Willandra Lakes Heritage team, NSW Parks. Collating and documenting the legacy datasets in the Willandra Lakes archive into a single repository was undertaken during 2015–2018. This resulted in a composite GIS, accompanying geodatabase archives, digital plan and aerial photographic archives, and help manuals that are stored on the NSW Parks server (Thomas 2018). This section will examine the issues of categorisation, salience, thresholding, and averaging with respect to the activity zones from the material cultural record.

Traditional cultural material and research focus

The Willandra Lakes archaeological record takes the format of both the material remains of the Aboriginal communities and the record of where previous research has been conducted. The material cultural remains are archaeological sites that can be expressed as point locations or as polygonal areas. These archaeological sites form the main part of the archaeological record for the Willandra Lakes (Additional file 1: Table S4) contains a full description of the limitations of each cartographic version of the archaeological record in conjunction with the 'Technical Supplement—Willandra Lakes Region World Heritage Area—GIS Curation and Consolidation Project' (Thomas 2018).

Categorisation of archaeological sites

Site locations are not fixed entities. As outlined above, the notion of the archaeological site is contentious. Focussing here not on the theory, the concept of the archaeological site is challenged by the erosion of the 'site', the mutability of the lunette landscape due to various wind/water erosional events, and the positional inaccuracy of the earlier legacy data sets.

To illustrate the issues attached to the concept of the categorisation of the site, Additional file 10: Fig. S9 shows a map of buffered point locations in tandem with different potential locations for the same site. This record needs ground-truthing to establish a current baseline for the 'sites' in the Willandra Lakes. The areas of research focus in the Willandra are predominantly on the Lake Mungo lunette, with the other lunettes as subsidiary focus areas. This can be substantiated by even a cursory look at the published material from the Willandra Lakes, summarised by Fitzsimmons et al. (Fitzsimmons et al. 2019). Long running projects conducted by Bowler and Stern have predominantly focussed on the Lake Mungo lunette. The research focus on these

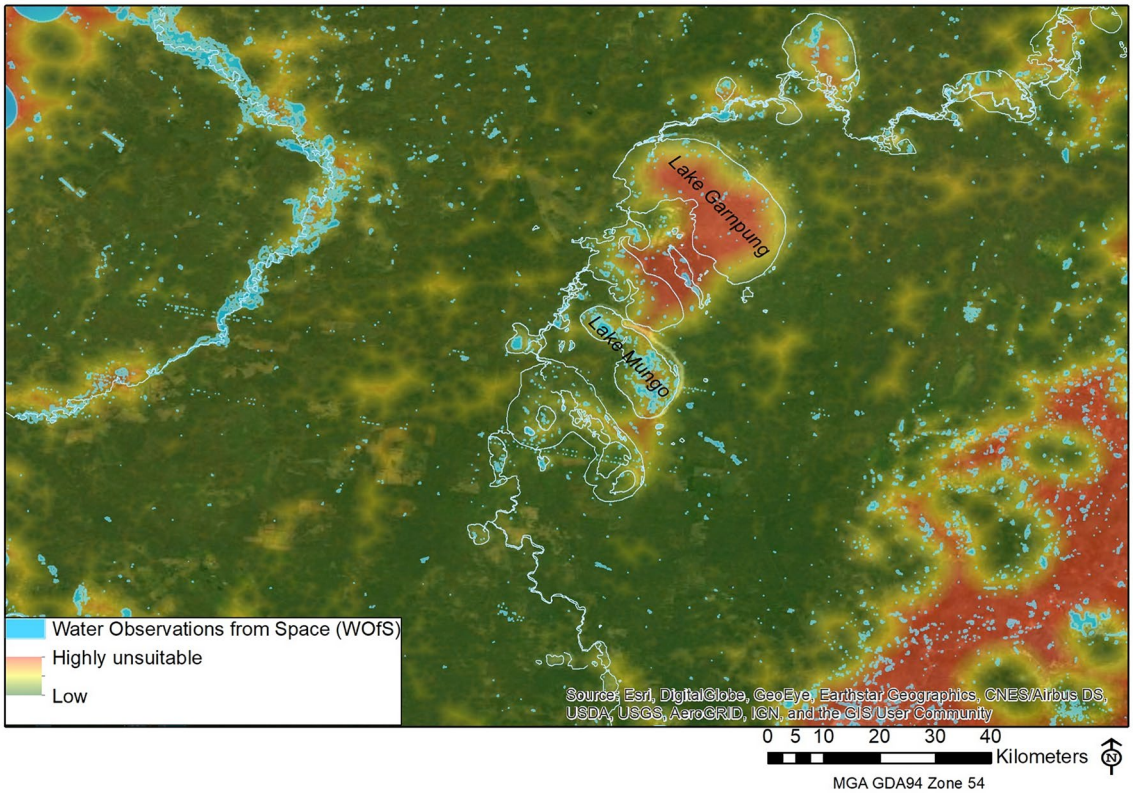

Fig. 7 Land unsuitable for use and occupancy, distances from ecotonal areas

lunettes is not an issue with respect to research, but it means that the archaeological record as it stands is not useful for a predictive GIS model for land suitability. Modelling the archaeological record from the 'presence only' data contained in 'sites' is not representative of the totality of the archaeological record because this is more a GIS model of areas of deposition and erosion on the landscape (Additional file 11: Fig. S10).

Given the state of the archaeological record in the Willandra, it does not make logical sense to create a predictive model based on the occurrence of archaeological sites. However, for the purposes of the Exploratory GIS model, a similar model of the land unsuitable for archaeological sites based on the extant archaeological record was created. This was an important exercise because it is standard GIScience practice to develop models from presence only data (Additional file 12: Fig. S11). To further enhance the discussion on the GIS model, this model could be assessed in direct proportions to the potential for finding archaeological sites within areas identified as subject to erosion, but it was outside of the bounds of this project to collate the information on erosional windows to the required detail. Additional file 11: Fig. S10 is an example of an output from these iterative additive models from the archaeological record. It is possible to see that the suitable areas for land use and occupancy overlap with the areas of research focus, erosion, and ecotonal areas (Additional file 12: Fig. S11). However, like nearly all GIScience predictive models, this model does not consider depositional history, age range of the site, site attributes, or any of the variables that create points of difference within the archaeological record. This is a main problem of a predictive model of the archaeological record based on presence only, averaged data from a temporally and spatially mutable landscape. The archaeological record of 'sites' is not a cultural record, nor is it a record of land use and occupancy—it is time to move away from these pseudo-scientific maps of the past, based on nothing more than where previous archaeologists have surveyed or erosion has exposed the activity layer.

Discussion

The arid zone in the Willandra Lakes Region World Heritage Area has been modelled as an area with refugia and isolated pockets of suitable land use zones (Hiscock 2008; Veth 1989). This is comprehensively not the case and a result of both European bias in identifying water features and the failure to recognise an active land use zone. Exploratory GIS models of hydrology, ecotonal

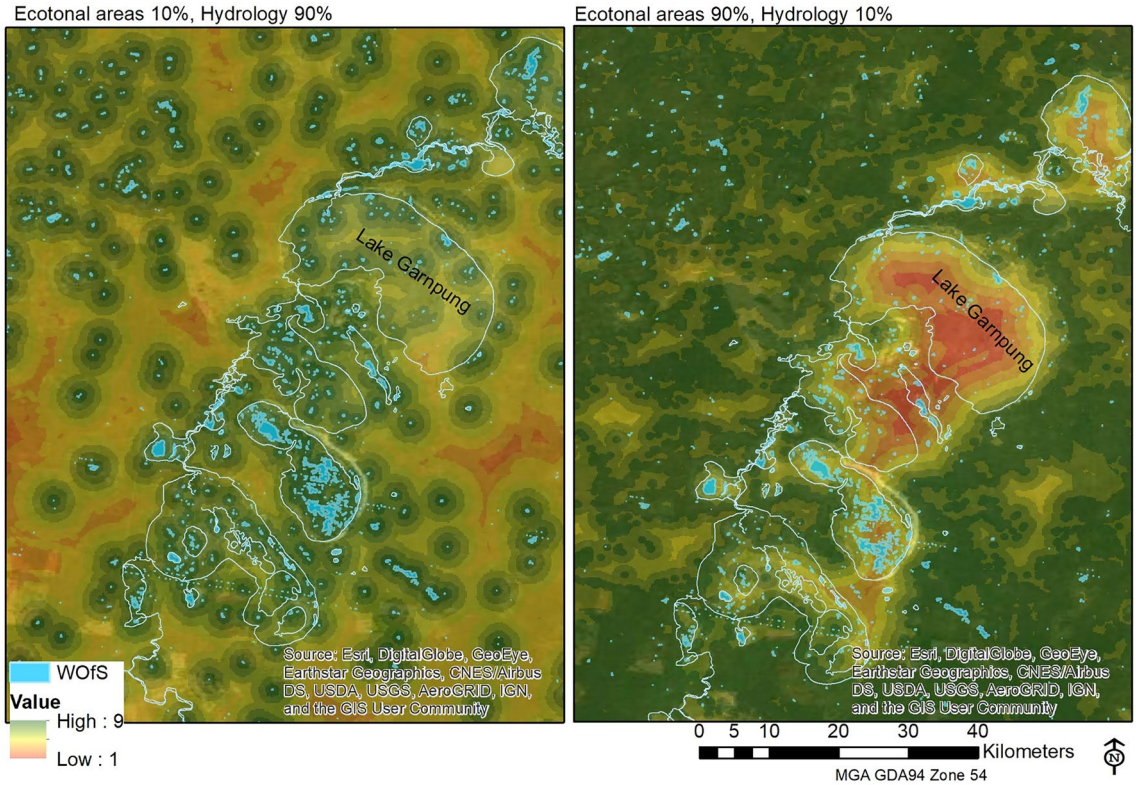

Fig. 8 Highly unsuitable areas of land use and occupancy, ratio models of Euclidean distances to water and vegetation compared

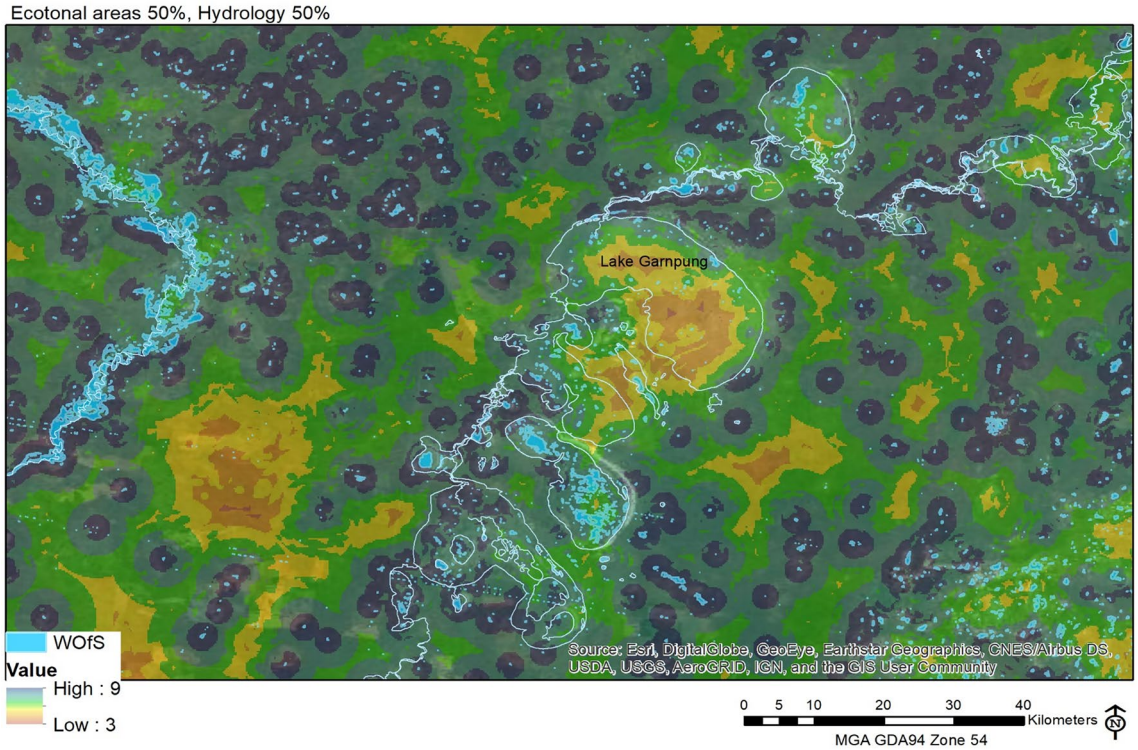

Fig. 9 Highly unsuitable areas for land use and occupancy, equal ratio ascribed to water and ecotones

areas, indicator species, land systems, and the material archaeological record allow us the potential to view the areas of 'unsuitable' land, but this is not the same as modelling areas where no possibility of land use or occupancy exists. WLRWHA is an active place and the wide range of possibilities of areas that could be classified as suitable should indicate the issues of single output predictive additive raster modelling of land use zones. Confirmation bias of GIS models is particularly apparent with retrofitted GIS modelling onto a past environmental state, especially a GIS model developed from a European view of appropriate hydrological or ecological zones.

In addition, both raster land suitability mapping and network mapping should be employed together in GIS modelling to provide internal and external shape descriptors. It is important to understand the range of micro and macro systems that are in place within a geographic area. The Willandra Lakes is not a system in isolation, but it is difficult to see zonal internal connections in a land suitability map. Also, this suitability map does not account for the passage of time and waves of land use and occupancy. These hydro-suitability maps only show the areas that may be affected by straight-line Euclidean distances to potential water features. Maps that show both external shapes defining the edges of water areas and internal shapes connecting areas between water resource zones are key to understanding the scale of potential connections and pathways in a purely object-based model of the landscape. Maps, like the human body, have both external features and internal skeletons linking places together. Combining Exploratory GIS techniques from both raster and vector backgrounds allows for visual and structural salience assessments of land suitability.

The additive GIS models above of the Willandra Lakes have also been constructed with no reference to the impact of the pastoral settlement. Referring in purely general terms, the land use zones in the former lower Darling run of NSW are mostly given over to animal husbandry and agriculture. In GIS modelling terms, this means all the basic elements of the model are affected by the effects of the pastoral settlement. Hydrological zones are affected by irrigation and water reallocation. Vegetation zones are affected by clearing, introduction of non-native vegetation, intensification, soil erosion, chaining around tanks and homesteads, and clearing of timber. To continue, the fences and the overland stock routes altered the vegetation and hydrological zones (Bates 2013; Benson 1991; Fiege 2005).

The GIScience modelling outputs above follow the common practice of using available hydrological and environmental data to map both land suitability and internal connections within resource zones. Exploratory design allows for multiple presentations of the data and helps plan fieldwork and visualise potential cultural contexts but, as stated above, these models cannot exist in isolation and performing one method to analyse data is at best short-sighted, at worse, precisely inaccurate GIS modelling. Furthermore, this type of modelling includes only visual salience of features and ignores the cognitive salience of a land use or occupancy zone. Cognitive salience is only brought into the picture or map with Participatory GIS (pGIS) work with the Mutthi Mutthi, Ngyiampaa, and Paakantji communities.

Conclusion

Exploratory GIS models unpack the myth of obtaining the culturally salient and suitable landform from our modern datasets. The current practice of defining areas of archaeological sensitivity from the material archaeological record and European conceptions of important water sources and vegetation zones is deeply flawed. Current GIScience modelling of land suitability for land use and occupancy is based on misconceptions of *terra nullius* and the biases that lead to classifying the arid zones as unsuitable for habitation. The way to mitigate the issues attached to categorisation, inferred salience, thresholding, or artificial systemisation of areas and human agency within a GIS model is through exploratory design and a truly integrated methodology with the First Nations communities and knowledge holders. If the GIS models are created in an iterative, collaborative, and exploratory fashion, they can be a starting point for archaeological fieldwork and mapping the cultural contexts surrounding the material traces within the archaeological record and understanding the concept of a habitable land use zone. The larger discussion on what an occupied or active-Country might look requires a reset on the current cultural resource management practice of assessing Country within a ranking or values system. Biocultural mapping is the key to understanding the intangible and the pathway to true modelling of land use and occupancy.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40068-023-00309-4.

Additional file 1: Table S1. Hydrology. **Table S2**. Vegetation. **Table S3**. Geomorphology, geology, and land systems. **Table S4**. Archaeological record.

Additional file 2: Figure S1. Hydrological data sources, WLRWHA

Additional file 3: Figure S2. Thresholding hydrology by one standard deviation, WLRWHA.

Additional file 4: Figure S3. Thresholding hydrology by quarter standard deviations, WLRWHA.

Additional file 5: Figure S4. Thresholding hydrology by natural breaks (jenks),WLRWHA

Additional file 6: Figure S5. Southern Mallee, pre-1750s

Additional file 7: Figure S6. NVIS pre-1788 vegetation mapping

Additional file 8: Figure S7. NSW Department of Environment Climate Change and Water, Pooncarie 1:250000

Additional file 9: Figure S8. Geological mapping, 1:250000

Additional file 10: Figure S9. Archaeological sites, a range of potential locations from legacy data

Additional file 11: Figure S10. Land unsuitable for archaeological sites based on the archaeological record

Additional file 12: Figure S11. Land subject to erosion, Bowler and Magee, 1973 (1:50000 photomosaic).

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Author contributions
KT, University of Melbourne, La Trobe University, Melbourne, Australia is the author of this work and all the figures and tables.

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Availability of data and materials
The data that support the findings of this study are available from the corresponding author, K.T., upon approval from the Willandra Lakes Region World Heritage Area Aboriginal Advisory Group. Restrictions apply to the availability of these data, which were used under strict Indigenous Cultural Intellectual Protocols (ICIP) for this study.

Declarations

Ethical approval and consent to participate
Ethical approval granted under La Trobe University Human Ethics Committee, Human–environment interaction, movement, and activity traces in the Willandra Lakes Region World Heritage Area (WLRWHA), HEC Number: HEC16-017.

Human and animal ethics
Ethical approval granted under La Trobe University Human Ethics Committee, Human–environment interaction, movement, and activity traces in the Willandra Lakes Region World Heritage Area (WLRWHA), HEC Number: HEC16-017.

Consent for publication
Initial consent given 20 October 2020 by WLWRH Aboriginal Advisory Group. Consent for final paper granted 13/04/2021 by WLWRH Aboriginal Advisory Group.

Competing interests
I declare that the authors have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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