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Large estimated size of the Australian Indigenous population before its extensive decline following colonial invasion

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Estimating the size of Indigenous populations in Australia before European colonial invasion is invaluable to truth-telling and reconciliation. Robust estimates of the population dynamics of pre-colonial Indigenous Australians are poor owing to lethal diseases, frontier and structural violence, and absence of systematic censuses. Here we review ethnographic observations, archaeological and genetic reconstructions, and modelled carrying capacity to infer Indigenous population size before colonial invasion. Congruency of the modelled and genetics-based (not historical or ethnographic accounts) estimates suggests a bootstrapped pre-colonial median of 2.22 million, or 0.29 people km^{-2}. This allows an estimate of the number of excess deaths in the post-colonial era. For a median pre-colonial population of 2.22 million, ~28,200 excess deaths per year (2.06 million deaths in total) would have had to occur over the late eighteenth and early nineteenth centuries from colonial invasion-related mortality to align with census records. These estimates speak to how the aftermath of invasion was experienced by Indigenous Australians, and recent census records show their survival and recovery since. We warn readers that the content of this study is confronting and possibly distressing.

Determining the size of pre-colonial Indigenous populations in Australia and the trajectory of demographic change since the start of colonial invasion in New South Wales in 1788 is important in current attempts to achieve reconciliation between Indigenous Australia and the broader Australian community. Recent studies with a focus on truth-telling are beginning to show that impacts of colonial invasion were more substantial than previously recognized[1–4]. Quantifying the magnitude of the change since the European invasion is essential for assessing and beginning to address the intergenerational trauma experienced by Indigenous communities today. It is also necessary to inform the suitability of modern socio-economic policies and the nature of support provided by Commonwealth and State governments to Indigenous communities. 'Closing the Gap'—an important policy framework for improving the lives of Indigenous Australians—was established in 2008 and includes targets around cultural well-being derived from late twentieth-century and contemporary data[5]. However, this policy would benefit from a longer record of demographic change.

Understanding the size and trajectory of change of Indigenous Australian populations can also inform archaeological, genomic and palaeo-environmental studies—whether the continent was occupied by only a few thousand or several million Indigenous people at the time of colonial invasion will fundamentally alter how such records

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are interpreted. There is a growing debate about whether Australia's Indigenous people were well-attuned land and sea managers who had minimal impacts on flora and fauna, or whether they were active agents of large-scale environmental change, resource enhancement and niche construction[5–9]. Quantifying the scale of the change is required to appreciate the extent to which Indigenous land management and transmission of Indigenous knowledge were impacted by invasion. Demography is an essential component of this debate, and a deeper understanding of population dynamics is required to inform ongoing and future landscape-management strategies based on traditional practices. For example, the application of Indigenous environmental management is becoming more commonplace (for example, cultural burning)[10,11], and estimating the scale of such activities before 1788, in part driven by population size and distribution, could inform the application of these practices today[12].

The fundamental challenge in determining population size before invasion is accounting for the initial impacts of disease[4] and frontier and structural violence[1–3], which resulted in largely undocumented demographic effects throughout the late eighteenth and early/mid-nineteenth centuries. We use the term 'frontier violence' to refer to direct lethal violence associated with colonial expansion, including massacres and other killings of Indigenous peoples. The term 'structural violence' refers to the indirect demographic impacts produced by forced removal from Country, societal fragmentation, assimilationist policies, constraints on and criminalization of traditional food procurement (resulting in reduced food intake and malnutrition), exploitative and forced labour, and negative health impacts[13–15]. Notably, smallpox—a highly virulent and deadly disease caused by the variola virus—was observed within 15 months of the First Fleet reaching Sydney Cove on Gadigal Country (Fig. 1), and recent analyses suggest that it had a massive negative impact on the population[4]. The spread and impact of this initial epidemic were likely restricted to the south-eastern portion of Australia[4], but subsequent outbreaks throughout the nineteenth century resulted in much of the remaining susceptible Indigenous population potentially being exposed to the virus[16].

Concurrently, an increasing colonial population established and expanded agriculture and pastoralism along the eastern and southern margins of Australia, resulting in widespread frontier violence[1–3,15,17]. Focused on the first half of the nineteenth century, but extending to the 1930s, killing of Indigenous people was prevalent and rarely punished, with some accounts suggesting that it was nothing less than a campaign of extermination[18]. Other contemporary communities have preferred the term 'war' to emphasize the ways that warriors defended their country in the face of colonial campaigns against them[17]. Although estimates of the number of people killed were rarely accurate in the historical accounts and increasingly omitted entirely after 1838 because of successful prosecution of perpetrators of the Myall Creek massacre[18] (Fig. 1), several recent studies have suggested that the numbers killed were at least in the tens of thousands and potentially >100,000 (refs. 1–3,19,20). In addition, structural violence continued and was also prevalent into the twentieth century[21–23]. It was not until the early twentieth century that anthropologists began to focus on the question of Indigenous population size, and not until 1971 was there a comprehensive census of Indigenous people[24] (abs.gov.au).

Previous population estimates using historical records

Observations of Indigenous people, including their population size and composition, began from the moment of first encounter and expanded with the onset of colonial invasion. Colonial accounts often refer to encounters with small bands of people and infrequent references to major gatherings of several hundred individuals[25–29]. Indeed, Arthur Phillip, the first Governor of New South Wales, referred to some 1,500 people living within a 16-km (10-mile) radius of Sydney Cove[28] (Fig. 1). Such examples of unsubstantiated population estimates were made across Australia throughout the nineteenth century[27,29,30], but there was no systematic census of Indigenous people during that period. Accounting associated with the distribution of blankets to Indigenous people, introduced by Governor Lachlan Macquarie[31] in Sydney in 1814 and continuing into the early twentieth century, provides perhaps some of the earliest quantitative data from which to estimate population size. However, although this is an important source of family information, these data are not robust, tracking only those who were present at distribution locales when blankets were distributed on a particular day each year. Across Australia, other colonial records of Indigenous numbers, such as ration depots, pastoral stations, missions and reserves, provide only patchy information. Such estimates are therefore unlikely to encompass the full cross-section of Indigenous populations in each region.

Radcliffe-Brown[32] compiled observations from a range of informants across Australia to provide the first continental-scale assessment of the Indigenous population. Applying these estimates, as well as some derived using basic assessments of environmental carrying capacity, he proposed a total population of between 250,000 and 300,000 people, equivalent to ~1 person 30.8 km^{-2} (that is, 0.032 people km^{-2}). Although this range is widely cited, most reported observations are derived from data collected late in the nineteenth century when populations had already been subjected to the impacts of colonialism. Radcliffe-Brown[32] was aware of this bias and suggested that his estimates were almost certainly low, despite many researchers referring to his estimate as the probable total, or even maximum, pre-colonial population size.

Between the 1950s and 1970s, many researchers built on those previous estimates. Research during that time focused either on (1) observed or recorded population densities and the extrapolation of these observations to regional or continental scales[33–35] or (2) using the number of documented tribal groups across Australia, and the average number of people within each group, to calculate a total population for the country[34,36]. These analyses continued to suggest a pre-colonial Indigenous population in the range of ~200,000–350,000 people. On the basis of different sources, Smith[37] proposed 314,500 as part of a comprehensive review of census data throughout the last 200 years, although he also acknowledged that this was an underestimate. Smith[37] provided the most robust post-invasion estimates available through a combination of records, suggesting around ~200,000 in 1850 and dropping to a nadir of ~80,000 by 1930. However, this latter value is an underestimate given the racialized administrative categories established in the latter nineteenth century that distinguished full Indigenous ancestry from those with mixed ancestry, with the latter typically excluded from censuses[15,24,38]. Modern census data since 1971 show an upward trend in population size from 1930, with modern Indigenous Australians adopting a tripartite definition of Aboriginality (inheritance, self-identification and community acceptance) and now numbering 983,700 (census size ≈ 813,000) as of 2021 (abs.gov.au/census).

Butlin[39] was the first to highlight systematically the potential impact of disease on Indigenous populations and that this phenomenon might have affected early colonial observations. He suggested that previous estimates were too low because of disease and applied early computer simulations to account for this, suggesting a pre-invasion population of 900,000. By 1986, Butlin[40,41] increased his estimate to 1.1 million (range 0.88–1.32 million). Butlin's[39] population estimate was largely supported by White and Mulvaney[42] and Mulvaney and Kamminga[43], but they considered that his values were slightly too high, and proposed a decrease to 750,000 to account for uncertainties. Specifically, they used the findings of both Radcliffe-Brown[32] and Butlin's[39] previous estimates to provide upper and lower boundaries within which they considered the value to be most likely. They acknowledged that the estimates of Radcliffe-Brown[32] were likely too low when considering colonial impacts (notably smallpox), but Butlin's[39] estimates were too high because he applied maximum carrying-capacity estimates across different environmental zones. This contrasted with historical observations suggesting that populations were generally maintained below

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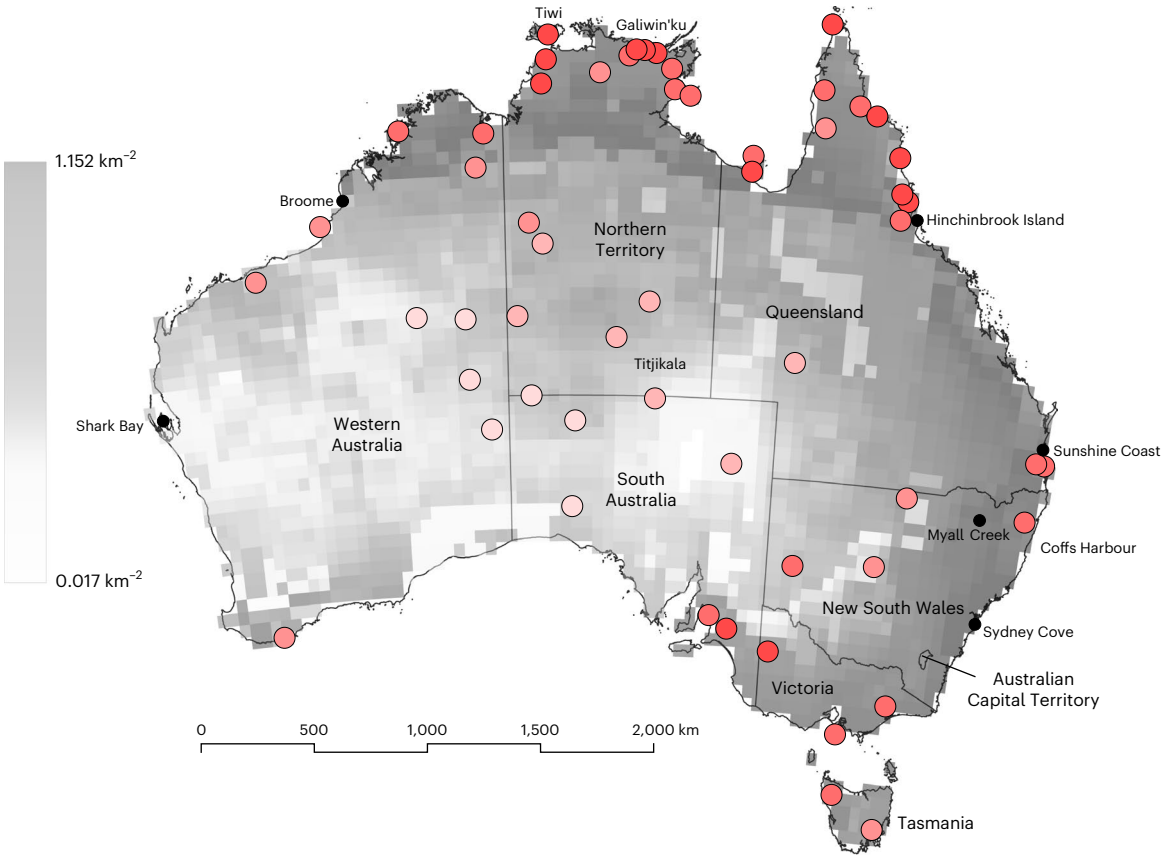


Fig. 1 | Distribution of ethnographic density point estimate and reconstructed carrying capacity across Australia. The 49 ethnographic entries from the Binford[44,45] hunter-gatherer database (red dots—darker red indicates relatively higher densities) overlaid on the HadCM3 (ref. 53) net primary production-derived estimates of human carrying capacities (expressed in people km^{-2}). Modern Australian states and territories indicated. Legend indicates relative population densities (greyscale). Also shown are several place names mentioned in the text.

optimum size, and overlooked the high variability in food resources across much of the continent that would have constrained the ability to sustain large populations. They further explored archaeological research at the time, particularly in south-western Victoria and Tasmania, which was producing population estimates around double those presented by Radcliffe-Brown[32]. On the basis of these regional case studies, they concluded that a doubling of Radcliffe-Brown's values was warranted, although the resulting estimates were still unlikely to approach those proposed by Butlin[39].

Although population change has been a consistent focus for archaeological research since the 1980s, specific quantitative values have not been substantively explored using documented sources since Mulvaney and Kamminga[43].

Approach and hypotheses

We present a review of estimates for the size of the pre-colonial Indigenous population derived using five independent approaches not based on ethnographic or historical data: (1) archaeological radiocarbon data, (2) two independent genetic estimates of effective population size and (3) two continental carrying-capacity models based on net primary production (see Methods for details). We assessed how closely these estimates align and then applied a demographic model to estimate the excess deaths implied by subsequent population decline. That model does not distinguish among deaths attributable to disease, frontier violence or structural violence because those processes are difficult to isolate reliably in the historical record, particularly because they often reinforced one another. Our aim is to explore the congruence of past estimates to identify a baseline that can shed light on the demographics of the Indigenous population before and following colonial impacts and that can assist in future truth-telling and socio-economic and environmental planning.

To achieve this aim, we tested three related hypotheses. (1) We hypothesized a linear relationship between reported anthropological point estimates of local density[44,45] and the density estimates predicted from the HadCM3-derived net primary production (that is, a 'carrying capacity' model); a linear (but not necessarily 1:1) relationship would confirm whether the model predicts a realistic density range across the area covered by the anthropological estimates[44,45]. (2) The available anthropological density estimates[44,45] span 1830–1978 and so encompass most of the period of demographic disruption brought about directly or indirectly by colonial invasion. We hypothesize therefore that the deviation between the anthropological[44] and modelled carrying-capacity density estimates should increase through time from 1788 (expressed as a ratio of modelled to anthropological densities). (3) We also hypothesized that the ratio should be lower in the tropical (lower) latitudes of Australia given the predominantly southern focus of the initial impact of colonial invasion.

Results

We summarize five independent approaches recently used to estimate the size of the pre-colonial invasion Indigenous population in Australia that do not rely on historical or ethnographic observations. We describe a bootstrapping approach to determine the congruence range of the estimates, comparing quantitative modelled outputs to historical population density estimates. We then constructed a demographic model estimating the number of excess deaths necessary to achieve the population declines inferred from pre-colonial estimates and late nineteenth-century observations.

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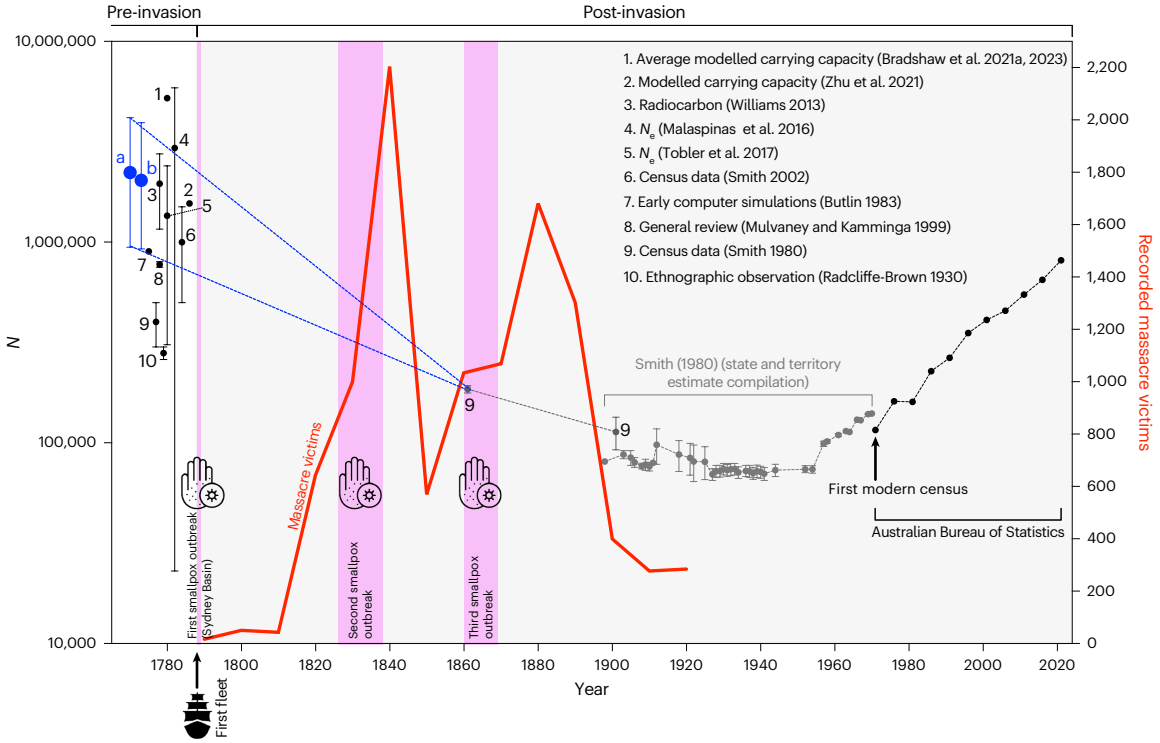


Fig. 2 | Trajectory of estimated Indigenous population sizes in Australia since European invasion. Timeline of putative population estimates of Indigenous (Aboriginal) Australians from just before colonial invasion in 1788 (jittered on the *x* axis for clarity; *y* axis on the $\log_{10}$ scale; Extended Data Fig. 1 with linear-scale *y* axis) up to the last full census in 2021. Three major smallpox outbreaks[4,16] are indicated in pink. Pre-colonial estimates include average modelled carrying capacity from (1) Bradshaw et al.[48,54] and (2) Zhu et al.[55]; (3) archaeological radiocarbon date reconstruction[46]; genetic effective population sizes (N_e) from (4) Malaspinas et al.[52] and (5) Tobler et al.[50]; and various historical estimates ((6) Smith[93]; (7) Butlin[39]; (8) Mulvaney and Kamminga[43]; (9) Smith[37]; (10) Radcliffe Brown[32]). Grey dots and ranges for 1861 and 1901 (indicated as '9') are derived from Smith[37] (his Fig. 8.6.3, p. 308). Grey dots from 1898 to 1970 and associated ranges are from the compilation of state and territory estimates by Smith[37], and black dots from 1971 to 2021 are census data from the Australian Bureau of Statistics (abs.gov.au/census). The blue dots and blue error bars indicate the median and bootstrapped 75% confidence interval (10,000 replicates) for the (a) modelled estimates (that is, carrying-capacity models[48,54,55], radiocarbon data[46] and N_e estimates[50,52]) and (b) without the Malaspinas et al.[52] N_e (given extremely wide confidence intervals). Also shown is the estimated total number of frontier massacre victims by decade from the 1790s to the 1920s (red line; right *y* axis) from the Colonial Frontier Massacres in Australia 1788–1930 database[1] (frontier violence records were only formalized in the 1880s; killings peaked in the 1820s–1860s and only ended by the 1930s).

Archaeological radiocarbon data

By applying the variation in average annual growth rate ('Gr_{Ann}') to an incrementing 'initial' founding population at 50,000 years ago, and a geometric growth-decline model, Williams[46] concluded that 1,000–2,000 people arriving 50,000 years ago would result in a population size of 1.2 million just before colonial invasion (ranging between 364,000 and 2.99 million depending on the size of the founding population applied and the degree of smoothing of the Gr_{Ann} across the 50,000-year record).

Although progressing the debate from the historical and ethnographic records, there are several limitations to the Williams[46] approach. The formation of the Gr_{Ann} considered and accounted for changing climatic and environmental change (indirectly through the archaeological data); however, there are few radiocarbon data before ~46,000 years ago, and this data gap constrains robust modelling of the initial peopling event (documented to have occurred at least 10,000 years earlier[47,48]). Although this is a time well before colonial invasion, uncertainty in the size of the 'founding' population affects the projected demographic parameter estimates. Williams[46] applied corrections for taphonomy—the loss of older archaeological deposits—to the dataset to compensate, but that approach also has limited validity before 25,000 years ago[49]. In the context of studies outlined in subsequent sections, Williams' estimates[46] might similarly underestimate pre-colonial population size because some of the earliest phases of peopling and exploration across the continent were not robustly considered. Despite this underestimation, Williams[46] included colonial impacts on Indigenous populations; however, limited data in the last 200 years made conclusions difficult to validate.

Genetic estimates of effective population size

Tobler et al.[50] used mitochondrial DNA (mtDNA) from 98 Australian-only lineages to estimate an effective maternal population size (N_e^f) of ~154,000 to 1.2 million by the time of colonial invasion (Tobler et al.[50]; their Extended Data Fig. 7). Assuming an equal adult sex ratio, this predicts a total effective population (N_e) of 308,000 to 2.4 million. The ratio of census to effective population size[51], N_c:N_e, is »1, which is evidence in favour of a total population of at least several million based on genetic evidence alone. Malaspinas et al.[52] (their Fig. S12.2) also used mtDNA as well as Y chromosome data to estimate N_e (N_e^f and N_e^m, for females and males, respectively), giving N_e^f = 11,480–421,314 (all mitochondrial genomes) and N_e^m = 205,016–2,935,490. Assuming an equal sex ratio, this places their total N_e range at 22,960–5,870,980.

Continental carrying capacity derived from net primary production

On the basis of the carrying capacity estimated from HadCM3-derived[53] net primary production[48,54], the estimated mean number of people in the entirety of Australia could have been as high as 5.22 million, or on average, an Australia-wide population density of 0.68 km^{-2}. This number depends on the underlying relationship between human density and net primary production; assuming the best-supported non-linear rotated parabolic relationship[48,54] shows that the highest human

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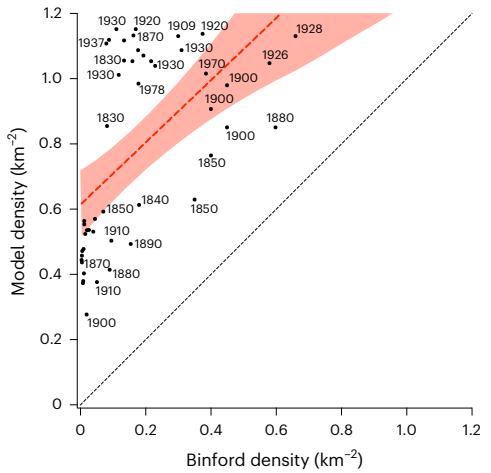


Fig. 3 | Comparison of modelled and enthnographic density estimates of Indigenous Australians. HadCM3 (ref. 53) net primary production-derived estimates of human carrying capacity (expressed as density: people km^{-2}) relative to 49 ethnographic entries from the Binford[44,45] hunter-gatherer database showing estimated densities (people km^{-2}). The dashed black line indicates the 1:1 relationship. The dashed red line and red shading show the linear regression and 95% confidence intervals of the predicted values (R^2 = 0.323; slope = 0.55–1.36; intercept = 0.52–0.71; model density = 0.9534 × Binford density + 0.6139).

densities would have occurred in the northern savannah region of Australia, the eastern and south-eastern coastal regions, and Tasmania[48,54]. The independent carrying-capacity estimate of Zhu et al.[55] applied to the Australian region gave a total population size of 1,556,314 people.

Congruence of estimates of pre-invasion population size

Including the five non-ethnographic/historical estimates (2× carrying capacity[48,54,55], radiocarbon[46,56], 2 × N_e[50,52]) into the bootstrap procedure provides a median of 2.22 million (75% confidence interval, 0.95–4.17 million), or 0.29 people km^{-2} (0.12–0.54 km^{-2}). Removing the Malaspinas et al.[52] estimate from the bootstrap procedure because of its higher uncertainty (0.023–4.87 million) provides a median of 2.03 million (75% confidence interval, 0.92–3.92 million), or 0.26 people km^{-2} (0.12–0.51 km^{-2}) (Fig. 2). These estimates of population density are not without precedent when compared with post-colonial estimates of hunter-gatherer densities in the temperate coastal regions of Australia (mean ± s.d. = 0.34 ± 0.24 people km^{-2} and an upper estimate of 0.81 km^{-2})[48], further afield for Neolithic/Palaeolithic peoples of the Levant and Near East (0.13–1.32 km^{-2})[57] or for New Guinean transient agriculturalists (4.37 ± 4.22 km^{-2})[48,58].

Testing bias hypotheses for historical data

A linear plot of our density estimates versus those from the Binford[44] database supports our first hypothesis that relative densities are similar between the two sources (Fig. 3). Our estimates are consistently higher than those of Binford; however, this is expected because Binford's data[44,45] reflect a population already affected by colonial invasion and our methods are aimed at estimating a pre-colonial invasion population size.

The spatially resampled boosted regression trees testing the remaining two hypotheses regarding expected bias explained 69.3 ± 14.5% (mean ± standard deviation) of the variation in the ratio of the two densities (HadCM3-derived carrying capacity[48,54] versus Binford[44,45]) (mean relative influence: year = 59.0 ± 0.7%, latitude = 41.0 ± 0.7%). The spatially resampled generalized additive models explained a mean of 69.2 ± 7.7% of the deviance, with a mean relative contribution of 67.3 ± 7.6% for year and 32.7 ± 7.6% for latitude. We found support for the second hypothesis that the deviation between the Binford[44,45] and carrying-capacity-estimated[48,54] density estimates increased through time (Fig. 4a), where there were a flat, low plateau pre-1900 and a steep rise after 1900. In possible partial agreement with the third hypothesis that the deviation between the two density estimates is lower in the tropical latitudes of Australia given the predominantly southern focus of the initial impacts of invasion, the ratio between densities was lowest in the highest latitudes (<20° S), increased between ~18° S and 26° S latitude (from just north of Hinchinbrook (Munamudanamy/Pouandiai) Island to just north of Sunshine Coast (Kabi Kabi) on the east coast and from Broome (Rubibi) to Shark Bay (Gathaagudu) on the west coast; Fig. 1) and then declined to a stable mid-range value in the most southerly latitudes (Fig. 4b).

However, 7 of the 49 density pairs with high (>20) ratios (either with high modelled density[48,54], low anthropological[44,45] density or both) were within the arid (≤250 mm year^{-1} mean total precipitation) and semi-arid (>250 and ≤370 mm year^{-1} mean total precipitation) zones of Australia[59] (in total, 12 of the 49 pairs were within these zones). Removing these pairs from the analysis revealed inconclusive trends for latitude (boosted regression tree mean coefficient of variation = 66.0 ± 17.1%) and a higher mean relative influence of year (71.7 ± 0.8%) relative to latitude (28.3 ± 0.8%). The resampled generalized additive models for the wet-only points explained 84.6 ± 10.5% of the deviance, with a mean relative influence of 80.6 ± 13.4% for year and 19.4 ± 13.4% for latitude.

The overall results show that although the carrying-capacity-estimated densities[48,54] in our model are higher than those in the Binford[44,45] database, the broad patterns are similar. Much of the disparity between the two estimates can be explained by time since initial colonial invasion, but an effect of geography (relative remoteness from primary colonial settlements) was inconclusive and might even suggest higher mean ratios at the lowest latitudes despite the peak around 20–25 °S (Fig. 4). This confirms our hypotheses regarding temporal biases in historical estimates (hypothesis 2), but any geographic bias (hypothesis 3) remains inconclusive. An additional spatial comparison between modelled population sizes and historical estimates from relatively undisturbed populations shows strong support for a power-law relationship (Extended Data Table 1, Extended Data Figs. 2 and 3 and Supplementary Appendix 2), suggesting that the carrying-capacity estimates[48,54] are at least the correct order of magnitude.

Estimate of excess deaths following colonial invasion

For a population at the bootstrapped mean pre-colonial estimate of 2.22 million to decline to 0.177–0.193 million by 1861 (73 years), an average of around 28,200 excess deaths per year must have occurred (Fig. 5a), with the rate itself likely varying through time. This means that in total, approximately 2.06 million excess deaths occurred over the 73 years from 1788 to 1861 (Fig. 5b). Results were similar when we projected to 1901 instead of 1861 (~21,000 excess deaths per year on average for a total of 2.37 million excess deaths; Extended Data Fig. 4). This translates to a mean instantaneous exponential rate of annual decline = −0.036 (Fig. 5a). Of course, given the wide uncertainty in the pre-colonial invasion estimates (75% confidence interval, 0.95–4.17 million), the total number of excess deaths could have ranged from ~0.7 million to 4.2 million (Fig. 5b).

Discussion

We have reappraised Indigenous population size before colonial invasion and demonstrated that it was likely far larger than previously proposed. Over the years, several different methods have been applied to determine the size of Indigenous populations in the past. Initially, these focused on ethnographic and historical observations of early post-invasion tribes, family groups and gatherings. Radcliffe-Brown[32] perhaps epitomized these approaches, and his downwardly biased estimate of ~300,000 has been used as the benchmark influencing all other studies for much of the mid- and late twentieth century. However,

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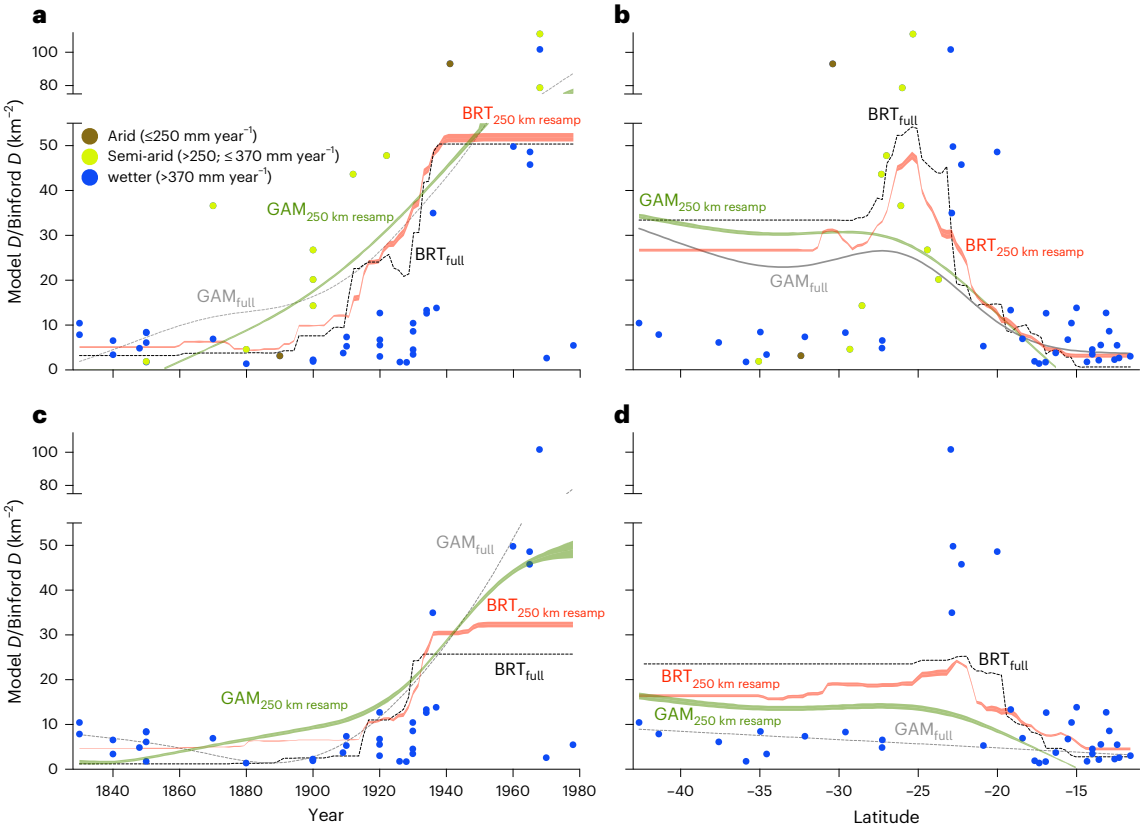


Fig. 4 | Temporal and spatial patterns of the ratio of modelled to ethnographic estimates of Indigenous population densities. a,b Ratio between the HadCM3 (ref. 53) net primary production-estimated carrying capacity in terms of human density (*D*, people km^{-2}) and the densities derived from the Binford[44] ethnographic database against year (**a**) and latitude (**b**) (100 spatially resampled adaptive boosted regression trees (BRT) and generalized additive models (GAM) with distance lag ≥250 km). Red- and green-shaded areas indicate 95% confidence intervals for the partial relationships predicted from the boosted regression trees and generalized additive models for each predictor, respectively. Also shown are the 'full' (non-spatially resampled) BRT and GAM fits in black- and grey-dashed lines, respectively. Points are coloured according to aridity definitions[59] (arid (brown), ≤250 mm year^{-1} mean total precipitation; semi-arid (yellow-green), >250 and ≤370 mm year^{-1} mean total precipitation; non-arid (blue), >370 mm year^{-1} mean total precipitation). **c**,**d**, After removing arid and semi-arid points, the refitted boosted regression trees and generalized additive models by year (**c**) and latitude (**d**).

it has become increasingly apparent that disease had a large impact on these populations[4]. For example, Dowling[60] suggested that the introduction of smallpox in 1789 might have resulted in a loss of 50% of the population, and Nitschke et al.[4] estimated that a loss of 40,000–240,000 people might have died from the disease in south-eastern Australia, estimates comparable to other contemporary observations of the impact of the disease[16]. Furthermore, there were subsequent smallpox outbreaks[16] in 1826–1838 and 1860–1869, as well as other new diseases such as measles[61], influenza[62], tuberculosis[63,64], leprosy[65], syphilis[66], typhoid, chicken pox, whooping cough, scarlet fever and mumps[67]. Frontier[1–3,15,18], and later, structural[21–23], violence would also have affected populations both through direct mortality and cumulative effects of assimilationist policies and racial exclusion. Thus, earlier population estimates are based on observations of an already compromised population and must be considered to reflect only a proportion of the pre-invasion population size.

Alternative approaches using archaeological, genetic and carrying-capacity methods all suggest higher estimates than those from historically biased approaches. Although Williams[46] was one of the first to explore methods that do not rely on historical or ethnographic observations, his estimates were among the most conservative, centring on 1.2 million. Limitations of the radiocarbon technique resulting from taphonomic biases, especially in the pre-Last Glacial Maximum period, suggest therefore that his estimates should be considered minima. Similarly, genetic data also suggest upper limits of effective population size from ~2.4 million[50] to ~5.9 million[52], acknowledging again that these likely do not represent the entire census population size.

Bradshaw et al.[48] proposed a population of ~5 million people. Despite being more complex, this type of carrying-capacity approach is similar to the methods applied by Campbell[33] and Radcliffe-Brown[32]—all of whom estimated densities of people. Although the Bradshaw et al.[48] estimates are higher than those produced through other techniques, additional testing by Binford[28,65] using early colonial observations of Aboriginal populations[44,45] (Supplementary Appendix 2) shows anticipated biases according to time since invasion, and those considered unaffected by initial diseases show that the carrying-capacity approach closely predicts these observations and indicates a robustness that is not easily achieved by other techniques.

When considering the various techniques applied, the balance of evidence supports a probable population of at least >1 million, but more likely 2–3 million, and potentially >5 million at the time of colonial invasion. Although our new estimates might appear high after nearly a century of low estimates cited in the literature, our median bootstrapped estimate still equates to 0.29 people km^{-2} (0.12–0.54 km^{-2}), well within observed population densities in temperate and tropical Australia during the colonial period[58]—noting that those very regions in which the observations were made would have already been subjected to colonial impacts. The median pre-colonial population size we estimate here also implies that the total human population (Indigenous + non-Indigenous) in Australia reached its post-colonial (and perhaps also during the last 60,000+ years[48,54,68]) minimum around 1847 at

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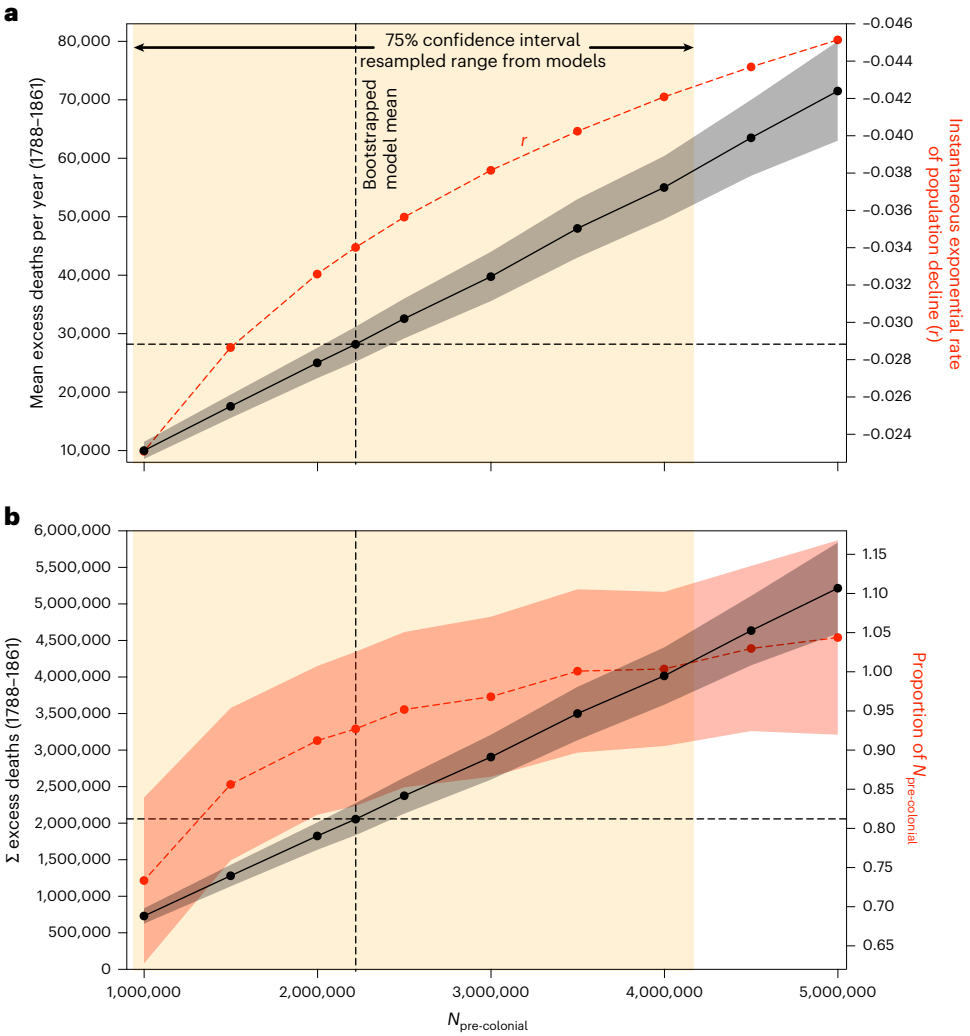


Fig. 5 | Estimated excess deaths of Indigenous Australians following European invasion. Excess deaths required to change a pre-colonial Indigenous population from sizes ranging between 5.0 million and 1.0 million to 0.178–0.193 million from 1788 to 1861 based on a stochastic demographic model. **a**, For different initial population sizes (*x* axis), the left *y* axis shows the average annual excess deaths that must have occurred for the population to reach the indicated target, expressed as an average annual instantaneous exponential rate of population decline (*r*) on the right *y* axis. The grey-shaded area indicates the 95% confidence intervals for the annual excess death estimate around the median (black line and black dots). The background peach colour indicates the 75% confidence interval of the resampled initial population sizes (10,000 replicates) derived from the modelled sources (that is, carrying-capacity models[48,54,55], radiocarbon data[46] and N_e[50,52] estimates; Fig. 1). The black vertical dashed line indicates the central tendency of those estimates (bootstrapped model mean), and the black horizontal dashed line indicates the annual excess deaths at that central tendency. **b**, For different initial population sizes (*x* axis), the left *y* axis shows the sum of the excess deaths from 1788 to 1861 required to achieve a population of 0.092–0.134 million, expressed as a proportion of the initial population size on the right *y* axis. Grey- and red-shaded areas indicate the 95% confidence interval for each measure (around medians indicated by black and red lines, respectively), and the vertical and horizontal black dashed lines are as in **a**.

~1.07 million (Extended Data Fig. 5). Our reconstruction also suggests that the size of the non-Indigenous population first exceeded that of the Indigenous population around 1847 on average (Extended Data Fig. 5).

Comparing our revised pre-invasion population estimates with those recorded during the colonial era exposes the scale of the catastrophe inflicted on Indigenous populations. We estimate that a median of 2.06 million additional people might have died through disease, and directly or indirectly by frontier violence, or by structural violence in the form of assimilationist policies and racial exclusion throughout the nineteenth and early twentieth centuries. Even adopting the lowest pre-invasion estimates of total population size, our model predicts that there would have been ~734,000 excess Indigenous deaths between 1788 and 1861. This post-invasion depopulation event is also evident from genomic analyses of 159 individuals from four Indigenous communities (Tiwi, Titjikala, Galiwin'ku and Yarrabah; Fig. 1) that suggest a decline of 1 to 2 orders of magnitude in effective population size over the last few hundred years[69] (their Fig. 5a). Although disease is considered to have been the main driver of this loss, recent exploration of frontier violence using government archival records (for example, Native Police in Queensland, and Police in the Kimberley, Western Australia) suggests that it caused far more deaths than are documented in published histories of Australia, with recent estimates suggesting that >100,000 people might have been killed in frontier violence[1–3,19,20]. Furthermore, our results suggest that the number of disease-related deaths was comparable and possibly much higher. When compared with Smith's estimate[37] for 1861, only about 7% of the median estimated population survived the initial invasion. Such changes would have been catastrophic to Indigenous people, their traditional customs and life ways. This situation would have been compounded by subsequent structural violence that continued into the mid-twentieth century[21–23]. However, Indigenous people adapted to their changing landscapes and social structures, modifying and continuing to pass on essential

Dreaming, kinship, lore and other Traditional Knowledges, as well as keeping language alive in various forms, to ensure retention by the broader Indigenous community. It is also unsurprising that such information might be fragmentary and/or incomplete across some parts of Australia where impacts were most extensive[70,71].

Although the Indigenous population has increased since the 1950s (Fig. 2 and Extended Data Fig. 5) from both intrinsic growth and a rise in the number of individuals identifying as Indigenous, contemporary (as of the 2021 census) Indigenous populations remain at only ~37% of their median estimated pre-invasion size (812,728/2,220,000). Assuming average intrinsic and non-demographic (that is, identifying as Indigenous) population growth observed since 1971 remains constant, it might not be until 2047 that the Indigenous population reaches parity with its estimated median size in 1788. It is in this context that reconciliation, engagement and future policy making must be prioritized with Indigenous people—people who continue to suffer intergenerational trauma from these historical events. Equally, the broader Australian community should embrace the rich culture that survived these events, and that remains an integral part of Australia's cultural fabric to this day.

Methods

Ethics and permissions

We obtained ethical approval for this study from the Flinders University Human Research Ethics Committee before data extraction and analysis (Ethical Clearance Number 9634). Australian university Human Research Ethics Committees are appointed legal authorities under Commonwealth of Australia law to assess and approve research in accordance with the National Statement on Ethical Conduct in Human Research and are registered with the National Health and Medical Research Council of Australia. This authority includes responsibility for determining the ethical acceptability of research involving, or having implications for, Aboriginal and Torres Strait Islander peoples.

Consistent with the Australian Institute of Aboriginal and Torres Strait Islander Studies Code of Ethics for Aboriginal and Torres Strait Islander Research principles of Indigenous self-determination, Indigenous leadership, impact and value, and sustainability and accountability, Aboriginal community representatives and Indigenous scholars identified the need for the project and contributed to the design of the project, including refinement of research aims, ethical considerations and dissemination pathways. Indigenous co-authors Shane Ingrey, Kirsty Beller, Lynette Russell, Raymond Tobler and Christopher Wilson contributed cultural knowledge, historical context and guidance on ethical engagement throughout the study. Lynette Russell, drawing on her extensive expertise in Indigenous histories, also contributed to the interpretation and contextualization of the research. Their involvement ensured that the research questions, the analysis of findings and the consideration of community impacts were grounded in Indigenous perspectives.

The author team includes both Indigenous and non-Indigenous researchers working across disciplines including ecology, mathematics, archaeology, history, demography, epidemiology and Indigenous studies. In addition to their scholarly contributions, Indigenous collaborators provided cultural and historical expertise and guidance on ethical engagement, while non-Indigenous authors recognize their positionality as researchers working within Australian academic institutions and the responsibilities associated with doing research on Indigenous histories.

Archaeological radiocarbon data

Williams[46] and Williams et al.[56] compiled a large dataset of 5,044 radiocarbon dates recovered from archaeological research since the 1950s from across Australia. They used this database to explore both qualitative and quantitative population change through time. Williams' approach[46] was to assume that each radiocarbon date reflected evidence of the activities of a discrete population at a particular point in time. These combined data provided a continent-scale indication of relative population size, with more radiocarbon data reflecting more people and vice versa. Williams[46] interpreted these changes as demographic responses to major climatic and environmental events, such as the Last Glacial Maximum and mid-Holocene climatic optimum. Binning the data into 200-year intervals and calculating the rate of change between bins produced a semi-quantitative index of relative increases and decreases in population size through time. Specifically, by comparing neighbouring 200-year data bins and applying a finite-difference calculation, Williams[46] converted the data to reflect average annual changes in population growth and decline (labelled 'Gr_{Ann}') across the 50,000-year dataset. He then applied a range of 'founding' populations to a geometric growth-decline model ($N_e = f(1+ Gr_{Ann})^t$, where N_e = effective population size, f = initial founding population followed by N_e in subsequent years and t = number of years), using Gr_{Ann} to quantify demographic growth and/or decline throughout the late Pleistocene, Holocene, up to the pre- and early-invasion period.

Although an innovative approach, Williams[46] identified several limitations with the technique, most notably the poor resolution and data averaging for critical parts of the timeline, including during the initial peopling of Australia and through the pre- and post-invasion periods.

Genetic estimates of effective population size

Various estimates of effective population size (N_e) for the pre-colonial Indigenous population have been calculated using mtDNA and Y-chromosome DNA[50,52]. However, census population size (N_c; that is, the number of individuals censused in a population) rarely equals N_e because of deviation from random breeding[51]. In fact, multispecies assessments estimate an average N_e:N_c ratio ~0.10 (ref. 51), and although the true ratio is unknown for Indigenous Australians before European invasion, N_e:N_c is almost certainly « 1. Nonetheless, we took the range of N_e derived from mtDNA from Tobler et al.[50] (their Extended Data Fig. 7) and doubled it (assuming an equal sex ratio) to infer total N_e (that is, because mtDNA-based analyses of N_e estimate the female component of the population[72]). Likewise, we took the N_e range of all mitochondrial genomes and all Y chromosomes from Malaspinas et al.[52] (their Fig. S12.2C,D), added them and took the resultant full range to infer total N_e.

Continental carrying capacity derived from net primary production

Bradshaw et al.[48,54] constructed a stochastic cellular-automaton model to predict the rate of settlement after the first people entered Sahul during the Late Pleistocene. The model was partially predicated on estimates of human carrying capacity (K, expressed in densities; people km^{-2})[48,54] derived from time-variant estimates of net primary production (P_p, in kg C m^{-2} $year^{-1}$) hindcasted using the LOVECLIM Earth system model[73]. Here we used the predicted relationship between P_p and K for non-agropastoralist societies[74] that already account for people's capacity to modify landscapes to improve resource yields. We further adjusted the relationship between P_p and K using a 180°-rotated parabola function of the form:

$$K = a(P_p - h)^2 + K_{max}$$

where we set $a = -3$ and h = median of P_p. This function ensures that maximum carrying capacity (K_{max}) occurs at mid-range P_p, because past humans likely struck a compromise between high productivity and ease of passage and/or visibility to hunt prey by tending towards ecotones of midrange productivity[75,76], a phenomenon also observed for large herbivores in sub-Saharan Africa[77]. Using this model[48,54], we extended the projections to the present, but instead used estimates of P_p derived from the more recent HadCM3 global circulation model[53] to calculate human carrying capacities. HadCM3 is potentially more accurate than LOVECLIM in estimating vegetation trends during the

Last Glacial Maximum in Sahul[78], so we determined it would provide better estimates of human carrying capacity for Australia immediately before colonial invasion.

We also included the approach of Zhu et al.[55] that used the Moderate Resolution Imaging Spectroradiometer estimates of net primary production (MOD17A3 product[79]) to predict 'hunter-gatherer' densities based on the fraction of production consumed. This process is parameterized for 'hunter-gatherer' dynamics within the Forager Dynamics in Global Ecosystem Model[55], which is coupled to the Organizing Carbon and Hydrology In Dynamic Ecosystems terrestrial biosphere model[80] to simulate the energy and water balance, vegetation dynamics and carbon cycle of land ecosystems. We chose scenario 2 (S2) of Zhu et al.[55], in which daily net primary production is replaced by the annual Moderate Resolution Imaging Spectroradiometer net primary production interpolated into daily values according to an observation-derived daily gross primary production product[81]. Zhu et al.[55] concluded that S2 is the most realistic scenario because other scenarios neglect the presence of 'hunter-gatherers' in arid ecosystems, including those in Australia. We extracted the grid cells covering Australia and summed the resultant population estimates derived from the grid-specific densities to a total population estimate for Australia, but we clipped grid cells to the Australia polygon to avoid overestimating population size in coastal cells. The R[82] code we translated from the Python code provided by Zhu et al.[55] (their supplementary software) is available at https://doi.org/10.5281/zenodo.20083870.

Congruence of estimates of pre-invasion population size

We developed a bootstrapping procedure to determine the central tendency of the carrying capacity (both approaches by Bradshaw et al.[48,54] and Zhu et al.[55]), radiocarbon data and genetic N_e estimates for the pre-colonial population (N), thereby avoiding the downward biases inherent in estimates reliant on historical records. To do this, we first calculated the standard deviation of the radiocarbon and the two N_e estimates, then computed 10,000 normally distributed deviates for each series using the 'rnorm' function in R[82]. For the single carrying-capacity-based estimates (one for each approach), we first computed the mean of the coefficient of variation from the other modelled ranges and used this to calculate a standard deviation for the carrying-capacity estimates. We then compiled 10,000 truncated normal deviates of the latter (upper limit = single estimate = 5.22 million) using the 'rtruncnorm' function in the truncnorm library[83] in R[82]. Finally, we combined the 10,000 deviates from each of the four models and calculated the median and upper/lower 75% confidence intervals.

Testing bias hypotheses for historical data

The carrying-capacity reconstructions of pre-colonial population size are the only spatially explicit model estimates at a fine-enough scale for comparison, so we compared point (overlapping grid cell) estimates of these reconstructions with the same point-estimate densities from the Binford[44] hunter-gatherer database. Binford's[44] database includes >200 variables incorporating various aspects of mobility, social organization, demography and subsistence for 339 ethnographically documented groups of hunter-gatherers. Using the 'LRB' function from the Binford library[45] in R[82], we extracted population density, area of coverage, spatial coordinates (latitude/longitude) and corresponding year for the 49 entries in Australia. Next, we overlaid these point coordinates onto a 0.5° × 0.5° latitude/longitude grid of Australia with the cell-specific densities derived from the HadCM3 net primary production model[48,54] (Fig. 1).

We first hypothesized a linear (but not necessarily 1:1) relationship between the Binford and the modelled density estimates if the carrying-capacity model predicts a realistic density range across the area covered by the 49 point estimates from Binford[44] (hypothesis 1). However, the Binford[44] estimates span 1830–1978 and so encompass the entire period of demographic disruption brought about directly or indirectly by colonial invasion. We also hypothesized that the deviation between the Binford[44] and modelled density estimates increased through time from 1788 (hypothesis 2). The deviation between the two density estimates should also be lower in the tropical (lower) latitudes of Australia given the predominantly southern focus of the initial impact of colonial invasion (hypothesis 3).

To test the last two hypotheses, we developed a spatially resampled, adaptive boosted regression tree (hybrid machine-learning) approach with the response coded as the ratio between model and Binford[44] densities, and the predictors of latitude and year, using the 'gbm.step' function in the dismo library[84] in R[82]. First, we calculated a Moran's I correlogram using the 'moran.test' function in the spdep library[85] based on a great-circle pairwise distance matrix calculated using the 'spDists' function in the sp library[86] in R[82]. We used this procedure to estimate the spatial lag where spatial autocorrelation was minimized while keeping enough samples to fit the boosted regression trees for each iteratively sampled dataset. Spatial dependencies occurred at the 250–650 km scale, with 250 km corresponding to where the autocorrelation was strongest (Supplementary Appendix 5). We therefore ensured that no two samples in the resampled datasets were <250 km apart. We ensured that the boosted regression tree algorithm applied an adaptive function to optimize the learning rate, step size and tolerance at each iteration. Most (75%) iterations adopted a learning rate = 0.02 (19% with 0.05; 6% with 0.01); step size of 12 (74%) or 13 (25%); tolerance = 0.002191 (49%), 0.002148 (26%), 0.002236 (22%) or 0.002284 (3%); and number of trees from 302 to 1,493 (median = 481) for 23–26 observations per iteration.

We also developed an adaptive generalized additive model approach implemented using the 'gam' function in the mgcv R library[87]. For each spatially resampled dataset, we set the k dimensions of the smoothing term to $\min(10, n_{term} - 1)$, where n_{term} is the number of unique 'year' or 'latitude' values in the resampled dataset. We set the error family to Gaussian and used the restricted maximum likelihood method. We also calculated the relative contribution of 'year' and 'latitude' terms in each 'gam' iteration using the 'predict' function in the stats library and then calculated the percentage variance for each term relative to total model variance.

However, 24.5% of the density pairs fell within the arid (≤250 mm mean annual precipitation) and semi-arid (>250 and ≤370 mm mean annual precipitation) zones of Australia[59], and 7 of these had high (>20) ratios of modelled density relative to Binford's densities[44,45]. We determined mean annual precipitation from the OzWALD annual precipitation grid[88] at a resolution of 0.05° × 0.05° for the years 1990–2013. Removing the pairs within the arid and semi-arid zones, we repeated both the resampled boosted regression tree and generalized additive model analyses. For these analyses, most (59%) iterations had a learning rate = 0.02 (21% at 0.05 and 20% at 0.01), a step size of 10 (66%) or 11 (34%), median tolerance = 0.00239 (range 0.002335–0.002513) and number of trees from 300 to 1,139 (median = 480) for a median of 21 observations per iteration.

Estimate of excess deaths following colonial invasion

To determine the number of excess deaths beyond those expected for an undisturbed population (that is, those resulting from disease, massacres and mortality associated with displacement and other colonial-related disturbances to Indigenous ways of life), we developed a stochastic population model using the age-structured matrix model developed for Indigenous non-agropastoralists by Bradshaw et al.[89]. We applied a density-feedback function that reduced survival evenly across all age classes to ensure average stability over the projection interval (see below) as developed by Bradshaw et al.[90]. Next, we resampled the survival and fertility vectors of the transition matrix assuming a standard deviation of 0.05μ (where μ = the mean age-specific survival or fertility estimate) based on a β and normal deviate function, respectively.

From this model, we obtained increasing values of annual 'excess' deaths (that is, beyond those expected from the age-specific survival

probabilities in the stable model) and subtracted this (separated by age class following the stable age structure derived from the deterministic matrix) from the updated abundance vector over a projection interval (73 years) from 1788 (colonial) to 1861 (Smith's[37] (his Fig. 8.6.3) reconstructed estimate of 0.177–0.193 million). Given the uncertainty of the Smith[37] estimate for 1861 (likely also underestimated), we also repeated the procedure for the projection interval from 1788 to 1901 (Smith's[37] (his Fig. 8.6.3) reconstructed estimate of 0.092–0.134 million).

For different 'initial' (that is, pre-colonial) total population sizes ranging from 5.0 to 1.0 million inhabitants (in 0.5 million increments and at 2.22 million as the median bootstrapped population estimates), we calculated the average annual and total number of excess deaths that would have been required to change the population from the initial abundance to 0.177–0.193 million by 1861 and to 0.092–0.134 million by 1901. We also expressed these outcomes in terms of the instantaneous exponential rate of decrease ($r = \log_e(N_{t+1}/N_t)$, where N_t = population size at time t) and the total excess deaths divided by the initial population size (proportion of pre-colonial N).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All relevant data for the analyses and results presented are available via Zenodo at https://doi.org/10.5281/zenodo.13451032 (ref. 91) and https://doi.org/10.5281/zenodo.20083870 (ref. 92).

Code availability

All relevant R codes for the analyses and results presented are available via Zenodo at https://doi.org/10.5281/zenodo.13451032 (ref. 91) and https://doi.org/10.5281/zenodo.20083870 (ref. 92).

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Author contributions

A.N.W. and C.J.A.B. designed, performed research and wrote the paper. C.J.A.B. analysed the data. S.U., L.R., M.I.B., R.T., C.J.A.B., F.S. and C.W. obtained funding. All authors reviewed, edited and provided contributions to the final paper.

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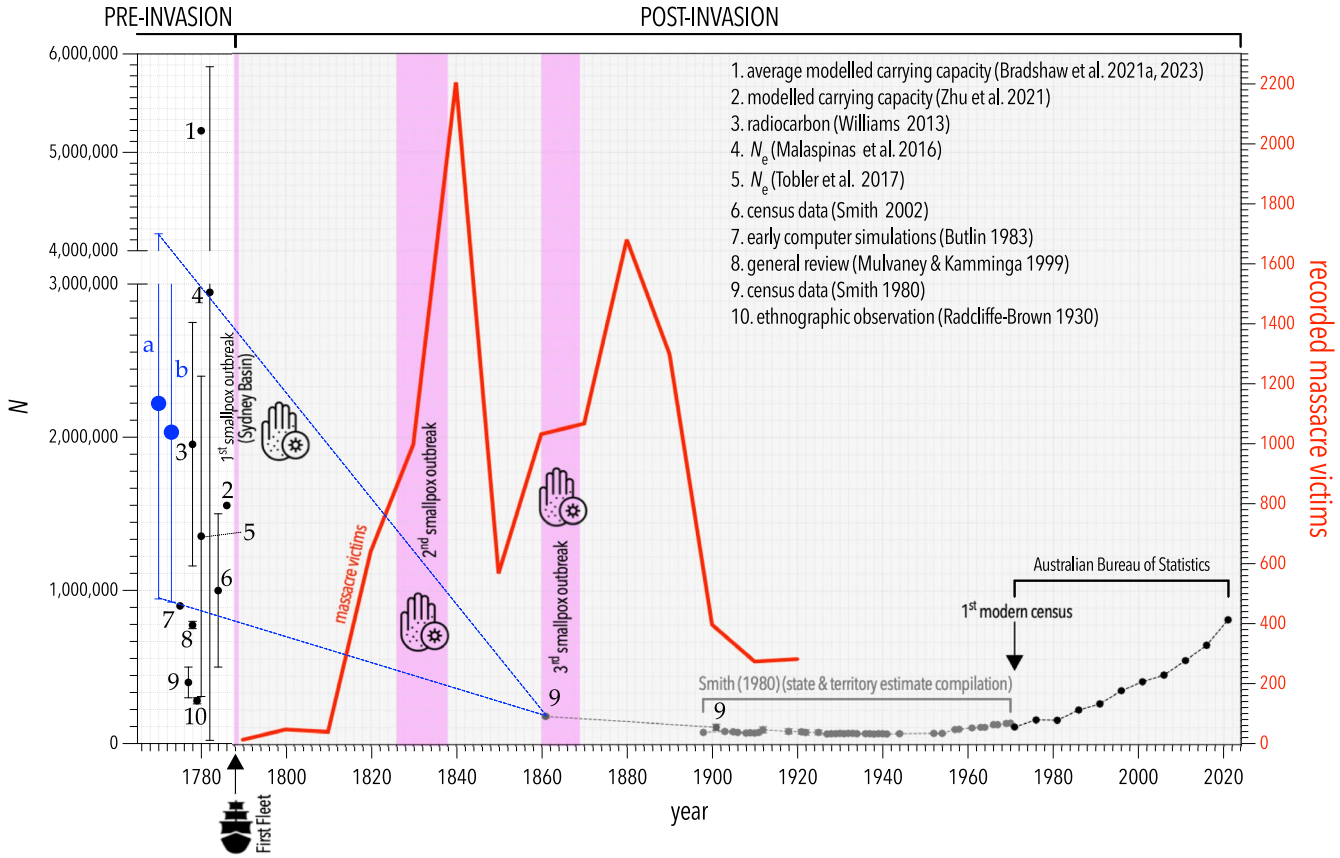
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Extended Data Table 1 | Historically reported and modelled population sizes for eight locations

ID	SITE	lon	lat	area	rep*N*	pred*N*	%Δ	ref
BB	Botany Bay	151.17	−33.993	416	366	478	30.6	**a**
BBKMP	Botany Bay Kurnell Meeting Place	151.221	−34.003	24.11	40	28	−30	**b**
BI	Bentinck Island	139.497	−17.067	150	123	170	38.2	**c**
DBI	Dorre & Bernier Islands	113.121	−24.992	100	40	43	7.5	**d**
EI	Erub (Darling) Island	143.76	−9.59	5.7	85	7	−91.8	**e**
PI	Possession Island	142.4	−10.72	5	10	6	−40	**b**
RI	Robbins Island	144.944	−40.692	99	45	50	11.1	**e**
SC	Sydney Cove	151.22	−33.869	489	1500	562	−62.5	**f**
IM	Ocean Beach, Isla Maria	148.032	−42.658	13	25	12	−52	**g**

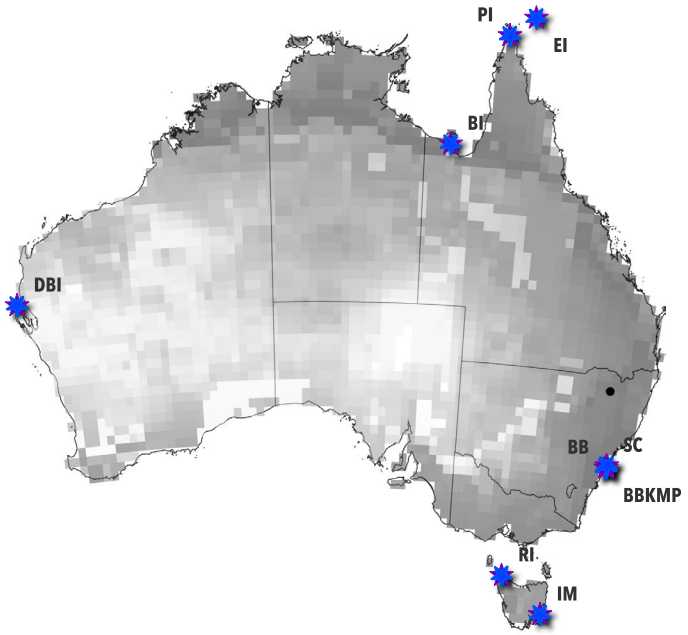
Comparison data for historically reported and modelled population sizes for eight locations (mostly islands) considered to pre-date colonial disturbance. **ID** = abbreviation (see map in Fig. S2); **SITE**: site name; **lon** = longitude (decimal degrees); **lat** = latitude (decimal degrees); **area** = area in km^2 to which historically reported *N* applies; **rep*N*** = historically reported *N*; **pred*N*** = carrying capacity-predicted *N*; **%Δ** = % difference between rep*N* and pred*N*; **ref** = source reference. **References (ref) cited in Table S1**: **a**: New South Wales Parliament[94]; **b**: Beaglehole[95]; **c**: Tindale[96]; **d**: Dampier[97]; **e**: Flinders[98]; **f**: Phillip[28]; **g:** Peron[99].

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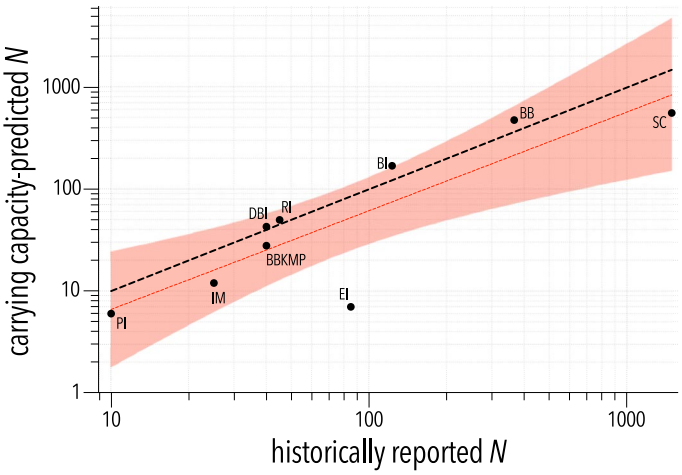
Extended Data Fig. 1 | Timeline of putative population estimates of Indigenous people up to the last full census in 2021. Timeline of putative population estimates of Indigenous (Aboriginal) Australians from just prior to colonial invasion in 1788 (jittered on *x* axis for clarity; *y* axis on linear scale; see main text Fig. 1 for graph with $\log_{10}$-scale *y* axis) up to the last full census in 2021. Three major smallpox outbreaks[4] are indicated in pink. Pre-colonial estimates include average modelled carrying capacity from Bradshaw et al.[48,54] and (2) Zhu et al.[55], (3) archaeological radiocarbon date reconstruction[46], genetic effective population sizes (N_e) from (4) Malaspinas et al.[52] and (5) Tobler et al.[50], and various historical estimates (6. Smith[93]; 7. Butlin[39]; 8. Mulvaney & Kamminga[43]; 9. Smith[37], 10. Radcliffe Brown[32]). Grey dots and ranges for 1861 and 1901 (indicated as '9') are derived from Smith[37] (his Fig. 8.6.3, p. 308). Grey dots from 1898–1970 and associated ranges are from the compilation of state and territory estimates by Smith[37], and black dots from 1971–2021 are census data from the Australian Bureau of Statistics (abs.gov.au/census). The blue dots and blue error bars indicate the median and bootstrapped 75% confidence interval (10,000 replicates) for the (a) modelled estimates (that is, carrying-capacity[48,54,55], radiocarbon[46], and N_e[50,52] models) and (b) without the Malaspinas et al.[52] N_e (given extremely wide confidence intervals). Also shown is the estimated total number of recorded frontier massacre victims by decade from the 1790 s to the 1920s (red line; right *y* axis) from the Colonial Frontier Massacres in Australia 1788–1930 database[1].

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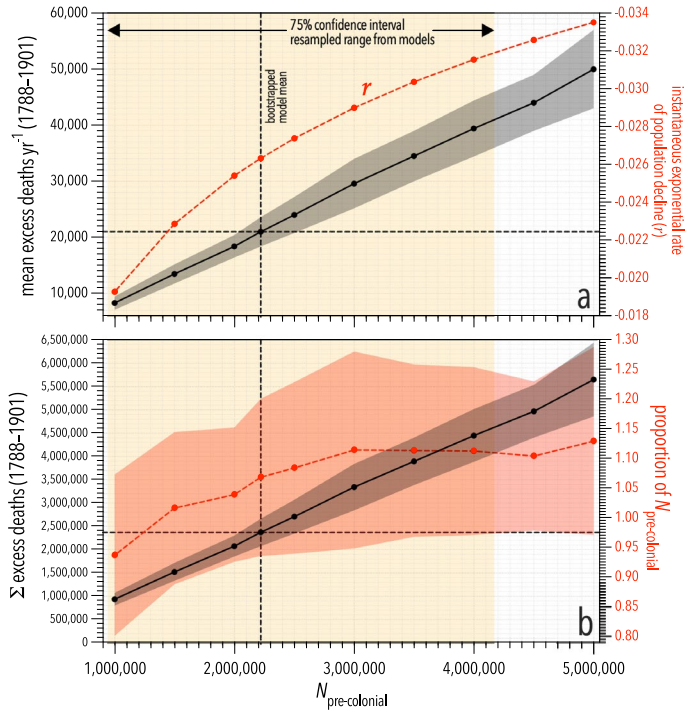
Extended Data Fig. 2 | Distribution of sites from Extended Data Table 1. Distribution of compared sites (blue stars) from Table S1 overlaid on the HadCM3[53] net primary production-derived estimates of human carrying capacities (greyscale expressed in people km^{-2}). Darker grey indicates relatively higher densities.

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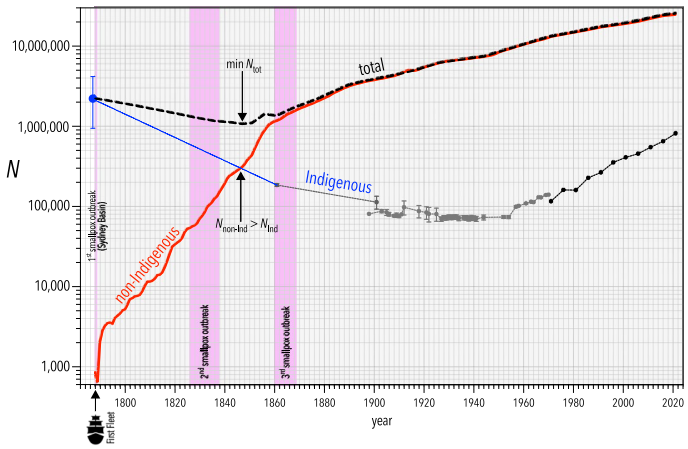
Extended Data Fig. 3 | HadCM353 net primary production-derived estimates of human carrying capacity *N* versus historically reported *N*. Power-law relationship between HadCM3[53] net primary production-derived estimates of human carrying capacity *N* and historically reported *N*. Red dashed line is the least-squares line of best fit ($\hat{y} = 0.2221x + 0.4415$; $R^2 = 0.73$); red-shaded area = 95% prediction intervals for line of best fit; black dashed line = 1:1 relationship.

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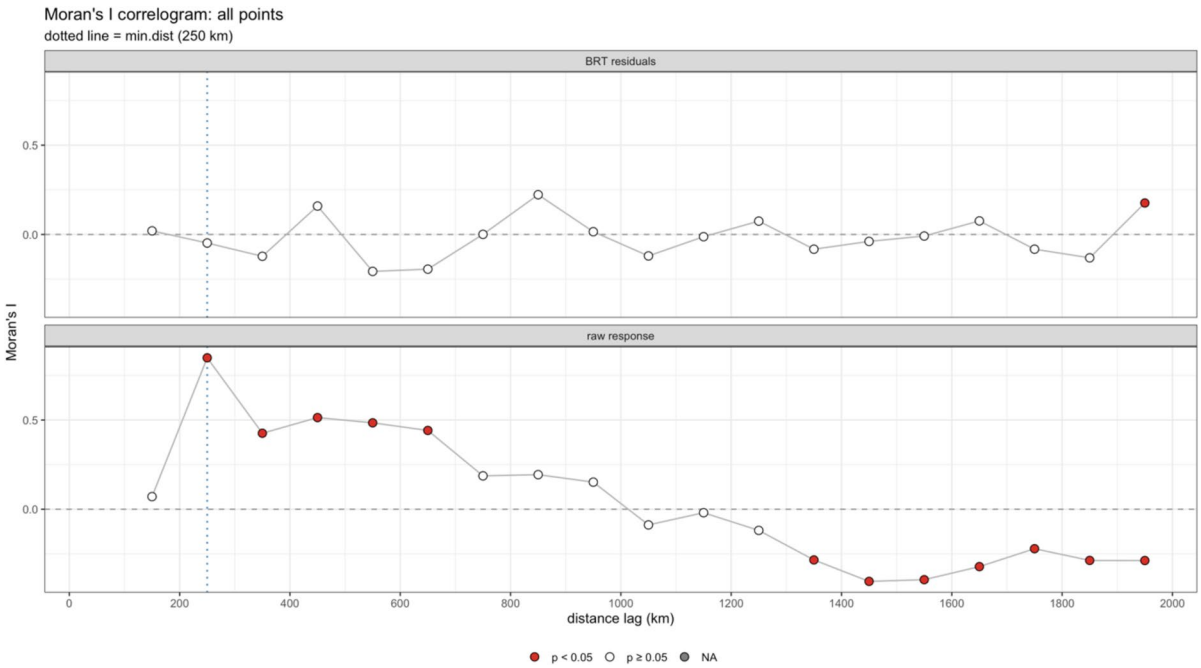
Extended Data Fig. 4 | Excess deaths. Excess deaths required to change a pre-colonial Indigenous population from sizes ranging between 5.0 million and 1.0 million to 0.092–0.134 million from 1788 to 1901 based on a stochastic demographic model. (**a**) For different initial population sizes (*x* axis), the left *y* axis shows the average annual excess deaths that would have to occur for the population to decline to the indicated target, expressed as an average annual instantaneous exponential rate of population decline (*r*) on the right *y* axis. Grey shaded area indicates the 95% confidence intervals for the annual excess death estimate. Background peach colour indicates the 75% confidence interval of the resampled initial population sizes derived from the modelled sources (that is, carrying-capacity, radiocarbon, and N_e models; Fig. 1), and the black vertical dashed line indicates the central tendency of those estimates (bootstrapped model mean) and the black horizontal dashed indicates the annual excess deaths at that central tendency. (**b**) For different initial population sizes (*x* axis), the left *y* axis shows the sum of the excess deaths from 1788–1861 required to arrive at a population of 0.092–0.134 million, expressed as a proportion of the initial population size on the right *y* axis. Grey and red shaded areas indicate the 95% confidence interval for each measure, and the vertical and horizontal black dashed lines are as in panel **a**.

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Extended Data Fig. 5 | Trajectory of the Indigenous population. Trajectory of the Indigenous population (median bootstrapped range *a* from Fig. 2) from pre-1788 to 2021 compared to that for the non-Indigenous population (in red; source: Australian Bureau of Statistics abs.gov.au/census). For the latter, we subtracted the Indigenous component from the total census values from 1971 onward. Australia's total population ($N_{tot} = N_{Ind} + N_{non\text{-}Ind}$) shown as a dashed black line. Also shown are the three smallpox outbreaks in pink. The size of the non-Indigenous population first exceeded that of the Indigenous population around 1847 on average ($N_{non\text{-}Ind} > N_{Ind}$). Around 1847 was the year when the total population size ($N_{tot} = N_{Ind} + N_{non\text{-}Ind}$) of Australia was at its lowest (min $N_{tot} \approx 1.07$ million) during the period 1788–2021, and possibly during the last 50,000+ years as well[48,54,68].

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Extended Data Fig. 6 | Boosted regression tree residuals. Top panel: boosted regression tree (BRT) residuals showing that essentially no Moran's *I* has a type I error < 0.05 at any distance lag, except for extremely long distances of 1950 km (that is, *latitude* predictor absorbs essentially all spatial structure in the response of the deviation between the Binford[44] and modelled density estimates). Bottom panel: for the raw response variable, there is a gap at short distances (< 200 km), then strong autocorrelation from 200–650 km (peaking at Moran's *I* = 0.62 at 250 km), decaying through ~1000 km before switching to negative autocorrelation at large spatial separations.

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Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	NA
Reporting on race, ethnicity, or other socially relevant groupings	We report on the Indigenous population size of Australia from prior to European invasion to the present, and projected over the next few decades. For 'Indigenous', we follow the Australian Bureau of Statistics (the entity responsible for censusing the Australian population) 'Indigenous Status Standard' available at https://www.abs.gov.au/statistics/standards/indigenous-status-standard/latest-release. We obtained ethical approval for this study from the Flinders University Human Research Ethics Committee prior to data extraction and analysis (Ethical Clearance No. 9634). Australian university Human Research Ethics Committees are appointed legal authorities under Commonwealth of Australia law to assess and approve research in accordance with the National Statement on Ethical Conduct in Human Research and are registered with the National Health and Medical Research Council of Australia. This authority includes responsibility for determining the ethical acceptability of research involving, or having implications for, Aboriginal and Torres Strait Islander peoples. Consistent with the Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS) Code of Ethics for Aboriginal and Torres Strait Islander Research principles of Indigenous self-determination, Indigenous leadership, impact and value, and sustainability and accountability, Aboriginal community representatives and Indigenous scholars identified the need for the project and contributed to the design of the project, including refinement of research aims, ethical considerations, and dissemination pathways. Indigenous co-authors Shane Ingrey, Kirsty Beller, Lynette Russell, Raymond Tobler, and Christopher Wilson contributed cultural knowledge, historical context, and guidance on ethical engagement throughout the study. Lynette Russell, drawing on her extensive expertise in Indigenous histories, also contributed to the interpretation and contextualisation of the research. Their involvement ensured that the research questions, the analysis of findings, and the consideration of community impacts were grounded in Indigenous perspectives. The author team includes both Indigenous and non-Indigenous researchers working across disciplines including ecology, mathematics, archaeology, history, demography, epidemiology, and Indigenous studies. In addition to their scholarly contributions, Indigenous collaborators provided cultural and historical expertise and guidance on ethical engagement, while non-Indigenous authors recognise their positionality as researchers working within Australian academic institutions and the responsibilities associated with doing research on Indigenous histories.
Population characteristics	The entire Indigenous population of the modern-day limits of the Commonwealth of Australia.
Recruitment	NA
Ethics oversight	NA

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Estimated and measured size of the Indigenous population from pre-European times (pre-1788) to the modern era, and to the near future. Additionally, a cohort-based model prediction of how many people might have died between European arrival and mid- to late 19th Century.
Research sample	No sampling done in this study; already published information.
Sampling strategy	No sampling done in this study; already published information.
Data collection	Data collected entirely from already published literature, or estimated from pre-existing models.
Timing	just prior to 1788 to mid-2050
Data exclusions	No data excluded
Non-participation	Not application
Randomization	Resampling techniques (e.g., bootstrapping) of population estimate ranges.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☐	☒ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☐	☒ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Palaeontology and Archaeology

Specimen provenance	Specimens already previously published.
Specimen deposition	See Williams (2013; doi:10.1098/rspb.2013.0486) and Williams et al. (2014; doi:10.11141/ia.36.6)
Dating methods	See Williams (2013; doi:10.1098/rspb.2013.0486) and Williams et al. (2014; doi:10.11141/ia.36.6)

☒ Tick this box to confirm that the raw and calibrated dates are available in the paper or in Supplementary Information.

Ethics oversight	See Williams (2013; doi:10.1098/rspb.2013.0486) and Williams et al. (2014; doi:10.11141/ia.36.6)

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Dual use research of concern

Policy information about dual use research of concern

Hazards

Could the accidental, deliberate or reckless misuse of agents or technologies generated in the work, or the application of information presented in the manuscript, pose a threat to:

No	Yes
☒	☐ Public health
☒	☐ National security
☒	☐ Crops and/or livestock
☒	☐ Ecosystems
☒	☐ Any other significant area

Experiments of concern

Does the work involve any of these experiments of concern:

No	Yes	
☒	☐	Demonstrate how to render a vaccine ineffective
☒	☐	Confer resistance to therapeutically useful antibiotics or antiviral agents
☒	☐	Enhance the virulence of a pathogen or render a nonpathogen virulent
☒	☐	Increase transmissibility of a pathogen
☒	☐	Alter the host range of a pathogen
☒	☐	Enable evasion of diagnostic/detection modalities
☒	☐	Enable the weaponization of a biological agent or toxin
☒	☐	Any other potentially harmful combination of experiments and agents

Plants

Seed stocks	NA - hindcasted climate models with estimates of net primary production
Novel plant genotypes	NA
Authentication	NA