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An environmental history of Moreton Bay hinterlands

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Abstract

Recent studies of local landscape and vegetation change have improved our understanding of the part Europeans have played in the evolution of subtropical Australia. Here, we focus on sedimentary and documentary evidence from the large, rural catchments draining to Moreton Bay. In the 1840s, the region underwent a transition from Aboriginal pastoralism to European grazing and agriculture. The first decades of European management brought changes to the floristic composition of the region's grasslands with only minor changes in the extent of forest and woodland. Changes in soil density in the catchment headwaters and valley floors associated with cattle and sheep grazing are linked to channel erosion in the middle and upper reaches of the river systems, accompanied by gullying in some headwater catchments. The erosion of waterways upstream is associated with a degraded riparian forest and the transport of muddy sediments into Moreton Bay. The timing of peaks in sedimentation, in the 1890s, 1950s and 2010s, was triggered by periods of enhanced rainfall and flooding. All of these factors are implicated in a tenfold increase in sediment loads into Moreton Bay since European settlement. Despite these impacts, changes to landscapes and soils in the region have been modest. In comparison with temperate south-eastern Australia, gully erosion has been limited in extent, the soils remain largely intact, and major changes in channel type have occurred on only a small proportion of rivers. This greater resilience in the Australian subtropics to the new European land uses is attributed to the naturally more variable climate and vigorous vegetation response to disturbance. However, sustainable management of these landscapes has not yet been achieved. The drainage network is presently unstable, leaving open the possibility of catastrophic system adjustment in the near future. This could produce dramatic increases in hill-slope and gully erosion and a metamorphosis of channel pattern in the trunk streams, similar to landscape responses documented in south-eastern Australia between 1850 and 1950.

Keywords: subtropics, land-use change, sediments, channels, gully, vegetation

Introduction

Recent studies of the shallow marine waters of Moreton Bay depict a landscape in crisis. Significant areas of clean sand within the Bay have been replaced by mud (1–4), the near-shore and estuarine waters are polluted by sediment, toxins and nutrients (5, 6), and seagrass and estuarine ecosystems are declining in both extent and health (7). Many of these changes point to unsustainable management of the hinterland. To address this through planning and adaptive management, an understanding of historical change, and the establishment of an environmental baseline are critical. We first need to know what the environment was like when Europeans arrived, how has it changed, and why? This is essential background information to an understanding of the responses and sensitivities of the catchments, rivers, and ecological systems that contribute to the health of Moreton Bay and its broader catchments.

Thanks to previous collaborative efforts to piece together the environment and history of Moreton Bay, parts of this complex landscape of islands, subtropical estuary and coastal plains are now well understood (8–10, Richards 2019 (11), this volume). The story of the hinterland has been slower to develop, and critical questions remain unanswered about the sensitivity or resilience of the largely rural catchment. The focus here is on the Logan River and Brisbane River catchment areas that lie outside suburban Brisbane and the Gold Coast, including their major tributaries, the Bremer, Lockyer, and the Stanley basins (Fig. 1). Together, the Brisbane

Figure 1. Map of Moreton Bay and major contributing river basins. The Brisbane and Logan basins occupy 82% of the total catchment area. Smaller contributing catchments drained by the Caboolture, North Pine, Coomera and Nerang rivers (shaded brown) have been extensively developed as suburban areas.

and Logan basins make up 82% of the total 21,200 km^2 catchment area for Moreton Bay. Today, similar proportions of native and plantation forest (50%), grazing pastures (40%), crop lands (6%) and urban areas (4%) occupy these catchments (12). At the time of the last compilation in 1998, the environmental history of the hinterland needed to be inferred from studies of landscape processes in temperate south-eastern Australia (13). Over the intervening 20 years, local data have been gathered from a number of Moreton Bay catchments, and their distinctive processes are beginning to be revealed. These catchments display some significant differences to their counterparts in eastern New South Wales and Victoria. This is hardly surprising considering that subtropical landscapes are hydrologically and geomorphologically distinct from those in the temperate zone. Rainfall is dominated by the summer monsoon and is highly variable, the vegetation response is rapid and vigorous, and the soils are conditioned by rapid chemical weathering. Here we review the land-use history, climate and floods, and changes in vegetation, landforms and erosion rates in the inland catchments of Moreton Bay, and compare their landscape responses to temperate areas of southern Australia.

European settlement

European settlers entered Moreton Bay in 1824 and have occupied its hinterland since 1841 when squatters established themselves on open grazing lands along the Brisbane River Valley. In many respects, the European settlement of Moreton Bay follows a parallel history to Port Jackson, but the subtropical environment yielded new challenges as Europeans expanded northward into the Torrid Zone. These new subtropical lands proved to be even more alien than their European homelands, described as ‘more a new planet than a new continent’ (14 p22). Apart from risks associated with remoteness and a widely dispersed population, the incidence of diseases was higher in the low latitudes, as were various ‘fevers’ including malaria, scrub typhus, dengue and leptospirosis (15). Mortality rates in the pioneering European population were high (16). The first penal settlement at Redcliffe failed within months owing to malaria and other health crises, failed crops, and to bloody clashes with the Aboriginal inhabitants (16 p64). Many of these problems persisted in the new establishment at Brisbane. The explorer and surveyor John Oxley’s promises in 1823 of ‘very fertile country…capable of producing the richest productions of the tropics’ turned out to be the reverse of the truth (17 p116). Experiments with cotton, sugarcane, bananas and corn failed regularly, and the area of land under cultivation remained at negligible levels for the first generation of settlement (16).

After 1866, the area of cultivated land increased slowly from 8 km^2 to 120 km^2 in 1887, and reached a roughly stable area of 500 km^2 in 1920, still then a meagre 4% of the catchment (18). Pastoral expansion was delayed by the restrictions imposed by the penal settlement, as well as the rugged volcanic ranges that encircled the Moreton Bay catchments. In the eight years following the closure of the penal settlement in 1842, wealthy British pioneer families rapidly occupied the rich pasturelands on the tablelands west of the Great Dividing Range and the fertile valleys that drain into Moreton Bay. These areas had been carefully maintained by Aboriginal societies for the husbandry of kangaroos and wallabies, and were now readily exploited for grazing by horses and cattle following the extirpation of their native inhabitants.

In 1860, 95% of Queensland’s wealth was generated from pastoralism, almost all of it owing to exploitation of Aboriginal grazing lands (16). The transition to European pastoralism was not without setbacks. Sheep grazing was introduced to Moreton Bay catchments in ~1844, but typically failed as the native pastures were depleted, usually within a decade (19, 20). In 1843 the explorer and scientist Ludwig Leichhardt reported that the kangaroo grasses in the region of Ipswich had lasted at least 12 years (21). Most sheep farms had reverted to cattle by 1880, but by the 1890s the large pastoral estates were deeply in debt to foreign interests, beset by economic depression (1891–1896), intense drought (1898–1905) and catastrophic floods (1890, 1893 and 1898) (16). Subsequently, livestock numbers declined dramatically in some sub-catchments of the Brisbane Valley and in others they remained static until 1905 (18). Attempts to encourage closer settlement and the break-up of the large pastoral runs through government legislation in 1884 (the *Land Act*) and 1887 (the *Repurchase Act*) resulted in a slow intensification of farming, particularly dairying and irrigated agriculture in areas such as the Lockyer Valley which possessed rich, basaltic soils (19, 22). The Lockyer has since become one of Australia's most productive agricultural valleys, but sediment transported out of this catchment by a flood in 2013 polluted the domestic water supply to one million people in Brisbane (23).

After forest land, grazed pastures remain the dominant land cover in the Moreton Bay hinterland (12), but much of the Moreton Bay catchment is in poor condition, with degraded waterways, channel erosion and gullying (19, 24–26). As in other parts of Australia, European Australians are still learning lessons from the country (27). After 180 years, sustainable land management of Moreton Bay seems to be still some way off.

Climate and floods

The vagaries of the climate in Moreton Bay's hinterland exceeded anything experienced by European settlers in southern Australia. Located at the southern limit of the Australian monsoon, intense downpours accompany tropical storms that stray south of their normal paths, some as fully developed tropical cyclones. More commonly these storms arrive as decayed tropical depressions, diminished only in the strength of the accompanying gales. Rainfalls of 500 mm over two or three days are not uncommon. The worst storm ever recorded occurred in 1893 when a series of tropical cyclones crossed the coast at Yeppoon, 460 km north of Brisbane, producing 77 inches (1956 mm) of rainfall over four days in the upper Stanley catchment. The 35.7 inches (907 mm) recorded at Crohamhurst on 2 February 1893 (28) remains the official Australian rainfall record for a 24-hr period (29). Climate variability in the region is enhanced by decadal cycles in rainfall superimposed on the erratic rhythms of the Southern Oscillation and other drivers of local climate (30, 31). The combined effect of these cycles, together with changing patterns in coastal circulation, make seasonal rainfall in South East Queensland (and its socio-economic impacts) difficult or impossible to forecast (30).

In the time since reliable observations began in the 1820s, Moreton Bay has experienced a number of extreme floods, even by Australian standards (18). South East Queensland is one of the few places where catastrophic floods need no aid to the imagination from palaeo-environmental archives or oral histories. Flood effects are well documented in the urban and rural environment while some, such as floods in 2011 and 1974, fall within the period of instrumental streamflow records. The physical legacy of these events in the floodplains upstream is visible from widespread stripping of confined floodplain areas, or may be dated from the beer bottles deposited in flood sediments (18, 32, 33). In 1893, floodwaters reached 32 m at the tidal limit of the Brisbane River, and peak discharge at Brisbane was estimated to be 16,000 m^3s^{-1} (18) The calamity destroyed all of Brisbane's bridges, washed away 150 houses and drowned 35 people (28, 34). Following the flood, detailed surveys of peak stages were conducted from the Bay to the upper reaches of the river (18). Eventually, these investigations led to the construction in 1984 of Wivenhoe Reservoir with a capacity of 1200 ML and a further 2000 ML of permanent flood storage to mitigate floods in the lower reaches (35).

This kind of hydrologic variability is difficult to imagine for those accustomed to the flooding patterns of Europe. A convenient way to evaluate flood severity in different regions is by comparing normalised flood growth curves, which show the relationship between flood size, given by the peak discharge, and its return period, as in Figure 2. Flood size is shown relative to the average flood in a region, in this case the conventional average mean annual flood ($Q_{2.33}$). The flood growth curve for tropical rivers (e.g. Guyana) that are supplied with predictably similar annual rainfall have 100-year floods that are similar in magnitude to their mean annual floods, while the ratio in moderately variable areas such as the U.K. is closer to four (36). In contrast, sub-catchments of the Brisbane River display ratios of 15 in some extra-coastal locations, diminishing to 3 in catchments such as the Bremer, which have their headwaters located closer to the coast (37). This implies that many parts of Moreton Bay's hinterland regularly experience catastrophic floods that would be rare events elsewhere in the world. Despite this, the inhabitants of Moreton Bay remain surprised at the severity of moderately severe floods such as occurred in 2011 (38). The largest events in the region's history occurred in ~1823, 1841 and 1893 (18), yet the 1974 flood remains the reference point for catastrophic floods in the popular consciousness.

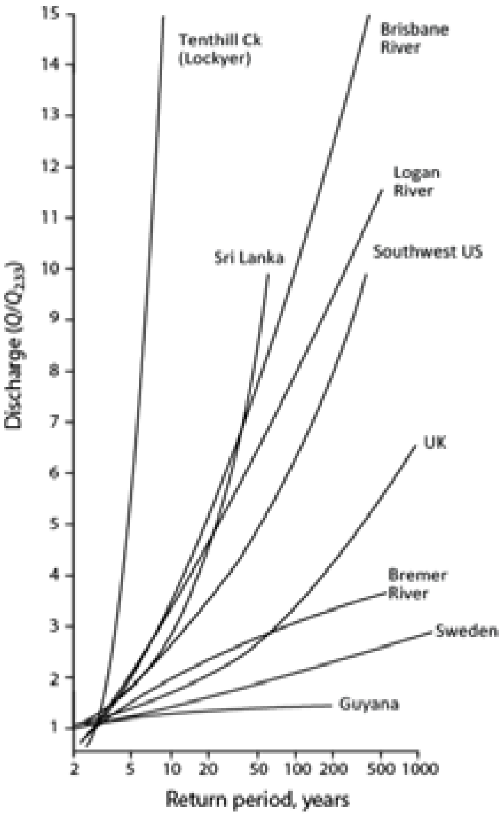

Figure 2. Flood growth curves for selected regions around the world compared to rivers in the Moreton Bay catchment (36, 37).

Vegetation cover and changing land management

The most obvious difference between the Moreton Bay landscape in the days of the pioneers and the landscape of later settlers is the change in vegetation. However, memories of the original vegetation cover have become distorted by rapacious clearing in recent decades, and by a long history of government support for forest removal (39, 40). There is a widespread perception of pre-European landscapes surrounding Moreton Bay as jungle and primeval forest, 'the result of some 60 millions of years of independent and unique evolution' (41 p1). This view tends to overlook, or at best to downplay, 50,000 years plus of human agency. The best evidence of pre-European landscapes in the Moreton Bay hinterland comes from the explorer and pioneer accounts between 1823 and 1834 (17). The first European explorers report mixed communities of forest and grassland: tall closed forests with a mix of sclerophyll and rainforest species on the steep slopes of the ranges, and open woodland, open forest and grassland on the plains. Patches of closed rainforest described as 'Araucaria scrubs' contrasted with the generally open country. The distribution of rainforest was observed by explorer Ludwig Leichhardt to reflect soil water availability (43), although the starkness of the boundary between the vegetation communities suggested, even to the pioneers, that Aborigines regularly burned the country (42). Much of the country inland from the coast was open. The surveyor James Burnett described

> *the whole of the country on the Brisbane…a very thinly wooded forest furnishing a rich and abundant pasturage, patches of scrub intervening in one or two places* (44 p28).

Explorer Edmund Lockyer in 1825 described the middle reaches of the Brisbane Valley as

> *very good on both sides… the country behind them having quite a park-like appearance. I saw Kangaroos in abundance… As far as I could see to the S and SW, the whole country appeared well timbered with forests of tall pines. And to the NW and NE. very few* (17 p191).

Four years later, explorer Alan Cunningham travelled to the north-west, where the Lockyer Valley appeared as a

> *fine plain, its larger portion stretched upward of three miles to the N.E., its length from north to south being not less than five miles (17 p317).* This was succeeded by *barren and frequently brushy country* and *grassy wooded hills…(17 p318) …Having rested…again encamped…on a spot so clear and open as not to allow the natives, whose hatchets we heard around, to surprise us in our tent* (17 p323).

Turning north towards the upper Brisbane River,

> *our whole stage was through an excellent tract of grassy country, sufficiently watered by small creeks …but indifferently wooded* (17 p326).

Leichhardt made similar observations on his travels through the newly settled country surrounding Moreton Bay in 1843. Along Laidley Creek were 'small plains without tree-growth … separated by light belts of forest' (21 p240). Towards Ipswich the party followed 'rough grass growth, park-like tree growth' (21 p240). The pattern continues to the north along the Stanley River: 'rich grassy vegetation' on the valley floors (21 p265) with moist depressions that contained a range of species including kangaroo and oat grasses (*Themeda* spp.), *Poa* tussocks, geranium and *Ajuga* (Austral bugle) and daisy species. (21 p265, 299, 300). Along Neurum Creek near Woodford 'beautiful flats are found, which would be very well suited to cultivation, dairies and paddocks' (21 p285). Stream banks were lined with 'scrubs' (21 p299) that included sclerophyllous casuarina and bottlebrush in drier areas such as Lockyer's Creek (21 p240). The higher hills were forested with hoop pine, *Angophora*, and tall gums (21 p240, 265).

These native pastures were captured by painter Conrad Martens in the first decade of European pastoralism during his tour of Moreton Bay, Darling Downs, and the Granite Belt in 1851–52. Sketches of the country at Coochin, near Boonah in the upper Logan catchment show valley slopes with grassy open eucalypt forest and grass trees opening onto grassed plains (Fig. 3a, 45). His depiction of Franklyn Vale, near Rosevale 40 km north-west of Boonah, shows sheep sheltering in the trees on an open plain (Fig. 3b). The wooded lower slopes of the ranges have a grassy understorey, and were sufficiently passable to allow Martens a view of the valley floor below Mount Beau Brummell and nearby hills. These ranges remain forested today although the trees have been cleared from the lowest foot slopes and lower hills.

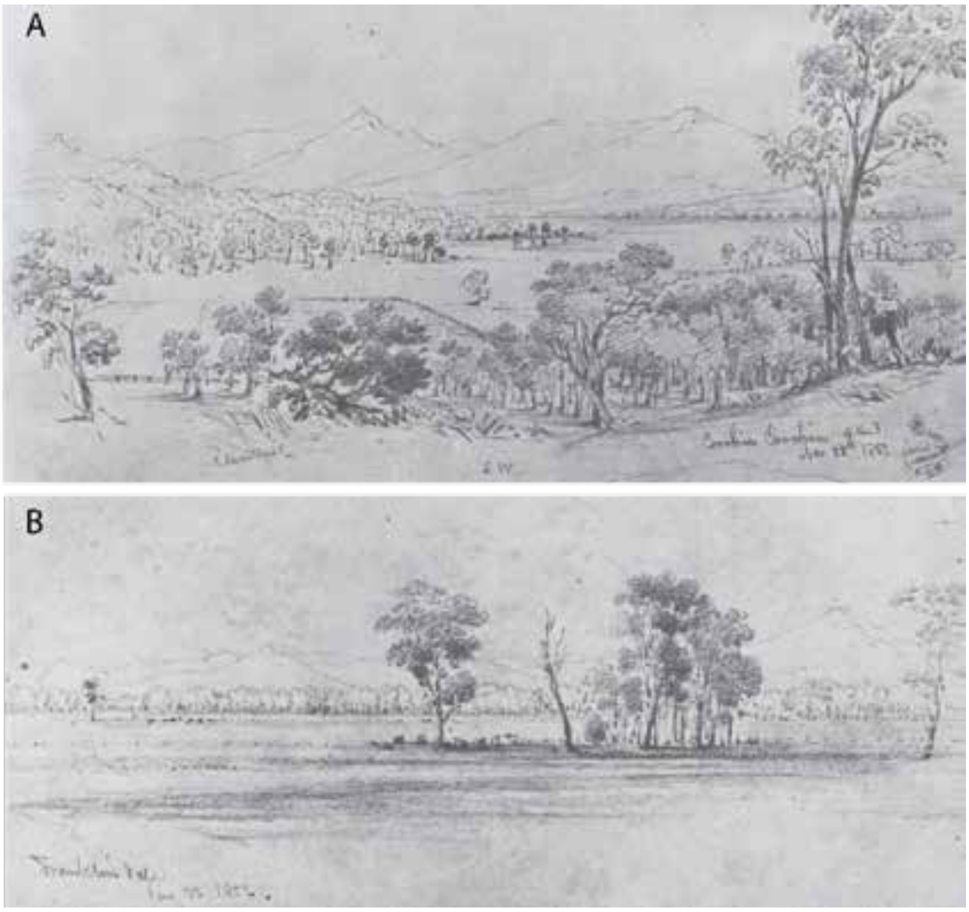

Figure 3. Impressions of the Moreton Bay hinterland in the first decade of European settlement. (a) Coochin Coochin, Qld, 28 Nov. 1851. The view is from the head station of Coochin near Boonah (Fig. 1) with Mount Moon and Mount Alford in the distance. The trees in the foreground follow the path of Teviot Brook (45) (b) Franklin Vale, 22 Jan. 1852. (Photographs courtesy C. Martens, Mitchell Library, Sydney).

These descriptions of open country, grassland or well-grassed open forest, the long-established paradigm of the Australian landscape under Aboriginal management, are easily applied to much of the Moreton Bay hinterland (14, 27, 46, 47). The open country provided easy access for explorers and was rapidly converted to sheep and cattle pastures. There is clear evidence of Aboriginal fire management from the explorer accounts (17), although the frequency of burning is difficult to determine owing to the use of fire as a weapon or deterrent against Europeans (48). In light of the pictorial and documentary evidence, it is strange that quantitative descriptions of vegetation change in South East Queensland are based on ‘a once continuous forest cover’ (41 p1), where ‘pre-clearing… generally equates to … pre-European’ (49 p13). The distinction may be a semantic one: very open forest is similar in structure to open savannah grassland, but ‘remnant vegetation’, has become synonymous for ‘forest’ in much recent literature. This implies that a 77% reduction in forest cover for the Moreton subregion (41) is an overestimate.

Some of the confusion about the extent of the pre-European ‘forest’ arises from geographical variations in the distribution of tall forest. Inland from the coast, rainfall declines from 1280 mm at Redcliffe on the coast (Station 40958: 2003–2017) to 770 mm at Gatton (Station 040082: 1897–2013, Fig. 1) (29). Further inland, forests and woodlands are typically open, with rainforest restricted to riparian zones and the better watered mountain ranges. Even in coastal areas, rainforest ‘brush’ or ‘scrubs’ were more common on the fertile, black, alluvial soils bordering the floodplains and river terraces, and this vegetation community features prominently in early accounts of the lower Brisbane River and explorations upriver by boat (17). Pollen records from the catchment inland from the coastal lagoons and lakes may eventually provide quantitative estimates of the magnitude of the regional changes in forest cover.

Some aspects of forest removal are well documented in the historical record from the 1850s, such as the selective extraction of prize timber species including red cedar, silky oak, blackbutt, hoop and kauri pine (50, 51). Private clearing of farmland outside the townships is less well recorded, but substantial rural clearing may not have begun until the 1880s, two generations after the introduction of European pastoralism. Mary Banks, whose father, David McConnell, established Cressbrook Station on the upper Brisbane River in 1842, noted the practice of ringbarking of large gum trees, associated with the transition to closely settled farms compared to the wild “Bush” of her youth, ~1865–75 (53 p79). Charles Cochrane-Baillie’s (Lord Lamington) memory of Cressbrook was that ‘the country is rugged near the hills and was heavily timbered…but the country was still Bush on the Brisbane River at this time’ (around 1900) (53 p8). Clearing had been encouraged by the changes in government legislation in the 1880s, but significant changes in agriculture were forestalled by drought and economic downturn in the 1880s and 1890s.

Changes in tree cover in the region have not been unidirectional. After the 1950s, there is some evidence of regrowth in areas that had been cleared for cropping, and a regional increase in forest density since the 1950s (54). In formerly cropped areas this may be owing to reduced agricultural intensity (19), but elsewhere in southern Queensland increases in woody vegetation have been attributed to a change in burning regimes (54) or to higher rainfall (55). Since 2013, clearing of rural lands has rapidly increased following the weakening of key statutory restrictions on land clearing (39). This has combined with suburban sprawl, in a region that now has the fastest growing population in Australia, and is consuming forest around already large urban centres (56).

Changing landforms and erosion rates

The impacts of European settlement wrought subtle changes on Moreton Bay's landforms and soils compared to catchments in southern Australia. This is not to understate the deleterious effects of soil erosion on water quality and ecological systems in riverine corridors and estuaries downstream. In a country naturally adjusted to low erosion rates, relatively small increases in erosion and sediment yield can have catastrophic and lasting consequences (4, 6, 7, 57). Yet, soils in the Moreton Bay hinterland catchments appear to have remained largely intact. Geochemical evidence from radionuclides in transported fluvial sediment indicates that erosion is focused along drainage lines and within existing river channels, with only a small contribution from hill-slope soils (12, 58). Grazing by European livestock did cause changes to soil structure and density. 'Virgin country' was known to be 'often boggy or "rotten", even on the ridges, owing to its loose formation', but 'when hardened by the trampling of stock it sheds a vast quantity of water that the subsoil previously absorbed' (59). The Government history provided a similar account of this change. 'On the spongy surface of virgin country, untrodden by any hoof, there was little "run" off the surface after rain, but when hardened by the tread of stock the creeks received a fairer share of the downpour' (51 p103). The consequences were flashier and ephemeral streams that dried in summer in places they had formerly flowed year-round (18). It remains unclear to what extent changes in the run-off regime influenced flood flows, and whether the destructiveness and frequency of catastrophic floods such as 1893 were at least partly the result of fundamental changes in catchment hydrology. The effect of changes in hydrology on flood flows to Moreton Bay remains a subject of ongoing investigation.

Changes to the drainage network in catchment headwaters occurred soon after European settlement. Initiation ages for the development of two gullies in the Bremer catchment have a weighted mean of 1840±9 AD (60). However, regionally the extent of gullying was small and mostly confined to highly erodible, sodic soils in the southern Brisbane and Logan catchments (24–26). Erosion along the larger river channels was relatively minor and was delayed until the 1890s, 50 years after European settlement of the hinterland. Early maps show that channel positions of the middle Brisbane and Lockyer rivers have largely been stable since 1885 implying that transport of sand and gravel along the major channels has not substantially increased (18, 61). Erosion has enlarged the channel cross-sections, mostly as a result of bank failures that are visible in early photographs on the Brisbane River from the 1890s. Many of the larger rivers display compound channels similar now in appearance to what was described by European explorers in the 1820s (18, 37). These were nested, channel-in-channel forms that are commonly found in regions with a naturally variable run-off regime. This channel form confers a high resilience to catastrophic floods, which can be accommodated by capacious channel dimensions. Despite this, bank failures occurred through the middle reaches of the Brisbane River during the flood-dominated decade of the 1890s, which saw large floods in 1890, 1893 (3 floods), 1896 and 1898. Since then, a cycle of bank erosion and infilling has recurred in major floods, most recently in 2011 and 2013 (18, 62–66).

The increased susceptibility of the Brisbane River to erosion may be explained by the progressive degradation of riparian forest along this and other major waterways in the region

(18). A comparison of riparian forest extent with sediment yield across South East Queensland suggested that erosion rates are enhanced up to 200 times along unforested streams (67). Degradation of riparian forest was also implicated in the catastrophic widening of one tributary in the upper Lockyer, where a well vegetated 10 m-wide stream with a clean sand and gravel bed transformed to a sparsely vegetated, 40 m-wide channel with a cobble bed (25). In the upper Logan, bed erosion and gullying has been such that the main channel is now deeply incised and is overtopped by floods with a recurrence interval of greater than 100 years (24). Sediment eroded from the upper Bremer River has been identified as sandy deposits in the lower tributary streams, with fine sediment being transported further downstream into Moreton Bay (26).

The bulk of sediments eroded from the Brisbane and Logan catchments are now stored within the fluvial floodplains and channels, with the remainder contributing to the infill of shallow embayed waters ~1500 km^2 in extent that make up Moreton Bay (2, 4). In the past decade, a number of sediment cores collected from the Bay have been used to reconstruct continuous records of catchment erosion. These suggest that sediment yields have increased by 3–9 times the pre-European rate in the Brisbane Basin (2, 6). The timing of the change is difficult to determine precisely with the available dating techniques, but sedimentation rates started to increase between 1840 and 1890 in the Brisbane River prodelta (2). This timing is also supported by ages determined by optically stimulated luminescence and radiocarbon for a shift in the ecology of the Bay between ~1842 and 1956, when increases in nutrients and sediments caused the replacement of sensitive branching corals with massive head corals (57).

Sedimentary records from intertidal areas around the perimeter of Moreton Bay indicate a further, dramatic increase in sedimentation rate after 1950 (5, 6). In 1949, mud was accumulating in the shipping channels of the Brisbane River ‘faster than dredges could remove it’ (68), and by 1951 there were calls for soil conservation in the upper watershed to reduce the rapid increase in silt levels over the previous decade (69). New gullies were also developing in the upper Logan and upper Brisbane catchments (60). The deluge of mud has been attributed to an increase in cropping in the Lockyer and Fassifern valleys (2), but the change has also been noted in the estuaries of the smaller catchments with different land-use histories (5). Shifts in climate may offer part of the explanation. Historical records suggest that episodes of channel erosion and gullying in both the 1890s and the 1950s coincided with periods of increased precipitation and flooding (18, 60, 70). The recent strong La Niña years, 2010–12, have produced the latest deluge of mud liberated by channel-bank erosion during floods in 2011 and 2013 (2, 4, 71).

The imprint of European land use in subtropical vs temperate regions

The transition from Aboriginal to European pastoralism with some cultivation induced a similar set of geomorphic adjustments across eastern Australia. In the Moreton Bay catchment area, the changes were relatively subtle compared with those reported in temperate south-eastern Australia. In the South East highlands of New South Wales and Victoria, gullying was the nearly ubiquitous consequence of European farming (72). Estimates from sediment infilling farm dams in the Southern Tablelands of New South Wales indicate that gullies contributed

80% of sediment eroded from small catchments (73). The proportion of gully sediments derived from Bromley Gully in the upper Avoca River in western Victoria was 80%, with the remainder derived from channel erosion (74). In some Moreton Bay catchments gullying of hillslopes is significant, such as in Knapp Creek and the upper Bremer River where it represents 89% and 76% of the sediment budget respectively, but in many catchments, such as the Lockyer, gullying is insignificant (Table 1). Sediment budgets for Moreton Bay catchments show that yields from all sources of erosion are two orders of magnitude lower than similar-sized basins in temperate south-eastern Australia (Table 1). This difference is all the greater considering that the peak of gully erosion occurred between 1850 and 1950 in south-eastern Australia while South East Queensland may be only now nearing its peak. Since 1950, natural gully revegetation and stabilisation in southern Australia have caused a slow reduction in sediment yields below the erosion peak of 200 times the pre-European rates (77). In contrast, gullies in South East Queensland remain active and are extending in some areas (60).

Table 1. Specific sediment yields and gully erosion for medium-sized catchments (10–100 km^2) in the Moreton Bay hinterland and south-eastern Australia.

Region/catchment	Catchment area (km^2)	Gully erosion (%)	Sediment yield ($t\ km^{-2}\ yr^{-1}$)
Moreton Bay hinterland			
Knapp Creek (24)	75	89	83
Bremer River (26)	123	76	43
Blackfellow Creek (25)	38	0	17
Temperate SE Australia			
Bromley Gully, Vic. (74)	16	90	2000
Southern uplands NSW and Vic. (131 catchments)(76)	50	-	1305
Jerrabombera Creek, NSW (75)	136	47	3255

Sheet-wash and rilling of hill-slopes are minor in both southern Australia and South East Queensland with most erosion concentrated on the stream lines. In the south, this has produced channelisation of small streams and metamorphosis of larger alluvial rivers from fine-textured stable channels that were sinuous or straight to coarse-textured, enlarged waterways that were braided in some cases (78, 79). In Moreton Bay, the larger rivers have developed wider channels through repeated cycles of bank erosion, but the single, compound channels have proved to be relatively resilient landforms in the face of larger and more frequent floods. In both subtropical and temperate zones, degradation of riparian forest has been an important factor influencing channel stability (79), but the more vigorous growth and recovery of vegetation in subtropical regions might be an additional aid to bank stability.

Conclusions

It should be encouraging to managers of Moreton Bay's catchments that, despite European settlement and agriculture, many aspects of the catchment's soils and vegetation have retained their pre-European characteristics. However, the drainage network presently shows the worst effects of land-use changes associated with settlement, with many of the headwater and middle reaches of the rivers showing erosion and instability, and sediment yields to Moreton Bay increasing towards the tipping point of ecological systems. It is worth noting that significant stores of floodplain and colluvial sediment exist throughout the catchment and could be released by catastrophic channel widening and gully erosion, further increasing the delivery of sediment to the Bay. The thresholds controlling channel metamorphosis and widespread gullying in this environment are largely unknown, and therefore the risks of unsustainable, irreversible change are palpable, even under the present climate regime. Future increases in climate variability raise the prospects for a major catchment readjustment, similar to that which occurred in much of south-eastern Australia a century earlier.

References

1. Maxwell WGH. 1970. The sedimentary framework of Moreton Bay, Queensland. Australian Journal of Marine and Freshwater Research. 21(2): 71–88
2. Coates-Marnane J, Olley J, Burton J, Sharma A. 2016. Catchment clearing accelerates the infilling of a shallow subtropical bay in east coast Australia. Estuarine, Coastal and Shelf Science. 174: 27-40
3. Coates-Marnane J, Olley J, Burton J, Grinham A. 2016. The impact of a high magnitude flood on metal pollution in a shallow subtropical estuarine embayment. Science of the Total Environment. 569: 716-731
4. Lockington JR, Albert S, Fisher PL, Gibbes BR, Maxwell PS, Grinham AR. 2017. Dramatic increase in mud distribution across a large sub-tropical embayment, Moreton Bay, Australia. Marine Pollution Bulletin. 116(1-2): 491-497
5. Morelli G, Gasparon M, Fierro D, Hu WP, Zawadzki A. 2012. Historical trends in trace metal and sediment accumulation in intertidal sediments of Moreton Bay, southeast Queensland, Australia. Chemical Geology. 300: 152-164
6. Samper-Villarreal J, Mumby PJ, Saunders MI, Barry LA, Zawadzki A, Heijnis H, Morelli G, Lovelock CE. 2018. Vertical accretion and carbon burial rates in subtropical seagrass meadows increased following anthropogenic pressure from European colonisation. Estuarine, Coastal and Shelf Science. 202: 40-53
7. Gibbes B, Grinham A, Neil D, Olds A, Maxwell P, Connolly R, Weber T, Udy N, Udy, J. 2014. Moreton Bay and its estuaries: a sub-tropical system under pressure from rapid population growth. pp.203-222. In: E Wolanski (Ed.) Estuaries of Australia in 2050 and Beyond. Springer, Dordrecht 292pp.
8. Davie P, Stock E, Choy DL (Eds). 1990. The Brisbane River: A Source-book for the Future. Australian Littoral Society—Queensland Museum, Brisbane 427pp.
9. IR Tibbetts, Hall NJ, Dennison WC (Eds). 1998. Moreton Bay and Catchment. pp.55–66. University of Queensland, Brisbane 645pp.
10. McPhee D. 2017. An Environmental History and Ecology of Moreton Bay. CSIRO, Canberra 208p.
11. Richards J. 2019. Historic change in the lower Brisbane River. In: Tibbetts, I.R., Rothlisberg, P.C., Neil, D.T., Homburg, T.A., Brewer, D.T., & Arthington, A.H. (Eds). 2019. Moreton Bay *Quandamooka* & Catchment: Past, present and future. The Moreton Bay Foundation. Brisbane, Australia. Available from: https://moretonbayfoundation.org/
12. Wallbrink PJ. 2004. Quantifying the erosion processes and land-uses which dominate fine sediment supply to Moreton Bay, southeast Queensland, Australia. Journal of Environmental Radioactivity. 76(1-2): 67–80
13. Neil DT. 1998. Moreton Bay and its catchment: seascape and landscape, development and degradation. pp.3–54. In: IR Tibbetts, NJ Hall, WC Dennison (Eds) Moreton Bay and Catchment. University of Queensland, Brisbane 645p.
14. Rolls E. 1994. More a new planet than a new continent. pp.22-36. In: S Dovers (Ed.) Australian Environmental History: Essays and Cases. Oxford University Press, Melbourne 281pp.

15. McFarlane RA, Sleigh AC, McMichael AJ. 2013. Land-use change and emerging infectious disease on an island continent. International Journal of Environmental Research and Public Health. 10(7): 2699-2719
16. Evans R. 2007. A History of Queensland. Cambridge University Press, Cambridge 328pp.
17. Steele JG. 1972. The Explorers of the Moreton Bay District, 1770–1834. University of Queensland Press, St. Lucia 386pp.
18. Kemp J, Olley J, Ellison T, McMahon J. 2015. River response to European settlement in the subtropical Brisbane River, Australia. Anthropocene. 11: 48-60
19. Shaw J. 1979. Land degradation in the Lockyer catchment. Division of Land Utilisation, Technical Bulletin no. 39. Queensland Department of Primary Industries 41pp.
20. Fitzgerald R. 1982. From the Dreaming to 1915: A History of Queensland. University of Queensland Press, St Lucia 354pp.
21. Darragh TA, Fensham, RJ. (Eds) 2013. The Leichhardt Diaries. Early Travels in Australia during 1842-1844. Queensland Museum, South Brisbane 540pp.
22. Powell B, Loi J, Christianos NG. 2002. Soils and irrigated land suitability of the Lockyer Valley alluvial plains, south-east Queensland. Department of Natural Resources and Mines 105pp.
23. Croke J, Thompson C, Fryirs K. 2017. Prioritising the placement of riparian vegetation to reduce flood risk and end-of-catchment sediment yields: Important considerations in hydrologically-variable regions. Journal of Environmental Management. 190: 9-19
24. Olley J, Ward D, Pietsch T, McMahon J, Laceby P, Saxton N, Rickard B, Rose C, Pantus F. 2009. Rehabilitation priorities Knapp Creek. Report to Healthy Waterways for the Healthy Country Project, Brisbane 42pp.
25. Olley J, Ward D, McMahon J, Saxton N, Pietsch T, Laceby P, Bengtsson F, Rose C, Pantus F. 2010. Rehabilitation priorities Lockyer focal area. Report to Healthy Waterways for the Healthy Country Project, Brisbane 61pp.
26. Olley J, McMahon J, Ward D, Saxton N, Pietsch T, Laceby P, Bland A, Rose C, Pantus F. 2010. Rehabilitation priorities Bremer focal area. Report to Healthy Waterways for the Healthy Country Project, Brisbane 67pp.
27. Gammage B. 1994. Sustainable damage: the environment and the future. pp.258-267. In: S Dovers (Ed.) Australian Environmental History: Essays and Cases. Oxford University Press, Melbourne 281pp.
28. Jones I. 1935. The floods of the Brisbane River. Journal of the Royal Historical Society of Queensland. 2(6): 288-295
29. BoM (Bureau of Meteorology). 2017. Climate data online. Available at http://www.bom.gov.au/. Accessed 6 June, 2018
30. Klingaman NP, Woolnough SJ, Syktus J. 2013. On the drivers of inter-annual and decadal rainfall variability in Queensland, Australia. International Journal of Climatology. 33(10): 2413-2430.
31. McMahon GM, Kiem AS. 2018. Large floods in South East Queensland, Australia: Is it valid to assume they occur randomly? Australasian Journal of Water Resources. doi: 10.1080/13241583.2018.1446677
32. Thompson C, Croke J, Fryirs K, Grove JR. 2016. A channel evolution model for subtropical macrochannel systems. Catena. 139: 199–213
33. Kemp, Unpublished data
34. Cook Margaret. 2017. A legacy of Brisbane's benchmark floods of 1893: creating dam dependence. Environment & Society Portal, Arcadia Spring 2017, no. 9. Rachel Carson Center for Environment and Society. http://dx.doi.org/10.5282/rcc/7870
35. Cook M. 2016. Damming the 'Flood Evil' on the Brisbane River. History Australia. 13(4): 540-556
36. Lewin J. 1989. Floods in fluvial geomorphology. pp.265-284. In: K Beven, P Carling (Eds) Floods: Hydrological, Sedimentological and Geomorphological Implications. John Wiley, Chichester 290pp.
37. Kemp J, Olley J, Haines HA. 2016. Flow variability and channel forms in southeast Queensland. pp. 241-249. In: GJ Vietz, AJ Flatley, ID Rutherfurd (Eds) Proceedings of the 8th Australian Streamflow Management Conference, 31 July - 3 August, 2016, Leura, NSW. River Basin Management Society 730pp.

38. Cook M. 2018. A river with a city problem, not a city with a river problem. Brisbane and its flood-prone river. Environment and History, 24(4):469-96. http://dx.doi.org/10.3197/096734018X15137949592034
39. Reside AE, Beher J, Cosgrove AJ, Evans MC, Seabrook L, Silcock JL, Maron M. 2017. Ecological consequences of land clearing and policy reform in Queensland. Pacific Conservation Biology. 23(3): 219-230
40. Bradshaw CJ. 2012. Little left to lose: deforestation and forest degradation in Australia since European colonization. Journal of Plant Ecology. 5(1): 109-120
41. Catterall CP, Kingston M. 1993. Remnant bushland of South East Queensland in the 1990's: its distribution, loss, ecological consequences and future prospects. Institute of Applied Environmental Research, Griffith University and Brisbane City Council, 97pp.
42. Watson D. 1988. Clearing the scrubs of south-east Queensland pp. 365-392. In: Frawley KJ, Semple NM (Eds) Australia's Ever Changing Forests. Proceedings of the first national conference on Australian forest history. Department of Geography and Oceanography, University College, Australian Defence Force Academy 529p.
43. Fensham RJ. 2013. For the sake of science: Ludwig Leichhardt as botanist and ecologist. Memoirs of the Queensland Museum. 7: 599-620
44. Gregory H. 1996. The Brisbane River Story: Meanders through Time. Australian Marine Conservation Society, Brisbane 202pp.
45. Steele JG. 1978. Conrad Martens in Queensland: The Frontier Travels of a Colonial Artist. University of Queensland Press, St. Lucia 150pp.
46. Jones R. 1969. Fire stick farming. Australian Natural History. 16(7): 224-228.
47. Griffiths T. 2002. How many trees make a forest? Cultural debates about vegetation change in Australia. Australian Journal of Botany. 50(4): 375–389
48. Fensham RJ. 1997. Aboriginal fire regimes in Queensland, Australia: analysis of the explorers' record. Journal of Biogeography. 24(1): 11-22
49. Neldner VJ, Wilson BA, Dillewaard HA, Ryan TS, Butler, DW. 2017. Methodology for survey and mapping of regional ecosystems and vegetation communities in Queensland, version 4.0. Queensland Herbarium, Brisbane 124pp.
50. Nissen JA. 1999. Creating the Landscape: A History of Settlement and Land Use in Mount Crosby. Unpublished MA thesis. University of Queensland, St Lucia 251pp.
51. Government of Queensland. 1909. Our First Half Century: A Review of Recent Progress. A. Cumming Government Printer, Brisbane 258pp.
52. Powell J. 1998. People and Trees: A thematic history of South East Queensland with particular reference to forested areas, 1823–1997. Queensland CRA/RFA steering committee report. Queensland and Commonwealth Governments, Australia 169pp.
53. Banks MM. 1931. Memories of Pioneer Days in Queensland. Heath Cranton, London 80p.
54. Butler DW, Fensham RJ, Murphy BP, Haberle SG, Bury SJ, Bowman DM. 2014. Aborigine-managed forest, savanna and grassland: biome switching in montane eastern Australia. Journal of Biogeography. 41(8): 1492-1505
55. Fensham RJ, Fairfax RJ, Archer SR. 2005. Rainfall, land use and woody vegetation cover change in semi-arid Australian savanna. Journal of Ecology. 93(3): 596-606
56. Garden JG, McAlpine CA, Possingham HP. 2010. Multi-scaled habitat considerations for conserving urban biodiversity: native reptiles and small mammals in Brisbane, Australia. Landscape Ecology. 25(7): 1013-1028
57. Lybolt M, Neil D, Zhao J, Feng Y, Yu KF, Pandolfi J. 2011. Instability in a marginal coral reef: the shift from natural variability to a human-dominated seascape. Frontiers in Ecology and the Environment. 9(3): 154-160
58. Olley J, Burton J, Smolders K, Pantus F, Pietsch T. 2013. The application of fallout radionuclides to determine the dominant erosion process in water supply catchments of subtropical south-east Queensland, Australia. Hydrological Processes. 27(6): 885–895
59. The Brisbane Courier. 1893; 25 February
60. Saxton NE, Olley JM, Smith S, Ward DP, Rose CW. 2012. Gully erosion in subtropical southeast Queensland, Australia. Geomorphology. 173–174, 80–87

61. Fryirs K, Lisenby P, Croke J. 2015. Morphological and historical resilience to catastrophic flooding: the case of Lockyer Creek, SE Queensland, Australia. Geomorphology. 241: 55–71
62. Thompson C, Croke J. 2013. Geomorphic effects, flood power, and channel competence of a catastrophic flood in confined and unconfined reaches of the upper Lockyer Valley, southeast Queensland, Australia. Geomorphology. 197: 156–169
63. Thompson C, Croke J, Grove J, Khanal G. 2013. Spatio-temporal changes in river bank mass failures in the Lockyer Valley, Queensland, Australia. Geomorphology. 191: 129-141
64. Grove RJ, Croke J, Thompson C. 2013. Quantifying different riverbank erosion processes during an extreme flood event. Earth Surface Processes and Landforms. 38(12): 1393-406
65. McMahon JM, Olley JM, Brooks AP, Smart JC, Rose CW, Curwen G, Spencer J, Stewart-Koster B. 2017. An investigation of controlling variables of riverbank erosion in sub-tropical Australia. Environmental Modelling & Software. 97: 1-15
66. Stout J, Olley J, Kemp J, Smolders K, McMahon J. In prep. The mechanics of wet flow failure along a major sub-tropical river system. Earth Surface Processes and Landforms
67. Olley J, Burton J, Hermoso V, Smolders K, McMahon J, Thomson B, Watkinson A. 2015. Remnant riparian vegetation, sediment and nutrient loads, and river rehabilitation in subtropical Australia. Hydrological Processes. 29(10):2290–2300
68. *Courier-Mail*, 1949: 23 February
69 *Courier-Mail*, 1951: 21 July
70. Haines HA, Olley JM. 2017. The implications of regional variations in rainfall for reconstructing rainfall patterns using tree rings. Hydrological Processes. 31:2951-2960
71. Coates-Marnane J, Olley J, Tibby J, Burton J, Haynes D, Kemp J. 2018. A 1500 yr record of river discharge inferred from shallow marine sediments in subtropical eastern Australia. Palaeoclimatology, Palaeogeography, Palaeoecology. 504:136-149
72. Scott A, Olley J. 2003. Settlement, erosion and muddy waters: lessons from the past. Murray-Darling Basin Commission, Canberra 20pp.
73. Neil D, Fogarty P. 1981. Land use and sediment yield on the southern tablelands of New South Wales. Australian Journal of Soil and Water Conservation. 4(2):33-39
74. Rutherfurd ID, Smith N. 1992. Sediment sources and sinks in the catchment of the Avoca River, north western Victoria. Report no. 83. Department of Conservation & Natural Resources, Victoria, Melbourne 58pp.
75. Wasson RJ, Mazari RK, Starr B, Clifton G. 1998. The recent history of erosion and sedimentation on the Southern Tablelands of southeastern Australia: sediment flux dominated by channel incision. Geomorphology. 24(4):291-308
76.Wasson RJ. 1994. Annual and decadal variation of sediment yield in Australia, and some global comparisons. International Association of Hydrological Sciences. 224:269-279
77. Olley JM, Wasson RJ. 2003. Changes in the flux of sediment in the Upper Murrumbidgee catchment, southeastern Australia, since European settlement. Hydrological Processes. 17(16): 3307-3320
78. Prosser IP, Rutherfurd ID, Olley JM, Young WJ, Walbrink PJ, Moran CJ. 2001. Large-scale patterns of erosion and sediment transport in rivers networks, with examples from Australia. Freshwater and Marine Research. 52(5): 1–99
79. Brierley GJ, Brooks AP, Fryirs K, Taylor MP. 2005. Did humid-temperate rivers in the Old and New Worlds respond differently to clearance of riparian vegetation and removal of woody debris? Progress in Physical Geography. 29(1): 27-49