Knowledge co-production for Indigenous adaptation pathways: Transform post-colonial articulation complexes to empower local decision-making☆

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ABSTRACT

Co-production between scientific and Indigenous knowledge has been identified as useful to generating adaptation pathways with Indigenous peoples, who are attached to their traditional lands and thus highly exposed to the impacts of climate change. However, ignoring the complex and contested histories of nation-state colonisation can result in naïve adaptation plans that increase vulnerability. Here, through a case study in central Australia, we investigate the conditions under which co-production between scientific and Indigenous knowledge can support climate change adaptation pathways among place-attached Indigenous communities. A research team including scientists, Ltyentye Apurte Rangers and other staff from the Central Land Council first undertook activities to co-produce climate change presentations in the local Arrernte language; enable community members to identify potential adaptation actions; and implement one action, erosion control. Second, we reflected on the outcomes of these activities in order to unpack deeper influences. Applying the theory of articulation complexes, we show how ideologies, institutions and economies have linked Indigenous societies and the establishing Australian nation-state since colonisation. The sequence of complexes characterised as frontier, mission, pastoral, land-rights, community-development and re-centralisation, which is current, have both enabled and constrained adaptation options. We found knowledge co-production generates adaptation pathways when: (1) effective methods for knowledge co-production are used, based on deeply respectful partnerships, cultural governance and working together through five co-production tasks—prepare, communicate, discuss, bring together and apply; (2) Indigenous people have ongoing connection to their traditional territories to maintain their Indigenous knowledge; (3) the relationship between the Indigenous people and the nation-state empowers local decision-making and learning, which requires and creates consent, trust, accountability, reciprocity, and resurgence of Indigenous culture, knowledge and practices. These conditions foster the emergence of articulation complexes that enable the necessary transformative change from the colonial legacies. Both these conditions and our approach are likely to be relevant for place-attached Indigenous peoples across the globe in generating climate adaptation pathways.

1. Introduction

Globally, Indigenous peoples are recognised as highly exposed to the impacts of climate change due to living in areas that experience rapid 'environmental change due to their latitude, topography, distance from the sea, soil quality' (Macchi et al., 2008) (p.21). Central Australia, where Aboriginal people are the dominant population outside the service town of Alice Springs, is such a region. Climate-change projections indicate a 4 °C increase in mean temperature by 2090, with more very hot days above 40 °C, fewer cold days and increased intensity

of extreme rainfall events (Watterson et al., 2015). These changes are expected to lower the liveability of an already-challenging arid climate (Healy, 2015). The vulnerability of central Australian Aboriginal people, and indeed Indigenous peoples globally, to impacts from climate change is compounded by their socio-economic disadvantage and chronic poor health; the burdens of the colonial history of dispossession; and the dominant societies' failures to account for Indigenous perceptions of risk in adaptation planning (Cameron, 2012; Lyons et al., 2019; Nursey-Bray and Palmer, 2018). Conversely, Indigenous peoples' knowledge can be an effective resource for adaptive capacity in response to climate change, and when linked to science through knowledge co-production, can stimulate necessary changes to institutional and governance arrangements thereby facilitating identified adaptation actions to occur (David-Chavez and Gavin, 2018; Head et al., 2014; Klenk et al., 2017; Lyons et al., 2019; Makondo and Thomas, 2018). However, ignoring the complex and contested histories of nation-state colonisation processes can result in naïve adaptation plans that increase vulnerability (Veland et al., 2013). In this paper, a team including members of a central Australian Aboriginal community (Ltyentye Apurte), investigates the conditions under which co-production between scientific and Indigenous knowledge can support climate change adaptation pathways among place-attached Indigenous communities; and uses the theory of articulation complexes to account for how nation-state colonisation continues to influence potential pathways.

'Adaptation pathways' is used here as a metaphor for a series of robust decision-making processes that enable responses to climate change in the face of environmental and social uncertainty (Wise et al., 2014). Adaptation pathways, in this sense of the term, are dynamic trajectories of change through an 'adaptive landscape' that evolves continuously due to changing climate and other biophysical variables. The purpose of generating pathways is to ensure that people remain, or move into, an adaptive space (where conditions improve and benefits increase or at least remain constant) and avoid movement into, or remaining in, maladaptive spaces (where conditions deteriorate and benefits decrease) (Prober et al., 2017). Multiple pathways of ongoing incremental adaptation exist for those already in an adaptive space, and people adopt pathways that reflect their values, cultures, world views and perceptions about what constitutes risk (Lyons et al., 2019). Nevertheless, transformative adaptation may be required either because the maladaptive space has shifted rapidly (e.g. through a sequence of extreme weather events), or because people are already required to endure a situation that does not protect their needs and values e.g. safety, security, equity and fairness (Zavaleta et al., 2018). Many Indigenous peoples whose societies have been, and continue to be, transformed by colonialism perceive that they are already living in maladaptive circumstances (Whyte, 2018).

Australian Indigenous societies, when supported to chart their own climate adaptation pathways, use these opportunities to strengthen their cultural institutions and assert their sovereignty, bringing climate adaptation into their larger project to maintain or re-build culture and connection to traditional territories or 'country', after the disruptions forced by colonisation (Nursey-Bray et al., 2013; Nursey-Bray and Palmer, 2018). Parsons et al. (2019) show, through their archival research, how successive generations of government policies and actions, founded on processes of Indigenous dispossession, created a profoundly path dependent system of managing rivers in the Rangitāiki Plains of Aotearoa New Zealand with increased flood vulnerability one of the direct consequences. They argue that re-centring the marginalised Māori values through formal recognition of Māori governance and knowledge within environmental management can help break this maladaptive path dependency.

Here a team including scientists, Ltyentye Apurte Rangers and other staff from the Central Land Council first undertook knowledge co-production activities to support the development of climate change adaptation pathways centred on community knowledge and values; and second reflected on the outcomes of these activities to unpack deeper

assumptions and contextual factors (Creswell, 2012; Crotty, 1998; Tengö et al., 2017). The research posed the question "under what conditions can co-production between scientific and Indigenous knowledge generate adaptation pathways among place-attached Indigenous communities?" We conducted the first phase of the research, knowledge co-production activities, in several steps to: (1) co-develop materials to support climate change understanding; (2) generate community responses to identify potential adaptation options; and (3) implement one adaptation option (erosion control). The second phase of the research, the deeper reflection and analysis, began with a consideration of the policy barriers and opportunities that determine which options are feasible to include in an adaptation pathway.

In the second phase, we found that the adaptation pathways approach, although well primed to engage historical perspectives through its focus on path dependency, did not yet offer explicit strategies to address how contests of power or power asymmetries inherent to colonial histories pose both policy barriers and opportunities (Bosomworth et al., 2017). We identified the theory of articulation complexes from cultural studies as helpful to elucidating how the ongoing impact of colonisation sets limitations and opportunities for adaptation pathways (Hall, 1985; Hutchins and Stormer, 2013). We define articulation complexes as social formations generated by linkages between place-attached Indigenous peoples and the emerging Australian nation-state. Different articulation complexes since colonisation can be characterised by distinctive ideologies and associated institutions and economies. We undertook desk-top historical research, and some interviews, to compile a relevant local history of articulation complexes in central Australia. From this history, we identified how each of these articulation complexes provided different barriers and enablers for Indigenous climate adaptation, although in all cases the colonial relations are characterised in part by domination and subordination (Grossberg and Slack, 1985; Hall, 1985). This analysis provided greater explanatory power in relation to understanding how the Ltyentye Apurte community navigates the barriers and enablers in the current articulation complex, characterised as re-centralisation.

We begin this paper with our research methods, founded in knowledge co-production approaches, explaining how these are applied in each of the two research phases. We next present the history and geography of the case study partnership site, with the Ltyentye Apurte community in central Australia. In the results section we present findings from the first phase of our research, the three knowledge co-production activities. We then present findings from the second phase of the research, beginning with presentation of our analytical framework and the results showing how climate adaptation options have been affected by the different articulation complexes in central Australia over time. We discuss how these articulation complexes drive decisions about climate change adaptation, identify how the complexities of relationships among settler-colonial state and Indigenous peoples affect climate adaptation globally and point to the need for transformative changes in these relationships. We conclude with identification of three conditions that enable co-production between Indigenous and scientific knowledge to generate adaptation pathways, identify the need for transformation and discuss global implications.

2. Methods

2.1. Research methods

Our research methods tailored established approaches to knowledge co-production (Ford et al., 2020b; Tengö et al., 2014, 2017) to the different requirements of the two research phases, and steps in each phase. Our research team included the Ltyentye Apurte Indigenous Rangers group, several other staff from the Central Land Council, an organisation representing Aboriginal people in central Australia, four scientists from Australia's national applied science agency (CSIRO) and a science educator from a local non-government Aboriginal
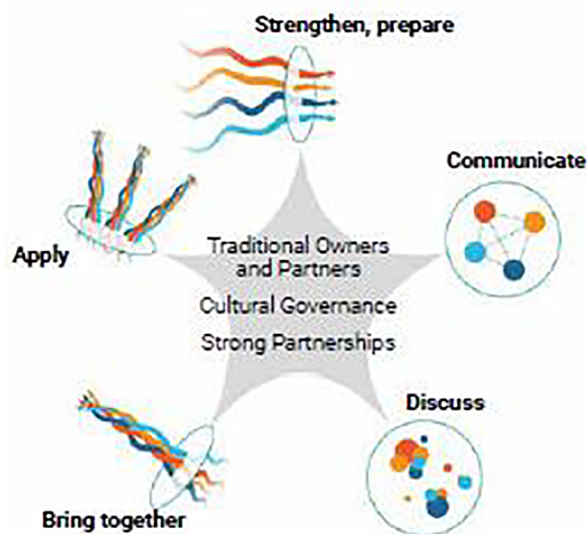
Fig. 1. Ethical framework and steps for knowledge co-production.

organisation (Tangentyere Council Aboriginal Corporation) (Walsh et al., 2015). The Indigenous collaborators have chosen to be collectively named among the co-authorship team as the 'Central Land Council' (CLC), reflecting their collectively owned knowledge system, and engagement by several different people in different aspects of the research.

Together, over a six year period from 2013 to 2019, we undertook the five tasks of weaving knowledge as identified by Tengö et al. (2017) and tailored to the Australian context (Ford et al. 2020a): *strengthen and prepare* aspects of the knowledge systems that will be shared; *communicate* by presentations in accessible forms (pictures, graphs); *discuss* and negotiate points of difference and commonality; *bring together* into diverse forms, (presentations, reports); and then *apply* the co-produced knowledge. These tasks are underpinned by a central ethical framework (Fig. 1) based on traditional owners and partners coming together to form relationships based on trust, respect, and adherence to cultural protocols. Cultural governance of the research is assured through the research-permit processes of the CLC, and the Ltyentye Apurte Rangers have a Traditional Owner Committee that guides their work. The partnership arrangements ensured that time and resources were available for the decision-making processes about knowledge co-production to be properly followed (Ford et al., 2020a).

The first step in phase one of the research, the activities to co-produce materials for climate change understanding, occurred during 2013–14, beginning with the Ltyentye Apurte Rangers assembling local data including photographs and recollections to construct their own weather and climate timeline, while other research team members assembled relevant meteorological data (*strengthen and prepare*). The Rangers, other research team members and people identified by the Rangers as having long-term local knowledge, compared this timeline with scientific weather and climate data during a workshop and explored evidence for change and trends (*communicate, discuss*). Subsequent co-production activities (*bring together*) centred on the causes, consequences and options for adaptation to climate change, and resulted in a co-developed powerpoint to support Rangers' presentations and a book (Mooney et al., 2014). The second step of the co-production activities, during 2014–15, involved the Rangers making presentations to sectors of their community in the local Arrernte language (*apply*) to generate options for adaptation pathways. Arrernte audiences were asked to rank a set of cards into three categories of importance. The cards featured plain English words and drawings in recognition of prevalent low text literacy. The audiences then discussed

the reasons for the ranking and how important actions could be implemented. Options presented on the cards included: cooler houses, more shade shelters, more shade trees, keeping the swimming pool open, bitumen road, bridge over erosion gullies, solar power, fix erosion gullies, and control of horses that impacted on soil erosion. We analysed the discussions to understand the processes by which the audiences navigated barriers to and enablers of adaptation to arrive at preferred options. In the third step of knowledge co-production activities the Rangers and other research team members worked together to implement one of these options, fixing and managing erosion gullies. This option aligned most closely with the Rangers' work program, priorities and existing skills and equipment. This third step applied knowledge co-produced in the first two activities and involved a second iteration of the tasks to *prepare*, *communicate*, *discuss*, *bring together* and *apply* knowledge about erosion processes.

In phase 2 of the research, during 2016–19, some members of the team worked to unpack the deeper assumptions and contextual factors driving the potential adaptation options available to and prioritised by the Arrernte community through their processes of navigating barriers and enablers. This deeper reflection and analysis approach draws on single-double-triple loop learning methods (Arevalo et al., 2010; Gupta, 2016), and the joint analysis phase of the multiple evidence approach (Tengö et al., 2014). We identified the theory of articulation complexes from cultural studies as helpful to elucidating how the ongoing impact of colonisation sets limitations and opportunities for adaptation pathways (Hall, 1985; Hutchins and Stormer, 2013). We derived an analytical framework from articulation complex theory that allowed us to probe how ideologies, institutions and economies intersected in different ways over time since colonisation, to produce a series of articulation complexes in central Australia and explain the barriers and enablers for Indigenous climate adaptation in each articulation complex.

Data used in the research include: quantitative time series weather data; qualitative data related to local historical events; interviews with senior Arrernte people; climate science presentations made by Ltyentye Apurte Rangers at three community events; potential adaptation options and discussions about these with the audiences at their presentations; a pictorial report on the project; activities on-country to develop responses to erosion caused by land use and accelerated by climate change; and reflective discussions between researchers and Rangers. Notes were taken by dedicated observers during knowledge sharing and action learning activities. Recordings of interviews about changes in weather and environment were conducted in Arrernte with senior people and translated to English. Documents were analysed through tabulation and matrix construction (Miles and Huberman, 1984). Other qualitative data were analysed in part through matrix/tabulation methods, and through thematic analysis involving coding and clustering of common themes aided by a data-analysis software tool (N-Vivo).

2.2. Case study history and geography: Ltyentye Apurte community

The case study site, Ltyentye Apurte, also known as Santa Teresa, is a community of around 600 people located on the traditional lands of Eastern Arrernte people, about 80 km south-east of Alice Springs in central Australia (Fig. 2). Genetic and archaeological evidence suggests Aboriginal populations spread across central Australia soon after arriving in the north around 65,000 BP (Before Present) (Clarkson et al., 2017). In the colonial era, after a gold rush to Arltunga, 90 km north-east of Alice Springs, attracted prospectors and miners to their land from the 1880s, Eastern Arrernte people developed economic relations with the non-Aboriginal colonists through the exchange of labour for food and shelter (PWCNT, 1999). The history of Ltyentye Apurte community can be traced back to the 1920s when Eastern Arrernte people moved into Alice Springs from the bush. The Catholic Church established a Mission and a school for them in Alice Springs which became known as 'Little Flower Mission'. The Mission was relocated to Arltunga during World War II (Australian Government, 2007). When water at Arltunga became contaminated by mining activities in 1952, the people
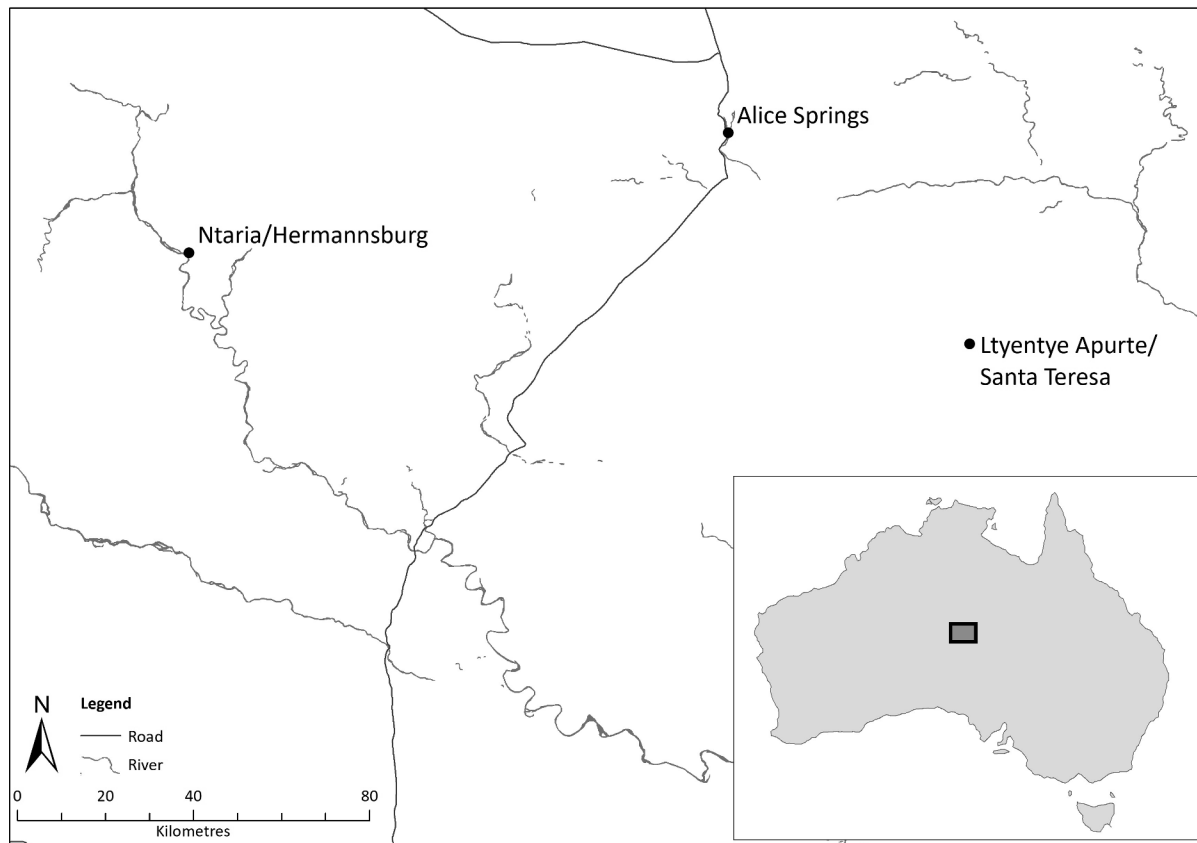
Fig. 2. Location of the Ltyentye Apurte community in central Australia, approximately 80 km south-west of Alice Springs.

were moved again, this time 75 km south-west to the current site of Ltyentye Apurte. The Santa Teresa Catholic Mission was established there in 1952 on land that the Catholic Church controlled through a government lease. The passing of the *Aboriginal Land Rights (Northern Territory) Act* [Cwlth] in 1976 resulted in the land being returned to the traditional owners. Today the community includes traditional owners, other Arrernte people, Aboriginal people from other groups who are married to Arrernte people and non-Aboriginal people (some with long standing connections) who are based in the community for work or service in the Catholic Church. Arrernte is the main language spoken amongst Aboriginal people, and the vast majority also speak English. A detailed timeline of events affecting the Ltyentye Apurte settlement and people since the 1800s is presented in the Supplementary Materials (Table S1).

Ltyentye Apurte is located within the limestone plateaux in the eastern MacDonnell Ranges recognised as part of the Santa Teresa Land System. Spinifex hummock grasses (*Triodia longiceps*) dominate the vegetation with scattered trees including *Acacia georginae, A. kempeana,* and *A. estrophiolata,* and *Eucalyptus camaldulensis* over *Chloris acicularis* grasses along watercourses (Perry, 1962). The climate is arid, and rainfall is highly variable. The nearest reliable weather station is in Alice Springs, although there are discontinuous records from nearer locations including Arltunga, Allambi and Ltyentye Apurte itself. Quantitative time series weather data analysed for the project show a positive trend in temperature (minimum, maximum and average), particularly more frequent very hot (> 40 °C) days, and increases in rainfall variability and intensity of extreme rainfall events (Table 1). Future projections under climate change as presented in Watterson et al. (2015) were supplied for the project indicate a markedly hotter climate with increasingly intense rainfall and an increase in median temperature of 4 °C by 2090 (Table 1). In 2020, these projections have turned out to be clearly conservative as Alice Springs experienced 57 days over 40 °C in 2019 and an increase in average daily maximum

temperature to 31.1 °C, which is 2.3 °C above the long-term average of 28.8 °C, and highest on record (BOM, 2020).

3. Results of knowledge co-production activities to support climate adaptation

3.1. Understanding climate change

The timeline of extreme weather events developed from data that the Rangers gathered from local knowledge sources aligned with meteorological data collated and analysed by the scientists. For example, one of the Rangers said:

My father told me there were heat waves with birds falling out of the sky in the late 70s and early 80s.

The quantitative data from nearby Alice Springs also revealed that the highest summer temperatures (prior to the highest recorded temperatures in 2013 and later) were in the late 1970s and early 1980s (Fig. 3).

Local people recalled big rains in the mid-1970s, with roads being closed for weeks, and helicopters dropping food to the community. The quantitative data from nearby Alice Springs showed 1974 as the year with the greatest annual rainfall (700 mm) (Fig. 3).

Displaying the two data compilations side-by-side on a large table allowed research participants to identify similarities (Fig. 4).

Timeline of major events, like floods, fires, droughts and other things people could remember … showed the knowledge of local people and how the events aligned with and matched weather patterns with those recorded with scientists (Ranger coordinator 2015).

Rangers were able to identify trends they were not otherwise conscious of:

Table 1
Major climate trends in central Australia presented in the knowledge co-production activities.

Climate variable	Historic data set (Australian Bureau of Meteorology)	Historic trend examples	Projection for 2090, under high emission scenario RCP 8.5 (Watterson 2015)	Examples of human and environmental impacts
Temperature				
Numbers of very hot days (> 40 °C) p.a.	Alice Springs 1942–2013	Number of very hot days increasing. 2013 had the most very hot days (42 days > 40 °C); and longest period of consecutive very hot days (19 days > 40 °C).	Many more very hot days 83 days > 40 °C annually.	Shorter and shorter periods of relief from heat stress.
Mean summer maximum temperature	Alice Springs, October to March 1942–2013	Hotter summer temperatures. 1 °C increase Highest summer means after 1990.	Much hotter summer temperatures. Increase between 2 °C and 6.1 °C (median 4.1 °C) for December to February, higher for October-November.	Heat stress, intensified psychosocial stress.
Mean winter maximum temperature	Alice Springs, April to September 1942–2013	Warmer winter temperatures. 1.5 °C increase.	Much warmer winter temperatures. Increase between 2 °C and 6.1 °C (median 4.1 °C).	Desiccation of water holes and reduced aquatic and water-reliant fauna.
Rainfall				
Annual rainfall (January to December)	Hermannsburg (Ntaria) 1889–2013	Increased variability since the 1970s, with higher rainfall years and drier years compared to earlier records. 2009 was driest year (90 mm) and 2010 was second wettest year (900 mm). Trends harder to see than for temperatures.	Continued very high variability. Increasingly intense heavy rainfall extremes. Trend in total annual rainfall is unclear, between 55% decrease and 25% increase (median 4% decrease).	Accelerated erosion with extremes of soil desiccation and vegetation cover loss from exposure to high intensity and prolonged rainfall. Intensified fire regimes following high rainfall, vegetation growth and fuel production. Insect disease vectors.

We … observed notable changes in those graphs and records, showed more days over 40 °C, also bigger floods happening in later times (Ranger coordinator 2015).

Recognition of these trends provided the foundation for knowledge exchanges about some of the causes, consequences and options for adaptation actions in response to climate change, including with Arrernte Elders. The Ranger coordinator summarised their input as:

Indigenous people of central Australia have been carers for country for generations, passing on important cultural knowledge for land management practices. Over time, our people have noticed changes in the weather and seasons. Seasons seem more mixed up. Bush tucker is not fruiting or flowering at the right time of year (Ranger coordinator 2015).

Elders also explained how some of the bush medicines were not as strong as they were in the past.

The Rangers made three presentations about climate change to Arrernte community groups as part of the project. A fourth presentation that had not been planned as part of the research project was made on the Rangers' own initiative without other research team members being present. Rangers and other research team members co-produced powerpoint slides to support the presentations. The slides used English language and the Rangers spoke in both English and Arrernte. The Rangers delivered on the plan that one of them had articulated earlier in the project:

I'm going learn this, learn all this, and put it in Arrernte so my mob can understand it.

Arrernte audiences were very grateful that the presentations were made in their own language and in a format that they could understand. For example, some people commented that they had seen a lot about climate change on television but hadn't previously understood what it was about.

Further work between the Ltyentye Apurte Rangers and the research team resulted in the publication of a book featuring both Indigenous and scientific knowledge, 'Climate Change: Learning about what is happening with the weather in central Australia' (Mooney et al., 2014) and conference presentations (Lander and Rangers, 2015; Walsh et al., 2015).

3.2. Community responses to potential adaptation options

Perceptions of risk among Rangers' audiences were clearly heightened by the presentations. Nevertheless, in subsequent discussions of adaptation options participants from the audiences did not rank options in any meaningful order indicating all the adaptation options were seen as equally important to them. Most of the adaptation options were things that the community had wanted, needed and attempted to achieve without success for quite a few years. Discussion among participants navigated the question of which options to prioritise by first identifying potential strategies required in order to progress an adaptation option and then considering constraints on implementation. Barriers arose from two main drivers: policies by government to re-centralise decision-making away from the Ltyentye and other Aboriginal communities, and lack of resources. Withdrawal of resources occurred as part of re-centralisation away from a local Ltyentye Apurte council to a regional council. When it became clear that they could not overcome a particular barrier they discussed another adaptation option, and in doing so identified potential strategies, implementation barriers and potential ways to navigate around these (Table 2).

For example, participants said that greater access to the community swimming pool would help them cope with extreme heat, but the community did not have the decision-making power to allocate resources to open and maintain the pool. They identified that while volunteers with necessary qualifications could help overcome this constraint, the Regional Council would still not pay for the extra electricity
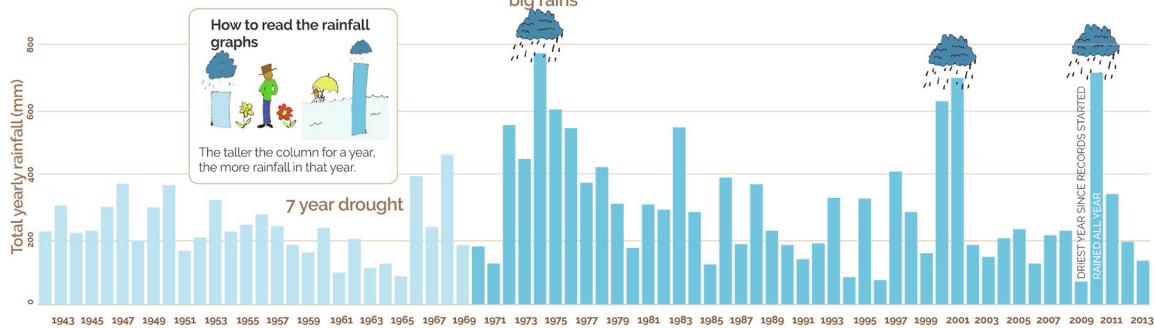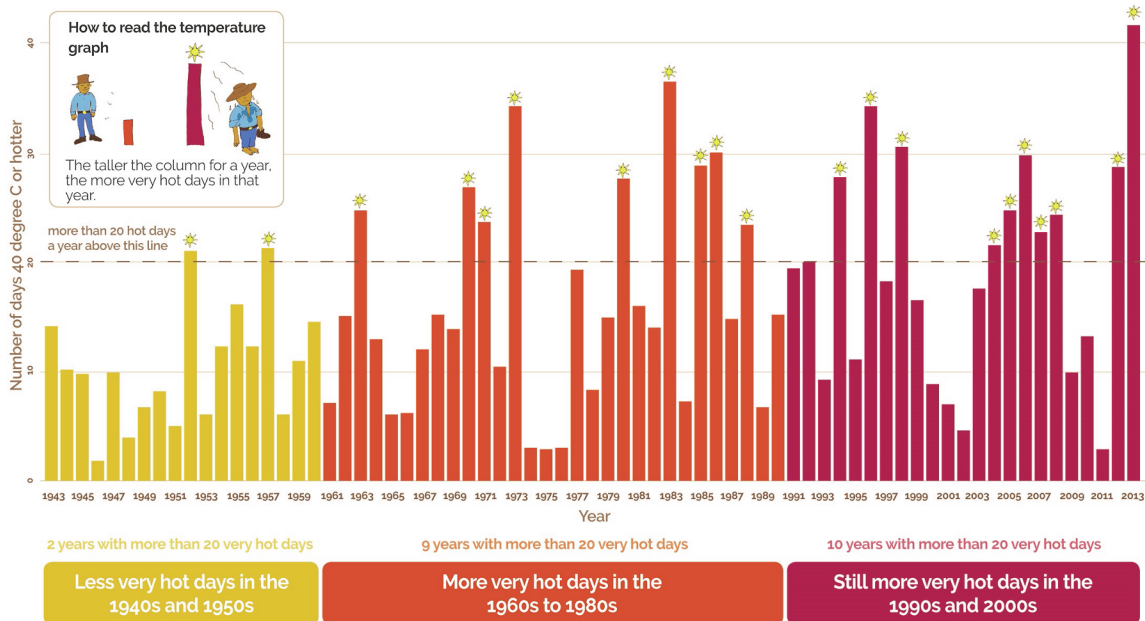
Fig. 3. Trends in (a) extreme rainfall events and (b) very hot days from the Rangers' presentations.

costs incurred. In relation to housing, participants identified that cooler and less crowded housing was sorely needed for people to be able to cope with the extreme temperatures. However, decisions about house design and improvements are not in community control. They identified that the responsible government authority was unresponsive to community priorities:

> They have been upgrading houses but not consulting the community … the floors in every house have been tiled. This makes the floors very slippery and because of this several people have broken bones. People are in old houses with no air conditioning. They sleep outside (Workshop Discussions, 2014)

Even though people felt they could themselves decide to buy an air-conditioner, they identified the lack of available technicians to install air conditioners as a constraint. The only action that discussants identified as within their capacity to implement was planting shade trees and installing shade cloth. They said the Ranger coordinator could access seedlings and shade cloth in Alice Springs and involve the

Ranger crew in planting shade trees and installing shade cloth.

Greater access to health services through an all-weather road to town would help people cope with climate impacts on health; however again discussants identified that the decision-making power to prioritise necessary resources lies outside the community. Comments were made that the government had less money than formerly and had low consideration for and awareness of the needs of Aboriginal communities. External organisations' consistent response was that there was little money for many identified adaptation options (for example, insulation in houses, more houses, bitumen road, bridge over gullies etc.). An experience of broken promises was communicated:

> The government has been promising, promising to make the road bitumen for years, mostly when there's an election coming on (Workshop participant, 2014).

While community members felt that action on almost all the potential adaptation options was beyond their capacity to implement or influence, the Ranger group was able to act to reduce risks from soil

Fig. 4. Timeline from local knowledge sources placed alongside quantitative data collated by the science team.

erosion. The Rangers were particularly concerned about a very large erosion gully on Yam Creek, which was and continues to threaten cutting the only access road from Alice Springs to the community:

> You need to stop those erosion areas. You can see where the erosion has spread and how the land has deteriorated. So that's our goal, is to try to prevent it from spreading more (Ranger, 2014).

Further consultation between the Rangers and their Traditional Owners Committee about this issue resulted in a decision that it needed to be addressed as part of the project (Lander and Rangers, 2015).

3.3. Implementation of one adaptation option – Erosion control

Implementation of the option to control erosion included further knowledge co-production activities. Field activities included demonstrations and experiments on infiltration and run-off of water that simulated the impact of predicted increases in rainfall intensity, and showed erodibility of different soil types. A visit to a cattle station 200 km to the north occurred to inspect a decadal program to repair gully erosion. These activities fostered co-learning between members of the science team and the Rangers that built shared understanding of: the extent and rate of spread of gully erosion around Ltyentye Apurte; the processes by which gully erosion is initiated and propagated; and the options for erosion management around and upstream of gullies. These lessons and experiences led the Rangers to trial new ways of managing erosion by building a set of control banks along the contour in one small catchment [using the method of Purvis (1986), see also Bastin (1991)] and establishing a monitoring system to quantify success (Walsh et al., 2015; Walsh and Sparrow, 2015).

The effectiveness of the control bank option over time, however, was compromised by inconsistent management of free-ranging horses, which trampled the control banks and led to bank breaching when heavy rainfall events generated surface flow in the catchment. Rebuilding of the control banks where they have been breached has not occurred due to loss of access to the necessary graders and heavy equipment and a turnover of Ranger coordinator staff with differing priorities. Further adaptation options now need to be explored associated with the management of free-ranging horses to prevent trampling of control banks.

4. Results of reflection and analysis of the colonial context

4.1. Theory of articulation complexes in colonisation

In the era of European colonisation from the 15th Century, colonial processes of territorial acquisition occurred through three

mechanisms: conquest; consent; or settlement of unoccupied lands (ALRC, 1986; Cooper, 2005). Nation-states established in any one of these ways on the territories essentially offered three options to pre-colonial societies: conform and assimilate with dominant colonial societies; relocate to places where they could continue to practise their traditional lifestyles to some extent; or resist and continue to challenge the dominant society through violent or non-violent means (Sissons, 2005). Nevertheless, from the very beginning of colonisation, Indigenous peoples also generated alternative and intermediate options, not envisaged in nation-state policy, through bringing their non-capitalist (e.g. common-property) modes of production into exchanges with capitalist modes of production (O'laughlin, 1975; Ostrom, 1990). Examples in Australia include Aboriginal people trading meat they had obtained through hunting for flour produced by colonialists (Anderson, 1984; Hill et al., 2001) and working as stockmen for colonial livestock owners which enabled them to remain living on their traditional lands with their families (Reynolds, 1990). Such interfaces between the practices of Indigenous/colonised and colonial societies are termed articulations – arenas where functions are connected but both sides of the colonial divide retain their distinct social forms and value systems (Hall 1985). These articulations change as the strategies of the colonists change (Berman, 1984) and as Indigenous knowledge, values and agency change, and are changed by, these post-colonial transformations (Radcliffe, 2019).

Ideologies are encoded in institutions (formal and informal rules and norms) that in turn reinforce the ideologies (Hall, 1985). Property rights in the form of entitlements or endowments exemplify institutions that produce and reproduce relations of domination and subordination within colonial articulation complexes (Emel et al., 1992). Economies, an aspect of institutions, reflect the encounter between capitalist and non-capitalist modes of production, consumption and accumulation. Articulation complexes are multi-scalar, involving institutions in the local community (e.g. religious practices or norms) and in national and state (provincial) legislation (e.g. providing land to a religious group to establish a mission). Articulation complexes are also multi-sector, involving government, community and industry actors in the nation-state.

While both colonised and colonisers have agency in articulation complexes, their choices are bounded by the nature of the historical conjuncture and the balance of forces in struggle at any time (Hall, 1985). Place-attachment among Indigenous peoples – their strong preference to remain on or near their traditional territories – drives path-dependency and stabilisation in articulation complexes. However, it can also contribute capacity for innovation through Indigenous knowledge of responses to changes in biophysical variables over millennia, for example in using seasonal calendars to monitor impacts on timing of flowering and fruiting of key plants, and adjust timing of fire management in response (Bardsley and Wiseman, 2016; Leonard et al., 2013). Social dynamics present opportunities for actors to generate new paths by creating novel coalitions of actors that challenge and modify dominant ideologies (Garud et al., 2010). Changes over time in the articulation complexes between Indigenous peoples in central Australia and the Australian nation-state help to illuminate how decision contexts shape contemporary climate adaptation pathways.

4.2. Central Australian articulation complexes and climate adaptation since colonisation

An articulation complex, therefore, can be conceived as the outcome of the interactions between the ideologies and economies/institutions of both the colonised (in this case the Ltyentye Apurte community), and the coloniser (in this case the Australian nation-state). Fig. 5 illustrates how the Altyerr, the Arrente ideology, and their customary laws, kinship systems and economies interact with the Australian nation-state, and their capitalist economies and laws/policies produced through parliamentary processes. Each of these sets of ideologies and economies/institutions are shown as woven together in recognition that each

Table 2
Adaptation options, strategies and constraints identified by the Ltyentye Apurte community, and outcomes.

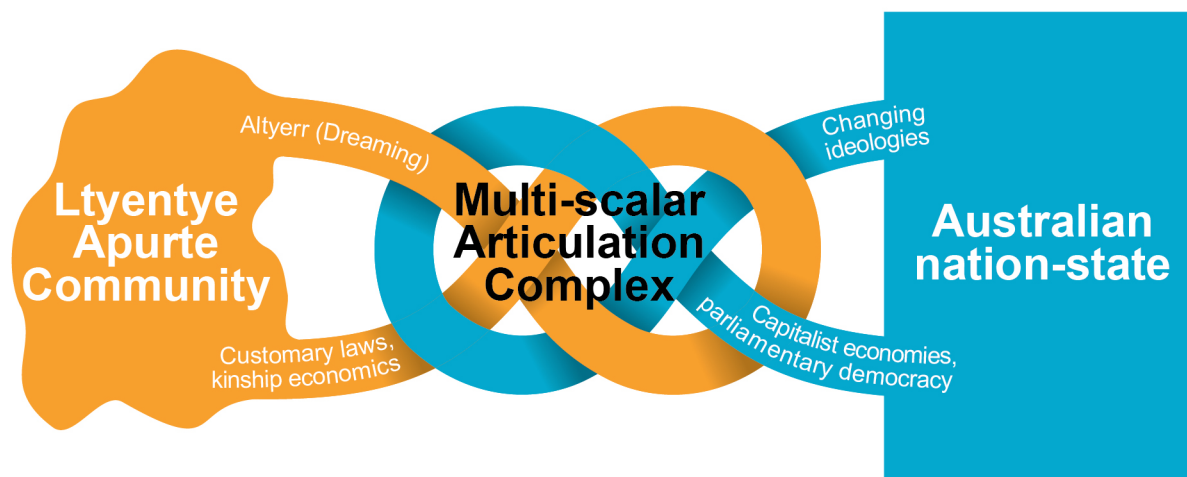| Adaptation option	1st strategy identified	Constraint	2nd strategy identified	Additional constraints	Outcome
Greater access to swimming pool	Open the pool more often.	Resource allocation decisions not under community control; Regional Council decision-makers won't invest, will only fund one day a week. Similar issues with access to other pools in remote communities in central Australia.	Voluntary workers open pool	Health, Safety and Environment barriers as a life-saver is required and limited availability on voluntary basis. Even with lifesaver, Regional Council are concerned about power and water costs.	Institutional driver toward mal-adaptive space. Knowledge sharing around life-saving skills has potential.
All-weather or most-weather road access to the community	A bridge on Alta and Yam Creeks for all-weather access.	Not cost effective, road is only closed for short periods due to flooded creeks.	Bitumen road from Alice Springs to Ltyentye Apurte.	Resource allocation decisions not under community control; NT government decision-makers won't invest. Bitumen road promised many times in the context of the election cycle.	Institutional driver toward mal-adaptive space. Also biophysical/technological driver as cars fall apart and accident risk is high.
	Manage gullies where erosion threatens extended road closure.	Knowledge of effective means to do this (erosion control methods implemented in early 2000s were not effective in stabilizing gullies).	Manage water, seed and silt movements over land (third option to move road higher up Yam Creek also discussed).	Resource availability – need a grader and bulldozer t to finish first set of structures.	Institutional and technological drivers towards adaptive space through knowledge-sharing between rangers, scientists and pastoralists.
Cooler houses	Better designed houses with insulation, flow-through ventilations, shading verandahs.	House design decisions not under community control. Some new houses worse than old ones.	Renovate houses for example by installing insulation.	Territory Housing (TH) unable to keep up with basic maintenance (promised AUD 9000 p.a. per house, but not evident). TH is now in Alice Springs, not on site, less responsive to repair requirements than previously, much longer wait. Policy/program change means CDEP teams can no longer provide assistance.	Institutional driver toward mal-adaptive space. A few improvements made, but without consulting community leading to new problems. e.g. tiling floors led to old people slipping and breaking bones.
Less crowded houses	More houses in Ltyentye Apurte community.	Territory Housing (TH) advised no overcrowding based on a survey. However, survey did not receive accurate responses as people thought it would lead to more rent being charged.	Informal housing. Partial use of housing e.g. sleeping outside.	Informal housing materials (corrugated iron) do not enable easy construction of cool options, and TH will not install air-conditioners in these.	Institutional and technological drivers towards mal-adaptive space. Knowledge sharing about where to sleep outside and remain cool.
More availability of shade	Plant more trees.	Resource allocation decisions not under community control; Regional Council decision-makers won't invest in trees.	Ranger Coordinator obtains trees with at low cost.	Accessibility of low-cost trees in community and Alice Springs.	Ranger Coordinator and Rangers have knowledge of how to access and plant low cost trees; potential to move towards adaptive space.
	Build more shade shelters.	Regional Council has built some but residents have no ready means of engagement with Council to ask for more to be built.	Install shade cloth on western sides of houses.	Shade cloth affordable but unavailable at local store, needs to be purchased in Alice Springs; unclear about how to install this although a low-level technology.	Ranger Coordinator and Rangers have knowledge of how to access and install shade cloth; potential to move towards adaptive space.
Lower power costs and impacts	Install solar hot water systems.	TH has installed some hot water systems but more needed. Resource allocation decisions not under community control. Tenants lack capital to install independently.	Install solar panels.	Tenants lack capital to install independently. Resource allocation decisions not under community control; Power and Water Authority decision-makers won't invest. Control power usage through a power card system.	Institutional driver toward mal-adaptive space.
More effective and efficient air-conditioning.	Change existing air-conditioners to more efficient designs.	TH will not invest in improving air conditioning. Resource allocation is not under community control.	Community tenants purchase own new air-conditioners.	People do purchase own air conditioners but there is no-one to install these, since closure of locally controlled employment program and lack of responsibility by TH.	Ditto. Knowledge sharing about how to install could be a partial solution.

Fig. 5. Articulation complex formed between the Ltyentye Apurte community and the Australian nation-state involving inter-mingling of the ideologies and institutions of each society.

maintains core elements and the characteristics of its origins. Of course, the Australian nation-state wields more power and is shown in Fig. 5 as larger than the Ltyentye Apurte community, reflecting the latter's enduring subordination.

Due to the highly dynamic nature of economies, socio-cultural practices, and policies, articulation complexes themselves are highly dynamic. This dynamism in the relationships and interactions between the Australian nation-state and the Ltyentye Apurte Community is reflected in a series of articulation complexes spanning > 100 years (Table 3) and reflects how Aboriginal people in central Australia were able to maintain some aspects of their worldview and lifeway while enduring subordination since colonisation. Key post-colonisation events that have affected central Australian Aboriginal people, and the Ltyentye Apurte community, are detailed in Table S1.

The start of the 'frontier' articulation complex in the 1850s (Table 3, Table S1) was marked by the early explorers' introduction of waves of disease and illness that spread rapidly through Aboriginal trade routes and preceded the settlement of European people. The preceding era of classical Arrernte lifeways is also included in Table 3 to contextualise the starting point of the frontier and subsequent articulation complexes. As noted above, archaeological and other evidence suggests that Aboriginal populations spread across Australia soon after arrival around 65,000 BP and that these people have stayed in specific areas for the subsequent millennia (Clarkson et al., 2017; Tobler et al., 2017). The 'classic' Arrernte worldview and lifeway is constituted by Altyerr (the Dreaming), Apmere (Country) and Tyerrtye (People) (Walsh et al., 2013). Altyerr underpins customary law, and thus roughly corresponds to both ideology and institutions, while Apmere and Tyerrtye together roughly correspond with the (subsistence) economy. Climate adaptation actions were integrated into practices of the Arrernte classical period:

> When people were travelling in the hot season they would travel at night and the early hours before sunrise. From experience they would know how long it is going to take to get to a certain place. They would begin their journey at whatever time in the early hours so that by the middle of the day they would be able to rest in the shade and be not too far from their destination. They might be only a few kilometres away and the trees will be throwing long shadows by the time they set off again for the last leg of their journey (Senior Eastern Arrernte Elder).

Territorial acquisition by Europeans met with both resistance – leading to violent conflict, massacres and imprisonment – and accommodation, for example through Aboriginal people trading work for food and safety, thereby establishing the 'frontier complex'. Traditional knowledge of country was a key asset for Aboriginal people to protect themselves and their lands, but superior and mechanised military force inevitably led to ceding of territory. From the 1890s, government policy changed to protection and assimilation, and Aboriginal people were moved to missions. As noted above, Eastern Arrente were moved to missions in Alice Springs from the 1920s and subsequently to other places outside Alice Springs. Some people nevertheless maintained access to their traditional lands, and many maintained aspects of their Indigenous knowledge systems, passing on stories of country and kin to children, some of whom were able to later return to those places. However, ideology, institutions and economy during the 'mission complex', most notably the forced removal of Aboriginal children from their families for assimilation, adversely affected Aboriginal people's capacity to adapt to the pace of environmental and social change. Environmental change at this time included irreparable damage to drinking waters, early waves of extinction of medium-sized mammals and the loss of access to many other bush-foods due to European over-exploitation by pastoralism pollution, and habitat transformation. The agreement of Australian Federal and State governments in the 1940s to allow Aboriginal families onto livestock grazing properties, and to provide them with rations, facilitated the co-evolution of the 'pastoral complex', with some groups now able to live on their traditional lands. Aboriginal people's knowledge of country ensured they were highly valued by the European settlers as livestock workers. This knowledge encompassed the impacts of weather on livestock management in the pastoral period:

> If animals eat the green grass just as it growing it is 'irlknge'kerte' i.e. it has a fair bit of water in it and it causes diarrhoea. Animals will lose condition. That happens in the winter time if there is fresh green growth. It's a like a cleansing time and people wouldn't hunt then. And even the farmers and people in the beef industry probably don't sell their cattle then either. The meat wouldn't be much good. The pastoralist would probably agist them out on a property that has dryer grass (Senior Eastern Arrernte Elder).

The 'land rights and welfare complex' from the 1970s was characterised by the granting of land rights in some areas, access to social service payments, and equal pay between Aboriginal and non-Aboriginal stockmen. In the same era, government support for rations to be provided to Aboriginal families on pastoral stations was removed and station owners became less tolerant of Aboriginal stock workers' families living on the stations. Aboriginal populations became more concentrated in church and government-run settlements. Some people found themselves converging or forced to live in the same place as large numbers of their extended family which supported aspects of their capacity to adapt to rapid changes. However other barriers emerged such

Table 3

Articulation complex, their intersecting ideologies, institutions, economies and the barriers and enablers these complexes have placed on adaptation. The main time period for each is illustrated but these complexes are not temporally discrete. Sources are found in S1.

Articulation complex name (core time period)	Intersecting ideologies of the articulation complex	Intersecting institutions and economies of the articulation complex	Constraints and enablers of capacity to adapt to environmental, social and economic change due to the articulation complex
Classical Arrernte (~50,000 BCE −1800 s)	Altyerr = Dreaming, Creation time	Customary laws, kinship networks based on skin-group sub-sections regulates land, resource, marriage etc., foraging and domiculture economies.	Enablers: Indigenous knowledge of country; Altyerr (the Dreaming), Apmere (Country) and Tyerrtye (People) underpinning Arrernte worldviews, lifeway and diversification strategies. Constraints: low levels of technology.
Frontier (~1850–1890)	Territorial acquisition meets accommodation and resistance	Explorers and colonisers, colonial constitutions, police, violence; emphasis on control of water and land resources to develop mining/pastoral economies; Aboriginal economies include cattle as resource, exchange work for food and safety with miners at Arltunga.	Enablers: Indigenous knowledge of country allowed evasion and some resistance while ceding territory; exchange of labour for resources, long distance of colonists from centres meant reliance on local peoples. Constraints: superior military force.
Mission (~1890–1940)	Protection of Aboriginal "dying race", assimilation of mixed-descent people	Christian Churches of diverse denominations; Catholic Church with Eastern Arrernte; rations for Aboriginal people on missions; governments remove children.	Enablers: Indigenous knowledge traditions supported learning about traditional lands despite people no longer being able to visit. Aboriginal people obtain roles in the Church. Labour in exchange for rations allowed some people to live on traditional lands with Missions. Constraints: Little access to market economy which is replacing customary economy as customary resources collapse from environmental change; family trauma and disintegration.
Pastoral (~1940–1970)	Dependency, labour exchange for rations, access to country	Native Welfare Ordinance makes Aboriginal people wards of the State. Pastoral Leases, government rations available for families on pastoral leases living alongside stockman. Governments continue to remove children.	Enablers: Indigenous knowledge of country and animals enable Aboriginal people to become highly valued as stockmen. Labour in exchange for rations, being on traditional lands with pastoralists. Aboriginal soldiers in WWII. Constraints: inequitable access to market economy through low wages; all aspects of family life controlled by nation-state.
Land rights and welfare (~1970–1990)	Land Rights, rights to equal access to social security in nation-state, rights to keep children	Equal pay for stockman ends the provision of rations on pastoral stations and families leave. Aboriginal Land Rights Act, Central Land Council, social security extended to Aboriginal people, Community Development Employment Program (CDEP).	Enables: Indigenous knowledge of country allows people to prove their connections to traditional lands required for Land Rights. CDEP supports a range of community-driven activities across self-determined work gangs. Family reunions enable cross-generational connections. Constraints: Welfare dependency, alcohol availability increases addiction levels.
Community development (~1990–2005)	Self-determination, de-centralization, recognition of Indigenous law, reconciliation, devolved Indigenous stewardship of country	Aboriginal and Torres Strait Islander Commission (ATSIC) established, Native Title Act, Council for Aboriginal Reconciliation, Australian government supports community arts centres, Indigenous Protected Areas commence.	Enablers: Indigenous knowledge of country enables people to establish their Native Title rights, and to engage in emerging economies e.g. Aboriginal art, Indigenous Protected Areas and Ranger programs. Constraints: Access to market economy continues to fuel alcohol addictions, lack of labour market opportunities entrench welfare dependency.
Re-centralization (with devolved land stewardship) (~2005-now)	Federal government policies of intervention in 'failed state'; Indigenous stewardship of country as asset to nation-state conservation goals	ATSIC abolished 2005, Northern Territory Intervention package of measures (e.g. compulsory income management); devolved land stewardship continues through Indigenous Protected Areas and Working on Country Program.	Enablers: Indigenous knowledge of country strengthens Indigenous land managers' roles support through government-funded stewardship programs. Constraints: Government centralisation of resources and limited ability of Indigenous peoples to make decisions about their money, their houses and many other aspects of their lives.

as welfare dependency and alcohol addiction. Indigenous knowledge was strengthened through requirements under the land rights legislation for evidence that substantiated claims to be Aboriginal owners of traditional lands.

The 1990s saw the emergence of a 'community development' complex where government articulated with Aboriginal people nationally and regionally through a new governance arrangement: the Aboriginal and Torres Strait Islander Commission, whose dual structure encompassed the national government agency responsible for Indigenous affairs administration and representative (elected) Indigenous decision-making bodies at regional and national levels. A policy of reconciliation was adopted in an attempt to address ongoing conflict and poor communication between Indigenous people and other Australians. The Community Development Employment Program (CDEP), financed by government and run by Indigenous community-based organisations, enabled people to work in locally relevant roles. For example, at Ltyentye Apurte, this work included collecting

firewood for families. New accommodations between colonial and Indigenous institutions were forced by High Court decisions that recognised the continuing existence of Aboriginal property rights that originated prior to colonisation. Policy support for devolving environmental stewardship to local groups, particularly farmers, but also Indigenous groups through Indigenous Protected Areas began to facilitate Indigenous people's re-engagement with their traditional territories and responses to environmental changes such as the control of invasive weeds (Dale et al., 2020).

This form of articulation between Aboriginal people and the state in land stewardship – institutionalised in government support for Aboriginal Ranger programs, such as at Ltyentye Apurte – has continued and grown within (and as a counter-direction in policy) to the subsequent, and current 're-centralisation' articulation complex (Pert et al., 2020). Notwithstanding this strengthened devolution of local land stewardship roles, the re-centralisation complex is predominantly characterised as one of centralised control of the nation-state over Indigenous peoples. This intensified when the Aboriginal and Torres Strait Islander Commission was abolished in 2005. Subsequently, direct national government control was rapidly scaled up through the Northern Territory Emergency Response of 2007 and consolidated by subsequent institutional changes underpinned by a discourse that Aboriginal communities represent a 'failed state' (Churcher, 2018). While the concept of Indigenous co-development with governments is emerging as a potential new ideology to underpin institutions, reflected in initiatives such as the co-designed Aboriginal and Torres Strait Islander Health Portal (DoH, 2018), articulation through re-centralisation remains dominant, with counter-narratives promoting the support for devolved Indigenous land stewardship subordinate within the overall complex (Table 4). Recent legal action by the Ltyentye Apurte community led to a ruling by the Northern Territory Civil and Administrative Tribunal (*Various applicants from Santa Teresa v Chief Executive Officer (Housing) [2019] NTCAT 7*) in February 2019 that the Northern Territory Government had breached its tenancy agreement and failed its legal obligations to provide safe, healthy and habitable public housing in remote communities. The decision may prompt institutional change that strengthen a new articulation complex emerging around the concept of co-development with greater emphasis on Indigenous agency.

5. Discussion: Articulation complexes to empower local decision-making and learning in climate adaptation

5.1. Articulation complexes as decision-drivers in climate adaptation

In the central Australian case study with land-attached Indigenous people, given the strong influence of the articulation complexes since colonisation on adaptation options, we argue that it is useful to consider the articulation complex – rather than the Ltyentye Apurte community itself – as the centre of the climate adaptation decision-making cycle (Fig. 6). Typically these cycles involve four steps: assess decisions and overall goals that may be affected by climate change; consider potential impacts of climate change; identify adaptation options and risk minimisation strategies; and select options, implement and monitor (Wise et al., 2014). However, for the Ltyentye Apurte community embedded in the current re-centralisation complex, potential options face significant barriers for implementation and require careful navigation of the imbalances in power and access to resources rather than simply being identified, selected and implemented. For example, in relation to the urgent need for cooler houses, the first two options prioritized – cooler houses, or more insulation on existing houses – encountered barriers due to the institutions of the Northern Territory government agency that constructs and owns the houses (Table 2, Fig. 6). The option of planting shade trees, on the other hand, aligns with the government support for devolved Indigenous environmental stewardship through the Ranger program. It can be immediately implemented as it reinforces existing key assets and requires Indigenous knowledge about trees and country (Fig. 6). Wise et al. (2016) have shown how prioritisation of adaptation actions in remote disadvantaged situations, where everything appears urgent, can be assisted by asking community members to score each option according to its reversibility ('low regrets') and feasibility (comprising a qualitative assessment of its cost effectiveness, opportunity cost, and existing capacity to implement the action). For the Ltyentye Apurte community audiences in this project, their own agency and ability to make decisions and learn appears to be an important factor determining the prioritisation of options.
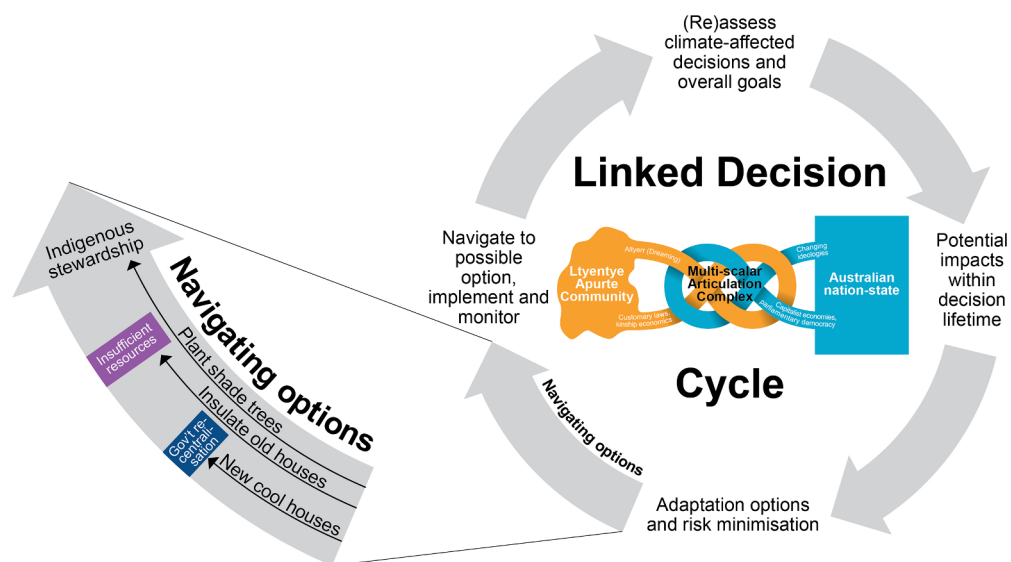
Table 4
Timeline of events in the re-centralisation processes.

Year	Timeline of events leading to the prevailing 'Re-centralisation' articulation complex event (including the subordinate counter-narrative for devolved land stewardship support)
2007	NT Emergency Response and Intervention from the Australian Government.
2007	All local community government councils disbanded, and assets redeployed either sold or centralized (from 8 community government councils and 14 incorporated associations for community management to 3 Regional Shires).
2007	CDEP scheme abolished in all remote NT communities, including Ltyentye Apurte.
2008	New Remote Community Jobs Program requires able-bodied individuals to work 16 h per week to remain eligible for social security in NT.
2008	Regional Shire takes over local governance and community development responsibilities in NT: roads, rubbish, parks, water, sewerage, children's services, youth development, night safety patrols, airstrip maintenance, house maintenance. Roles and assets of many community organisations were taken over.
2008	System of devolved grants raised Indigenous share of Australian government 'Caring for country' funding to 20%.
2008	Increases in Australian government 'Working on country" and Indigenous Land Corporation grants led to Indigenous Ranger groups being established and resourced – grown nationally to 123 groups employing 839 full time equivalent positions by 2019.
2009	Ltyentye Apurte Ranger group established.
2014	Indigenous Protected Areas form > 40% in area of Australian National Reserve System.
2014	Australian Prime Minister announces people on unemployment benefits in remote communities need to work 52 weeks a year to remain eligible. This is double the time required of urban people.
2016	Australian Lawyers for Remote Aboriginal Rights (ALRAR) surveyed 70 houses in Santa Teresa in early 2016.
2016	Grata Fund supported class action lawsuit launched against the NT Government by 70 households in Ltyentye Apurte about failure to action 600 urgent repairs, including leaving buildings structurally unsound, without running water, sewerage and ventilation despite the sustained desert temperatures above 40 °C in summer and below zero in winter.
2018	Northern Territory Civil and Administrative Tribunal (NTCAT) Northern Tribunal hears the case, including an initial four-days session in Ltyentye Apurte, taking evidence through interpreters.
2019	Northern Territory Civil and Administrative Tribunal (NTCAT) finds that the NT Government is legally obliged to provide habitable housing in remote communities. Compensation payments are required.

Fig. 6. Articulation complex as the decision-driver in the climate change adaptation decision cycle, leads to navigating, rather than selection of, options for implementing adaptation through cooler houses.

Despite some capacity to act on identified adaptation actions, the current trajectory Ltyentye Apurte Community-Australian nation-state complex is in a maladaptive space as adaptation options are limited due to the constraints of re-centralisation of decision-making and resources (Fig. 7a). Transformative change needs to occur whereby the trajectory is altered away from the maladaptive space and towards an adaptive one. A new articulation complex is needed to enable the most effective adaptation options to be selected in the Ltyente Apurte community in conjunction with government and other parties powerful within the articulation complex (Fig. 7b).

5.2. Empowering Indigenous peoples' decision-making and learning for climate change adaptation

Many place-attached Indigenous peoples find themselves in a similar context as the Ltyente Apurte community – seeking transformative change towards the adaptive space (Fig. 7b). Indeed, Whyte argues that Indigenous peoples are already experiencing the dystopian futures portrayed by climate change narratives and have experienced repeated apocalypses as a result of the disasters of colonisation and associated violence (Whyte, 2018). In Australia, and other developed world contexts – such as Canada, New Zealand, the United States of America, Norway, Denmark – governments have sought to accommodate Indigenous claims through renewed forms of legal and political recognition, typically involving: (1) land settlements; (2) economic development initiatives; and (3) self-government agreements (Coulthard, 2014; Ford et al., 2020a; Howitt, 2020). Coulthard (2014) argues that although these recognition regimes have replaced genocidal practices of exclusion and assimilation with a more conciliatory set of discourses and practices, the relationships between nation-states and Indigenous societies remain colonial in their substance, based on patterns of domination rather than the reciprocal relations and obligations characterising Indigenous ways of living. Replacing these colonial relationships with new relationships based on negotiation, consent, trust, consensus, accountability, reciprocity, and resurgence of Indigenous culture, knowledge and practices is critical for building the large coalitions of actors needed to combat climate change (Ahearn et al., 2019; Nursey-Bray et al., 2020; Whyte, 2020, 2018).

For place-attached Indigenous communities then, the articulation complex creates a context that enables and constrains decisions and actions. The necessary transformative changes towards an adaptive space requires a different relationship with the nation-state, a new

articulation complex (Fig. 7b). The current re-centralisation complex, characterised by a withdrawal of decision-making power from the local community, also includes a policy to devolve environmental stewardship to local control, supported by government-funding, with specialist programs for Indigenous stewardship alongside those targeted to farmers (Table 3). This policy has empowered Indigenous agency and Indigenous knowledge of land management to enable adaptation action to control soil erosion. Our analysis of articulation complexes over the period since colonisation shows how Indigenous knowledge and practices – of country, of animals, of ways of learning, of kinship connections, of land management – are common enablers of adaptation to change (including climate change) throughout all periods (Table 3). Policy settings between the nation-state and the Indigenous societies to form new articulation complexes that support and strengthen Indigenous knowledge, priorities and practices will expand opportunities for local decision-making and learning and are therefore likely to prove more effective for generating climate adaptation pathways.

6. Conclusion: Conditions where knowledge co-production generates adaptation pathways

What then are the conditions under which co-production between scientific and Indigenous knowledge can support climate change adaptation pathways among place-attached Indigenous communities? The findings from the first phase of our research, the knowledge co-production activities, demonstrate that the Ltyentye Apurte community were able to gain improved understanding of climate change, to identify some potential adaptation options, and to take action on one of these, namely erosion control. These positive steps towards generation of climate change adaptation pathways affirm the usefulness of these knowledge co-production methods. These methods are based on a central ethical framework of traditional owners and partners coming together to form relationships based on trust, respect, adherence to cultural protocols and cultural governance; and working together through five co-production tasks: *prepare, communicate, discuss, bring together* and *apply* (Fig. 1). Nevertheless, these activities also demonstrated that the Ltyentye Apurte community faces many barriers that impede implementation of proposed climate adaptation options. Current government policy to re-centralise decision-making control and resources limits opportunities for local-decision making and learning to generate adaptation pathways based on identified options. For example, no local decision-making is possible in relation to changes to housing,

Transformative change enabled through policy that supports local decision-making and learning

Figure A, adapted from Fazey et al. 2014, shows how multiple decision points along a pathway provide opportunities for ongoing incremental change (solid lines). However, transformative change (dashed lines) may be required to avoid moving into the maladaptive space as the shape of the adaptive space changes.

Figure B illustrates the position for the Ltyentye Apurte community, already enduring conditions that can be regarded as maladaptive. However, the limited opportunities for local decision-making and learning within the current recentralisation complex provide only for incremental change, resulting in movement further into the maladaptive space e.g. houses cannot be changed but tree-planting insufficient to adapt to extreme temperatures.

Opportunities for transformative change rely on the emergence of new articulation complex to creates potential for movement into the adaptive space. This requires new Australian nation-state policy that provides opportunities for local decision-making and learning e.g. new passively-cooled houses.
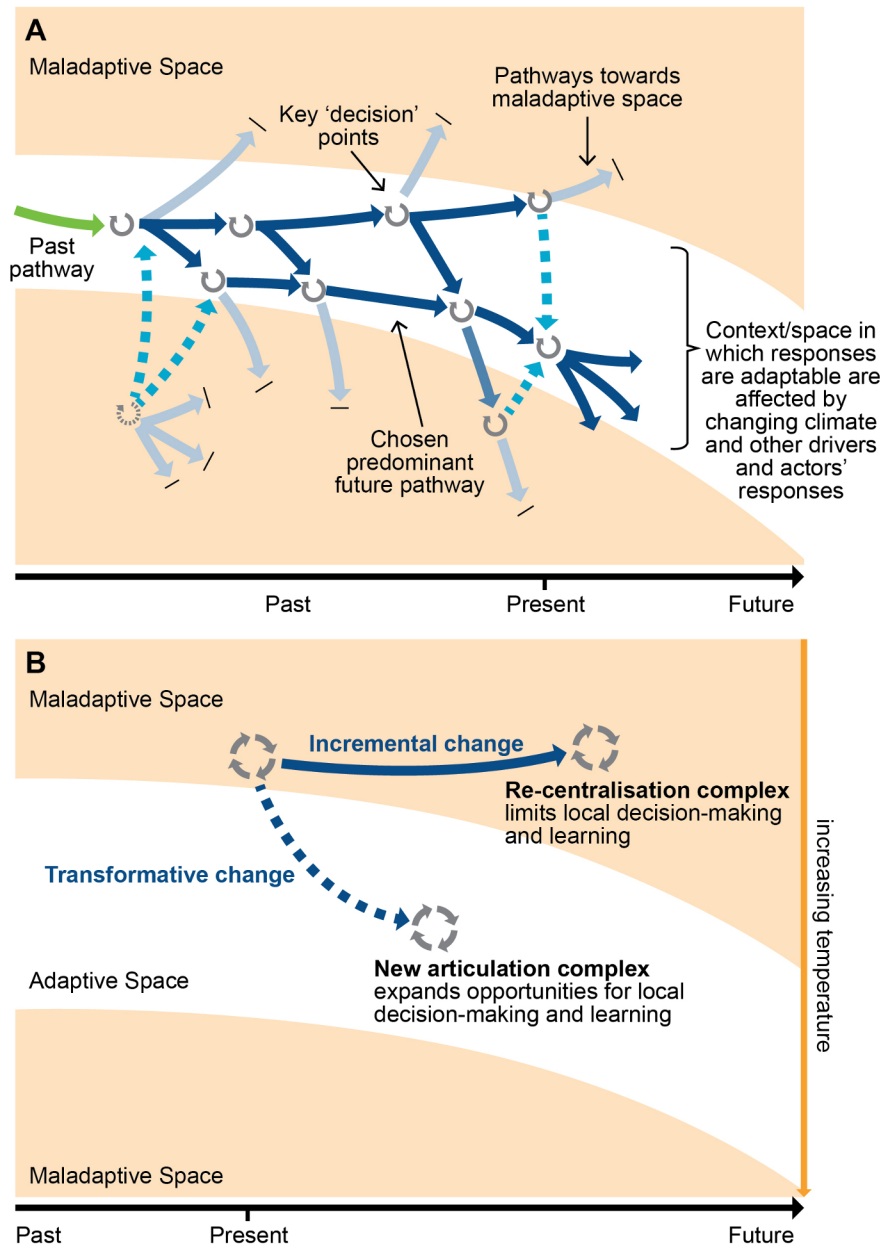

Fig. 7. Incremental and transformative pathways.

or to operate the local swimming pool. On the other hand, the government policy of devolving environmental stewardship to local control (Dale et al., 2020; Pert et al., 2020), and associated targeted funding for devolved Indigenous environmental stewardship enabled the local decision-making and learning required to implement one of the proposed adaptation options, erosion control.

The second phase of the research, the deeper reflection and analysis, used the theory of articulation complexes from cultural studies to probe how the ongoing impact of colonisation sets limitations and opportunities for adaptation pathways. From historical analysis, we showed how the Arrente people faced barriers to adaptation since colonisation as part of the frontier, mission, pastoral, land-rights and community-development articulation complexes. In many cases, these barriers resulted in trajectories towards, rather than away from, the maladaptive space. On the other hand, Indigenous knowledge and practices have been a common enabler of adaptation across all the articulation complexes. Connection to country/place is central to the Indigenous knowledge used to generate adaptation pathways and a fundamental strength for adaptation by place-attached Indigenous communities, who use their culture and values to strategically navigate available opportunities (Wilson, 2019). Nevertheless, the Ltyentye Apurte community, like Indigenous peoples in colonised contexts across the world, now find themselves in a context that greatly limits their local decision-making, learning and agency to take action. Transformative change towards a new position within the adaptive landscape requires a different relationship with the nation-state, a new articulation complex. Nation-state policy settings that empower local Indigenous decision-making and learning appear to be a critical condition under which co-production between scientific and Indigenous knowledge can support generation of climate change adaptation pathways among place-attached Indigenous communities. These policy settings in turn both create and rely on new relationships with nation-states based on trust, consent, accountability and reciprocity, in order to respond to the climate crisis (Whyte, 2020, 2018).

In summary, co-production between scientific and Indigenous knowledge can support climate change adaptation pathways among place-attached Indigenous communities when (1) effective methods for knowledge co-production based on deeply respectful partnerships, cultural governance and working together through the five co-production tasks are used; (2) Indigenous people have ongoing connection to their traditions and territories to maintain their Indigenous knowledge; and (3) the relationship between Indigenous peoples and the nation-state empowers local decision-making and learning, which in turn creates and requires consent, trust, accountability, reciprocity, and enables resurgence of Indigenous culture, knowledge and practices. When these conditions are in place, articulation complexes can emerge that drive transformative change away from the current maladaptive state.

Of course, achieving this new relationship is no easy task, and (Whyte, 2020) argues that we may already have passed a "relational tipping point" for climate change action and justice, drawing an analogy with scientifically-defined "ecological tipping point". A relational tipping point is one which prohibits the emergence of the new relationships – between Indigenous societies and other societies' governments, nongovernmental organizations, and corporations – that he argues are required to effectively respond to climate change (Whyte, 2020). Nevertheless, our knowledge co-production activities supported Ltyentye Apurte Rangers to take pragmatic tactical actions to realise immediate adaptation actions; and the deeper reflection and analysis identified how empowerment of local decision-making and control can help remove barriers to the implementation of other options. Ongoing adaptive pathways of knowledge co-production with Indigenous people that explicitly address the impacts of colonisation can support effective climate change adaptation actions and identify institutional changes necessary for their implementation. Other Indigenous peoples and local communities may find the articulation

complexes approach useful to connect the past and the future in explorations of potential transformative change (Pereira et al., 2018). Our analytical approach has provided tools for understanding and addressing the ongoing impact of colonisation in working with Indigenous people in climate adaptation research and is worthy of further testing.

CRediT authorship contribution statement

Rosemary Hill: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualization, Writing - original draft, Writing - review & editing. **Fiona J. Walsh:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. **Jocelyn S. Davies:** Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing - review & editing. **Ashley Sparrow:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - review & editing. **Meg Mooney:** Conceptualization, Investigation, Methodology, Writing - review & editing. **Central Land Council:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing - review & editing. **Russell M. Wise:** Conceptualization, Methodology, Validation, Writing - review & editing. **Maria Tengo:** Conceptualization, Methodology, Validation, Visualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2020.102161.

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