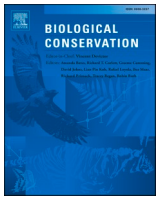
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The return of the kinga (saltwater crocodile): Population 'bust then boom' shapes shifting baselines in Indigenous biocultural knowledge in northern Australia

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ABSTRACT

The saltwater crocodile (*Crocodylus porosus*) can be regarded as a cultural keystone species for many Indigenous societies around the world, including for many Aboriginal clans in northern Australia. Here the regional population of *Crocodylus porosus* suffered a decline, almost to extinction, with unregulated commercial hunting between the 1940s to the early 1970s. Following protected status, saltwater crocodile populations made a rapid recovery. This research documents the perceptions and experiences of this rapid (within living memory) 'bust then boom' saltwater crocodile population change, among a regional group of Indigenous Australians (comprising several clans) from the Alligator Rivers Region of western Arnhem Land and Kakadu National Park in the Northern Territory. Using semi-structured interviews, archival work and on-Country (place-based) learning, significant influences on the continuity of Aboriginal people's contemporary engagement with freshwater Country were identified. In particular, the loss of access to freshwater customary harvesting sites and to key harvested species, and as a driver of adaptive changes in harvesting methods and consumption preferences for saltwater crocodile meat and eggs. Importantly, the experiential losses from restricted access to waterbodies were found to have significant impact on opportunities for inter-generational knowledge transmission, according with more recent applications of the Shifting Baseline Syndrome to Indigenous Ecological Knowledge. Findings demonstrate the need for monitoring and management programs of cultural keystone species, like the saltwater crocodile, to include Indigenous-led biocultural knowledge programs as a means of supporting local and Indigenous Knowledge systems. This is particularly critical in cross-cultural, First Nations, and joint-management contexts.

1. Introduction

In a time of both unprecedented global environmental change and awareness of the contribution of Indigenous knowledge to navigating these changes, it is important to understand how drivers of social-ecological change have impacted and continue to shape local and Indigenous human-environment interactions. Unregulated commercial hunting to meet the demands of global markets in pelts, hides, meat or skins has a long history, causing serious fluctuations, if not crashes, in the populations of targeted species (e.g. Dolin, 2010; Antunes et al., 2016). These species are also often species of cultural significance for local and Indigenous communities (for example bison, fur seals, beavers, whales). The local human impacts of the over-exploitation characterizing unregulated commercial hunting, are not only felt at the point of population crash, but likely as an ongoing legacy effect, as for many other impacts of colonization. Even with successful population recovery programs, legacy effects can continue to shape and exert pressure on Indigenous peoples' abilities to sustain local socio-cultural, ecological and economic relationships. The impacts of unregulated commercial hunting and such significant species population perturbations require attention not only in terms of species recovery programs but also for their influence on broader human-environment interactions, including associated biocultural changes. The cultural keystone species concept, after Garibaldi and Turner (2004), provides one such relevant approach,

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reflective of a more holistic, social-ecological systems approach, for examining human dimensions of ecological change (Garibaldi and Turner, 2004; Berkes et al., 2003).

Cultural keystone species in an Indigenous social-ecological system context include species that may be important in diverse ways, including ceremonially, spiritually, in narratives, or materially, as a source of medicine, technology or food (Garibaldi and Turner, 2004). As such, cultural keystone species include those that are harvested or which critically shape, Indigenous customary harvesting practices. Here 'customary harvesting practices' refer to the hunting, fishing or collecting of natural resources for subsistence purposes. 'Subsistence' may include not only direct consumption, but also social-cultural and economic purposes like ceremonial practices, maintaining social networks, and the potential to support local economic enterprises. Customary harvesting is a practice that incorporates all three 'pillars' of Indigenous Ecological Knowledge (IEK), those of 'knowledge, practice and belief' (Berkes, 2017). IEK, also known as traditional knowledge, biocultural knowledge or Indigenous knowledge (IK), is built upon highly localized observations and understandings of environmental change, derived from close experiential learning which are transmitted through oral memory and social practices, across generations (Berkes, 2017; Fernández-Llamazares et al., 2015). Customary harvesting requires, generates, sustains and perpetuates Indigenous biocultural and ecological knowledge. Such practices can also engage, reinforce and sustain social networks, resource management rules and institutions, and are underpinned by a belief system recognizing both human and non-human agency in the environment. This includes, for example, the associated rituals to manage abundance or renewal and the health of people and land/sea country (Rose, 1996; Bawaka Country et al., 2015; Cinner and Aswani, 2007). Importantly, even a single customary resource can support multiple values, in directly connecting people with their beliefs and environment (e.g. 'Country'[1]) (Walsh et al., 2013). Therefore, where customary harvesting practices are impacted, there are consequences for IEK and its transmission across the generations.

Indigenous knowledge is not only critical in shaping strong cultural continuities, including beliefs, language, social networks and health and well-being locally (e.g. Biddle and Swee, 2012; Garnett et al., 2009), but is increasingly recognized as playing valuable roles in re-shaping unsustainable, extractive Western human-environment relations (Magallaes, 2018). IEK has been recognized as a critical contributor to the global scientific knowledge base necessary to respond to global environmental change (Alessa et al., 2015; Turner and Clifton, 2009; Berkes, 2017; Huntington, 2011). For example, IEK can assist in addressing scientific knowledge gaps in areas remote or otherwise as yet without a record of western scientific monitoring (Ens et al., 2015; Huntington, 2011) and provide new understandings of biophysical or phenological interactive processes (Armatas et al., 2016). Supporting the continuity of Indigenous knowledge systems requires an understanding of the drivers of change influencing Indigenous knowledge transmission. This paper considers the legacy effects of historical, unregulated commercial hunting of a cultural keystone species, on contemporary customary harvesting practices and IEK transmission.

The Shifting Baseline Syndrome (SBS) (Pauly, 1995, 2019) offers a means of examining changes in IEK and adaptive responses, in recognizing the socially constructed nature of environmental knowledge. The concept highlights the risks of using inappropriate baselines, for example, without sufficient historical depth, which can result in failing to notice gradual 'shifts' or declines in the 'generational' baseline (generational amnesia), or failing to identify and incorporate prior declines in population assessments. To combat this, Pauly supported incorporating diverse forms of historical data to extend and more accurately reflect, the population change over time (Pauly 1995). Originating in fisheries science, the SBS concept continues to be applied to explore social contexts in fisheries (e.g. Watson et al., 2016; Ringer et al., 2018), and has increasingly been applied in conservation science and management more broadly (e.g. Alleway and Connell, 2015). The application of SBS has emerged in diverse disciplines such as environmental restoration (Hirsch, 2020), environmental history (e.g. Gaynor, 2014), and psychology (Kahn, 2002). There have been several advances in the application of the concept (e.g. Papworth et al., 2009) and more recently in the context of Global Environmental Change and IEK supporting adaptive capacity (Fernández-Llamazares et al., 2015). Importantly, Fernández-Llamazares et al. (2015) posit demonstrating the existence of SBS requires not only a discernable difference in generational experiences of environmental norms, but evidence of a perceptible and locally-relevant ecosystem or biological change, and should account for intergenerational communication. Only relatively recently and in a limited number of studies to date, has the application of SBS to Indigenous knowledge associated with ecological change emerged (Kai et al., 2014; Fernández-Llamazares et al., 2015; Bao and Drew, 2017). Here the concept the SBS is applied to the case study of historical unregulated commercial hunting and recovery of the saltwater crocodile, and its implications for Indigenous freshwater customary harvesting practices.

The saltwater crocodile (*Crocodylus porosus*) is a species that was subject to unregulated commercial hunting causing dramatic population declines across its distribution, for the global crocodile skin trade between the 1940s until the 1970s. Fortunately, the risk of extinction was recognized in time and protection from commercial hunting, followed by regulated, sustainable-use programs and ongoing population monitoring have resulted in a contemporary conservation success story. The saltwater crocodile populations have made strong recoveries (Webb and Manolis, 1989; Fukuda et al., 2011). However, the impact of this 'bust then boom' crocodile population change on the human communities living closely alongside this top-order predator has had scant recognition in the literature (Brackhane et al., 2018b; Fukuda et al., 2014; Brackhane et al., 2019) and the implications for local or Indigenous people's aquatic resource use practices, are as yet, largely undocumented.

As a top order predator, with a long lineage of human-crocodile cultural affiliations in many regions around the world, including northern Australia, the saltwater crocodile clearly fits this definition of a cultural keystone species (see Garibaldi and Turner's (2004) Index of Identified Cultural Influence). Unequivocal data sets exist to demonstrate evidence of the crocodile population change (as required by Fernández-Llamazares et al. (2015), towards evidence of the SBS). Contemporary Indigenous freshwater resource use practices in northern Australia have also been documented (e.g. Jackson et al., 2014; Altman, 1987; Russell-Smith et al., 1997), though less often in regard to historical (post-colonization) ecological drivers of change. This research provides the first empirical evidence of the influence of the saltwater crocodile's population fluctuation for an Indigenous social-ecological system, that of Bininj people's freshwater customary harvesting practices from the Alligator River Region, Northern Territory of Australia.

2. Research context and methods

2.1. Study region characteristics

The 'Alligator Rivers Region' is located in the wet-dry tropical belt of the Top-End of the Northern Territory of Australia and comprise five major catchments, with the floodplains comprising ~20,000 km^2 of KNP and ~8000 km^2 of western Arnhem Land (Fig. 1). The South and the East Alligator Rivers were the focus for this study as much of the freshwater customary harvesting activities in the region are

[1] 'Country' is used here in an Indigenous Australian sense of a 'nourishing terrain', a living entity, encompassing the physical and metaphysical, linking people to ecosystems in a holistic way, synonymous with life and within which all life is interdependent ROSE, D. B. 1996. *Nourishing Terrains*, Canberra, ACT, Commonwealth of Australia.

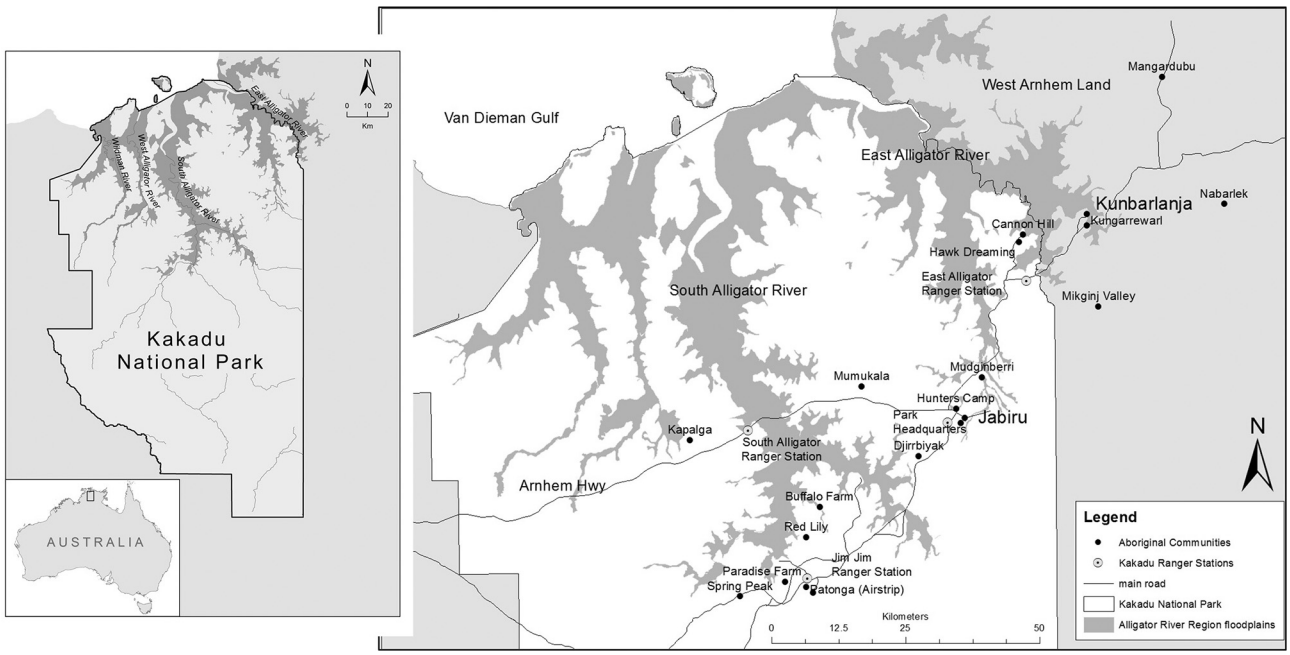


Fig. 1. Alligator Rivers Region, encompassing the coastal floodplains (dark grey) of Kakadu National Park (KNP) and western Arnhem Land. Inset below highlights the South and East Alligator River systems and the regional towns of Kunbarlanja (formerly Oenpelli, western Arnhem Land) and Jabiru (KNP) as well as smaller Aboriginal outstations, and ranger stations within KNP.

concentrated in these more accessible systems. The coastal floodplains lie in a narrow elevation band only approximately 20–140 cm above mean sea level and tidal influence can extend, for example, on the East Alligator River, >90 km upstream, making them highly susceptible to small fluctuations in river discharge and climatic variation in sea level (Finlayson and Woodroffe, 1996; Finlayson et al., 1997).

Kakadu National Park (KNP) is jointly managed between Aboriginal Land Owners and the Australian Government National Parks department, Parks Australia (Director of National Parks, 2016). Across KNP's border of the East Alligator River, western Arnhem Land is Aboriginal owned freehold land with access and governance facilitated through the Northern Land Council (a statutory representative body), and services provided by multiple levels of government. There are multiple clans and language dialects spanning the floodplain region, with Kunwinjku (to the east, associated with western Arnhem Land) and Kundjeyhmi (the south-central region around Nourlangie Creek) being dominant dialects. Saltwater crocodiles are known locally as kinga[2] in Bininj Kunwok, this being the preferred spelling for the Kunwinjku dialect spoken at Kunbarlanja (Gunbalanya), while Kundjeyhmi speakers (KNP) may have used the orthography of ginga in the past. Regional Aboriginal population demographics include a highly mobile population, skewed towards youth, largely located in the major service towns of Gunbalanya (hereafter referred to as Kunbarlanja, using Bininj Kunwok spelling, 1116 people, 88.6% Indigenous) and Jabiru (1081 people, 24.3% Indigenous) (Australian Bureau of Statistics, 2016). Mobility on-Country and between towns is facilitated by numerous 'outstations', which are residences built on traditional homelands where smaller family groups live or visit (Fig. 1).

Customary resource use is legally recognized under the *Aboriginal Land Rights* (*Northern Territory*) *Act* (1976), the *Native Title Act* (1993), the *Environmental Protection and Biodiversity Conservation Act* (1999), and in the lease agreement of federally managed Parks (Director of National Parks, 2016). Aboriginal landowners and residents of the region continue their engagement in aquatic resource use practices, where customary beliefs and governance protocols continue to shape access, harvesting methods and the distribution of catch (Ligtermoet, 2016; Ligtermoet, 2018). Indigenous knowledge holders identify six major seasons in the region and these shape interaction with country and harvesting practices (Russell-Smith et al., 1997; Narndal et al., 2015; Ligtermoet, 2018).

Key freshwater aquatic resources comprising freshwater customary harvest of most significance in this study are identified in Table 1 (further detail can be found in Ligtermoet, 2016, 2018). Of note is that most in-stream aquatic resources (e.g. freshwater mussels *Velesunio angasi*, Arafura filesnake *Acrochordus arafurae*, and the aquatic plants) are predominantly harvested by women, as are aestivating northern long-necked turtles (*Chelodina rugosa*). Both genders engage in fishing practices, while men are the primary waterfowl hunters. Waterfowl are now harvested using shotgun; however, magpie geese (*Anseranas semipalmata*), for example, were traditionally hunted using weighted throwing sticks from elevated platforms, at the edges of floodplains (Ligtermoet, 2018).

Saltwater crocodiles occur in tidal rivers, coastal floodplains, swamps and billabongs across northern Australia. Though usually occupying the lower reaches, they can be found over 100 km inland from the coast (Webb et al., 1984) and, despite their name, in freshwater systems. In terms of quantified evidence for the changing status of the saltwater crocodile population, Fukuda et al. (2011) provide evidence regionally, as well as for individual rivers, for what they describe as almost complete recovery of the crocodile populations. Standardized monitoring of the Northern Territory's saltwater crocodile populations in tidal rivers began in 1975, following protection in 1971. Initial recovery (1971–83) was under complete protection and a second phase of recovery (1984–2009) incorporated managed wild egg harvest, with results supporting this had no detrimental impact on the populations (Fukuda et al., 2011). When viewed as a single population across all 12 rivers surveyed, Fukuda et al. (2011) predicted for the monitoring period of 1975–2010, a conservative increase from 1.47 to 5.26 (>3 times) crocodiles sighted/km surveyed. They noted, however, the real

[2] Term for saltwater crocodile in the local dialect, Bininj Kunwok, underlined for distinction from English language.

Table 1
Key species, methods of harvest and primary gender engaged in harvest.

Key species	Kunwinjku name	Common name	Contemporary method	Gender of harvester (predominantly)
E.g. *Scleropages jardinii*, *Lates calcarifer*, *Neosilurus* spp., *Hephaestus fuliginosus*	Djeng [collectively]	Fish [collectively][a]	Net or hand line	Both
Chelodina rugosa	Ngalmangiyi	Long-necked turtle	Fire & crow bar (digging stick)	Female
Acrohordus arafurae	Kedjebe	Arafura file snake	In-stream hand collected	Female
Velesunio angasi	Karnubirr	Freshwater mussel	In-stream hand collected	Female
Anseranas semipalmata	Manimunak	Water fowl-magpie geese	Shot from margins of floodplain billabongs	Male
Nymphaea spp.	Manburrangkali	Water lily species	In-stream hand pulled	Female
Eleocharis dulcis	Mankuladj	Water chestnut	Hand dug from floodplain	Female

[a] Further details on regional freshwater customary harvesting found in Ligtermoet (2016).

Table 2
Number of Aboriginal respondents interviewed by age and gender cohort.

Age	Number of women		Number of men	
	Kakadu	Kunbarlanja	Kakadu	Kunbarlanja
Younger (<35)	0	0	3	5
Middle aged (approx. 35–<50)	5	4	5	10
Senior/elder (approx. >50)	8	11	3	12
Total[a]	13	15	11	27

[a] One middle aged female and one elder male were counted in both Kakadu and Kunbarlanja, speaking for their experiences and country spanning both sides of the East Alligator River.

recovery since protection (1971) with an estimated baseline of 0.1 crocodile sighted/km surveyed, was likely to be closer to >50 times increase in abundance (Fukuda et al., 2011).

2.2. Methodology and methods

This research emerged from broad inquiry seeking to identify past experiences of social-ecological change influencing customary harvesting practices in order to support sustaining the practice through anthropogenic climate change. It involved asking the initial descriptive questions (what, how, when, where, with whom) to understand contemporary customary harvesting and the key freshwater species harvested. Had there been significant changes to these practices in lived experience, and if so, what had driven these changes? How did people respond to the changes and what were the implications for their harvesting practice (as a practice that was in one an economic, spiritual and social-cultural practice). The rebounding saltwater crocodile population was identified early on and unanimously by Bininj people as a major driver influencing contemporary freshwater customary harvesting practices (Ligtermoet, 2018), prompting this paper.

Indigenous research methodologies (e.g. Smith, 1999) underpinned the research process, for safely and ethically engaging with traditional ecological knowledge. This included recognition of the influence of gender (Herod, 1993) and power differentials (Smith, 1999; Kovach, 2009) on researcher-respondent interactions, requiring ongoing, critical self-reflexivity to minimize the risk of perpetuating inequities (e.g. the 'deep colonizing' effects described in Rose, 1999). This research was undertaken with Human Ethics approval (ANU), including the consent and approval of Traditional Owners in Kunbarlanja, and KNP (see declaration). In KNP, the lead author's access was facilitated as part of a National Environmental Research Program funded project, 'Threats to floodplain biodiversity and cultural values' focusing on invasive weeds and climate change (Adams et al., 2018; Bayliss et al., 2016; Dutra et al., 2018). For the work in West Arnhem Land this process was facilitated through the Northern Land Council and subsequently, through close engagement with my Bininj co-authors to ensure the lead author spoke with the right people.

2.2.1. Oral histories and interviews

This research drew on direct oral testimonies of environmental changes affecting people's ability to sustain their freshwater customary harvesting practices. Semi-directed interviews were undertaken between 2012 and 2014 with Traditional Aboriginal Owners, Aboriginal residents and rangers, both men and women, predominantly middle aged and Elders. The skewed weighting of 'Elder' interviewees was a result of the age-dependent nature of Aboriginal biocultural knowledge and authority as well as the nature of the broader study seeking to identify significant social-ecological changes in living memory. Snowball sampling following the recommendations of Traditional Owners and rangers also identified further resident respondents within the Kunbarlanja community. The demographics of interviewees are provided in Table 2. In several instances, repeat or follow up interviews were possible, providing opportunities for iterative learning following the initial identification of the kinga as a significant driver of change in freshwater harvesting practices.

2.2.2. On-Country visits facilitated place-based learning

The author participated in over 40 trips 'on-Country' with Traditional Aboriginal Owners (TOs) and Aboriginal rangers, during 27 field visits between 2012 and 15, to understand environmental change in important resource use areas and in-stream aquatic customary harvesting practices. On-Country visits were crucial to facilitate place-based learning. In an Australian Indigenous world view, Country has sentience and agency which provides the critical context for knowledge sharing; Country guides and facilitates knowledge holders' abilities to share and teach (Woodward and Marrfurra Mctaggart, 2015). Country plays an essential role in the co-production of knowledge (e.g. Wright et al., 2012; Bawaka Country including Suchet-Pearson et al., 2013). Importantly, place-based research can provide opportunities to support the maintenance and transmission of Indigenous knowledge and attachment to important landscapes (Jackson and Douglas, 2015). As the author found, in facilitating access to Country with senior knowledge holders, opportunities for respite from community pressures and for intergenerational and cross-cultural knowledge sharing were also possible, with many trips also including extended family members.

2.2.3. Archival work

Archival material of the region was accessed (Northern Territory Archive Services, AIATSIS records, State Library of NSW). In particular, the Church Missionary Society collection (State Library NSW) held records from the Oenpelli (Gunbalanya) Anglican mission, including photographs, personal and government letters and reports, record and log books such as 'Agriculture and Stock' of the (1925–1975). Any archival findings of community interest (recorded names, photos, any crocodile hunting records) were shared with Kunbarlanja resident research collaborators. Searches of the grey literature relating to saltwater crocodile management issues in the region included historical management plans and online newspaper articles (1900–2018; Google and National Library of Australia's Trove search facilities).

2.2.4. Analysis

Data analysis involved thematic coding of interview material to identify key impacts of the rebound in the saltwater crocodile population. This included changes in accessibility to various aquatic places and species, harvesting method, other ecological impacts, and impacts on social practices and knowledge transfer. Responses were age stratified (younger, middle-aged, Elder) to consider intergenerational differences though, for the reasons stated above, there were fewer 'younger' respondents, all of whom were employed rangers. Consideration was also given to male and female responses given the highly gendered nature of customary harvesting knowledge and practice in many cases (though not all) of the freshwater species targeted. We provide evidence of oral testimony with direct quotes.

3. Results

Firstly, we provide a brief history of human-crocodile interactions in the Alligator Rivers Region incorporating local experiences and observations of the commercial hunting period, and the crocodile recovery era, following legal protection. Secondly, we provide an analysis of the oral testimonies illustrating the impact of the saltwater crocodile's rapid population recovery on contemporary Aboriginal freshwater harvesting practices, and traditional crocodile management knowledge.

3.1. A brief history of human-crocodile interactions in ARR

3.1.1. Prior to unregulated commercial hunting era

Deep time human-crocodile interactions are documented through rock art paintings in the Kakadu and Arnhem Land region. While freshwater crocodiles (*Crocodylus johnstoni*) appear in rock art from around 20,000 years ago, saltwater crocodiles appear from the 'estuarine period' of floodplain formation, c 8000 years ago, following the post-glacial era of sea level rise (Pooley, 2014). A rich body of creation stories, art, song and dance from the western Arnhem region feature saltwater crocodiles (Berndt and Berndt, 1989; Taylor, 1996). Early twentieth century photographs taken in the region by adventurer-photographer Reichenbach ('Ryko'), for example, show Aboriginal men hunting and hauling in a crocodile using spears, from the bank and a floating kuluyambi, or paperbark raft (Reichenbach, in J.W. Stokes Collection, c1916). Despite these photographs likely being 'staged', as Ryko was known to do (Poignant, 1996), they do illustrate customary means of hunting saltwater crocodiles. Aboriginal people have a long history of accessing water bodies to harvest in-stream resources in ways that clearly required navigating the presence of saltwater crocodiles, including wading and swimming to collect resources by hand, spearing from the shallows, and trapping and netting for fish resources, such using a traditional fishing, or walabi net (Fig. 2). Given the influence of saltwater crocodiles on Aboriginal social, cultural and customary economic life, substantial knowledge of crocodile life history, behaviour and habitat distribution to reduce risk in aquatic contexts would have been necessary to co-exist, and continues to be necessary for this renewed co-existence today.

British colonization of the Northern Territory, as across Australia, heavily impacted the demographics of First Nations' populations and later, crocodile population ecologies. First Nations' societal, economic and cultural lives were ruptured or seriously disrupted through disease, conflict, re-settlement in reserves and missions, or gradual migration to centers of colonial economic opportunities (Harvey, 2002; Keen, 1980; Reid, 1996; Ritchie, 2009). Crocodile populations were subject to an era of commercial hunting for skins in the mid twentieth century (1940s–1960s) (Webb et al., 1984).



Fig. 2. Customary fishing using a walabi.
Fish would be herded into the walabi nets, usually requiring people to wade, between ankle and waist deep, in the water. (Source: State Library NSW, CMS Collection, Hart 1925-45, Folder 5, 0EH 536, Courtesy of Anglican Board of Mission Australia.)

3.1.2. Unregulated commercial crocodile hunting (mid 1940s–1970)

Commercial hunting of crocodiles for their skins in northern Australia began in 1945, with the population then estimated at ~100,000 individuals (Webb et al., 1987). Crocodiles were hunted particularly intensively between 1945 and 1971 as civil wars in Africa disrupted traditional supplies to Europe with an estimated 113,000 skins traded (Webb et al., 1984). In the Alligator Rivers Region, the crocodile skin industry, as for other remote industries such as the buffalo hide, was dependent on the labour of Aboriginal people (Fig. 3). For example Lockwood (1947:1) writing for *The Mail*, described:

> '*Without natives there would be no crocodile shooting for profit, just as without them there would be no buffalo shooting and a lot of other things in this country. They are the backbone of the croc camps, and on their goodwill the shooter is almost completely dependent.*'

Customary biocultural knowledge of Country, its waterways and its predatory inhabitants would have no doubt been essential to reduce the dangers of engaging in this high-risk enterprise.



Fig. 3. 'Crocodile skins' (no date, though pre 1950s).
Source: Library & Archives Northern Territory, Litchfield, Jessie, PH0110/0731. (Retrieved 2022, September 30, from https://hdl.handle.net/10070/721805)

Many Aboriginal respondents had family members who participated in commercial crocodile hunting, often alongside the buffalo hide and occasionally, the dingo pelt, economies. Senior linguist at Injalak Arts Centre, Andrew Manakgu, for example, described how his father, Mirndabal Manakgu worked as both a buffalo and crocodile hunter. Manakgu Jnr. recalled joining him, as a 12 year old, in the school holidays; '*out on dugout canoe, hunting along the East Alligator* [River] *with Balanda* [non-Aboriginal person] *rifle and harpoon and torch at night.*' (31/10/12). Mirndabal would

> '*go with other people, holding torch, when no moonlight. See the croc's red eyes. Didn't go for the biggest ones, too scared. He'd bring hides here, salt them, people were paid in rations, money came later.* […] *Men and women working. Women washing hides in water, laying on ground, salting, it was hard work for them too. Mum used to help Dad when shooting over at Red Lily area.*'
>
> (Andrew Manakgu, Kunbarlanja, 1/8/2014)

Anderson Nalorlman, an Adjumarllarl ranger, described how his father would walk from Kunbarlanja to the other side of the East Alligator River (~17 km), staying overnight and come back with 2–5 dingo pelts and 10–11 crocodile skins he would sell to the missionaries at Oenpelli (Kunbarlanja, 19/6/14). Two generations of the Nayinggul family, senior Traditional Owners, were crocodile hunters. Connie Nayinggul's father, Jacob Nayinggul, would use a dinghy and harpoon for the saltwater crocodile. Connie described how the old people would usually go out hunting for a whole week, then bring the skins back to the barge landing, for the women to rub them down with coarse salt to preserve them, as they did for preserving buffalo skins (Kunbarlanja, 20/6/14).

For Timothy Nadjowh and Isaiah Burrunali (Kunbarlanja), their work during this era as local crocodile hunters took them all over floodplain Country, including over at Cannon Hill and to Cooper's Creek in the north-east. The Oenpelli Mission provided the conduit to market from Kunbarlanja. Archival records from the Church Missionary Society document the Oenpelli mission benefitting from the sale of skins, for example Reverend Ronald Ash (1957) noted; '*Oenpelli mission does a fair amount of business in crocodile skins.*' (Ash 20/5/1957) and a lodge of monthly expenditure includes payments for crocodile skins from mid-1956 to late 1970 (Ligtermoet, 2018). There were also mission records of income from crocodile skins and payments made to specific local hunters (1967–70), evidence of the final stages of engagement in the commercial industry prior to protection measures (Ligtermoet, 2018). For those around the South Alligator River, greater mobility was essential to access markets. Elizabeth Pettersson described how her father would travel to Pine Creek, over 200 km away, to sell skins from crocodile hunting in the region that is now Kakadu.

The commercial crocodile skin trade all but extinguished saltwater crocodile populations across northern Australia. The main commercial crocodile hunting era spanned ~20 years, and was experienced first-hand by the present cohort of Elder aged residents. The low prevalence of saltwater crocodiles would have greatly reduced the frequency of human-crocodile interaction, at least with unknown crocodiles, reducing the risk of attack while accessing waterbodies for freshwater resources. The Elder and middle-aged generations recall easily swimming and wading to collect in-stream resources by hand, using traditional netting, and spearing practices (see Table 3). They and their children (e.g. born 1950s–70s and thus helping their parents harvesting through the 1960–80s) were the generations who could access waterbodies with a much-reduced risk of crocodile attack. During the 1970s, crocodile numbers were so low, people almost forgot they were around. For example, Senior Mirrar women Annie Ngalmirama and Nida Mangranbarr described how as girls; '*We didn't really worry about crocs - used to think there were no crocs then!*' (Kakadu, 3/12/14). This low-level of crocodile risk is the experiential baseline against which contemporary environmental conditions are being compared.

Table 3
Examples of respondent's in-stream aquatic resource collection practices, prior to the recovery of saltwater crocodile (kinga) population.

Illustrative comment	Respondent, age class, interview date, location
'When using fish traps, long time ago and old fishing nets - when no kinga. Now can't do anything. I was there swimming with them [old people using nets]. [EL: Did you help?] Yes, I helped with that old net. Used a walabi, used a spear, used to hit the water-bang it, swimming round, with biggest mob children.'	Adrian Gumurdul, male, >50, 7/11/14, Kunbarlanja
'As a girl, would use string fishing basket, throwing net to go for fish. Also swimming, to herd fish at river or billabong. Not today - lots of crocs.'	Garnbaladj Nabegeyo, female, >50, 25/7/12, Kunbarlanja
'Old way of fishing - old people used to make nets, used to scare fish to go in the net, used to get water lily, went deep in billabong, got heaps… When no crocs, go waist deep, take net to bank, open, take back. Maybe two to five hours to fill with fish for family.'	Maxwell Garnarradj, male, 35–50, 2/11/12, Kunbarlanja
'We had no crocodiles then… used to get around billabong, water lily, and fruit of water lily. Now can't get because of crocodiles. And same with mussels. We used to swim and get water lily and everything.'	Connie Nayinggul, female, 35–50, 22/7/12, Kunbarlanja
'Could swim in billabong, collect water lily, before could go for mussels when no croc, just here [pointing to Kunbarlanja billabong] but not now. If no crocs would swim there again.'	Doreen Djorlom, female, 35–50 8/9/12, Kunbarlanja

3.1.3. Crocodile protection and population recovery

The Australian saltwater crocodile population was believed to have dropped to only 3000 animals, just prior to their protection in the Northern Territory in 1971 (Webb et al., 1984). The path to protection, population recovery and sustainable use has been well documented (Webb et al., 1984; Webb and Manolis, 1989; Webb et al., 1987; Fukuda et al., 2011; Fukuda et al., 2020). The population is now 100,000 or more with an estimated 21,000 individuals over 3.5 m long in the Northern Territory (Wood, 2014). Fukuda et al. (2011:1253) suggested the saltwater crocodile population of the NT 'is achieving full recovery from uncontrolled hunting (1945–71)'. Regionally, the removal of the feral Asian water buffalo (*Bubalus bubalis*) during the Brucellosis and Tuberculosis Eradication Campaign (BTEC) in the 1980s would also have facilitated the recovery of the population given the evidence of buffalo impacts to saltwater crocodile habitat and nesting areas (Leach et al., 2009). The subsequent increase in feral pigs (*Sus scrofa*) would also likely have provided a food resource for the saltwater crocodile, though also some predation pressure as pigs were also known to prey on eggs and hatchlings (Leach et al., 2009).

Following a period of low risk, the probability of a crocodile attack has since increased rapidly. Since 1971, 24 people have been killed by crocodiles in the Northern Territory; 14 of those were between 2005 and 2014 (Jenkins et al., 2017). Another 50 have survived attacks (Caldicott et al., 2005; Wood, 2014). In KNP and Kunbarlanja people have observed the increase in numbers. In KNP, for example, Ranger Fred Hunter described:

> '*In the early 90s, for example at Jim Jim Falls* [a confined waterhole frequented by tourists], *there used to be just one* [crocodile moving into the area each wet season]. *In the 2000s, now there's 3 or 4 there. For the first time we're finding them in more distant places.*'
>
> (6/11/14, Kakadu)

The increased threat to life posed by the increased saltwater crocodile abundance is very real. Local Aboriginal families have suffered the loss of family members: '*Nowadays family, even tourists being eaten.*' (Connie Nayinggul, 20/6/2014). Given at least two generations of Aboriginal people have experienced freshwater environments in the

relative absence of saltwater crocodiles, this rapid increase in numbers has implications for freshwater customary harvesting practices.

3.2. Impacts of 'bust then boom' in crocodile population on contemporary engagement with freshwater country

The recovery of the saltwater crocodile population after a period of commercial hunting induced scarcity has changed both crocodile distribution and behaviour in a short period. Not only are they appearing in places they were not previously observed, but respondents also described changes in crocodile behaviour. Crocodiles were perceived as being more aggressive, with large cohorts of young male crocodiles competing for resources and lacking fear of being hunted (prevalent during the commercial hunting era). This has generated constrictions in people's access and engagement with aquatic places on Country, including the relative ease, the frequency, duration, the timing within a season, the locations accessed, the species targeted, the methods used and at times, the composition of the family/social group sharing the activity (i.e. the need to restrict children's access). It has proved a profound shift in experience, as this testimony reveals:

> '*That crocodiles is a big story. It won't let us go in billabong.* […] *Crocodiles stopped us doing what we want to do. Now they're coming back.*'
> Connie Nayinggul, (Incue billabong, Kunbarlanja, 28/10/14)

Below, firsthand accounts of the impacts of saltwater crocodiles are presented, including details on accessing aquatic places, key freshwater resources, consumption preferences and biocultural knowledge transmission, with illustrative testimonies provided in accompanying tables.

3.2.1. Loss of access to freshwater places

The 'boom' in numbers of crocodiles have reduced people's access to virtually all freshwater places that people used to swim at or engage with. Illustrative testimonies on the loss of access to important harvesting places and associated harvesting are provided in Table 4. Access has been restricted both spatially, in terms of the number of safe places depending on surrounding geomorphology or clarity of water, and temporally, i.e. safer late in the dry season when water levels have dropped. A small number of places in KNP were mentioned by some as safe to still swim, being sufficiently shallow from which to observe approaching crocs. For example, Sean Nadji described Sandy Creek, in KNP; '*Narrudj, can swim there, it's easy to see if they're there, if the water is low enough*' but other places, like Arkumungenar (near Cannon Hill) where he swam as a youth, were no longer safe. Respondents described restrictions in the location, ease, and length of time to camp safely, because of heightened crocodile risk. Harvesting techniques requiring physical immersion in water bodies, including swimming, wading, and feeling with hands for collecting filesnake, freshwater mussels and water lilies have been restricted by the necessity to stay out of the water and reduce the likelihood of injury from crocodiles. The loss of these aquatic, immersive experiences are heavily felt. For example, Jessie Alderson (Elder) describing, given it's '*Too dangerous with crocs. I do miss that feeling in the water, very much.*' (Kakadu, 4/11/14).

3.2.2. Loss of access to key species and means of practicing customary harvesting

Traditional fishing practices once widely used in living memory, such as fishing in-stream in groups using walabi nets have since been abandoned, given it is no longer safe to swim or wade waist deep and people are now limited to throwing a hand line from the bank (Table 4). Respondents also reported the end to the use of canoes to assist in catching fish (Table 4). Loss of access (or reduced access) to key in-stream resources, including file snake, water lilies and freshwater

Table 4
Comments illustrating loss of access to key places and harvesting activity or method(s).

Place| harvesting activity or method (s)	Comment (method and resource highlighted in bold)	Respondent, age class, interview date, location
Manlabbarl (Kunbarlanja billabong)| swim	'Would go here [Kunbarlanja billabong], and Red Lily and White Lady for buffalo. Also could **swim there for filesnake, turtle**, but not today, just croc in mud, that kinga, can't go there.'	Alfred Nayinggul, male, >50, 11/10/13 Kunbarlanja
Manlabbarl (Kunbarlanja billabong)| swim, net fishing	'no crocs at all, used to **swim** all day, enjoying ourselves [as a girl]. Used to get some **water lilies**, used to **help old people with nets**.'	Lois Nadjamerrek, female, >50, 27/9/13 Kunbarlanja
Mikginj| swimming, camping, children's fishing	Connie described how they used to go swimming in the main river channel in the Mikginj Valley [outstation] when she was young but couldn't anymore because of too many kinga; 'No swimming now because of crocs… Also **can't stay as long in some camping areas, or overnight, or let kids go fishing**. Big fear of kinga.'	Connie Nayinggul, female, 35–50, 17/9/13; 20/6/14, Kunbarlanja
Spring and waterfall| swim	'Spring, waterfall for **swimming, fishing** (bream), always caught a **fish, filesnake**. Can't go swimming there now - too many crocs.'	Nipper Gumurdul, male, 35–50, 4/10/2013, Kunbarlanja
Manlabbarl (Kunbarlanja billabong)| customary net fishing	Notes: Marlene's parents used the **walabi (customary fishing net**). Marlene knows how to make the net. Just adults, usually partners went. 'But too many kinga for [using] walabi now.'	Marlene Burrunali, female, >50, 4/10/13, Kunbarlanja
Manlabbarl (Kunbarlanja billabong)| swim, modified raft	'Fishing [from bank] ok, but have to be careful. No swimming. But long ago there used to be **swimming**. Had **drum boat, and rafts** of floating mats. Used to go in until ~10 years old [mid 1990s], then parents stopped us. Unsafe, got worried.'	Timothy Nabegeyo, male, <35, 17/6/14; 18/6/14, Kunbarlanja
Cahill's Crossing| canoe	'…at Cahill's Crossing, grandmother and father used [canoes]. Now no [use of] **canoes** because of kinga.'	Connie Nayinggul, female, 35–50, 8/10/14, Kunbarlanja
Yellow Water| swim	'Can't even go swimming now. Yellow Water, used to go **swimming for filesnake and freshwater mussels**…Can still go for filesnake, feel with crowbar, reach down and grab. Have someone watching, can smell croc when there. I still go, lot of people still look for it [**filesnake]**, but **don't swim** for it.'	Elizabeth Pettersson, female, >50, 23/7/14, Kakadu
Kakadu| swim, feeling with hands in reeds	'Not so many crocs in the old days either…Go in for filesnake, big mob, now too many crocs and grasses. I haven't seen anyone **feeling around in the reeds like they used to, fishing with their hands**.'	Fred Hunter, male, 35–50, ranger, 23/7/13, Kakadu
West Kakadu| swim, camp	'Crocodile numbers are the big one [regarding changes affecting harvesting]. They're everywhere now. New ones coming in, lot more of them […] Croc still getting stuck in floodplains and creeks more. Used to be a place on the western boundary of the park where we'd go **camping and swimming** - can't go there anymore.'	Victor Cooper, male, >50, 10/9/14, Kakadu

mussels, was repeatedly referred to (examples provided Table 5). Increased difficulty in accessing magpie goose eggs and only being able to shoot goose as they fly over land (in order to safely retrieve, as opposed to landing in shallow water) were also described (Table 5). Both men and women shared a clear perception of heightened risk and loss of harvesting and accessing aquatic places due to the rebound in crocodile numbers. Many women, however, reported keenly feeling the loss of access to those aquatic species, for example Elizabeth Pettersson, describing feeling '*very sad for now, we love things in the water*' (Kakadu, 23/7/14).

3.2.3. Change in consumption preferences for crocodile meat and eggs

Another consequence of the shifts in saltwater crocodile population from commercial hunting to protection has been a change in consumption preferences for saltwater and freshwater (*Crocodylus johnstoni*) crocodiles. This does not include the totemic or other cultural affiliations that prohibit consumption for some individuals or clan groups. The end of commercial hunting meant the supply of meat as a by-product of skin harvest declined, as Isaiah Burrunali, a crocodile shooter aged ~30 when the commercial era ended, recalled: '*Can't eat, can't shoot 'em. Stopped eating then as couldn't shoot them.*' (23/10/2014). Descriptions of saltwater crocodile consumption ranged from 'in the past', to 'sometimes' and to 'still eaten', though the latter was usually only in reference to any problem crocodiles shot for removal (Table 6). This was partly out of reduced necessity, given there was 'less access to shops' (Table 6) in prior generations, but also given the re-emergence of the saltwater crocodile's 'man-eater' status. The recent fatal attacks on humans and their companion dogs were clear reasons given by individuals in their decision to no longer consume saltwater crocodile meat (Table 6). Similarly, in a 1993 study on traditional floodplain resource use, Minnie Alderson explained; '*Sometimes we would eat kinga here, before, but not now because they eat dogs.*'(Lucas and Russell-Smith, 1993, p.38). Instead, respondents described freshwater crocodiles as the preferred subsistence choice, and more likely to be eaten, though several respondents commented on their decline in abundance as the saltwater crocodile numbers recovered and with the arrival of invasive, poisonous cane toads (*Rhinella marina*).

The inherent risk in harvesting saltwater crocodile eggs (nests are guarded by adult female saltwater crocodiles) was also a clear deterrent for egg consumption (Table 6). This largely appears now only practiced in the course of professional employment, for example the Adjumarllarl Rangers in western Arnhem Land were at times engaged in egg collection by helicopter, for supplying commercial crocodile farms in Darwin (S. Laker, Adjumarllarl Ranger coordinator, 2012, pers. Comm., 25 July), or is outsourced to contractors. Royalties go to the TOs and provide a small but much needed income for the Adjumarllarl ranger group.

Table 5
Comments illustrating the loss of access to 'in-stream' freshwater resources.

Freshwater resource	Comment	Respondent, gender, age class, interview date, location
Fish, mussels, water lilies	'Billabong has plenty of food - fish, mussels, water lily, but this time very hard from crocodile.'	Timothy Nadjowh, OA male, >50, 18/6/14, Kunbarlanja,
Water lilies, mussels	'We had no crocodile then…used to get water lily and fruit of water lily in the billabongs. Now can't get because of crocodiles. And same with mussels. Don't know where croc came from. We used to swim and get water lily and everything.'	Clara Nganjmirra, female, >50, 22/7/12, Kunbarlanja
Water lilies	'Water lilies and stems, too many crocs - can't get.'	Julie Narndal, female, >50, 30/10/12, Kunbarlanja,
Mussels	[Can you still go for mussels?] 'When water level has gone down, where not too deep or frightened for crocodile.'	Doreen Djorlom, female, 35–50, 31/11/12, Kunbarlanja
Fishing	'Kinga [saltwater crocodile] now, don't like to go fishing. Walk around Injalak [Kunbarlanja] billabong, easily see 4–5 crocs, so many, filling up.'	Andrew Manakgu, male, >50, 11/10/13, Kunbarlanja,
Filesnake	'Filesnake, used to be heaps, now crocodile will take you if you try.'	Shaun Namarnyilk, male, 35–50, 31/10/14, ranger Kunbarlanja
Filesnake	'Lot of crocs, hard to get filesnake… A long time ago when I was little… we'd swim in the billabong… I was ten [~20–30 years ago]… People don't swim anymore….too many crocs for filesnake. Only [go] for turtle now [on floodplain with crow bar].'	Jill Roberts, female, 35–50, 25/7/13, Kakadu
Magpie geese eggs	'Eggs are hard to get - water still high and crocs roaming on floodplain. Need airboat, Dell's brother and friends bring goose eggs back'	Dell Hunter, female, >50, 21/6/12, Kakadu
Mussels, magpie geese eggs, filesnake	Mussels: 'used to go chest deep to get them - but now no way with croc. Don't get anymore. That croc makes it really hard.'; 'Used to walk to get [goose] eggs. Can't walk in water anymore - crocs.'; 'Plenty of feed here - fish, filesnake, mussels, red water lily - still there, but too many croc - can't even swim for filesnake. Used to go swimming for mussels and filesnake – now croc…I don't know where croc used to swim before'.	Annie Ngalmirama female (35–50), and Nida Mangranbarr female (>50), 5/12/14, Kakadu
Magpie geese	VC: 'for goose shooting, used to go way out in water and mud.'; Anon: 'Can't do that no more. Goose, only shoot from the air [when flying over land], there's no more ground shooting. Used to use a lure to hook and pull in fallen birds. But gave this up - croc would get them.'	Victor Cooper, male, >50, 10/11/14; Anon., 2014, Kakadu
Freshwater prawn, mussels	'Areas used to swim, knew where old drums were for yabbies. Didn't worry about crocs then, but my kids, they can't go for yabbies, my kids mainly for turtle and fishing. No more swimming in billabongs. Used to collect mussels, now can't.'	Andy Garnarradj, male, 35-50, 2/11/12, Kunbarlanja

Table 6
Comments illustrative of consumption preferences for saltwater and freshwater crocodile meat and eggs.

Comment	Respondent, gender, age class, interview date, location
'Now, don't eat [saltwater] crocodile, but used to eat. People used to take all the time. Don't like so much anymore, don't want to eat - they're eating other people. Still like croc eggs, still eat, boil them up. You can get if make a lot of noise.'	Elizabeth Pettersson, female, >50, 23/7/14, Kakadu
'Crocs [saltwater] Bininj can still eat but not the big ones, not man-eaters. Freshwater crocs, yes tasty, still get some, just get small crocs.'; In response to 'Do you still eat [saltwater] crocs?': 'The young ones. More freshwater crocs eaten, because harmless, small teeth. Still get eggs. Nayinggul and Gumurduls [family names of two respective clans, East Alligator/West Arnhem region] eat saltwater croc eggs. Big ones [adult crocodiles] taste bit too old, not fresh. Too big, might eat person, be a man eater, people then feel don't want to eat it. Best one is freshwater croc. Eggs are really good. Nest in the sand. Like sea turtle, you follow up their track. For saltwater one, has folded grass around, can see all the nest. For freshwater, follow track, we still eat.'	Connie Nayinggul, female, 35–50, 29/7/14; 28/10/14, Kunbarlanja
'Not me, I don't really like that meat anymore. I had a lot as a young girl.'	Julie Narndal, female, >50, 17/7/14 Kunbarlanja
'Saltwater croc is still eaten, but not like goose, just pest crocs. People don't really get themselves very often. Freshwater crocs still eaten and their eggs. Saltwater croc eggs not so much.'	Nourlangie Rangers, 35–50, male, 10/9/14, Kakadu
'Don't eat croc eggs anymore.'	Marlene Burrunali, female, 35–50, 4/10/13, Kunbarlanja
'Some old people ate croc eggs - scary to harvest. Croc nests all along East Alligator channel. Ate eggs as a child'	Nipper Gumurdul, male ranger, 35–50, 4/10/2013, Kunbarlanja.
'Eat turtle eggs more than croc eggs. Nowadays don't eat croc eggs, bit dangerous.'	Andrew Manakgu, male >50, 19/9/13, Kunbarlanja
'Freshwater croc, still eat. Shot or speared. Saltwater croc eggs, still eat on East Alligator side.'	Isaiah Burrunali, male, >50, 23/10/14, Kunbarlanja

3.2.4. Impacts on biocultural knowledge

Given IEK relies on enacting knowledge and experiential learning, the loss of access to water places on Country directly influences biocultural knowledge transmission. This affects IEK on two fronts presented below; firstly, customary knowledge related to crocodile management knowledge and secondly, that for engaging with freshwater resources and managing Country more broadly. Some customary crocodile management knowledge and techniques may have been lost or are no longer in use. This is partly through reduced need to employ such knowledge during the period of crocodile scarcity, and partly due to a reduced essential need to risk encounters for these subsistence resources, as alternatives like shop food became more accessible.

The effectiveness of traditional knowledge for managing crocodiles has in some ways been rendered less effective. Some risk management techniques remain effective. For example, many people commented on being able to detect crocodile presence by the foul stench of crocodile breath; '*can sense them watching, can smell them- like rotting meat- if you smell it, then get out the water*' (anon., female, Kakadu 17/9/13) and '*Can smell when they open mouth, resting on bank. Dog barks alerts us.*' *(Isaiah Nagurrgurrba, male, Kunbarlanja, 11/10/2013)*. However, other customary crocodile management techniques (based on local Aboriginal biocultural knowledge of crocodile behaviour) have been rendered less effective, as crocodile behaviour has purportedly changed in the post-protection era. For example, several respondents described how in their experiences, the older women knew how to make slapping noises with their hands in the water, to replicate the sound of a gunshot to scare away the knowing crocodiles. This technique coincided with, and likely carried over for some time from, the commercial hunting era, where surviving crocodiles had learnt to fear gunshot sound. Joe Nagawalli, a younger KNP Ranger, recalled as a young boy:

> '*swimming with the old ladies* […]. [They would] *be pumping the water to warn saltwater croc.* [The croc] *Would take off. Would make a special noise - amplified underwater, a popping sound, bit like gunshot. Would make the one big croc show himself and usually take off.*'
>
> (Kakadu 10/9/14)

Post-protection, this method was described as less effective for deterring younger cohorts of crocodiles who had no exposure to and thus no fear of gunshots. Elizabeth Pettersson described the increasingly aggressive crocodile behaviour; '*With crocs, can't get in. Used to make big noise in water and crocs would move. Make big splash. Now - just take you straight away*!' (23/7/14, Kakadu).

Part of the contemporary KNP crocodile management strategy includes behavioural management in areas of high human visitation, including subjecting crocodiles to negative encounters with humans (Director of National Parks, 2004). 'Scaring' the crocs by catching and putting them through some uncomfortable procedures (while also collecting data) before release aims to counter the increased curiosity crocs are displaying for motorboats, and to deter them from approaching boats in the future.

In addition to changes in the learnt behaviour of the new cohorts of crocodiles, it is quite likely that structural changes in crocodile population is influencing crocodile behaviour in response to lack of established hierarchy in expanding into new habitat. Heightened aggressive behaviour is a likely outcome of cohorts of similarly aged individuals competing and to recolonize areas, including areas where the older 'boss crocs' who would have maintained hierarchy in their home territory are absent. Customary crocodile management knowledge suggests people were familiar with crocodile behaviour in this 'normal' crocodile hierarchy. For example, Sean Nadji described swimming as a youth at a location near Cannon Hill only with the knowledge of one old dominant resident saltwater crocodile '*keeping the others in line* […] *but with him gone I wouldn't risk it now*' (5/11/2014). The Nourlangie Rangers also commented on the new cohorts and how croc removal doesn't necessarily solve the problem; '*The risk of removing big crocs, too many others come in. Smaller crocs are a bit bolder. Older ones have knowledge of the past.*' (10/9/14, Kakadu). The changes in crocodile hierarchy and behaviour post-protection now pose a greater, less predictable risk. The primary strategy of risk avoidance and only entering the water when it is very shallow and very clear, remains the only safe one.

Loss of opportunities for aquatic experiences and experiential learning, impeds knowledge transmission. There was collective concern among parents and grandparents throughout the region, of not being able to share their aquatic harvesting knowledge and experiences with younger generations. Respondents shared stark differences in intergenerational experiences. For example;

> '*Kids see photos of us twenty years ago swimming for filesnakes and just can't believe it. We used to go swimming in the arms of rivers and get filesnakes. Kids go along the edge now, a lot go with crowbar.*'
>
> anon. (female, Kakadu, 2013)

Adults now in their twenties, youth and children, for example, have never been able to practice or observe customary fishing practices. A mother (anon., Kakadu, 2014) described the difficulties in accessing in-stream resources for the younger generation:

> '*Fishing, it's really hard for kids - they all want to have a go. In my day that was fine, but now, we have to say* '*Oh don't fish there, too risky*' […] *Kids learn by fishing, but now they can't.* […] *Kids would say 'Mum, I want to get that, or try that' and I'd have to say,* '*Well we'd need to get an airboat, sorry kids*'.'

Instead of impromptu trips requiring little material resources, access to equipment like an airboat requires a level of resourcing unavailable to the majority of Bininj harvesters, with obvious equity implications. There are also implications for the degree of freedom children now experience in aquatic places on Country. For example, Victor Cooper (Kakadu) described how it is '*much harder to take kids out hunting and fishing, really have to warn them about crocs*' (21/6/12) and that you '*can't let kids go wandering around now*' (10/9/14).

The loss of these harvesting experiences, while felt at the personal level (see access impacts), also represents loss of collective, shared experience among families and broader social groups. These are the opportunities for experiential learning and engaging with family and ancestors on-Country through customary harvesting, and it concerned both grandparents and parents:

> '*Would have been good to show grandkids how to swim for filesnake in water, let them get the real feel for it. But not now, don't know what you might grab*.'
>
> Jessie Alderson (Kakadu, 4/11/14)

> '*For filesnake, as a young girl, growing up, I would be put in the water, to learn how to feel for it in the roots and root mats, learn the technique. How to handle them, so you can safely grab it by the head and throw it up on bank for the kids to get… It would be a big family event, with grandparents, aunties - big gatherings… it's so lovely, the little ones to old ones together. My kids are not seeing that, not experiencing that.*'
>
> anon. (Kakadu, 2014)

Given the difficulties in entering the water, people are responding and adapting with creative alternatives. In some instances, people are using turtle hunting crowbars or digging sticks to prod the edges of billabongs in search of filesnake. For example, Jessie Alderson (Kakadu, 4/11/14) explained; '*Crocs there now, never swim, but can get filesnake with the crowbar.*'

This is evidence of experimenting with and adapting harvesting practices in striving to sustain access to in-stream resources.

4. Discussion

The most obvious implication of the immediate threat to life that such abundant and widely distributed saltwater crocodiles pose is that people stay out of the water, spend less time engaging with aquatic places and restrict their children's freedom near waterways, out of life-preserving necessity. The cessation of in-stream harvesting practices has had significant socio-cultural impacts, most particularly, the loss of experiential learning and transmission of knowledge, along with the social engagement that comes with sharing these harvesting practices and loss of experience in navigating crocodile risk. These are direct impacts on two of the key determinants of adaptive capacity for sustaining customary harvesting and related cultural practices in times of rapid social-ecological change that is: continued access to Country (including the aquatic places therein), and the opportunity to transmit knowledge and practices across generations.

4.1. Shifting baselines in biocultural knowledge

The conditions of this study accorded with those identified as evidence for shifting baseline syndrome (e.g. as outlined in Papworth et al., 2009; Fernández-Llamazares et al., 2015). Along with the clear prior evidence of biological change (crocodile population) this study illustrates clear changes in the experiences of the aquatic harvesting environment within the lifetime of middle-aged to Elder generations from those born prior to or following the crocodile 'bust and boom'. Fernández-Llamazares et al. (2015) found both age-related differences in the perception of change and a decrease in the intergenerational sharing of environmental knowledge. As in this study, they found one of the reasons for declining intergenerational knowledge sharing was changing patterns in certain subsistence practices, and suggest this is an example of an environmental change that has occurred faster and at a magnitude beyond what customary biocultural knowledge has been able to respond to (Fernández-Llamazares et al., 2015), with potentially serious implications for adaptive capacity (Bao and Drew, 2017). While there is evidence of adaptive measures taken, demonstrating both the resilience and determination of some harvesters to continue to access cultural keystone species (e.g. modified techniques for filesnake harvesting, hand line fishing from the bank), there is clear space for recognition and means of supporting Bininj people's ongoing engagement with freshwater Country and culture.

In this study, respondents clearly identified the experiences of these social-ecological change as one encompassing loss, despite it stemming from a species that 'belongs' (i.e. not introduced). This experience of rapid crocodile abundance change contributes to a distancing of people from Country and kin relations through the loss of direct experience of the environment (Pyle, 1993), in this instance from the aquatic environment through in-stream harvesting practices. The loss of direct experience of the environment is an impact more commonly associated with introduced invasive species, such as the semi-aquatic weed para grass (*Urochloa mutica*) and the cane toad (*Rhinella marina*) (Ligtermoet, 2018), and other direct causes of biodiversity loss. For example, Kai et al.'s (2014: p7) study on the effects of tropical forest biodiversity loss on local ecological knowledge in China, found similar intergenerational loss of experience: '*younger people cannot experience the sights and sounds of forests animals that their parents grew up with*'. So while several studies demonstrate the parallel nature of declines in biodiversity and cultural diversity (Maffi, 2005; Turvey et al., 2010), this study provides evidence of a less recognized environmental driver of experiential loss of customary practices, through the legacy of extreme (and externally driven) fluctuations in crocodile population (accompanied by changes also in customary harvester's subsistence need and preferences).

4.2. Local adaptation to global market opportunities and conservation drivers

The dramatic social-ecological changes wrought by the 'bust-boom' shift in saltwater crocodile population arose in response to external drivers; global commercial markets and changing western conservation values. It presents an example of global forces influencing local-scale adaptive capacity. Local Aboriginal people directly influenced the commercial hunting era, and shaped the development of sustainable use practices in the post-protection era, in having to rapidly respond and manage the implications of the turn-around in crocodile protection status. At the same time, local Aboriginal freshwater cultural practices have been intimately affected by the crocodile population changes these economic and policy shifts entrained. This accords with Ringer et al. (2018) who seek to highlight that causes of degraded access or equity, commonly found in systems experiencing shifting baseline syndrome, are a result of a specific history of policy choices. Cavalier et al. (2022) also found insufficient focus on the role that larger forces (e.g. markets, social injustice) play on the adaptive capacities of societies, in considering drivers of human-crocodile coexistence. This social-ecological change provides an analogue for adaptation, but one which must not be considered in isolation from the impacts of colonization (e.g. Veland et al., 2013).

Contemporary regulated commercial harvesting of saltwater crocodile adults and eggs has grown gradually since the 1980s (Walsh and Whitehead, 1993; Austin and Corey, 2012). Egg harvesting programs feature as an integral part of the 'incentive-driven' Northern Territory conservation program for saltwater crocodiles and have proven both sustainable and no hinder to the full recovery of saltwater crocodile population (Fukuda et al., 2020). Leach et al. (2009) also point out the broader environmental gains of legalized crocodile egg harvest, which requires landowners to improve the management of invasive species harmful to crocodile nesting habitat, such as feral water buffalo, feral pigs and mimosa (*Mimosa pigra*). These are all species with detrimental ecological impacts for floodplain Country, including the aquatic systems and their associated cultural values (Ligtermoet, 2018).

International demand for Australian crocodile skins continues to grow (McCarthy, 2014) and tapping into this economic opportunity represents another way of applying knowledge of Country to engage with the market economy and derive income from living on-Country in remote Indigenous Australia. Sustainable use programs see income generated from the harvesting of crocodile eggs on Aboriginal lands to supply commercial crocodile farms, reinvested into land management activities (Austin and Corey, 2012; Austin and Garnett, 2011). Yet crocodile management and related livelihood opportunities on Aboriginal lands, in Australia at least, continues to attract ongoing debate between local communities and the Northern Territory and Federal Governments. In many cases, external decision-making by distant centers of power, heavily influences local autonomy in sustainable saltwater crocodile management. For example, in 2014 the Federal government (Canberra, ACT) rejected a proposal by local Northern Territory Indigenous community, despite NT government support, for regulated trophy hunting (Wilson and Jokic, 2014). Additionally, there can be layers of socio-cultural responsibilities relating to crocodile management on Aboriginal lands, and in a region spanning different management tenures (e.g. national park vs Aboriginal freehold land) and multiple clan groups with differing cultural affiliations for the crocodile (e.g. totemic responsibilities), different management possibilities and preferences are likely. In engaging with saltwater crocodiles as cultural keystone species, it is critical to recognize the potential for diversity among Indigenous people's preferences for crocodile management, including in the establishment of commercial enterprises (Palmer, 2001; Pooley, 2014).

4.3. Ways forward and recommendations

Even with the removal of 'problem' saltwater crocodiles, ease of access for in-stream harvesting may never return to that experienced by the generation of and immediately following the peak 'croc-hunting days', nor will the material need of accessing aquatic resources return to that of pre-colonial times, or even those times prior to the "shop days" (when access to supermarket food reached the region). Saltwater crocodiles will continue to spread into new emerging habitat, and where human habitation is concerned, prompt further human-crocodile interaction. The marginalization of Indigenous knowledge in managing human-crocodile interaction is evident in the lack of attention to date, for Australian Indigenous people's observations of social-ecological change arising from the legacy of commercial crocodile hunting. Recognizing and reinvigorating Aboriginal biocultural knowledge and practices to help live alongside kinga will only become more critical into the future. This is relevant for local and Indigenous populations living alongside saltwater crocodiles around the world, where the recovery of crocodile populations have increased instances of human-crocodile conflict (Brackhane et al., 2018a; Sideleau et al., 2021).

A way forward is to incorporate programs engaging with and supporting biocultural knowledge, alongside existing or re-designed crocodile conservation science programs in joint management contexts (Table 7). A social-ecological systems approach assists here, where for example, standard crocodile population monitoring could be re-framed as monitoring of a cultural keystone species (Garibaldi and Turner, 2004; Noble et al., 2016). Further, in recognizing an Indigenous worldview that positions human-crocodile interactions as relational, it becomes possible to recognize a suite of values attached to both crocodiles and to freshwater customary harvested species, that connect people to County and Bininj knowledge system/beliefs (for example, after Walsh et al., 2013). Additionally, Whyte (2013) encourages reflecting on Indigenous Knowledge (TEK therein) as a collaborative concept, inviting continual learning across diverse knowledge systems in the shared stewardship or caring for Country. In this light, crocodile monitoring and management presents clear opportunities for engaging with and supporting related Indigenous knowledge and affected cultural practices, and for building shared learnings in managing the growing frequency of human-crocodile interactions. This could incorporate Indigenous storytelling practices and build opportunities to support

Table 7
Recommendations for re-envisaging saltwater crocodile population monitoring and management to support Indigenous Knowledge systems.

Domain of consideration	Aspects to consider
Knowledge considerations	• The IK system(s) underpinning human-crocodile relations in the region in question • The crocodile as a 'cultural keystone species' (e.g. Garibaldi and Turner, 2004) • Potentially developing a *locally relevant* human-crocodile relational framework (e.g. Walsh et al., 2013) • Multiple-Evidence Base approaches can guide working with different knowledges in conservation science (Tengö et al., 2014, Tengö et al., 2017, Pyke et al., 2021)
Governance considerations	To develop new forms of monitoring or management partnerships requires trust and transparent decision-making processes. Recognizing: • these programs ideally would be Indigenous led (e.g. Latulippe and Klenk, 2020; Austin et al., 2019), co-developed through partnerships between local Indigenous knowledge holders and researchers • the adoption of knowledge co-production approaches (e.g. Turnhout et al., 2020) and specifically decolonising approaches (e.g. Hill et al., 2020; Maclean et al., 2022) will support this • the potential for diversity among Indigenous groups for management preferences • the endangered status of many Indigenous languages and the potential for linguistic diversity within a program area • the need to navigate the interactions between local/Indigenous and State governance and land tenure systems in relation to crocodile management preferences, policies and legal requirements.
Potential program level considerations (of a biocultural crocodile monitoring & management program)	• Spanning possible socio-cultural, economic (material), spiritual aspects of local human-crocodile co-existence • Provision for providing opportunities for intergenerational knowledge sharing and learning on-Country • Translation into economic opportunities for Indigenous partners (e.g. rangers on Country, or where desired, sustainable harvest enterprises) • IK of broader related ecologies influenced by the saltwater crocodile • IK related to customary harvested species and practices influenced by the saltwater crocodile • The development of locally relevant, biocultural monitoring indicators to track, not only crocodile population or related ecological changes, but potential stressors to sustaining related IK • Sufficient and sustainable funding and resourcing.

intergenerational knowledge sharing (Fernandez-Llamazares and Cabeza, 2018; Wright et al., 2012). Such programs could increase the understanding of the ecological implications of the crocodile 'bust then boom' for other species (Jessen et al., 2022), and support local linguistic continuity or diversity. Such programs would ideally also integrate culturally relevant indicators for monitoring (e.g. DeRoy et al., 2019; Hanspach et al., 2020). There remains tremendous opportunity to extend or re-shape crocodile related research and monitoring programs to draw on both Western and Indigenous science & knowledge. Knowledge co-production methodological processes for engaging with diverse knowledge systems, such as Multiple-Evidence Base approaches (Tengö et al., 2014; Tengö et al., 2017; Pyke et al., 2021) and decolonizing methodologies (e.g. Maclean et al., 2022; Smith, 1999) can provide paths forward for doing so. This can assist in redressing the marginalization and loss of Indigenous knowledge while strengthening our shared understandings of environmental change and sustainable environmental management.

5. Conclusion

Settler-driven shifts in the population of the saltwater crocodile, as a top-order predator and cultural keystone species, represent an important social-ecological driver of change shaping the capacity of Indigenous peoples in northern Australia to sustain and adapt their freshwater customary harvesting practices, including the intergenerational transmission of biocultural knowledge. The post-protection recovery of the saltwater crocodile population is a conservation science success story. This study demonstrates, however, the prior limited recognition of the legacy effects of historical unregulated commercial hunting upon local Indigenous landowners. Re-envisaging crocodile monitoring and management programs, where such endeavours are collaboratively developed and Indigenous-led, would ensure that related local or Indigenous customary knowledge and practices, are in the first instance, recognized, and secondly, supported in a practical sense. This study also demonstrates the valuable role of applying the shifting baseline syndrome and drawing on multiple evidence base and methodological approaches including environmental and oral histories, to identify contemporary social-ecological impacts or legacy effects, and reduce the risk of assessing social-ecological change against inappropriate timeframes or only one knowledge domain. This is critical in an era seeing rapid social-ecological change generating multiple external stressors for sustaining local Indigenous culture and languages, globally.

Declaration of competing interest

The authors have no conflicts of interest to declare. This research was undertaken with ANU Human Research Ethics Approval (Protocol number 2011/532), research permits from the Northern Land Council (2012 ID 34349, 2013 ID: 42093, 2014 ID: 48079) and a Kakadu National Park research permit RK 787. Consent to participate was sourced from respondents as outlined and required under the conditions of the ANU Human Ethics approval.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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