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Synchronous abortion events in the grey-headed flying-fox (*Pteropus poliocephalus*)

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ABSTRACT

Context. The grey-headed flying-fox (*Pteropus poliocephalus*) is a vulnerable species endemic to eastern and south-eastern Australia. Environmental stressors are important contributors to physiological stress, leading to synchronous abortions. **Aims.** We investigate the possibilities of weather conditions and anthropogenic disturbances contributing to synchronous abortion events in a grey-headed flying-fox (*Pteropus poliocephalus*) roost. **Methods.** We recorded observations of two synchronous abortion events in a flying-fox roost in Tamworth, New South Wales (NSW), Australia, during October 2017 and August 2019. **Key results.** Roost searches found ~200 (October 2017) and 41 (August 2019) foetuses, equating to ~0.5% and >0.1% of adults present at the time, respectively. Neither event was associated with significantly colder than average temperatures nor hot extremes (>42°C). Synchronous abortions cannot be easily attributed to unusually cold or hot site conditions. However, the surrounding region suffered from rainfall deficiencies, known to cause failure of flowering in diet plants, in the 6 months preceding both abortion events. Notably, no rainfall deficiency occurred in 6 months preceding August 2015 when colony size was also large, and no synchronous abortions occurred. **Conclusions.** Natural background rates of abortions are unlikely to explain the abortion events. The 2017 abortion event coincided with intense harassment of flying-foxes using noise agents; thus, it is possible that physiological stress was a contributor. The 2019 abortion event was associated with harassment of lesser intensity but coincided with a severe food shortage throughout surrounding regions. **Implications.** While it is not possible to attribute the synchronous abortion events conclusively to a single factor, the results suggest that the combination of chronic physiological stress from food shortage and acute stress from anthropogenic disturbance may have precipitated both synchronous abortion events.

Keywords: abortion, anthropogenic disturbance, bats, environmental stressors, flying-fox roost, foetal loss, Pteropodidae, reproductive failure.

Introduction

Cases of foetal loss or miscarriage in animals and humans have been associated with maternal physiological stress (Beydoun and Saftlas 2008; Adams *et al.* 2018). Environmental stressors such as extreme weather events and food shortages can be important contributors to physiological stress (Moshkin *et al.* 2003), as well as biological stressors such as infectious agents (Budasha *et al.* 2018; Gharekhani and Yakhchali 2019). Physiological stress can also be brought on by anthropogenic disturbances (Tennessen *et al.* 2016; Szott *et al.* 2019). Gravid mammals are particularly susceptible to physiological stress owing to the high nutritional demands of gestation (Ladyman 2008; Ladyman *et al.* 2010; Fontaine 2012). Mammals such as flying-foxes (*Pteropus* spp.) undertake highly nomadic movements (Roberts *et al.* 2012; Welbergen *et al.* 2020) in response to continual spatial and temporal shifts in food availability (Nelson 1965; Eby *et al.* 1999), and are therefore susceptible to landscape-wide food shortages (Parry-Jones *et al.* 2016). They are also known to incur physiological stress as a result of extreme weather events (Welbergen *et al.* 2008) and anthropogenic disturbances to their arboreal roosts, including deliberate actions to disperse entire colonies (Edson *et al.* 2015). While these stressors have been associated with mass abortions and premature births in flying-foxes (Hall *et al.* 1991), these events remain poorly documented and thus, our understanding of the underlying causes is limited.

The grey-headed flying-fox (*Pteropus poliocephalus*), a federally listed vulnerable species endemic to eastern and south-eastern Australia (Department of Agriculture, Water and the Environment 2021*a*), is a seasonal breeder. Females typically produce one pup annually (Martin *et al.* 1996). Mating occurs from February to May (Martin and McIlwee 2002; Connell *et al.* 2006), with pups born between September and November (Martin *et al.* 1987; Eby 1995). Pups remain with their mothers for at least 3–4 months (Martin *et al.* 1996; Welbergen 2011).

We report two synchronous abortion events in the grey-headed flying-fox, and investigate the possibilities of extreme temperatures, rainfall deficiencies and anthropogenic disturbances being causal factors.

Materials and methods

We recorded observations of two synchronous abortion events in a flying-fox roost in Tamworth, New South Wales (NSW), Australia, during October 2017 and August 2019. This roost is situated along the Peel River and is at times occupied sympatrically by grey-headed flying-foxes and little red flying-foxes (*Pteropus scapulatus*). The roost is also situated close to human settlements, which sometimes leads to amenity impacts for local residents (Tamworth Regional Council 2017) and consequently deliberate harassment of flying-foxes by the community. Foot access within the roost varies due to thick understorey vegetation and steep riverbanks, in addition to some areas being privately owned. Wildlife carers routinely monitor accessible parts of the roost to search for injured flying-foxes. State and local government staff also routinely access the roost to undertake quarterly counts of flying-foxes as part of the National Flying-fox Monitoring Program (Department of Agriculture, Water and the Environment 2021*b*) and additional counts when the local population is large.

During synchronous abortion events, we recorded the number of aborted foetuses (identified as aborted animals from being unfurred) observed and the area of the roost searched to provide some understanding of underestimates. Where possible, foetuses were removed to avoid double-counting in subsequent site visits. Foetal losses were attributed to the grey-headed flying-fox based on our observations corresponding within the months preceding grey-headed flying-fox birthing season, and birthing season of little red flying-foxes occurring at another time of the year (April, May; Eby 1995). We used existing records of grey-headed flying-fox counts (Department of Agriculture, Water and the Environment 2021*b*; Department of Planning, Industry and Environment, unpubl. data) to ascertain the number of adult individuals present in the roost around the time of the synchronous abortion events. Thus, we determined the proportion of aborted foetuses as a percentage of the number of adult individuals present at the corresponding time.

To assess the possibility of extreme weather conditions contributing to synchronous abortion events, weather data (daily maximum and minimum temperatures from 1993–2020) were downloaded from the Australian Bureau of Meteorology (2021*a*) and examined to determine whether October 2017 and August 2019 varied significantly from these months in other years. Historical rainfall maps (Australian Bureau of Meteorology 2021*b*) were also examined to assess rainfall in the 6 months preceding the synchronous abortion events, specifically to determine whether rainfall deficiencies occurred within these periods. We extended these analyses to cover August 2015, during which roost monitoring records show there was a large number of grey-headed flying-foxes present (Department of Agriculture, Water and the Environment 2021*b*), to provide an assessment whether the synchronous abortion events observed were associated with natural background rates of abortions. We also gathered information on residents deliberately harassing flying-foxes to identify possible relationships with aborted foetuses being found.

Three foetuses collected on 18 August 2019 were submitted to the Department of Primary Industries for diagnostic testing for possible detections of Australian bat lyssavirus and Hendra viruses.

Results

October 2017 synchronous abortion event

During the first synchronous abortion event in October 2017 (exact date unknown), an area of 3 ha was searched, representing 35% of the total occupied area of the roost. This resulted in approximately 200 grey-headed flying-fox foetuses recorded. These foetuses were unfurred and found scattered across the ground throughout the searched area of the roost. They were wet to touch, and not in advanced stages of decomposition, indicating they were recently aborted.

Close to the time the foetuses were recorded, population estimates determined there were some 40 000 grey-headed flying-foxes present in the roost (Fig. 1). Thus, the recorded foetuses equated to approximately 0.5% of the adult grey-headed flying-foxes present. However, this percentage was likely a substantial underestimate given that only 35% of the total occupied area of the roost was searched for foetuses during this event.

Notably, large numbers of flying-foxes had been present in the roost for 5 months preceding the October 2017 synchronous abortion event (Fig. 1). These enlarged

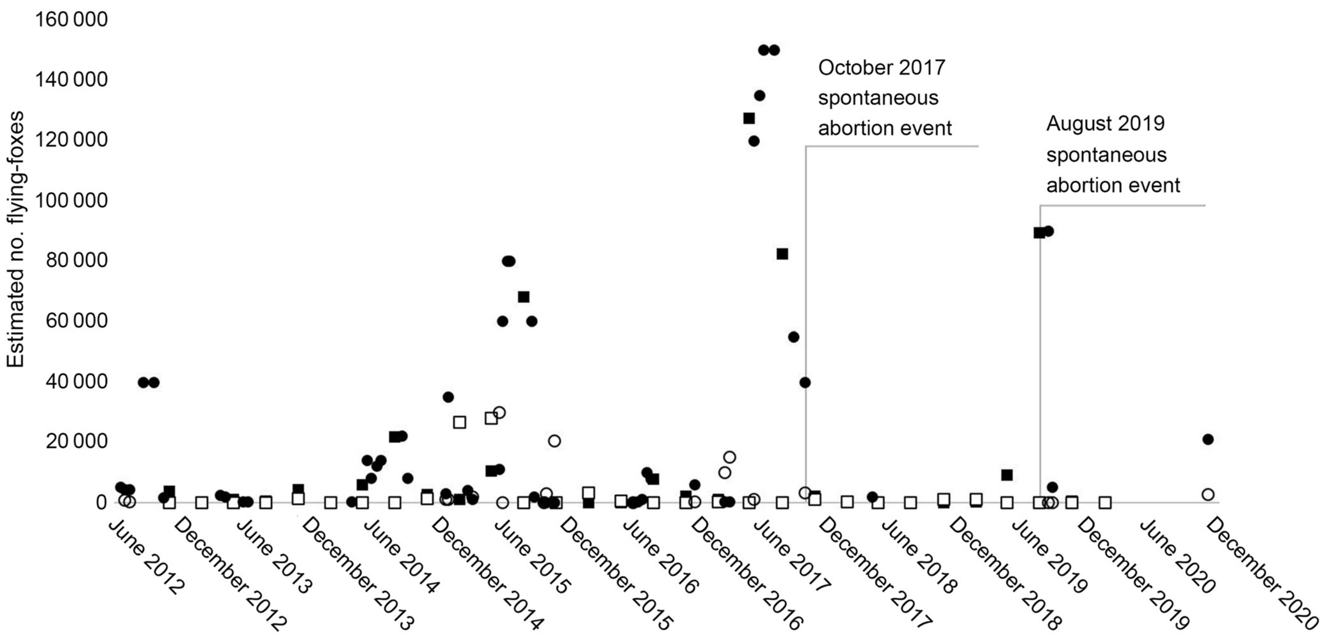

Fig. 1. Flying-fox population estimates from the time the Tamworth flying-fox roost formed in June 2012–December 2020. Estimates of grey-headed flying-foxes are shown in black and estimates of little red flying-foxes shown in white. Population estimates gathered as part of the National Flying-fox Monitoring Program (Department of Agriculture, Water and the Environment 2021*b*) are shown as squares and additional counts undertaken by the Department of Planning, Industry and Environment and/or Tamworth Regional Council are shown as circles.

numbers stimulated negative reactions from the local community, leading to members of the public harassing flying-foxes using noise agents such as starter pistols, air guns and clanging metal pots (J. Price, pers. obs.). At times, flying-foxes were being subjected to near-continuous disturbance.

August 2019 synchronous abortion event

The second synchronous abortion event was recorded between 15 and 18 August 2019, during which 41 flying-fox foetuses were accounted for. However, this likely represents an underestimate as the foetuses were collected only within a 2.7-ha area representing approximately 35% of the total occupied area of the roost (Fig. 2). The remaining 65% of the roost was inaccessible. During the initial site visit on 15 August, 32 flying-fox foetuses were collected from the ground. Similar to the first synchronous abortion event, the foetuses were unfurred, wet to touch, and not in advanced stages of decomposition (Fig. 3). These foetuses were also scattered on the ground throughout the patrolled area. Six additional foetuses were found the following day but not removed (T. Soderquist, pers. comm.). Three additional foetuses were collected on 18 August 2019; these were diagnostically tested and confirmed negative for Australian bat lyssavirus and Hendra viruses (Department of Primary Industries, unpubl. data).

On 16 August 2019, there were an estimated 89 450 grey-headed flying-foxes present (Fig. 1), such that recorded foetuses equated to less than 0.1% of the adult grey-headed flying-foxes present. Again, this percentage was likely a substantial underestimate given that only 35% of the total occupied area of the roost was searched for foetuses during this event.

There was some deliberate harassment of flying-foxes by members of the public immediately preceding this synchronous abortion event but not to the level of intensity of the 2017 event (J. Price, pers. obs.).

Analysis of weather patterns

One-way ANOVAs of minimum daily temperatures revealed that temperatures in August 2019 were no different from average ($F_{1,830} = 0.821$, $P = 0.365$). While the minimum daily temperature went down to −3.5°C (Fig. 4), this happened 5 days after the synchronous abortion event and was well within the range of August minimum daily temperatures observed at the site. The minimum temperatures in October 2017 were warmer than average ($F_{1,831} = 6.548$, $P = 0.107$), with no sub-zero temperatures recorded.

The maximum daily temperatures in August 2019 were significantly warmer than in other years ($F_{1,887} = 9.065$, $P = 0.003$), albeit at no time did they approach temperatures close to 42°C. Maximum daily temperatures in October 2017 were not significantly different from average ($F_{1,872} = 3.276$, $P = 0.071$).

Historical rainfall maps show that the area surrounding the Tamworth roost was suffering from serious to severe

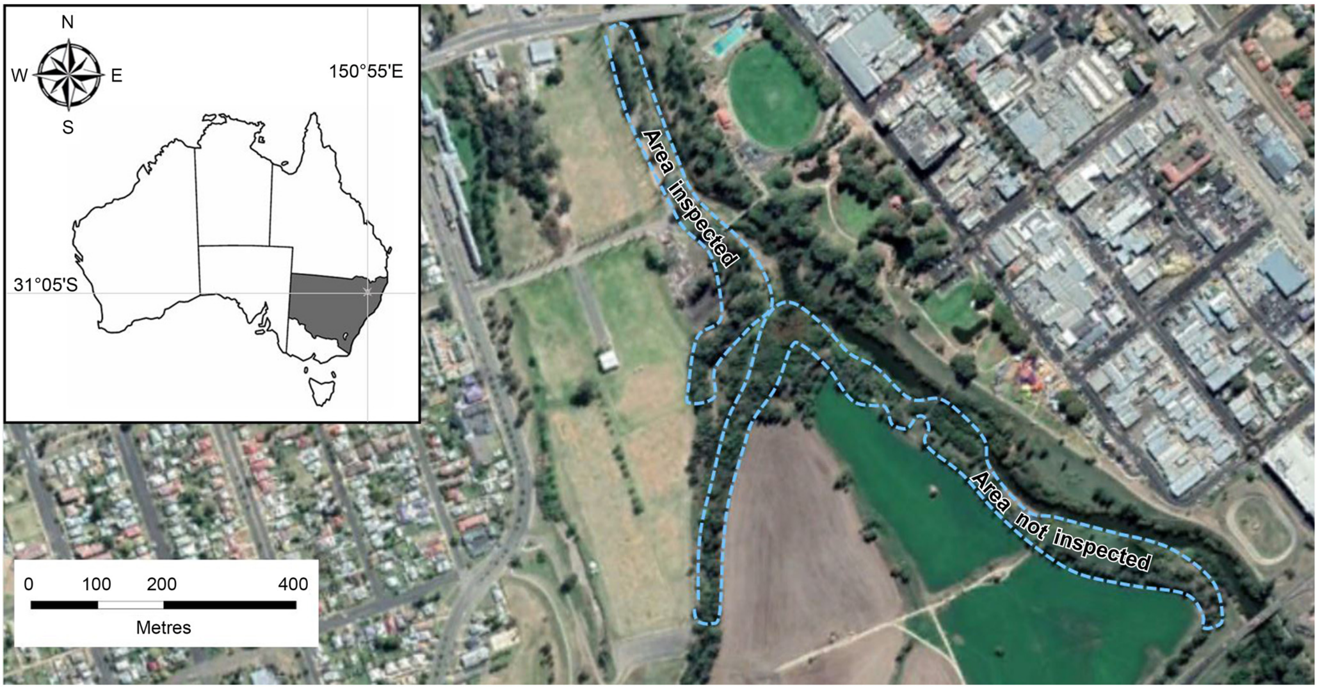

Fig. 2. Area of the Tamworth flying-fox roost that was searched for flying-fox foetuses in the August 2019 synchronous abortion event. Note: the roost also extends to a disconnected patch of vegetation to the north-east, which is not shown here. There were no flying-foxes present in that area during the synchronous abortion event.

Fig. 3. Grey-headed flying-fox foetuses removed from the roost site on 15 August 2019. Photo: J. Price.

rainfall deficiencies during the 6 months preceding the two synchronous abortion events (Fig. 5). In contrast, no rainfall deficiency was recorded for the 6 months preceding August 2015 when no synchronous abortion event occurred, and there were similar numbers of flying-foxes in the Tamworth roost (Fig. 5).

Discussion

Both synchronous abortion events were temporally associated with relatively high numbers of flying-foxes in the Tamworth roost (Fig. 1) and thus, it could be argued that the events simply reflected natural background rates of abortions in the species. However, while the natural background rates are currently unknown, this seems an unlikely explanation because: (1) the events were highly concentrated in time; and (ii) the population was at a similar size in 2015 (Fig. 1) during which time no synchronous abortion event was observed, despite close monitoring of the roost.

During 2017, members of the public harassed flying-foxes, at times subjecting flying-foxes to near-continuous disturbance. It may thus be possible that physiological stress sustained from such disturbances contributed to synchronous abortions. Harassment of flying-foxes also occurred during the time flying-fox numbers increased in 2015 and 2019, but not to the same level of intensity (J. Price, pers. obs.).

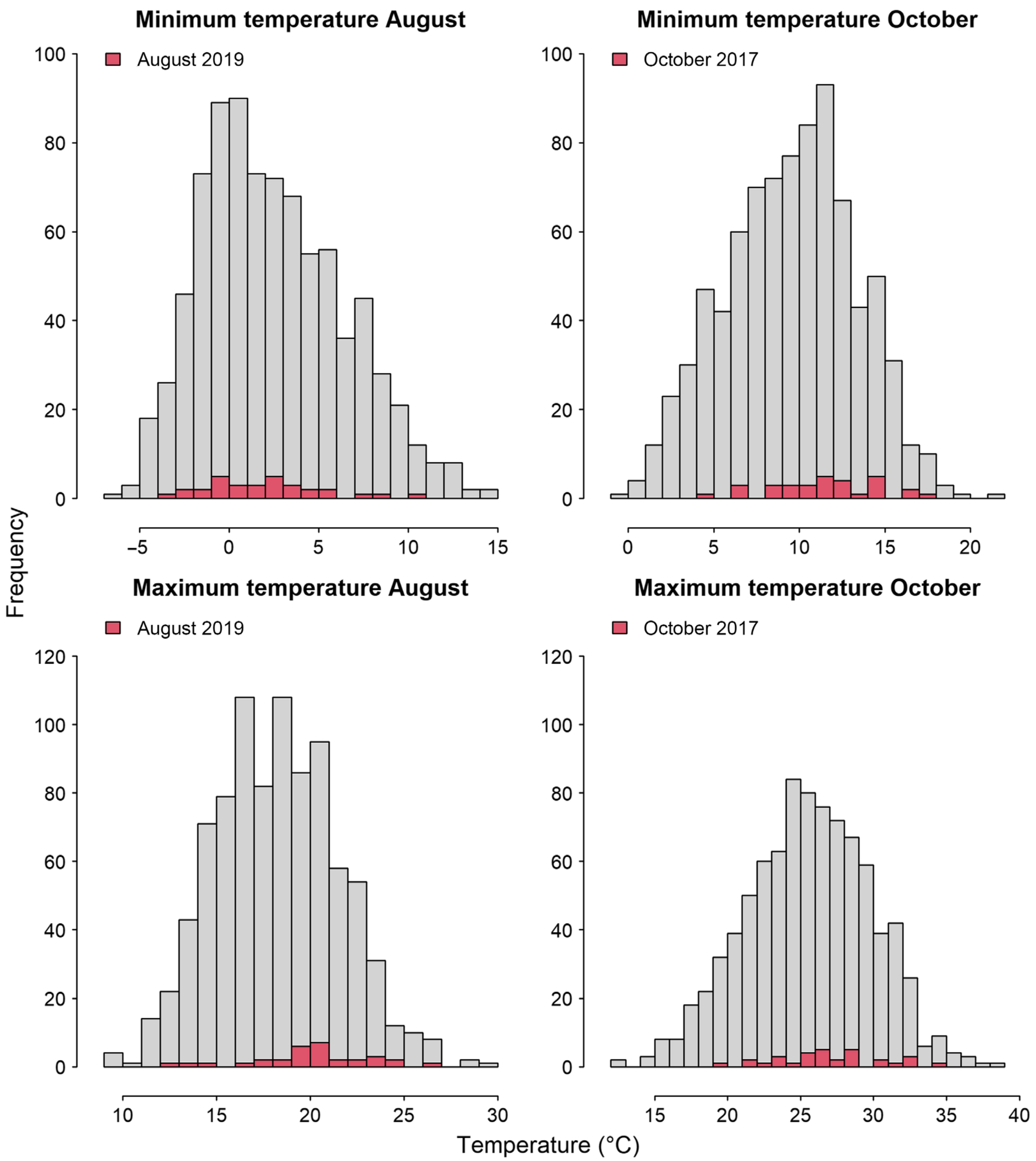

Fig. 4. Frequency histograms showing the minimum and maximum daily temperatures (°C) for the months of August and October from 1993 to 2020 (grey bars). The maximum and minimum daily temperatures for August 2019 and October 2017 (when the synchronous abortion events were observed) are shown as red bars.

Alternatively, extreme weather conditions may have contributed to the synchronous abortion events. Our analysis found that neither event was associated with significantly colder than average temperatures. Therefore, the synchronous abortion events cannot easily be attributed to unusually cold conditions at the site. In addition, neither event was associated with daily hot extremes close to 42°C that are known to be associated with heat stress in *Pteropus* species (Welbergen *et al.* 2008). Therefore, the synchronous abortion events can also not easily be attributed to unusually hot conditions at the site.

However, the area surrounding the Tamworth roost was suffering from serious to severe rainfall deficiencies in the 6 months preceding the two abortion events. Such rainfall deficiencies are known to cause failure of flowering in the grey-headed flying-fox primary food plants

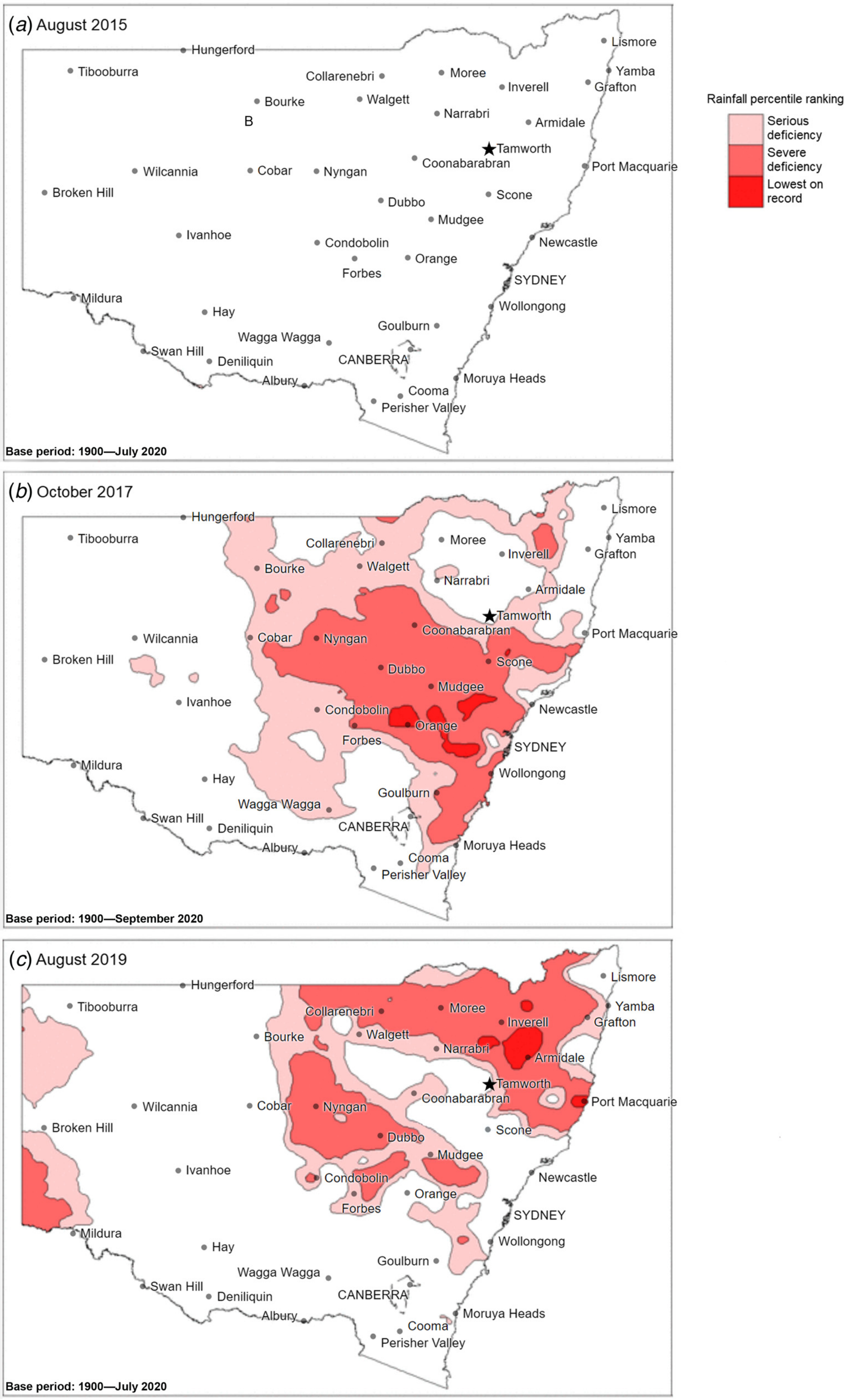

Fig. 5. Six-monthly rainfall deficiency maps for New South Wales and the Australian Capital Territory for (*a*) from 1 February 2015 to 31 July 2015, (*b*) from 1 April 2017 to 30 September 2017; i.e. the 6 months preceding the synchronous abortion event in October 2017, and (*c*) from 1 February 2019 to 31 July 2019. The location of Tamworth is marked with a star.

(e.g. Giles *et al.* 2018). Notably, no rainfall deficiency was recorded for the 6 months preceding August 2015 when the population was also high, and no abortion event occurred.

The synchronous abortion event of October 2017 followed a severe widespread food shortage affecting flying-foxes in NSW and Queensland over the preceding 2016–2017 austral summer, which was associated with mass mortalities of neonates (e.g. Taylor *et al.* 2017) and unusually high numbers of flying-foxes rescued by wildlife carers (Hoh 2017; Mo *et al.* 2021*a*). However, there were no reports of malnourished live and dead flying-foxes in the region at the time of this synchronous abortion event.

The synchronous abortion event of August 2019 coincided with wildlife carers observing large numbers of malnourished live and dead flying-foxes throughout the coastal areas of northern NSW and south-eastern Queensland (Cox 2019; Heathcote 2019), which was indicative of a widespread food shortage spanning from at least July to December 2019. In these regions, dead flying-foxes were reportedly found throughout townships (Mo *et al.* 2021*b*) and visibly malnourished flying-foxes were observed roosting alone away from established roosts. Although such indicators of the food shortage were not reported in Tamworth, flying-foxes in our study site were notably not in optimal body condition (J. Price, pers. obs.) and the correlation in timing suggests that these synchronous abortions were possibly associated with the effects of this food shortage.

In conclusion, the synchronous abortion events of 2017 and 2019 were both associated with large colony sizes and severe rainfall deficiencies in the preceding 6 months. The 2017 event was associated with near-continuous harassment of the colony and followed a widespread food shortage earlier in the year, whereas the 2019 event was associated with harassment of lesser intensity but coincided with a severe food shortage throughout the region. Evidence indicates that gravid females were likely under chronic physiological stress by the time of the synchronous abortion events, due to delayed (2017) and concurrent (2019) effects of food shortage, and such stress is associated with abortions and premature parturition in mammals (Wilmut *et al.* 1986; Guinet *et al.* 1998; Waldner 2014). In addition, anthropogenic disturbance can cause acute physiological stress in wildlife (Tennessen *et al.* 2016; Szott *et al.* 2019), which can also result in abortions and premature parturition in mammals (e.g. Moberg 2000; Dolman and Moore 2017) and more so in malnourished individuals (e.g. Gallagher *et al.* 2021). While it is not possible to attribute the synchronous abortion events conclusively to a single factor, the results suggest that the combination of chronic physiological stress from food shortage and acute stress from anthropogenic disturbance may have precipitated both synchronous abortion events. Due to the retrospective nature of the study, no necropsies and histological examinations were performed on aborted foetuses, which prevented investigation of possible roles of infectious agents apart from three foetuses testing negative in routine diagnostic screening for Australian bat lyssavirus and Hendra viruses.

Our study highlights the need for better documentation of these synchronous abortion events along with the context in which they occur to better understand the scale of the impacts of these events on the species and to help identify their underlying causes. Abortion events involving flying-foxes in Australia can be reported to Wildlife Health Australia via their wildlife incident form (Wildlife Health Australia 2021). Body mass, forearm length and sex of foetuses, count of foetuses per day and the number of days aborted foetuses are observed would be useful information to capture in the field during observations. Necropsy and histological examination of a subsample of fresh foetuses would also be useful for determining whether there are any infectious agents that may have contributed to abortions. Until we have a better understanding of what causes these events, it would be precautionary to avoid disturbing flying-fox colonies during gestation, and especially during times of food shortage.

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Data availability. Information on synchronous abortion events reported in this manuscript can be obtained from the authors. Data from the National Flying-fox Monitoring Program is available from the Australian Department of Agriculture, Water and the Environment's website at https://www.environment.gov.au/webgis-framework/apps/ffc-wide/ffc-wide.jsf.

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