Association between severe cyclone events and birth outcomes in Queensland, Australia, 2008–2018: a population based retrospective cohort study

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Abstract

Objective: Investigate an association between severe tropical cyclones (TCs) and birth outcomes in an Australian population.

Methods: We analysed over 600,000 singleton livebirths collected through the Queensland Perinatal Data Collection between 2008 and 2018. We estimated the odds ratios (ORs) of adverse birth outcomes using logistic multi-level modelling.

Results: Exposure to TCs in early pregnancy was associated with significantly higher odds of preterm births in affected compared to unaffected areas during the TC year [OR=1.28, 95%CI=1.11, 1.49, p=0.001] and slightly significant higher odds in affected areas during TC years compared to non-TC years. Significantly higher odds of low birthweight births were associated with mid-pregnancy exposure to cyclone Marcia [OR=1.62, 95%CI=1.00, 2.40, p=0.016] .

Conclusions: Findings aligned with studies demonstrating an association between exposure to environmental stressors in early to mid-pregnancy and adverse birth outcomes.

Implications for public health: There is limited research into TCs and perinatal health in Australia despite most of the population residing along coastlines and TCs presenting one of the nation's most devastating weather events. This study will inform public health practice and contribute to further research into mitigating environmental risks faced by pregnant women.

Key words: cyclone, low-birthweight, preterm, DOHaD, SGA, Queensland

The first 1,000 days of life are crucial in a child's cognitive and physical development.[1] The fetus is sensitive to environmental stressors that can influence their biology and future health.[2] Natural experiments provide an ethical approach to investigating maternal stress and birth outcomes and their use is recommended when exploring the impact of natural hazards.[3] Climate change and population growth have increased interest in the impact of severe tropical cyclones (TCs) on perinatal health.[4] Studies in Australia, however, remain limited despite the country's seasonal TCs that mainly affect three states (Queensland, Northern Territory and Western Australia) with largely coastal dwelling populations.[5] This study aims to address this gap by analysing multiple TCs and low birthweight (LBW), premature and small for gestational age (SGA) births in an Australian population.

The Developmental Origins of Health and Disease (DOHaD) framework examines the impact of early life environmental cues on adult health using evolutionary, genetic, epidemiological and medical research.[6] This study applies the DOHaD framework to provide epidemiological evidence for an association between environmental stressors and an adaptive shift in phenotypes (i.e. weight at birth and pregnancy duration). Stress can alter pregnancy hormone levels and have a negative impact on fetal development and shorten pregnancy duration.[7] Prenatal stress is associated with increased risk for preterm delivery, reduced fetal growth and LBW.[8] In this study, we hypothesise that stress has a negative impact on fetal growth and pregnancy duration, resulting in smaller babies and earlier births, respectively. Following TCs, mothers are exposed to subjective distress (i.e. psychological impact of the perceived risk) and objective stressors (e.g. loss of loved ones). Internationally, studies have supported associations between maternal TC exposure and gestational age and birth weight but only one has explored this association in Australia to date.[4] For example, Sun et al.[9] assessed just under two million preterm births across TC affected US counties and supported more preterm births during exposed compared to unexposed periods.

The pregnancy stage during which a stressor is experienced can further influence outcomes as fetal systems are continuously undergoing significant, rapid and sequential developmental changes.[10] Early pregnancy stressors can retard growth and development due to the level of nutritional processing and other sensitivities of the early embryonic stage; mid pregnancy exposure would affect the interaction between the placenta and fetus as the placenta grows faster during this

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Submitted: August 2021; Revision requested: March 2022; Accepted: May 2022
The authors have stated they have no conflicts of interest.

Aust NZ J Public Health. 2022; 46:835-41; doi: 10.1111/1753-6405.13273

stage resulting in placental overgrowth and inhibited fetal growth; in late pregnancy, fetal growth would recover from short-term stressors with consequential accelerated fetal growth.[11,12] Therefore, we hypothesise that TC stressors experienced earlier in pregnancy would result in smaller babies and preterm births due to disrupted fetal growth and parturition regulation.

Climate change is driving the frequency and intensity of extreme weather events.[13] Internationally, TC epidemiology has provided insights into the association between TC disasters and perinatal health.[4] For example, increased LBW and preterm births were observed after Hurricane Katrina in New Orleans,[14] Hurricane Charley in Florida[15] and Hurricane Catarina in Brazil,[16] and increased neonatal morbidity following Hurricane Harvey.[17] Australian studies into the impact of disaster events on perinatal health have focused on non-TC events such as pregnancy loss following the Port Arthur mass shooting in Tasmania[18] and increased preterm births and reduced birthweight following the Victorian bushfires.[19] Others have recruited participants after the disaster event.[20] Building on a pilot study supporting increased preterm births following a single severe TC event,[21] this study will use a large administrative perinatal dataset to retrospectively analyse birth outcomes before and after three severe TCs that affected Queensland, Australia.

We hypothesise that severe TCs will result in population level changes in birthweight and gestational age at birth in affected areas and these trends will be more pronounced during TC years when compared to non-TC years. We further hypothesise that the pregnancy stage at which TC exposure occurs will influence birth outcomes. Findings from this study will contribute knowledge about TC epidemiology in Australia and globally and provide a defensible approach to the retrospective analysis of population data and multiple disaster events.

Methods

Study population

Queensland is Australia's third largest state with over four million residents and more than 7,000km of coastline along which most of the population lives.[22,23] Between 2008 and 2018, Queensland experienced three category 5 TCs: cyclones Yasi (2011), Marcia (2015) and Debbie (2017). We used birth records collected through the Queensland Perinatal Data Collection (QPDC) from 1 July 2008 to 30 June 2018 to examine birth outcomes. Cases were removed if the mother was not a usual resident of Queensland (n=6,598), the pregnancy resulted in multiple births (n=10,742) or stillbirths (n=4,288), and where birthweight (n=182) or gestational age (n=125) were unknown (Supplementary Figure 1). We split the 647,634 remaining singleton livebirths into cohorts based on maternal geography and time of exposure (Table 1).

We used two variables to measure birth outcomes: gestational age at birth (weeks) and birthweight (grams). Gestational age was recorded in completed weeks and birthweight the first weight recorded after birth. Small for gestational age (SGA) births were defined as a birthweight less than the 10th percentile.[24]

Geography of exposure

Cyclones Yasi, Marcia and Debbie were declared disaster events requiring the allocation of government relief funding.[25-27]. National Disaster Relief Recovery Arrangement (NDRRA) data reports disaster relief funding allocations to local governments in Australia. TC exposure was therefore measured using Local Government Area (LGA) geographical boundaries. We measured the level of TC impact as a proportion of the total number of available NDRRA activations following each event. Using disaster declarations to classify exposure can over represent affected areas, as declarations are primarily intended for the provision of assistance,[28] therefore, LGAs with a high proportion of NDRRA activations were visually validated against meteorological TC path data to ensure they aligned with the most severe portion of the TC (Supplementary Figure 2). Mapping outputs were generated using esri ArcMap 10.8.1 software.

Time of exposure

Month of birth was used to estimate the pregnancy stage during the month of the TC using an adaptation of an estimation method used by Fuller (2014).[29] Gestation was estimated to have begun a maximum of 40 weeks (9 months) before birth, excluding the month of the TC event (Supplementary Figure 3). This was then used to create both time (year) and geographic cohorts:

- We used year cohorts to compare births during the year of the TC (exposed) and births in the same areas during the previous non-TC year (unexposed).
- We used geographic cohorts to compare births in TC affected and unaffected LGAs during the year of the TC.

Statistical analysis

Logistic mixed-effects regression models were used to account for fixed effects across covariates and random effects between geographical areas. We fitted three main models for each birth outcome (LBW, preterm, SGA): (1) TC affected areas only by year of TC event. This model compared TC years (by pregnancy stage) and non-TC years; (2) TC unaffected areas only by year of TC event (this was used to make the same comparison as in (1), but we expected to find no effect as there were no TCs in those areas. This model was included as a confirmation that our modelling was sound); (3) TC affected and unaffected areas in the same TC year. This model compared affected areas (by pregnancy stage) with unaffected areas during the TC year.

We selected covariates based on an *a priori* analysis of factors known to influence premature births and LBW in an Australian population. These variables included maternal age, marital status, maternal identification as Aboriginal or Torres Strait Islander (Indigenous status), infant sex, smoking during pregnancy, socioeconomic status, maternal country of birth, remoteness and season of birth (Supplementary Table 1). We dropped any cases where covariate values were missing (Supplementary Figure 1). We used a variance inflation factor (VIF) to test for collinearity between the covariates and outcomes and between the covariates alone. All covariates and outcomes had a VIF <5 indicating no collinearity. We developed TC exposure cohort variables as detailed above and summarised in Supplementary Table 1. LGA random effects accounted for variation between LGAs and moderated the probability of Type I and II errors.

Effect size was measured using odds ratios (OR). The variance between LGAs was measured using variance components. Fitting LGA as the random effect with 13 groups in Yasi (2011), five groups in Marcia (2015) and eight groups in Debbie models (2017). We selected a mixed-effects analysis model by calculating the intraclass correlation coefficient (ICC) on an empty model containing no covariates. The ICC tested the degree of homogeneity of the three birth outcomes. Less than 5% of the chance of observing an outcome was explained by between LGA variation.

Table 1: Descriptive statistics (%) for cyclone affected and unaffected areas during the cyclone year. This includes demographic and socio-economic characteristics as a proportion of births in utero at the time of three severe cyclone events: cyclones Yasi (2011), Marcia (2015), and Debbie (2017).

	Cyclone Yasi (2011)		Cyclone Marcia (2015)		Cyclone Debbie (2017)		Qld[a]	Australia[a]
	Affected (n=6,587)	Unaffected (n=37,557)	Affected (n=2,126)	Unaffected (n=33,158)	Affected (n=6,655)	Unaffected (n=15,859)		
Birth outcomes								
Low birthweight (<2,500g)	5.24	4.49	5.03	4.89	5.73	5.61	6.9	6.6
Preterm (< 37 weeks)	7.18	6.11	7.01	6.71	7.83	6.93	9.4	8.6
SGA[b]	10.10	9.15	7.67	8.91	8.20	9.48	8.6	9.4
Maternal age								
35 years and over	17.29	20.24	13.97	20.42	15.52	24.55	21.9	25.0
Less than 35 years	82.71	79.76	86.03	79.58	84.48	75.45	78.1	75.0
Marital status								
Never married	12.83	11.66	13.22	14.85	20.98	16.96	n.a	n.a
Separated/divorced/widowed	1.64	1.45	0.94	1.40	1.92	1.50	n.a	n.a
Married/de facto	85.53	86.89	85.84	83.75	77.10	81.54	n.a	n.a
Indigenous status								
Indigenous Australian	12.96	4.26	7.90	6.88	7.02	7.86	7.5	4.8
Non-Indigenous	87.04	95.74	92.10	93.12	92.98	92.14	92.5	94.7[c]
Maternal country of birth								
Australia	85.29	75.39	86.22	70.69	73.57	64.84	71.3	64.1
Other	14.71	24.61	13.78	29.31	26.43	35.16	28.9	35.9
Infant sex								
Male	51.36	50.98	51.32	51.70	51.95	52.17	51.6	51.4
Female	48.64	49.02	48.68	48.30	48.05	47.83	48.4	48.6
Smoking during pregnancy								
Yes	15.35	12.69	12.65	9.26	13.24	8.19	11.6	9.3
No	84.65	87.31	87.35	90.74	86.76	91.81	88.4	90.7
Parity								
Zero (nulliparous)	14.08	15.88	12.68	16.04	12.85	16.81	41.4	42.7
Two	46.56	47.45	49.83	48.91	44.02	50.97	33.7	35.1
Three	21.84	21.84	23.48	20.65	23.04	19.96	14.7	14.0
Four or more	17.52	14.83	14.01	14.40	19.73	12.27	5.6	4.8
IRSAD quintile[d]								
1 (most disadvantaged)	28.18	23.03	21.50	20.83	36.23	16.85	n.a	n.a
2	39.71	13.92	26.34	15.00	20.21	11.76	n.a	n.a
3	17.49	25.13	50.85	20.29	30.23	11.58	n.a	n.a
4	12.34	20.15	1.32	24.24	12.41	26.13	n.a	n.a
5 (most advantaged)	2.28	17.77	0.00	19.64	0.92	33.68	n.a	n.a
Remoteness[e]								
Major cities	0.00	72.43	0.00	66.83	47.95	67.27	64.8	73.6
Inner regional	14.39	20.88	88.10	11.16	40.14	10.28	18.4	16.3
Outer regional	84.09	4.56	11.90	18.27	10.97	16.47	13.7	7.8
Remote	0.52	0.80	0.00	2.05	0.95	2.85	1.8	1.4
Very remote	1.00	1.34	0.00	1.69	0.00	3.13	1.3	0.9
Season of birth[f]								
Summer	n/a	n/a	n/a	n/a	20.41	10.71	n.a	n.a
Autumn	35.21	34.59	34.67	34.16	23.25	22.50	n.a	n.a
Spring	31.79	32.22	30.95	32.24	21.38	32.48	n.a	n.a
Winter	33.00	33.20	34.38	33.61	34.97	34.31	n.a	n.a

Notes:

SGA = Small for gestational age

IRSAD = Index score of Relative Socio-economic Advantage and Disadvantage

Qld = Queensland

a. Queensland (n = 60,431), Australia (n = 303,054)

b. Liveborn singleton births with a birthweight below the 10th percentile for their gestational age and sex.

c. 0.6% not stated

d. Based on the Australian Bureau of Statistics Index score of Relative Socio-economic Advantage and Disadvantage.

e. Remoteness based on relative access to services using the Accessibility and Remoteness Index of Australia (ARIA+).

f. Based on Australian seasons, Summer (Dec – Feb), Autumn (Mar-May), Winter (Jun-Aug), Spring (Sep-Nov).

Full models were adjusted by adding all covariates and exposure variables (Table 1) to reduce bias towards strong effects and provide estimates of both significant and non-significant effects. We tested the performance of the fitted (adjusted) model using an Area Under the Receiver Operating Characteristics (AUROC) curve. All models had an AUROC value >5 which supported the model distinguishing between the presence and absence of an outcome between LGAs. We visually tested for goodness of fit by plotting observed and predicted outcomes against a diagonal of predicated probability. All statistical analysis was conducted using StataIC 16 software.

Results

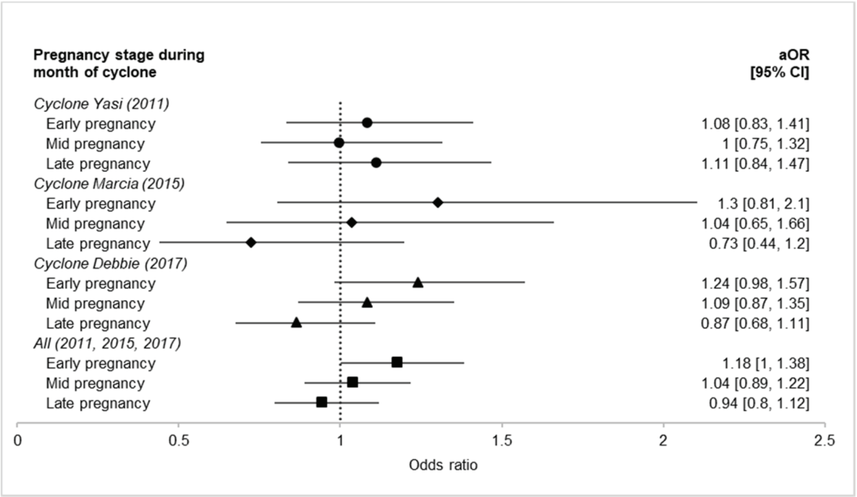
Of 15,368 births in affected and 86,574 births in unaffected areas, affected areas had higher proportions of preterm and LBW births. They also had a higher proportion of mothers aged less than 35 years, living in areas of relative disadvantage and in regional to remote Queensland. Unaffected areas tended to have higher proportions of nulliparous mothers and mothers residing in *Major cities* (Table 1).

Low birthweight

During the TC year, cyclone Yasi affected areas had significantly higher odds of LBW births than unaffected areas [OR=1.28, 95%CI=1.01, 1.63, *p*=0.042], particularly for mothers in mid-pregnancy [OR=1.38, 95%CI=1.02, 1.88, *p*=0.039]. Mid-pregnancy exposure to cyclone Marcia was similarly associated with significantly higher odds of LBW births [OR=1.6, 95%CI=1.10, 2.40, *p*=0.016] (Figure 2a).

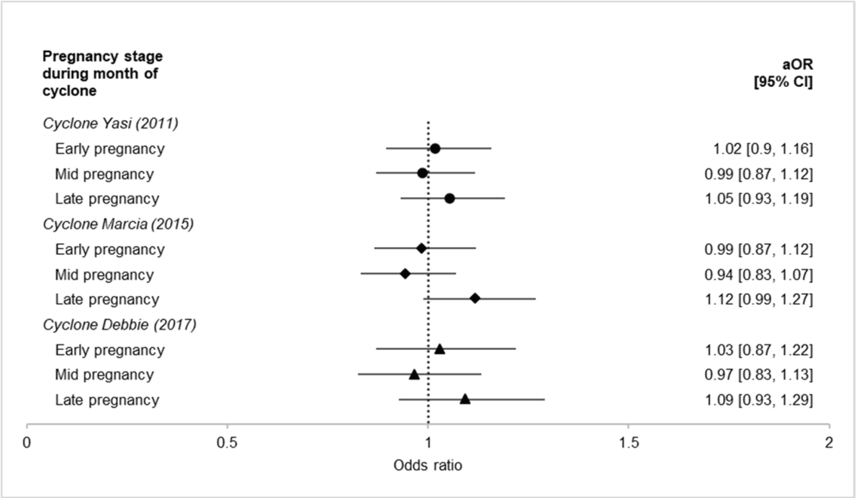
Figure 1: Logistic mixed effects regression of association between three severe cyclone events and recorded preterm births, <37 weeks, effect size measured as an adjusted odds ratio (aOR) with a 95% confidence interval (CI). Comparison between (a) affected areas during the cyclone year and the same areas during a non-cyclone year (b) control test run on unaffected areas during the cyclone year and the same areas during a non-cyclone year.

a. Affected areas during cyclone year and non-cyclone year (exposure groups)



Referent group set as 'non-cyclone year' (women pregnant in the same cyclone affected areas in the year preceding the cyclone). Mixed effects logistic model grouped by LGA. Each cyclone and 'All' represent a separate model adjusted for maternal age, marital status, Indigenous status, infant sex, smoking during pregnancy, socio-economic status, maternal country of birth, remoteness, season of birth, and parity.

b. Unaffected areas during cyclone year and non-cyclone year (control groups)



Referent group set as 'non-cyclone year' (women pregnant in the same cyclone unaffected areas in the year preceding the cyclone). Mixed effects logistic model grouped by LGA. Each cyclone and 'all cyclones' represent a separate model adjusted for maternal age, marital status, Indigenous status, infant sex, smoking during pregnancy, socio-economic status, maternal country of birth, remoteness, season of birth, and parity.

Preterm births

Across all three events, TC exposure in early pregnancy had higher odds of preterm births during the TC year when compared to women in the same areas during a non-TC year. Using an aggregate measure of all TCs found significantly higher odds of preterm births in affected areas during a TC year than a non-TC year [OR=1.18, 95%CI=1.00, 1.38, *p*=0.048] (Figure 1a). These trends were additionally supported by a comparison of unaffected areas across all three TC events that showed minimal variation in the odds of preterm births in unaffected areas between TC and non-TC years (Figure 1b).

During the TC year, we found higher odds of a preterm births following early pregnancy exposure for women in affected areas when compared to unaffected areas. Using an aggregate measure of all TCs, this effect was significant with higher odds of preterm births following early pregnancy exposure in TC affected areas relative to unaffected areas [OR=1.28, 95%CI=1.11, 1.49, *p*=0.001] (Figure 2b).

Small for gestational age births

The odds of SGA births varied across individual TC events and between TC and non-TC years. Broken down by individual TC events, there was an inconsistent association between TC exposure and SGA births both between the TC year and non-TC years and between affected and unaffected areas during the TC year. Areas affected by cyclone Debbie had significantly lower odds of SGA births than unaffected areas during the TC year [OR=0.74, 95%CI=0.63, 0.86, *p*<0.001], particularly for mothers in early [OR=0.65, 95%CI=0.50, 0.84, *p*=0.001] and mid-pregnancy [OR=0.72, 95%CI=0.58,0.91, *p*=0.005]. No significant effect was observed in the aggregate measure.

Discussion

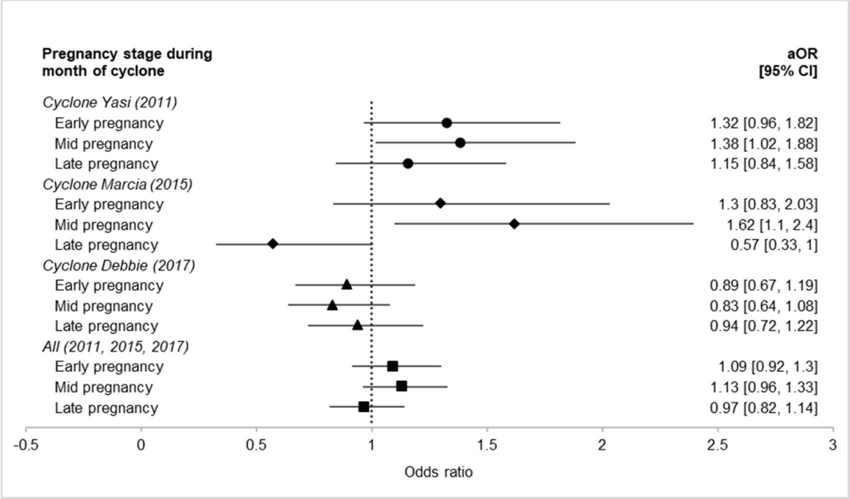
TC exposure in early pregnancy was associated with significantly higher odds of preterm births (Figure 1, Figure 2b), while mid-pregnancy exposure was associated with higher odds of LBW (Figure 2a). Early to mid-pregnancy exposure to cyclone Debbie was associated with lower odds of SGA births. A large proportion (48%) of cyclone Debbie affected areas were in *Major cities* when compared to Yasi and Marcia affected areas, which were in regional to remote areas (Table 1). Births in *Major cities* would have access to a wider range of antenatal care services, and this could drive more positive perinatal outcomes.[30] In the United States, government and non-government health authorities provide disaster guidelines for pregnant women at any stage of pregnancy.[31] In Australia, there is a dearth of guidelines despite the frequency of flooding, bushfires and tropical storm events. Current publicly accessible Australian disaster guidelines focus on risk in women at over 36 weeks gestation.[32] Our results suggest that there is an increased need to also manage risks faced by women in early to mid-pregnancy.

Women in the later stages of pregnancy are at a higher risk of restricted mobility, labour during or just after a disaster and displacement with a newborn.[33] However, environmental stressors can also affect women in the earlier stages of pregnancy impacting fetal development.[34] The stress response is regulated by the hypothalamic-pituitary-adrenocortical axis through the production of corticotropin-releasing hormone (CRH), which is also synthesised by the placenta and rises throughout gestation. Following a stressful event, prematurely elevated circulating CRH early in pregnancy has been associated with preterm and LBW births.[35] In a longitudinal study following the Quebec Ice Storm, women in their first and second trimester during the storm had shorter gestation lengths and lower birthweights when compared to those exposed in their third trimester.[36] As pregnancy progresses, mothers can also become less sensitive to the effects of stress.[10] Studies of earthquakes supported decreased sensitivity to exposure later in pregnancy where women reported reduced perceived stress in their third trimester while earlier pregnancy exposure was associated with shorter gestation.[37] Women in the earlier stages of pregnancy during a disaster are further exposed to post-disaster disruption to health services, household break up and domestic violence, nutritional deficits and reduced economic or social support for a longer period than those exposed later in pregnancy.[38] Early to mid-stages of pregnancy are a vulnerable period particularly for the unborn child's immediate and long-term health risk.

Preterm and LBW births have later life health impacts. In the short term, both are associated with under-developed organs at birth that result in health complications such as restricted brain development, respiratory problems, hypoglycaemia and increased clinical load in neonatal intensive care units.[39] Complications of preterm births are the most common cause of neonatal deaths in high- and middle-income countries.[40] In their own reproductive years, LBW females are at increased risk for hypertensive disorders of pregnancy.[41] Of further concern is the association between preterm and LBW births and the increased risk of obesity, cardiovascular and metabolic risk, and neurocognitive and emotional development in later life[42] and this compounds the already high prevalence of these conditions in high-income countries. Cardiovascular and renal disease contribute significantly to loss of healthy life in Australia.[43] Coronary heart disease remains the leading underlying cause of death in Australia, particularly in males (13% of deaths).[44] This study points to an association between disaster exposure and the increased risk of later life disease and therefore an opportunity for early

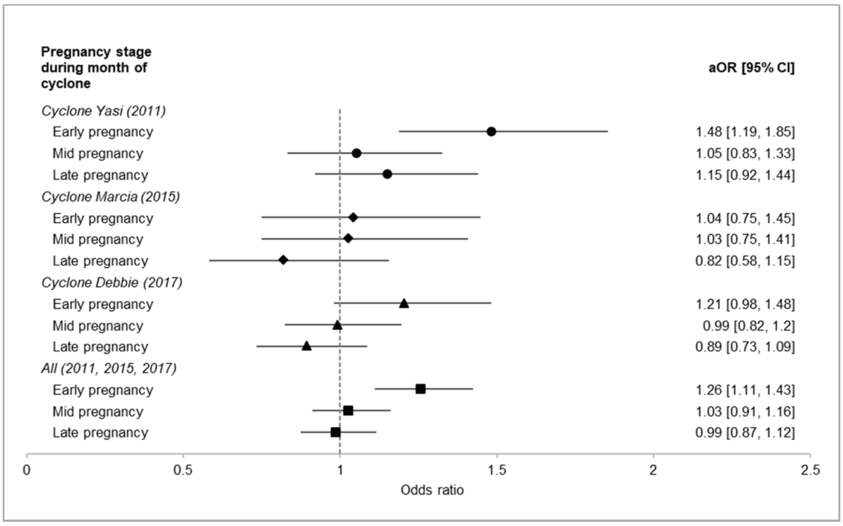
Figure 2: Logistic mixed effects regression of the association between three severe cyclone events and (a) low birthweight births, <2,500g and (b) preterm births, <37 weeks. Effect size measured as an adjusted odds ratio (aOR) with a 95% confidence interval (CI). Comparison between affected and unaffected areas during the year of the cyclone events.

a. Affected and unaffected areas during cyclone year (low birthweight births)



Referent group set as 'unaffected' (women pregnant in unaffected areas during the year of the cyclone). Mixed effects logistic model grouped by LGA. Each cyclone and 'All' represent a separate model adjusted for maternal age, marital status, Indigenous status, infant sex, smoking during pregnancy, socio-economic status, maternal country of birth, remoteness, season of birth, and parity.

b. Affected and unaffected areas during cyclone year (preterm births)



Referent group set as 'unaffected' (women pregnant in unaffected areas during the year of the cyclone). Mixed effects logistic model grouped by LGA. Each cyclone and 'All' represent a separate model adjusted for maternal age, marital status, Indigenous status, infant sex, smoking during pregnancy, socio-economic status, maternal country of birth, remoteness, season of birth, and parity.

intervention as a component of multi-sectoral strategies to reduce chronic disease burden.

TC events had different associations with birth outcomes that could be driven by the TC impact measurement used or characteristics of affected areas. TCs analysed were categorised by the Australian Bureau of Meteorology as category 5 severe storms.[45] However, this study relied on government disaster funding allocations to measure impact aggregating TC impact to large geographical areas. This crude assessment failed to account for differences in storm intensity, which may vary locally depending on topography and characteristics of the communities affected. For example, cyclone Debbie made landfall in smaller coastal and regional communities in the Whitsunday (R) local government area, but the same disaster support was recorded for less vulnerable major cities such as the Gold Coast (C) (Supplementary Figure 2). Although geographical and population characteristics were controlled for in statistical modelling, mediating variables can cause residual confounding and contribute to inconsistent association with birth outcomes. For example, individuals living in the same area could have vastly different experiences of the same disaster event.

Disaster resilience is influenced by socioeconomic status and past experiences. In Australia, disadvantaged communities are more likely to have these vulnerabilities and have been found to be disproportionally affected by bushfire, flood and storm events.[46] We found that across all three TC events a higher proportion of affected than unaffected areas were classified as disadvantaged (Table 1). Findings supported disparities in the communities affected further emphasising the importance of conducting research within this area in Australia to better understand the implications and key points of intervention.[28]

Strengths and limitations

The large sample size gave sufficient statistical power to infer impact, however, in a mixed-effect model, a small number of groups (LGAs) could limit this power. The study design assumes a mother was at her place of usual residence at the time of the TC events. Reverse causality due to population movement around the time of the TCs was possible because of our study design.[47] Disaster events are associated with mass evacuations and some people do not return to affected areas. The ability to evacuate depends on resources for relocation.[48] The mixed-effects model used aimed to address these population changes by controlling for both fixed and random effects within and between geographical areas, respectively. Data on the strength and length of the TC were not available and were unable to be controlled for in this study. The LGA geographical areas used were large government-based spatial units with boundaries subject to change annually affecting temporal analysis. Future research would benefit from quantifying impact and outcomes using population based spatial units such as Census tracts.

Birthweight measurement was subject to measurement bias because it was the first weight after birth or on the date admitted, the latter potentially later than the former. A newborn can lose up to 10% of bodyweight in the days after birth.[49] The calculation of gestational age at birth was based on maternal recollection of last menstrual period and the skills and equipment used influenced the level of accuracy of recorded data.[50]

Implications for public health

Our findings identify TCs as risk factors for consideration in formulating early intervention public health strategies. This paper outlines multiple areas within Australia's existing public health infrastructure that would benefit from reviewing their ability to monitor the needs of women at all stages of pregnancy during natural disasters. This would include health system planning for disasters, public health communication and general access to health services.

A conceptual framework for the effect of disasters on perinatal health recommended key interventions for public health monitoring, disaster planning and resilience building in America.[38] In Australia, tailored maternal mental health and antenatal support could mitigate the effects of experiencing disasters during pregnancy. Identifying maternal mental health triggers associated with disasters allows targeting vulnerabilities in this priority group including remoteness, sociocultural factors and young first-time mothers.[51] The BRAVE Foundation provides support to young first-time mothers and PANDA provides mental health support but both services do not have dedicated resources for disaster preparation and recovery during pregnancy.[52,53]

Furthermore, an Australian Royal Commission into natural disasters called for additional planning for the health needs of pregnant women in evacuations and evacuation centres and the need for dedicated spaces.[54] Current Australian pregnancy clinical care guidelines have limited advice on how to support a pregnant woman exposed to a disaster.[55] Continuity of midwifery carer (MCoC) models offer support during the prenatal, intrapartum and postnatal period and have been supported as improving maternal and neonatal outcomes. Following the 2010-11 Brisbane floods, infants of mothers experiencing MCoC had better outcomes than those receiving standard care.[56] Updates to existing guidelines should include emphasising the pre- and post-disaster assessment of vulnerabilities in women pregnant in areas prone to seasonal TCs including an evaluation of her support networks and the encouraged use of MCoC services.

Our findings will support current policy and programs that prioritise prevention and early intervention in ensuring the health of Australia's children and the future health of the nation.[57] This includes expanding existing health priorities to disaster settings such as: vulnerable younger first-time mothers, interventions in the first 1,000 days of life where the most impact can be made, antenatal and post-natal mental health service provision and through the early reduction of the adult risk of chronic conditions, which are the leading cause of illness, disability, and death in Australia.

Funding

This research is supported by an Australian Government Research Training Program (RTP) Scholarship.

Ethics

Full human ethical approval (unconditional) was granted for this research by the Australian National University Human Research Ethics Committee under protocol #2018/419 and by the Queensland Department of Health, PHA 00419.

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Supporting Information

Additional supporting information may be found in the online version of this article:

Supplementary Figure 1: Process flow illustrating data preparation process including data compilation, exclusions, and final analysis cohorts.

Supplementary Figure 2: Number of Queensland National Disaster Relief and Recovery Arrangements (NDRRA) following tropical cyclones A. Yasi, B. Marcia and C. Debbie and the corresponding cyclone paths as produced by the Australian Bureau of Meteorology.

Supplementary Figure 3: Estimated pregnancy stages applied in this study (early, mid, late pregnancy) based on gestational age in weeks and months, trimester timing, the perinatal period and assessment of gestational age at birth (preterm, term or post-term).

Supplementary Table 1: Outcome and confounder variables, selected based on a priori analysis of relevant literature, used as adjustment factors in regression modelling.