Abstract (250 words max)

Natural environments – green spaces, blue spaces (such as lakes, rivers and beaches), and biodiversity –have potential health benefits. However, there is lack of knowledge about the relationships between these environments and adolescent emotional health. Our study assessed the relationship between the natural environments of residential neighbourhoods and the emotional health of adolescents living in urban New Zealand. Data from 4575 adolescents were drawn from the 2012 wave of the Youth2000 survey series. Emotional health was assessed using the World Health Organization-5 Well-being Index and depressive symptoms were measured using the Reynolds Adolescent Depression Scale-short form. Measures of greenness, vegetation diversity, blue spaces, and a composite available nature index were calculated for participant residential neighbourhoods (within 400 meters, 800 meters, and 1600 meters of the residential address). Cross-classified multilevel linear models were used to assess relationships between each natural environment exposure and each emotional health outcome, and adjusted for sex, age, ethnicity, household deprivation, and neighbourhood deprivation. Results showed significant relationships between reduced depressive symptoms and increased mean greenness, presence of native vegetation, and having a higher nature availability index. Unexpectedly, greater variability in greenness was associated with reduced wellbeing. Our study provides novel evidence of the importance of natural environments for the emotional health of adolescents, adding to mounting evidence that it is important to protect, rehabilitate and plan for natural spaces in urban areas.

Keywords (3-6): adolescence; wellbeing; mental health; greenness; blue space; biodiversity

Research highlights (3-5, max 80 characters each)

- Higher greenness associated with reduced adolescent depressive symptoms
- More natural features associated with reduced adolescent depressive symptoms
- No relationship between blue space and adolescent emotional health

Introduction

Natural environments – green spaces, blue spaces (lakes, rivers and beaches), and biodiversity – have potential emotional health benefits (Frumkin et al., 2017), with increasing evidence demonstrating the protective role of green spaces on adult emotional health (Alcock et al., 2014; de Vries et al., 2016; Gascon et al., 2018; Gascon et al., 2015), and emerging evidence indicating that blue spaces and biodiversity may also support an adult's emotional health (Aerts et al., 2018; de Vries et al., 2016; Dempsey et al., 2018; Fuller et al., 2007; Gascon et al., 2017; Mavoa et al., 2019; Nutsford et al., 2016; Völker and Kistemann, 2011; White et al., 2013).

However, there is less understanding of whether different aspects of natural environments are protective of the emotional health of adolescents. For example, a recent systematic review of greenness and mental health only identified four studies of greenness and mental health in children and none for adolescents (13 years or older) (Gascon et al., 2015). To the best of our knowledge, since this 2015 review, only a handful of studies have explored associations between greenness and the emotional health of adolescents, and these have all demonstrated that increased greenness is related to better emotional health outcomes (Dadvand et al., 2015; Dzhambov et al., 2018; Mennis et al., 2018). These studies have been conducted in Barcelona, Spain (Dadvand et al., 2015), Plovdiv, Bulgaria (Dzhambov et al., 2018), and Richmond, Virginia, United States (Mennis et al., 2018).

While some studies have found that blue spaces are beneficial to the emotional health of adults (Gascon et al., 2017), this evidence is sparse, and there is little evidence for adolescents in the field. Similarly, the paucity of existing evidence (Aerts et al., 2018; Dean et al., 2011) suggests that there may be potential wellbeing benefits of exposure to more biodiverse areas (Aerts et al., 2018; Fuller et al., 2007; Taylor et al., 2017). However, to date, research in this area has only been conducted with adults.

Given the global mental health burden, where mental, neurological and substance use disorders account for 13% of the total burden of disease (WHO, 2013), and the importance of addressing the emotional wellbeing of adolescents (Gluckman and Hayne, 2011; WHO, 2013), it is essential that we improve our understanding of the relationship between the natural environment and adolescent emotional health. Therefore, the aim of our study was to assess the relationship between the neighbourhood natural environment (greenness, blue spaces, and biodiversity) and the emotional and mental health of adolescents living in urban New Zealand. To the best of our knowledge, our study is the first to examine relationships between multiple aspects of the natural environment and adolescent emotional and mental health. Results of our study will have implications for policy makers and practitioners in designing and maintaining planned spaces, in particular cities, so that they are designed to better support the emotional health of urban populations.

Methods

Protocol

Our study used data from the 2012 wave of the Youth2000 survey series, which is the most recent wave of a repeat cross-sectional survey conducted with representative samples of New Zealand secondary school students (NZ high school years 9 -13 , aged approximately 12-19 years) in 2001, 2007, and 2012 (Clark et al., 2013). We used the 2012 wave of data since it most closely matched the time period relevant to the exposure data (which covered the period 2012-2018). In 2012, surveys were self-completed utilising multimedia computer-assisted self-interviewing technology (M-CASI) on internet tablets (Denny et al., 2008). The survey comprised the key areas of: culture and ethnicity; home and family; school; nutrition, exercise and activities; health and emotional health; substance use and gambling; sexual health; injuries and violence; and neighbourhood and spirituality (Clark et al., 2013). Items were read out via a voice-over (students could only hear the voice-over for their own survey on individualised headphones) and these items were also provided in written format on-screen. The survey was anonymous and was delivered in Te Reo Māori (the indigenous language of New Zealand) and English.

Participants were asked for their permission to enter their residential address into a geo-coding program to ascertain the census meshblock and their census area unit (CAU) number for their usual place of residence (AHRG, 2013). Meshblocks are Statistics New Zealand's smallest geographic unit for statistical data (Statistics New Zealand, 2013). Participants who lived across more than one home were asked to enter the address where they spent most of their time. The address data were deleted once the meshblock and CAU number were identified to preserve participant anonymity. Ethical consent to conduct the survey was provided by the University of Auckland Human Ethics Committee (ref 2011/206). Methods and measures specific to our study are described below.

Outcome measures: Emotional and mental health

Emotional wellbeing was measured using the World Health Organization-5 Well-being Index (WHO-5) (Bech et al., 2003). The WHO-5 consisted of five statements where respondents are asked to answer in relation to the last two weeks: "I have felt cheerful and in good spirits," "I have felt calm and relaxed," "I have felt active and vigorous," "I woke up feeling fresh and rested," and "My daily life has been filled with things that interest me". Response options and scoring were: All of the time (5), Most of the time (4), More than half of the time (3), Less than half of the time (2), Some of the time (1), and At no time (0). Scores were summed and could range from 0-25 with a higher score indicating greater wellbeing.

Depressive symptoms were assessed using the Reynolds Adolescent Depression Scale-short form (RADS-SF), which has been shown to have high internal reliability and a high correlation with the full-length Reynolds Adolescent Depression Scale in New Zealand adolescents (Milfont et al., 2008). Participants were asked how they usually felt, and were given 10 statements (specifically "I feel happy," "I feel lonely," "I feel like hiding from people," "I feel sad," "I feel like hurting myself," "I feel I am no good," "I feel I am bad," "I feel mad about things," "I feel bored," and "I feel like nothing I do helps anymore"). Response options and scoring were: Almost never (1), Hardly ever (2), Sometimes (3), and Most of the time (4). "I feel happy" was reverse coded and scores were summed resulting in a RADS-SF score ranging from 10 – 40 with a higher score indicating greater depressive symptoms.

Exposure measures: the natural environment within residential neighbourhoods

The three aspects of the natural environment were assessed using a range of measures: green spaces (average greenness), biodiversity (variation in greenness, vegetation diversity, presence of native vegetation), blue spaces (inland water density, distance to coast), and a composite available nature index. These exposure measures were calculated for three representations of residential neighbourhoods using ArcGIS 10.6 (ESRI, Redlands) and linked to the Youth2000 survey data based on meshblock identifier.

<u>Residential neighbourhood representations</u>

New Zealand 2013 meshblocks were used as the basis for the three different representations of residential neighbourhood. Three different sized neighbourhood representations were created by buffering (i.e. expanding the boundary of) each meshblock by 400, 800, and 1600 meters. The average size of urban meshblocks where participants resided was 25 hectares (slightly larger than 20 Ha, the average size of urban meshblocks in New Zealand). In comparison, the average size of the three residential neighbourhood representations was 140 Ha (400 m neighbourhood), 353 Ha (800 m neighbourhood), and 1080 Ha (1600 m neighbourhood).

<u>Greenness</u>

Greenness was assessed using the normalised difference vegetation index (NDVI). The NDVI is calculated from spectral data obtained from satellites, and is based on the fact that healthy vegetation absorbs more energy in the red wavelength and reflects more infrared (Rhew et al., 2011). The NDVI has been shown to have a high correlation with expert ratings of greenness (Rhew et al., 2011), and has been used in numerous population- based health studies (Markevych et al., 2017). The NDVI ranges from -1 to 1, values less than zero generally indicate water, cloud, snow, or moist soil, values around zero indicate rock or dry soil, and NDVI values nearer +1 represent highly vegetated surfaces (Emerson, 1998).

We used Google Earth Engine (GEE) to calculate NDVI across New Zealand. A custom script extracted Landsat 8 satellite imagery (30 metre by 30 metre resolution) for the period 1-31 January 2014, which calculated NDVI for each image, and extracted the greenest cloud-free pixel. This produced a composite 'greenest January 2014' NDVI dataset across all of New Zealand, which was downloaded from GEE. We used 2014 satellite data because the Landsat 7 satellite that captured imagery for 2012 was affected by a hardware failure resulting in missing data in the images.

To ensure that the NDVI data used in our analyses to determine greenness did not include water features, we subsequently erased all water features from the NDVI data and then extracted only NDVI values greater than zero for subsequent analyses. This approach has been taken by other researchers (Markevych et al., 2014). However, it is important to note that not all NDVI scores less than zero represent water; they may also include snow and moist soil (Emerson, 1998). The water feature data is described in the next section.

We used QGIS software (QGIS Development Team, 2018) and the 'Zonal Statistics' function to calculate the mean and standard deviation of the NDVI values of the land surface only within each neighbourhood representation (Table 1). NDVI data that were a water feature, or had a score of less than zero were not included in these calculations. Mean NDVI within a meshblock is a measure of average neighbourhood greenness. The standard deviation of the NDVI was included for two reasons. First, this study is interested in relationships between biodiversity and adolescent emotional health and variation in greenness is hypothesised to be a proxy for biodiversity (Gould, 2000). Second, previous research has demonstrated that variability in greenness was associated with health benefits, such as reduced odds of obesity (Pereira et al., 2013), coronary heart disease and stroke in adults (Pereira et al., 2012).

<u>Water/blue spaces</u>

The 2013 meshblock boundaries dataset was used to estimate the location of the New Zealand coastline. The ArcGIS 'Near' function was used to calculate the Euclidean distance from the single meshblock boundary to the coast in meters. From this we created a measure indicating whether or not the participant lived within 1600 meters (Euclidean distance) of the coastline. Spatial data on inland water feature polygons (river, canal, lake and pond) were downloaded from the LINZ Data Service on www.koordinates.com. These data were converted to raster format (10 m grid cell size, maximum area cell assignment type) for computational purposes. Inland water features in this raster dataset represent larger water bodies and ranged from 100 m^2 to 612 km^2 (i.e. Lake Taupo, New

Zealand's largest lake). Water bodies such as creeks may not be represented. The presence of inland water within each neighbourhood was assessed using the 'Zonal Statistics' function in QGIS which summarised the total area of inland water within each neighbourhood. Presence of water was assigned when the total area was greater than zero. Living near the coast and having inland water in the neighbourhood represent greater blue space presence.

Biodiversity

Biodiversity is defined as 'the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems' (United Nations, 1992). While biodiversity can include diversity of genes, our research focuses on the diversity of flora species present in the residential neighbourhood. Since there is a lack of data, we use three proxies for biodiversity. The first is the standard deviation of NDVI described above, which is a potential proxy for biodiversity (Gould, 2000) that as yet is unconfirmed with mixed evidence to date (Schmidtlein and Fassnacht, 2017). Two additional biodiversity proxy measures were calculated as follows. Following methods used by Donovan et al. (2018), we calculated two measures using land cover data: 1) the total number of different natural land cover types, and 2) the presence of native vegetation land cover within the neighbourhood (see Table 1). (Burghardt et al., 2009; Clarkson et al., 2018)However, the land cover data is a representation of the dominant land cover in an area and cannot distinguish between specific species. We chose native vegetation presence as a proxy because biodiversity tends to increase with native plants (Burghardt et al., 2009).

Available nature index

Previous research has demonstrated that combined natural features are associated with health and wellbeing (Gidlow et al., 2016; Huynh et al., 2013). Similarly, the combination of natural features may be more important for an adolescent's emotional health than any individual aspect of the natural environment. Therefore, we constructed a simple composite index of available nature for each different sized neighbourhood. Four distinct elements of the natural environment were included in the index: greenness, vegetation diversity (a single element), coast/sea, and inland water. We defined availability of high intensity greenness as mean NDVI >= 0.6, since values greater than 0.6 correspond to dense vegetation (USGS, 2018). Vegetation diversity was defined as > 2 distinct vegetation classes in the neighbourhood. Availability of coast/sea was defined as living within 1600 meters Euclidean distance of the coastline. Availability of inland water was defined as the presence of any inland water in the neighbourhood. The available nature index was created by summing the availability of the four different elements of nature present in the neighbourhood and splitting the index into three categories: 0-1 natural elements, 2 natural elements, 3-4 natural elements. These three categories were chosen since there were small numbers of participants with zero elements and four elements.

Table 1. Spatial measures of the natural environment: description and data sources.

Measure (unit)	Description	Source	Year
Greenness/vegetation measure			
Mean NDVI (dimensionless, possible values in the current study 0-1)	Average greenness in the neighbourhood. We hypothesised that higher levels of greenness would be associated with better emotional health.	Landsat 8 satellite imagery	2014
Blue space measures			
Lives within 1600 m of coast (yes/no)	A dichotomous variable indicating whether or not participants lived within 1600 meters of the coastline. We hypothesised that living near the coast would be associated with better emotional health.	Meshblock boundaries	2013
Any inland water (yes/no)	Presence of any inland water in the neighbourhood. We hypothesised that presence of inland water would be associated with better emotional health.	River, canal, lake, and pond polygons sourced from the LINZ Data Service (https://data.linz.govt.nz/) and licensed for reuse under the CC BY 4.0 licence	2018
Biodiversity measures			
Std dev. NDVI (dimensionless)	Standard deviation of greenness. We hypothesised that higher standard deviations of greenness are a proxy for biodiversity and would be associated with better emotional health.	Landsat 8 satellite imagery	2014
Vegetation diversity (number of vegetation types)	Number of unique vegetation land cover types in the neighbourhood. We hypothesised that greater vegetation diversity would be associated with better emotional health.	Land cover database v 4.0, Ministry for the Environment	2012
Native vegetation presence (yes/no)	Presence of at least one native vegetation land cover type in the neighbourhood. We hypothesised that having at least one type of native vegetation land cover in the neighbourhood would be associated with better emotional health.	Land cover database v 4.0, Ministry for the Environment	2012
Combined measure			
Available nature index (score from 0-4)	Number of different natural features in the neighbourhood. We hypothesised that having more	Refer above	Refer above

natural features would be associated with better emotional health.

Demographic information and participant characteristics

Participants were asked to specify their age in years, sex (based on the question “What sex are you?” with the binary option of either male or female), and how many homes they had (one/two or more). Participants were asked to identify the ethnic groups that they identified with. Responses included one of 22 specified ethnicities. Their ethnic group was then classified into: Māori, Asian, Pacific, European, and Other (e.g. those of Middle Eastern, Latin American, and African heritage) using the New Zealand ethnic prioritisation method (Lang, 2002).

Household and neighbourhood deprivation

Previous research using the Youth’12 dataset has demonstrated that both household and neighbourhood measures of socioeconomic deprivation are important for understanding health outcomes and should be assessed separately (Denny et al., 2016). Therefore, we included measures of both. Households were defined as deprived if they met two or more of the following criteria: lack of a car; lack of a telephone; lack of a computer/laptop; moved homes two or more times in the last 12 months; no parent at home with full time employment; students perceptions that parents worry about not having enough money to buy food; no family holiday in the last 12 months; living room or garage used as a bedroom; and more than two people per bedroom (Denny et al., 2016). Neighbourhood level deprivation was assessed using the New Zealand Index of Multiple Deprivation (IMD) (Exeter et al., 2017).

Sample

The 2012 wave of the Youth2000 survey comprised 8500 participants. Of these we were able to link 8392 to meshblocks (Figure 1). Rural meshblocks can be large compared with urban meshblocks. For instance, in 2013 the average size of urban mesblocks was 20 hectares, whereas the average size of rural meshblocks was 2359 hectares. To ensure that our measures of the natural neighbourhood environment were specific to residential neighbourhoods we restricted our analyses to urban participants only. Therefore we excluded the 1257 participants who did not live in urban areas, as defined by Statistics New Zealand’s Urban Rural Profile (Statistics New Zealand, 2004). We also excluded another 2054 participants who reported having more than one home address, since we were unable to adequately assess residential neighbourhood environments for these participants. Of the remaining 5081 participants, 323 had missing data for one or more variables and were excluded from the analyses. This left us with an analytic sample of 4758 secondary school students residing in New Zealand's urban areas.

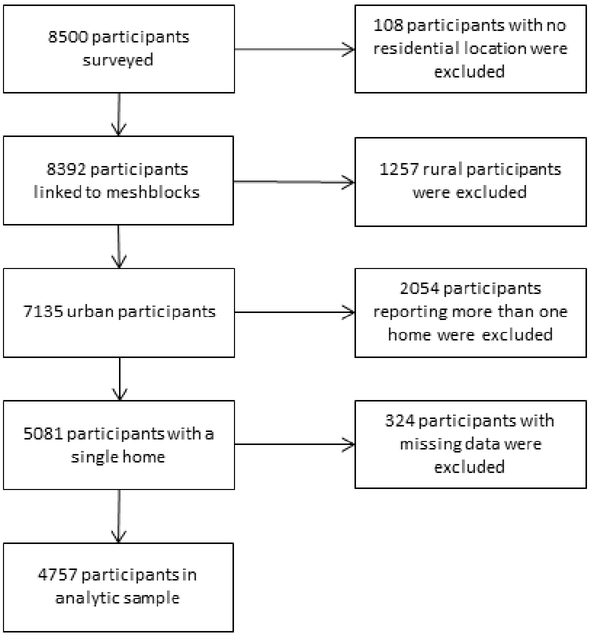

Figure 1. Sample inclusion.

Statistical analyses

T-tests and Pearson's chi-squared tests were carried out to compare the proportion of participants across key demographic categories and outcomes (sex, age, prioritised ethnicity, household deprivation, wellbeing, depressive symptoms) for those included (n = 4757) and excluded (n = 3743 from the analytic sample.

Since participants were clustered in both certain residential areas and in schools, we used cross-classified multilevel linear models to investigate the relationship between the natural environment and emotional wellbeing (WHO-5, RADS-SF). The multilevel models had two levels. The first was the individual level. At the second level both census area unit and school identifier were specified as random effect variables to represent the cross-classified nature of the data. All models controlled for age, sex, prioritised ethnicity, household deprivation, and neighbourhood deprivation. Model fit was assessed with the Akaike information criterion (AIC). All statistical analyses were conducted in Stata/IC 13.1.

Results

Table 3 presents sample characteristics for the full sample of the 2012 wave of the Youth2000 survey (n = 8500) and the analytic sample (n = 4757). Pearson's chi-squared tests showed that there were significant differences between the participants included in and excluded from the analytic sample in terms of sex ($p < 0.001$), prioritised ethnicity ($p < 0.001$), and household deprivation (p <

0.001). The analytic sample had more females, as well as fewer students of Māori and European ethnicities than the excluded sample. T-tests demonstrated that the depression score (RADS-SF) was significantly lower for participants included in the analytic sample (p = 0.018)

Table 3. Sample characteristics.

	Full sample (n = 8500)		Analytic sample (n = 4757)		Test of independence[a]
	n (%)	Mean (sd)	n (%)	Mean (sd)	p
Age					0.275
13 and under	1838 (21.6)		1032 (21.7)		
14	1896 (22.3)		1050 (22.1)		
15	1755 (20.7)		959 (20.2)		
16	1578 (18.6)		885 (18.6)		
17 and over	1433 (16.9)		931 (17.5)		
Sex					<0.001
Female	4575 (54.5)		2692 (56.6)		
Male	3814 (45.5)		2065 (43.4)		
Prioritised ethnicity					<0.001
Māori	1681 (20.1)		787 (16.5)		
Asian	1033 (12.3)		711 (14.9)		
Pacific	1186 (14.2)		782 (16.4)		
European	3976 (47.4)		2184 (45.9)		
Other	507 (6.1)		293 (6.2)		
Household deprivation					<0.001
Deprived	803 (22.1)		881 (18.5)		
Not deprived	6780 (79.8)		3876 (81.5)		
Index of Multiple Deprivation		5.8 (3.0)		5.7 (2.9)	0.219
WHO-5		16.1 (5.9)		16.3 (5.6)	0.068
RADS-SF		19.7 (6.5)		19.4 (6.4)	0.018

[a]Pearson's chi-squared test (categorical data) or t-test (continuous data)

Participants lived in relatively green neighbourhoods, regardless of the size of the neighbourhood assessed (mean NDVI = 0.5; Table 4). An NDVI of 0.5 is on the high end of moderate greenness by international standards, reflecting the relatively high greenness of New Zealand's urban spaces compared to other countries (Richardson et al., 2010).

Approximately one-third of participants had some native vegetation in their 400 meter neighbourhood, but this increased to 79.2% in the 1600 meter neighbourhood. A similar pattern was observed in relation to the presence of inland water, with approximately one-quarter having inland water in the 400 meter neighbourhood compared with 88.7% having this within the 1600 meter neighbourhood. Just over half of the adolescents lived in a meshblock that was less than 1600 meters from the coast. Most adolescents had two or more natural elements (high intensity greenness, vegetation diversity, coastal water, inland water) within their neighbourhoods, with 56.6% of adolescents having 3-4 of these within the 1600 meter neighbourhood.

Table 4. Natural environment characteristics for the analytic sample (n = 4757).

	400 m		800 m		1600 m		No buffer	
	n	**mean (sd)**	**n**	**mean (sd)**	**n**	**mean(sd)**		
Greenness								
Mean NDVI	4757	0.51 (0.09)	4757	0.52 (0.08)	4757	0.53 (0.08)		
Biodiversity proxies								
SD NDVI	4757	0.13 (0.03)	4757	0.14 (0.03)	4757	0.15 (0.03)		
Vegetation	4757	2.37 (1.35)	4757	1.23 (0.59)	4757	0.58 (0.21)		
	n	%	n	%	n	%	n	%
Any native vegetation								
Yes	1804	37.9	2629	55.3	3699	77.8		
No	2953	62.1	2128	44.7	1058	22.2		
Blue space								
Any inland water								
Yes	1255	26.4	2471	51.9	4066	85.5		
No	3502	73.6	2286	48.1	691	14.5		
Distance to coast (meters)								
<= 1600							2215	46.6
> 1600							2542	53.4
Available nature index nature index (number of natural elements)								
0- 1	1550	32.6	964	20.3	306	6.4		
2	2352	49.4	2268	47.7	1867	39.3		
3-4	855	18.0	1525	32.1	2584	54.3		

m=meter; sd=Standard Deviation; NDVI= normalised difference vegetation index

The standard deviation of greenness (NDVI) was the only natural environment measure associated with wellbeing in fully adjusted models (Table 5). Variability in greenness was included in the analyses as an as yet unconfirmed proxy for vegetation diversity that we hypothesised would have a positive relationship with wellbeing. However, unexpectedly the models detected significant negative relationships, with increased variability in greenness being associated with lower levels of wellbeing for the 800 m ($p = 0.037$) and 1600 m ($p = 0.022$) neighbourhoods.

Table 5. Results of fully adjusted[1] multi-level cross-classified models assessing associations between the natural environment and the WHO-5 wellbeing index (n = 4757).

	400 m			800 m			1600 m			No buffer		
	Coef.	95% CI	AIC	Coef.	95% CI	AIC	Coef.	95% CI	AIC	Coef.	95% CI	AIC
Mean NDVI	1.10	-0.93, 3.13	29724.96	1.68	-0.47, 3.83	29723.89	1.18	-1.09, 3.45	29724.90			
SD NDVI	-4.72	-10.40, 0.96	29723.97	**-6.36**	**-12.33, -0.40***	29721.68	**-7.50**	**-13.91, -1.09***	29720.90			
Vegetation	0.03	-0.09, 0.16	29725.52	0.05	-0.24, 0.34	29725.71	-0.29	-1.14, 0.56	29725.27			
Any native vegetation	0.03	-0.33, 0.38	29725.75	-0.01	-0.37, 0.34	29725.79	0.29	-0.15, 0.73	29724.02			
Any inland water	0.24	-0.13, 0.61	29724.58	0.24	-0.08, 0.57	29723.36	0.05	-0.41, 0.51	29725.79			
Within 1600 m of coast										0.11	-0.27, 0.48	29725.47
Available nature index												
0-1	Ref.		29723.53	Ref.		29724.34	Ref.		29726.25			
2	0.01	-0.37, 0.39		0.10	-0.33, 0.53		0.21	-0.47, 0.90				
3-4	0.43	-0.06, 0.91		0.37	-0.10, 0.84		0.38	-0.30, 1.07				

[1]models adjusted for sex, age, ethnicity, household deprivation, and neighbourhood deprivation. AIC = Akaike information criterion.

*p<0.05, **p<0.01, ***p<0.001

Mean greenness (NDVI), presence of native vegetation, and the nature availability index were all significantly associated with the RADS-SF in fully adjusted models in the expected (negative) direction (Table 6). Higher levels of mean greenness in the 400 meter ($p = 0.024$) and 800 meter ($p = 0.035$) were significantly associated with reduced depressive symptoms. Having native vegetation within the 1600 m neighbourhood was associated with reduced depressive symptoms ($p = 0.009$). Finally, having three or more natural environment features in the neighbourhood (400 meter and 1600 meter) was significantly associated with reduced depressive symptoms (400 meter $p = 0.006$; 1600 meter $p = 0.035$). The 800 meter available nature index and the 800 meter standard deviation of greenness models did not converge.

The goodness of fit, as measured by AIC, for Mean NDVI (400 and 800 m), native vegetation (1600 m), and available nature index (400 m) models are within 10 units of each other, indicating a similar goodness of fit (Burnham and Anderson, 2004). However, the 1600 m available nature index model has an AIC of 30918, indicating that this model does not fit the data as well as the other models with statistically significant associations.

Table 6. Results of fully adjusted[1] multi-level cross-classified models assessing associations between the natural environment and the Reynolds Adolescent Depression Scale - Short Form (n = 4757).

	400 m			800 m			1600 m			No buffer		
	Coef.	95% CI	AIC	Coef.	95% CI	AIC	Coef.	95% CI	AIC	Coef.	95% CI	AIC
Mean NDVI	**-2.64**	**-4.94,-0.34***	30895.39	**-2.80**	**-5.23, -0.36***	30895.44	1.92	-4.50,0.66	30832.56			
SD NDVI	4.48	-1.95, 10.91	30898.68	dnc			7.12	-0.14, 14.37	30831.07			
Vegetation	-0.00	-0.15, 0.14	30895.68	0.11	-0.22, 0.44	30895.08	0.27	-0.70, 1.24	30895.30			
Any native vegetation	-0.32	-0.72, 0.09	30893.49	-0.13	-0.53, 0.27	30895.14	**-0.65**	**-1.16, -0.16****	30889.10			
Any inland water	-0.27	-0.68, 0.15	30894.54	-0.23	-0.60, 0.13	30894.07	-0.15	-0.67, 0.38	30895.43			
Within 1600 of coast										-0.33	-0.75, 0.09	30893.49
Available nature index												
1	Ref.		30890.99	Ref.			Ref.		30918.39			
2	-0.22	-0.60, 0.26		dnc			-0.42	-1.19, 0.36				
3	**-0.82**	**-1.37, -0.27****		dnc			**-0.84**	**-1.62,-0.06***				

[1]models adjusted for sex, age, ethnicity, household deprivation, and neighbourhood deprivation. AIC = Akaike information criterion.

*p<0.05, **p<0.01, ***p<0.001

dnc = model did not converge

Discussion

Our study is the first to examine the relationship between multiple natural environment measures and adolescents' emotional health. Increased levels of greenness in the 400 meter and 800 meter neighbourhoods were significantly associated with reduced depressive symptoms. This finding aligns with evidence on the emotional health benefits of green space for New Zealand adults (Nutsford et al., 2013), and supports the accumulating evidence demonstrating greener environments are associated with a range of positive health outcomes in different population groups (Fong et al., 2018; Gascon et al., 2015; Twohig-Bennett and Jones, 2018; van den Berg et al., 2015).

To the best of our knowledge, our study is the first to explore relationships between biodiversity and adolescent emotional health. We calculated several proxy measures of vegetation diversity: variability (standard deviation) of greenness, number of types of vegetation, and the presence of native vegetation. Measuring vegetation diversity is a challenge, and at this spatial extent and scale requires the use of secondary data. Our relatively coarse proxy measures were chosen based on measures used by other researchers (Donovan et al., 2018; Gould, 2000; Schmidtlein and Fassnacht, 2017) and availability of data. We found that presence of native vegetation in the 1600 meter neighbourhood was significantly associated with reduced depressive symptoms. However, we also found that variability in greenness in the 1600 meter neighbourhood was associated with reduced wellbeing. It may also be that variability in greenness measure may be picking up different aspects of the environment such as variability in land uses. Disentangling the multiple and interacting measures of the environment will be an important step forward.

Our inconsistent vegetation diversity findings, together with the coarseness of the vegetation diversity measures suggest that our vegetation diversity results should be interpreted with caution. However, considering that studies with higher resolution biodiversity data have demonstrated positive relationships between biodiversity and emotional health (Cox et al., 2017; Fuller et al., 2007; Luck et al., 2011), our findings also indicate that further research into both measurement of biodiversity, and assessment of relationships with emotional health is warranted.

None of the individual blue space measures were significantly associated with emotional health. Of the two other studies known to the authors that have examined the relationships between blue spaces and adolescent emotional wellbeing, one found associations between presence of blue space (inland water and coast combined) in school neighbourhoods and the wellbeing of Canadian students in urban areas, but not in rural students (Huynh et al., 2013). The other found no clear link between blue spaces and the mental health of Bulgarian adolescents (Dzhambov et al., 2018). The different findings may be due to the different contexts of the diverse study locations (e.g. weather and culture), and/or to the type of blue spaces assessed. For instance, our study distance to coast, the Canadian study assessed area of all blue spaces, and the Bulgarian study only assessed area of inland water since the study city was not located near the coast. The contextual differences between New Zealand, Canada, and Bulgaria could explain the different results. For example, as a relatively small nation with several islands, New Zealand has a greater ratio of coast to land.

Understanding the relationships between different types of blue space and a range of health and wellbeing outcomes will be important for future research since different blue spaces have different characteristics. For example coastal waters have noticeably different sounds, smells, and views, and also facilitate different activities compared to inland waters (e.g. surfing and wind surfing compared to fresh water fishing). Similarly, different types of inland waters (e.g. a stagnant pond versus a flowing river) may generate different health and wellbeing benefits. For example, the 'sounds of nature' associated a river (e.g. flowing water) will differ from those associated with a stagnant pond (e.g. sounds of fauna near/around a pond). However, measuring different blue spaces will require appropriate data, which is a challenge.

We found that adolescents with three or more natural elements in their residential neighbourhoods had, on average, lower rates of depressive symptoms than those with less natural elements, suggesting that having more natural environment characteristics may be more important than a single element of nature. While there are exceptions (Gidlow et al., 2016; Huynh et al., 2013), most of the research on nature and health has focused on single elements and typically assesses the two closely aligned constructs of green space or greenness (Ekkel and de Vries, 2017; Markevych et al., 2017). Therefore, our findings also highlight the importance of considering more than just greenness or green space exposures when examining the emotional health benefits of the natural environment. It will be important for future nature and health research studies to assess: the wellbeing benefits of a wide range of measures of the natural environment (Frumkin et al., 2017); the combined effects of different elements of natural environments; and also whether specific combinations of environmental features are more important than others. This will require overcoming challenges in sourcing appropriate data and creating the relevant metrics.

In the New Zealand context, the importance of natural environments is consistent with Māori assertions about the central importance of the natural environment to wellbeing (Hatton et al., 2017; McNeill, 2017). More specifically, that Māori are physically and spiritually connected to land, mountains, seas and rivers and places – an intrinsic linking of both ecosystems and human health (Panelli and Tipa, 2007). The effects of colonisation and urban growth on Māori, have seen significant negative impacts on Māori, so the development of urban natural spaces will be an important strategy to improve equity (Ryks et al., 2014). Future research exploring differing relationships between natural environments and emotional health for Māori and other ethnic groups will inform equity and wellbeing strategies.

Study strengths and limitations

To the best of our knowledge, our study is the first to assess multiple aspects of the natural environment and biodiversity and emotional health in adolescents. It was strengthened by comprehensive exposure and outcome measures. Three aspects of the natural environment around residential addresses were assessed - greenness, vegetation diversity, and blue space - along with a composite available nature index. Following best practice recommendations (Brownson et al., 2009), the exposure measures were calculated at multiple scales. Furthermore, we analysed two different measures of emotional health – wellbeing and depressive symptoms.

There were a number of limitations associated with our study. First, we lacked precise residential address data and therefore used meshblocks as proxies for the residential address. While this means there may have been some misspecification of the natural environment characteristics, the restriction of the analytic sample to urban participants minimised this issue. Second, the measures of natural environment were restricted by data availability. Therefore, while small water bodies, such as creeks, may be of relevance to adolescent emotional wellbeing, we only assessed the presence of larger bodies of water such as substantial rivers, lakes, and the ocean. Only having data on large water bodies also influenced our greenness measure. We decided to exclude all NDVI scores less than zero to ensure that water was excluded from NDVI. However, since NDVI scores less than zero are not necessarily water, we may have also excluded non-water areas. Our blue space measures only assessed presence of blue space and did not determine whether the blue space was publicly accessible. The simple presence of blue space may have wellbeing benefits (e.g. via the views and sounds linked to a nearby blue space) regardless of whether or not people can physically access the blue space. However, other wellbeing benefits such as those accrued via physical activity may require physical access to the blue space such as via beach access points and public land. Similarly high resolution vegetation data were not available, therefore we used a process established by Donovan et al. (2018) that used vegetation land use classes as proxies for different vegetation types. Finally, while we were able to measure greenness and vegetation land use types, due to lack of data we did not measure the presence of green spaces (e.g. formal parks or public open spaces) within the residential neighbourhood, which might also be important for adolescent emotional health.

Conclusion

Our study provides evidence that living in greener neighbourhoods is associated with improved emotional health for urban dwelling young people. Multiple natural elements in a neighbourhood are also important for young people's emotional health. Ensuring the presence and availability of natural environments in urban areas could independently promote mental health.

Our findings add to mounting evidence that it will be important to protect, rehabilitate and plan for natural spaces in our cities, especially since the natural environment has the potential to support the health and wellbeing of entire populations, (as opposed to targeted health interventions aimed at individuals), and has a number of other health enhancing benefits for adolescents.

Acknowledgements

Youth'12 was funded by the Ministries of Youth Development, Social Development, Justice, Health, Department of Labour, Families Commission and the Health Promotion Agency (formerly ALAC). SM is supported by an Australian National Health and Medical Research Council Early Career Fellowship (grant number 1121035). MS is supported by a Health Research Council of New Zealand Sir Charles Hercus Research Fellowship (grant number 17/013).

References

Aerts, R., Honnay, O., Van Nieuwenhuyse, A., 2018, Biodiversity and human health: mechanisms and evidence of the positive health effects of diversity in nature and green spaces, *British Medical Bulletin* **127**(1)**:**5-22.

AHRG, A. H. R. G., 2013, The Health and Wellbeing of New Zealand Secondary School Students in 2012: Youth'12 Prevalence Tables, in: *Youth2000 Survey Series*, University of Auckland.

Alcock, I., White, M. P., Wheeler, B. W., Fleming, L. E., Depledge, M. H., 2014, Longitudinal Effects on Mental Health of Moving to Greener and Less Green Urban Areas, *Environmental Science & Technology* **48**(2)**:**1247-1255.

Bech, P., Olsen, L. R., Kjoller, M., Rasmussen, N. K., 2003, Measuring well-being rather than the absence of distress symptoms: A comparison of the SF-36 mental health subscale and the WHO-Five well-being scale, *International Journal of Methods in Psychiatric Research* **12**(2)**:**85-91.

Brownson, R. C., Hoehner, C. M., Day, K., Forsyth, A., Sallis, J. F., 2009, Measuring the Built Environment for Physical Activity State of the Science, *American Journal of Preventive Medicine* **36**(4)**:**S99-S123.

Burghardt, K. T., Tallamy, D. W., Gregory Shriver, W., 2009, Impact of Native Plants on Bird and Butterfly Biodiversity in Suburban Landscapes, *Conservation Biology* **23**(1)**:**219-224.

Burnham, K. P., Anderson, D. R., 2004, Multimodel inference: understanding AIC and BIC in model selection, *Sociological methods & research* **33**(2)**:**261-304.

Clark, T., Fleming, T., Bullen, P., 2013, The prevalence of health and wellbeing issues of New Zealand's young people attending secondary schools. Methodology and results from the Youth'12 national youth health and wellbeing survey, *Auckland: The University of Auckland*.

Clarkson, B., Kirby, C., Wallace, K. J., 2018, Restoration targets for biodiversity depleted environments in New Zealand.

Cox, D. T., Shanahan, D. F., Hudson, H. L., Plummer, K. E., Siriwardena, G. M., Fuller, R. A., Anderson, K., Hancock, S., Gaston, K. J., 2017, Doses of neighborhood nature: The benefits for mental health of living with nature, *BioScience* **67**(2)**:**147-155.

Dadvand, P., Nieuwenhuijsen, M. J., Esnaola, M., Forns, J., Basagaña, X., Alvarez-Pedrerol, M., Rivas, I., López-Vicente, M., De Castro Pascual, M., Su, J., Jerrett, M., Querol, X., Sunyer, J., 2015, Green spaces and cognitive development in primary schoolchildren, *Proceedings of the National Academy of Sciences of the United States of America* **112**(26)**:**7937-7942.

de Vries, S., ten Have, M., van Dorsselaer, S., van Wezep, M., Hermans, T., de Graaf, R., 2016, Local availability of green and blue space and prevalence of common mental disorders in the Netherlands, *BJPsych open* **2**(6)**:**366-372.

Dean, J., van Dooren, K., Weinstein, P., 2011, Does biodiversity improve mental health in urban settings?, *Medical hypotheses* **76**(6)**:**877-880.

Dempsey, S., Devine, M. T., Gillespie, T., Lyons, S., Nolan, A., 2018, Coastal blue space and depression in older adults, *Health & Place* **54:**110-117.

Denny, S., Lewycka, S., Utter, J., Fleming, T., Peiris-John, R., Sheridan, J., Rossen, F., Wynd, D., Teevale, T., Bullen, P., 2016, The association between socioeconomic deprivation and secondary school students' health: findings from a latent class analysis of a national adolescent health survey, *International journal for equity in health* **15**(1)**:**109.

Denny, S. J., Milfont, T. L., Utter, J., Robinson, E. M., Ameratunga, S. N., Merry, S. N., Fleming, T. M., Watson, P. D., 2008, Hand-held internet tablets for school-based data collection, *BMC Research Notes* **1**(1)**:**52.

Donovan, G. H., Gatziolis, D., Longley, I., Douwes, J., 2018, Vegetation diversity protects against childhood asthma: results from a large New Zealand birth cohort, *Nature plants* **4**(6)**:**358.

Dzhambov, A. M., Markevych, I., Hartig, T., Tilov, B., Arabadzhiev, Z., Stoyanov, D., Gatseva, P., Dimitrova, D. D., 2018, Multiple pathways link urban green-and bluespace to mental health in young adults, *Environmental research* **166:**223-233.

Ekkel, E. D., de Vries, S., 2017, Nearby green space and human health: Evaluating accessibility metrics, *Landscape and Urban Planning* **157:**214-220.

Emerson, C. W., 1998, Multi-scale fractal analysis of image texture and pattern, Marshall Space Flight Center, The University of Alabama in Huntsville, Huntsville.

Exeter, D. J., Zhao, J., Crengle, S., Lee, A., Browne, M., 2017, The New Zealand Indices of Multiple Deprivation (IMD): A new suite of indicators for social and health research in Aotearoa, New Zealand, *PloS one* **12**(8)**:**e0181260.

Fong, K. C., Hart, J. E., James, P., 2018, A review of epidemiologic studies on greenness and health: Updated literature through 2017, *Current environmental health reports* **5**(1)**:**77-87.

Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn Jr, P. H., Lawler, J. J., Levin, P. S., Tandon, P. S., Varanasi, U., Wolf, K. L., 2017, Nature contact and human health: A research agenda, *Environmental health perspectives* **125**(7).

Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., Gaston, K. J., 2007, Psychological benefits of greenspace increase with biodiversity, *Biology letters* **3**(4)**:**390-394.

Gascon, M., Sanchez-Benavides, G., Dadvand, P., Martinez, D., Gramunt, N., Gotsens, X., Cirach, M., Vert, C., Molinuevo, J. L., Crous-Bou, M., Nieuwenhuijsen, M., 2018, Long-term exposure to residential green and blue spaces and anxiety and depression in adults: A cross-sectional study, *Environ Res* **162:**231-239.

Gascon, M., Triguero-Mas, M., Martinez, D., Dadvand, P., Forns, J., Plasencia, A., Nieuwenhuijsen, M. J., 2015, Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review, *Int J Environ Res Public Health* **12**(4)**:**4354-79.

Gascon, M., Zijlema, W., Vert, C., White, M. P., Nieuwenhuijsen, M. J., 2017, Outdoor blue spaces, human health and well-being: A systematic review of quantitative studies, *Int J Hyg Environ Health* **220**(8)**:**1207-1221.

Gidlow, C. J., Randall, J., Gillman, J., Smith, G. R., Jones, M. V., 2016, Natural environments and chronic stress measured by hair cortisol, *Landscape and Urban Planning* **148:**61-67.

Gluckman, P., Hayne, H., 2011, Improving the transition: Reducing social and psychological morbidity during adolescence, *Office of the Prime Minister's Science Advisory Committee, Auckland*.

Gould, W., 2000, Remote sensing of vegetation, plant species richness, and regional biodiversity hotspots, *Ecological Applications* **10**(6)**:**1861-1870.

Hatton, W., Marques, B., McIntosh, J., 2017, Mātauranga Māori and Therapeutic Landscapes, in: *The IAFOR International Conference on Global Studies 2017: Official Conference Proceedings. Barcelona, Spain: The International Academic Forum. Retrieved from http://papers. iafor. org/wp-content/uploads/conference-proceedings/CITY/CITY2017_proceedings. pdf*.

Huynh, Q., Craig, W., Janssen, I., Pickett, W., 2013, Exposure to public natural space as a protective factor for emotional well-being among young people in Canada, *BMC public health* **13**(1)**:**407.

Lang, K., 2002, Measuring ethnicity in the New Zealand population census, Statistics New Zealand Wellington.

Luck, G. W., Davidson, P., Boxall, D., Smallbone, L., 2011, Relations between urban bird and plant communities and human well-being and connection to nature, *Conservation Biology* **25**(4)**:**816-826.

Markevych, I., Fuertes, E., Tiesler, C. M. T., Birk, M., Bauer, C. P., Koletzko, S., von Berg, A., Berdel, D., Heinrich, J., 2014, Surrounding greenness and birth weight: Results from the GINIplus and LISAplus birth cohorts in Munich, *Health & Place* **26:**39-46.

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., De Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M. J., 2017, Exploring pathways linking greenspace to health: Theoretical and methodological guidance, *Environmental research* **158:**301-317.

Mavoa, S., Davern, M., Breed, M., Hahs, A., 2019, Higher levels of greenness and biodiversity associate with greater subjective wellbeing in adults living in Melbourne, Australia, *Health Place* **57:**321-329.

McNeill, H. N., 2017, Maori and the natural environment from an occupational justice perspective, *Journal of Occupational Science* **24**(1)**:**19-28.

Mennis, J., Mason, M., Ambrus, A., 2018, Urban greenspace is associated with reduced psychological stress among adolescents: A Geographic Ecological Momentary Assessment (GEMA) analysis of activity space, *Landscape and urban planning* **174:**1-9.

Milfont, T. L., Merry, S., Robinson, E., Denny, S., Crengle, S., Ameratunga, S., 2008, Evaluating the short form of the Reynolds Adolescent Depression Scale in New Zealand adolescents, *Aust N Z J Psychiatry* **42**(11)**:**950-4.

Nutsford, D., Pearson, A. L., Kingham, S., 2013, An ecological study investigating the association between access to urban green space and mental health, *Public Health* **127**(11)**:**1005-11.

Nutsford, D., Pearson, A. L., Kingham, S., Reitsma, F., 2016, Residential exposure to visible blue space (but not green space) associated with lower psychological distress in a capital city, *Health & place* **39:**70-78.

Panelli, R., Tipa, G., 2007, Placing well-being: A Maori case study of cultural and environmental specificity, *Ecohealth* **4**(4)**:**445-460.

Parece, T. E., Campbell, J. B., 2017, Assessing Urban Community Gardens' Impact on Net Primary Production using NDVI, *Urban Agriculture & Regional Food Systems* **2**(1).

Pereira, G., Christian, H., Foster, S., Boruff, B. J., Bull, F., Knuiman, M., Giles-Corti, B., 2013, The association between neighborhood greenness and weight status: an observational study in Perth Western Australia, *Environmental Health* **12**(1)**:**49.

Pereira, G., Foster, S., Martin, K., Christian, H., Boruff, B. J., Knuiman, M., Giles-Corti, B., 2012, The association between neighborhood greenness and cardiovascular disease: an observational study, *BMC public health* **12**(1)**:**466.

QGIS Development Team, 2018, QGIS Geographic Information System., Open Source Geospatial Foundation Project.
Rhew, I. C., Vander Stoep, A., Kearney, A., Smith, N. L., Dunbar, M. D., 2011, Validation of the normalized difference vegetation index as a measure of neighborhood greenness, *Annals of epidemiology* **21**(12)**:**946-952.
Richardson, E., Pearce, J., Mitchell, R., Day, P., Kingham, S., 2010, The association between green space and cause-specific mortality in urban New Zealand: an ecological analysis of green space utility, *BMC public health* **10**(1)**:**240.
Ryks, J., Howden-Chapman, P., Robson, B., Stuart, K., Waa, A., 2014, Maori participation in urban development: challenges and opportunities for indigenous people in Aotearoa New Zealand, *Lincoln Planning Review* **6**(1-2)**:**4-17.
Schmidtlein, S., Fassnacht, F. E., 2017, The spectral variability hypothesis does not hold across landscapes, *Remote sensing of environment* **192:**114-125.
Statistics New Zealand, 2004, New Zealand: An Urban/Rural Profile, Statistics New Zealand, Wellington.
Statistics New Zealand, 2013, Geographic definitions.
Taylor, L., Hahs, A. K., Hochuli, D. F., 2017, Wellbeing and urban living: nurtured by nature, *Urban Ecosystems***:**1-12.
Twohig-Bennett, C., Jones, A., 2018, The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes, *Environmental research* **166:**628-637.
United Nations, 1992, Convention on biological diversity.
USGS, 2018, NDVI, the Foundation for Remote Sensing Phenology, U.S. Geological Survey.
van den Berg, M., Wendel-Vos, W., van Poppel, M., Kemper, H., van Mechelen, W., Maas, J., 2015, Health benefits of green spaces in the living environment: A systematic review of epidemiological studies, *Urban Forestry & Urban Greening* **14**(4)**:**806-816.
Völker, S., Kistemann, T., 2011, The impact of blue space on human health and well-being–Salutogenetic health effects of inland surface waters: A review, *International journal of hygiene and environmental health* **214**(6)**:**449-460.
White, M. P., Alcock, I., Wheeler, B. W., Depledge, M. H., 2013, Coastal proximity, health and well-being: results from a longitudinal panel survey, *Health & place* **23:**97-103.
WHO, 2013, Mental Health Action Plan 2013–2020, World Health Organisation, Geneva, Switzerland.