APPENDIX A: Hutchinson Drought Indices and summary measures

This appendix gives a description of the data and data preparation used to create drought pattern measures that quantified drought in Australia during the 2001-08 'Big Dry' drought. A summary of these steps in given in subsection of 2.1. of the paper's method section.

(i) Raw rainfall data

Monthly rainfall data were provided by the Australian Bureau of Meteorology and gridded monthly rainfall data were calculated at a resolution of 0.25 degree of latitude-longitude for the whole of Australia. Interpolation of rainfall data onto the grid using the Barnes Scheme meant that there were no missing data for any part of the continent (Jones and Weymouth, 1997; Koch et al., 1983). Rainfall data for the period 1890-2008 were used because historical rainfall data (1890-2000) were needed to establish baseline pre-existing average seasonal rainfall levels in Australia against which levels of relative dryness could be calculated during 2001/02-2007/08.

(ii) Hutchinson Drought Indices and methods of calculation

Brief introduction to the Hutchinson Indices

We calculated two different drought indices using the Hutchinson method (Hanigan, 2012; Smith et al., 1992). These indices are robust predictors of relative dryness. They measure the dryness of small geographical regions benchmarked against historical rainfall data, that is, the deviation of current precipitation in a particular place from the long-term moving average for that place. The indices were designed to replace the Palmer Index (Palmer, 1965), a complex index that attempts to account for rainfall but also moisture loss from evaporation, run-off and other factors, making it impractical to calculate for large scale research. Hutchinson Indices have been used to good effect in recent studies (Hanigan et al., 2012; Nicholls et al., 2006).

Some dryness is considered a normal part of weather variability, particularly in Australia, which has the world's most variable climate. The two Hutchinson procedures that we used (the 'count-method' and the 'sum-method') can be used both to track relative dryness and to estimate when persistent dryness should be considered to qualify as a drought period. These procedures are based on previous research by Smith et al (1992) that examined the association between relative dryness in Australia during the 1980s and government declarations of Agricultural drought during the same period. Their calculation is described in Smith et al., (1992) however we provide the detail necessary for readers to reproduce them

here. Briefly, both Hutchinson methods identify when dryness meets a drought threshold, but one measure, the 'count-method' index, simply captures how often the threshold is met so it is particularly sensitive to capturing duration of dryness (number of months in drought). In contrast the 'sum-method' index also captures how far beyond the drought threshold the dryness extends, so it also captures information about the intensity of dryness (how dry it was during the period of drought), as well as duration. Both indices can be used to capture drought characteristics that are important considerations in quantifying drought.

Calculating the initial Hutchinson Score

The 'Hutchinson Score', is a preliminary score that needs to be calculated to create the Hutchinson Indices that are derived from it. The Palmer Index, which informed its design, used negative scores to indicate relative dryness and positive scores to indicate relative wetness. In keeping with with this concept, the Hutchinson Score calculates rolling six-monthly rainfall totals (previous six months up to and including the nominated month) and expresses them as percentiles compared to the rainfall totals for the same sequence of six months over the past century (1890-2008). The percentiles are then linearly rescaled so that -4 corresponds to the 1st decile, 0 to the 5th decile and 4 to the 9th decile.

For instance, to calculate the Hutchinson Score for June 2001 in a particular region (*Region A*), the six-month average rainfall for January to June for *Region A* is calculated and compared to the six-month average rainfall distribution for *Region A* for the 100 years spanning 1901 to 2000. Supposing the average rainfall for our six months in *Region A* was 19.5 mm, we could find where that estimate lies in the long-term distribution and assign it its percentile ranking. Say it lay in the 23rd percentile (that is, for 23 percent of the time, the rainfall for the six-month period in question was not greater than 19.5 mm), that estimate would lie in the 3rd decile and our our index score would be -2.7 (see Figure 1). Similarly, to calculate the rolling six monthly average for March 2003, you would calculate the average rainfall for the six months from October 2002 to March 2003 and then compare it to the historical averages for each of the periods October to March from 1903 to 2002.

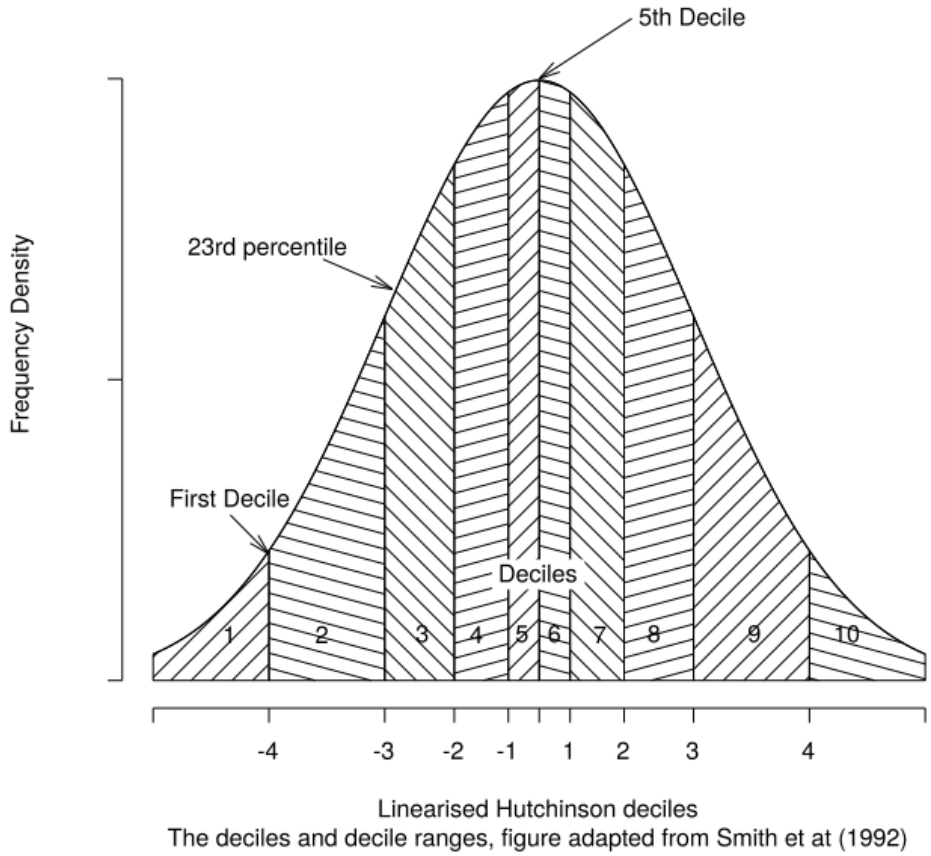

Figure 1: Hypothetical historical data normally distributed showing the Hutchinson Score of -4 to +4 (x-axis)

To reiterate, the historical data for a given six month period is represented by the normal distribution. The most recent six month rolling rainfall estimate is compared to the historical data, given a percentile score and, therefore, placed within one of the deciles where it is given a score between -4 and 4. A score of 0 means that the rainfall that fell during the six month period in question exceeded the one hundred year average for the same six month period no more than 50% of the time. Thus positive scores represent relative wetness for the time of year and negative scores represent relative dryness for the time of year. Using this scale, -1 equates to the start of relative dryness that could turn into drought if it meets a Hutchinson Index threshold over time.

Two Hutchinson Index accounting procedures (count-method and sum-method) were used to create composite measures out of the Hutchinson Scores, so that two different indices of drought were created. One index focused on dryness duration and the other index incorporated both dryness intensity and duration.

Duration measure: The 'count-method' index

The count-method index converts the Hutchinson Score into a measure focused on dryness duration. It counts the number of months in relative dryness (when the Hutchinson Score reached or fell below the threshold of -1). Four months of relative dryness is considered normal variability, however more than four months in relative dryness (i.e. at least five months) is the threshold that marks the beginning of a drought period (Smith et al., 1992). Month five of relative dryness becomes month one of drought. When the Hutchinson Score for a month rises above -1 this marks the end of the drought period. Counting towards the five month dryness threshold for a new drought period re-starts when next the Hutchinson Score again falls to or below -1.

Figure 2 shows the count index across the years 2001-2008 for three different hypothetical regions with differing dryness patterns. It shows a line at the threshold of 5 for each of the graphs, marking five months (or more) of relative dryness, which, as stated is the value of the index that defines the region as entering a period of drought. The first region has a very long period of relative dryness (21 months from late 2001 to mid-2003, 17 of which are classified as drought). The second region has four relatively short periods of dryness that could be classified as drought (counting above the threshold line there is one period of drought lasting 5 months, then one of 3 months, then two 4 month periods). Note that Region 2 experienced four months of relative dryness four times that did not get classified as drought. Region 3 had four periods of drought, one with a single month that would qualify as "in drought". The last period of drought in Region 3 lasted 13 months, with relative dryness experienced for 17 months.

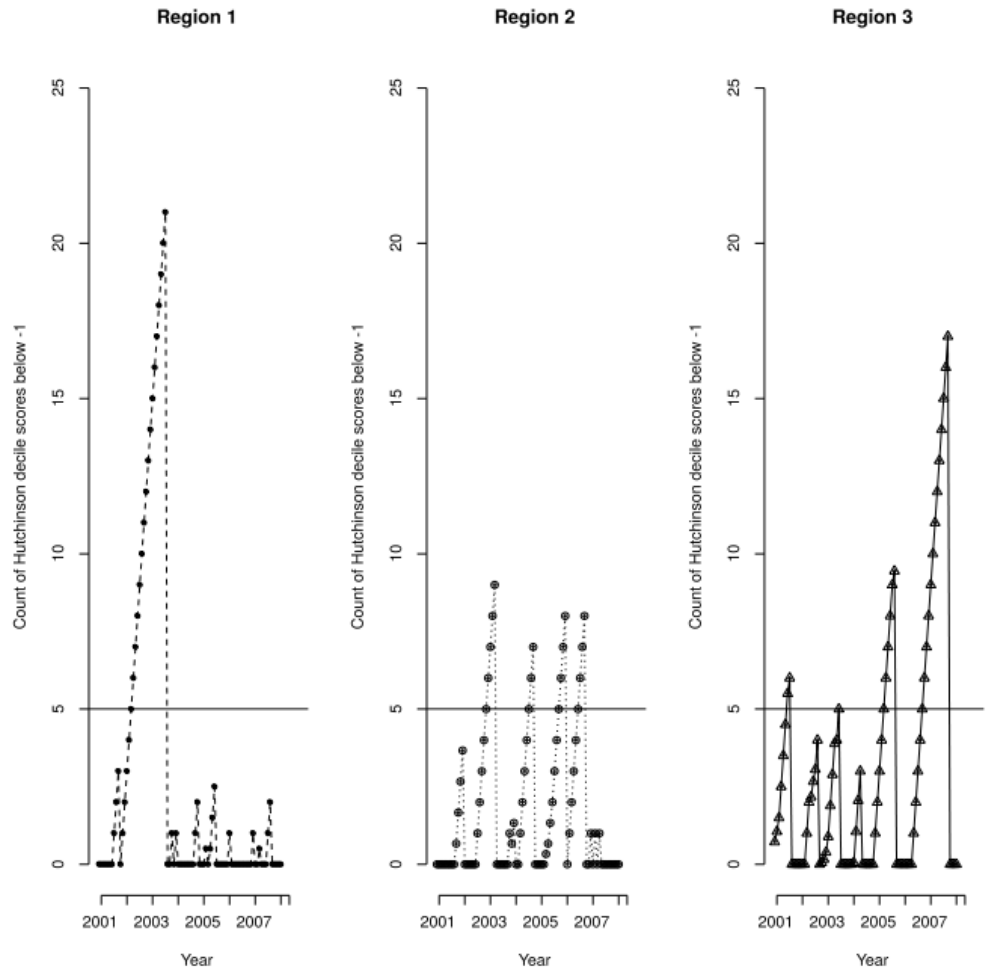

Figure 2: Hutchinson 'count-method' Index (indicating number of months in drought) calculated for three illustrative regions

Duration and Intensity: The 'sum-method' index

The second procedure quantifies a 'sum-method' index. It sums how far the Hutchinson score falls below -1 before it again rises above -1 (i.e., until the weather stops being relatively dry for that time of year). The sum is re-set to zero at this point and restarted each time the drought index again falls below -1. Based on the work of Smith et al. (1992), the threshold summed score to mark the start of a drought period is set at -17.5. In Figure 3, we show the same three hypothetical regions with the three differing drought patterns using the sum measure. The patterns are very similar to those shown in Figure 2 although some of the shorter dryness periods which attain drought status using the count-method do not achieve drought status using the sum-method. This alternative method of measuring relative dryness gives a different insight into conditions in the three regions, for example, although our illustrative Region 2 was often in relative dryness that did not pass the threshold for drought,

these periods were not intensely dry relative to historical conditions and one period of relative dryness that lasted well over 4 months was not relatively dry enough to qualify as a drought period when using the sum-method index.

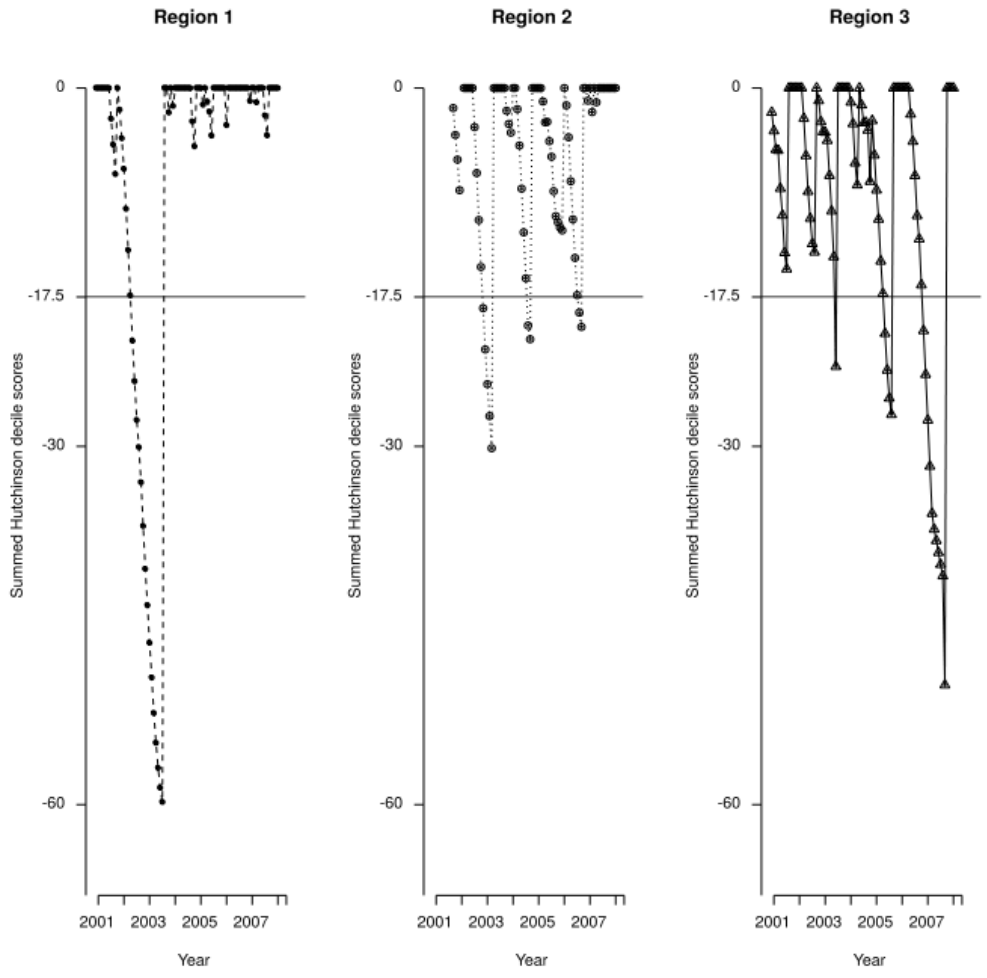

Figure 3: Hutchinson 'sum-method' Index (combining duration and intensity of dryness) calculated for three illustrative regions

(iii) Summary measures of Hutchinson Index drought occurring during the 'Big Dry'

Hutchinson Indices were calculated for every month of the seven years of dryness in Australia spanning the 2001/02—2007/08 'Big Dry' for every 2001 Census Collection District in Australia (hereafter 'District'). This was accomplished using a PostgreSQL database with the PostGIS spatial extension managed by the National Centre for

Epidemiology and Population Health at The Australian National University (see Hanigan, 2012 and https://github.com/swish-climate-impact-assessment/DROUGHT-BOM-GRIDS). Each month that a region attained or maintained a threshold score of >=5, that month was recorded as a month of count-method drought. Each month that a region attained or maintained a threshold score of -17.5, that month was recorded as a month in sum-method drought. However in addition to months in drought, the Hutchinson Indices also captured a variety of other information regarding the duration, dryness and cyclical nature of drought periods throughout Australia. To capture this complexity, the Hutchinson Indices were used to calculate eight novel summary measures for dryness occurring during 2001/02—2007/08. A customised computer program was written in Delphi to create the summary measures and it is available in online supporting information (see: https://alliance.anu.edu.au/access/content/group/ef3c25b4-f29f-485e-9277-773ca37d36ce/NewDroughtVariables/NewDroughtVariables.zip).

Duration

We calculated four duration measures based on the number of months in drought recorded by the count-method index and the sum-method index for the seven year period examined:

- Total number of months recorded in count-method drought periods.
- Total number of months recorded in sum-method drought periods.
- Total number of months recorded in drought periods that met both the count-method and sum-method threshold.
- Longest number of months spent in a period of unbroken relative dryness (i.e. the longest period where Hutchinson score did not rise above -1).

Intensity

Standardised dryness intensity was calculated to capture the average intensity of dryness for all drought period cycles. This was calculated by dividing the total number of months a District was in sum-method drought period conditions by the number of drought cycles (providing an average time per drought cycle), and then dividing the cumulative average sum measure (i.e., the measure of the dryness intensity counter) by this ‘time in drought period’ quotient. This measure made it possible to compare the intensity of the drought between the regions across the seven years.

Cycles of drought

Three measures of drought cycles were calculated for the data collection period:

- *Sum-method cycles*: Number of times a District entered into drought according to the sum-method.
- *Count-method cycles:* Number of times a District entered into drought according to the count-method.
- *Both-methods cycles:* Number of times a District entered into drought that met the threshold for both sum and count-method drought.

(iv) Drought extremity measures for the 'Big Dry'

To identify the presence of extreme drought conditions, four summary measures were dichotomised at the 90th percentile (or as close as possible):

- C*onstant drought* identified those cumulatively experiencing 20-32 total drought period months that met the threshold for both sum-method and count-method drought (sum-method months and count-method months were not examined separately because they were very highly correlated: *Pearson's r* = .933, 95% CI: .930—.94).
- *Very dry drought* identified those experiencing the most intensely dry sum-method drought periods using the standardised dryness intensity measure.
- *Extreme sum cycles* identified those cumulatively experiencing 5-6 total sum-method drought period cycles.
- *Extreme count cycles* identified those cumulatively experiencing 6-7 total number of count-method drought period cycles (sum-method months and count-method cycles were examined separately because they were not very highly correlated: *Pearson's r* = .59, 95% CI: .57—.61).

In addition, the extreme condition of a *recent long dry period* was based on the number of months in relative dryness (i.e. dryness with a Hutchinson score of -1). A dichotomous measure identified unbroken periods of dryness lasting for at least 12 straight months in the past 24 months (2005-2007/08).

(v) Preliminary analysis to identify patterns of dryness

To characterise patterns of dryness exposure throughout the 'Big Dry', we used two-step cluster analysis in IBM SPSS 19 to examine the distribution of extreme drought characteristics across Districts in Australia (see online supporting information: https://alliance.anu.edu.au/access/content/group/ef3c25b4-f29f-485e-9277-773ca37d36ce/NewDroughtVariables/Extreme%20drought%20measures%20and%20dryness%20pattern%20types.sps). Cluster analysis identifies patterns of shared characteristics among people or places, or 'natural groupings'. Cluster analysis is an iterative exploratory procedure in which the researcher reduces and varies the set of measures included in the analysis based on theoretical considerations, parsimony (the minimum number of variables required to deliver a stable and meaningful solution) and statistical indicators of how important each measure is to the cluster solution (tested using Schwarz's Bayesian Criterion (Schwarz, 1978)).

In the first step of the cluster analysis, geographical areas were arranged in multidimensional space according to their exact distance from each other on every selected measure (i.e., on their experiences of multiple extremes of dryness over seven years); in the second step, Districts were classified into clusters according to the degree to which they had identical or near-identical characteristics with each other and differed significantly from all other clusters. Members of clusters (in this case, Districts) are thus very similar to each other and very different from all other clusters on a given set of criteria (in this case, dryness characteristics).

Repeated cluster analyses showed that, while drought *cycles* were not consistently informative, a highly stable cluster solution was returned when three indicators of extreme conditions were used: *constant drought*, *very dry drought,* and *recent long dry period*. These variables showed that, during the 2001/02—2007/08 'Big Dry', the sample population of Districts was patterned with five different types of dryness: (i) zero-to-moderate drought, (ii) very dry drought, (iii) recent long period, (iv) constant drought, and (v) constant drought with a recent long period (see Table A). Note that the total number of months spent in drought was similar across the 'constant' drought and the 'constant drought with a recent long period' categories. We also reiterate that, except for the zero-to-moderate drought classification, these drought pattern classifications measured *extreme* dryness, or dryness over and above an allowance for normal variability. During the 'Big Dry', dry conditions were very common

even though they may not always have quite met the criteria for being 'in drought'. Thus, for example, a 'recent long dry period' typically signalled around 16 months in unbroken dryness during the past 24 months.

Table A. Distribution of dryness patterning in an Australian population sample during the 'Big Dry' of 2001-08 (N= 5,012).

Variable	% population exposed
Zero to moderate	47.26
Very dry	12.30
Recent long period (only)	30.10
Constant drought (only)	3.41
Constant drought & recent long period	6.94

References

ABS Statistical Geography, Catalogue no.1216.0 ISSN 1441 1814.

Hanigan, I.C., 2012. Monthly drought data for Australia 1890-2008 using the Hutchinson Drought Index. Australian Data Archive. DOI: 10.4225/13/50BBFD7E6727A.

Hanigan, I. C., et al., 2012. Suicide and Drought in New South Wales, Australia, 1970-2007. Proceedings of the National Academy of Science USA. Vol 109 no 35, p13950–13955, doi: 10.1073.

Jones, D. A., Weymouth, G., An Australian monthly rainfall dataset. Technical Report Australia Bureau of Meteorology, 1997.

Koch, S. E., et al., 1983. An Interactive Barnes Objective Map Analysis Scheme for Use with Satellite and Conventional Data. Journal of Applied Meteorology. 22**,** 1487-1503.

Nicholls, N., et al., 2006. Inter-annual rainfall variations and suicide in New South Wales, Australia, 1964–2001. Int J Biometeorol. 50**,** 139-143.

Palmer, W., Research paper: Meteorological Drought. Vol. 45. U.S. Department of Commerce Weather Bureau, 1965.

Smith, D., et al., 1992. Climatic and Agricultural Drought: Payments and Policy. Centre for Resource and Environmental Studies, Australian National University, Canberra, ACT.

Stain, H. J., et al., 2011. The psychological impact of chronic environmental adversity: Responding to prolonged drought. Soc Sci Med. 73**,** 1593-1599.

APPENDIX B: Household, Income and Labour Dynamics in Australia (HILDA) Survey data and sampling technique

Survey instruments and conduct

The HILDA Survey includes four survey instruments, which ask respondents to report on a range of aspects in their lives, including labour market and family dynamics, wellbeing and socioeconomic information. Three of these instruments are interviewer conducted, and one is a self-complete questionnaire, in which respondents are asked about their health and psycho-social characteristics. Each wave of the self-completion questionnaire includes a special focus supplement that varies from year to year. The survey has been conducted each year since 2001 and eleven waves of the Survey are currently available for licensed users. Data for this study were taken mostly from the Self-Completion Questionnaire for Wave 7. However, occupation, income support and community satisfaction items were taken from Wave 7's interviewer-administered 'Responding Person Questionnaire'.

Each year, participants decide whether to consent to participate when contacted by interviewers. The ethical design and conduct of the survey is monitored and approved by both the University of Melbourne's Office for Research Ethics and Integrity and the Australian Government's Department of Families, Housing, Community Services and Indigenous Affairs (which also monitors and approved our secondary use of the data). Ethical standards are established by the Australian Government's National Health and Medical Research Council and are consistent with the Declaration of Helsinki.

Complex survey design and analysis technique

The HILDA Survey had a two-stage sampling design in which a random sample of Districts was selected, and within these, a random sample of households was selected. The Survey's protocol was approved by the Australian Government Department for Families, Housing, Community Services and Indigenous Affairs and more detail is available on the HILDA website (http://www.melbourneinstitute.com/hilda).

To account for the complex survey design, data was examined using HILDA Survey sample weights and clustering at the District level. It was decided, based on the work of Cameron and colleagues (Cameron et al., 2011), that clustering at the District level was most appropriate for our analysis because the drought measures were calculated at the District level. Note that the strata variable designed for analysis of the HILDA dataset therefore could not be used because it is based on clustering at the household level. However, clustering within households is taken into account by clustering at the District level because stata's

cluster-robust variance estimate (Liang and Zeger, 1986; Rogers, 1993) will account for secondary clustering if it is nested within the higher order cluster (Pepper, 2002) and households are nested within Districts. Importantly, although our design made Districts the appropriate level at which to cluster, we conducted sensitivity analyses and found that the pattern of results remained the same if the strata and household clustering survey commands were used and doing so did not introduce new overlaps into the confidence intervals.

References

Cameron, A. C., et al., 2011. Robust Inference with Multi-way Clustering. Journal of Business and Economic Statistics. 29 238-249.

Liang, K.-Y., Zeger, S. L., 1986. Longitudinal data analysis using generalized linear models. Biometrika 73**,** 13-22.

Pepper, J. V., 2002. Robust inferences from random clustered samples: an application using data from the panel study of income dynamics. Economics Letters. 75**,** 341-345.

Rogers, W. H., 1993. Regression standard errors in clustered samples. Stata Technical Bulletin 13**,** 19-23.

APPENDIX C: Supplementary table

Table C. Descriptive characteristics across the 5 clustered dryness conditions

Measures		Dryness conditions				
		Zero to moderate 47.26% (.03)	Very dry 12.30 % (.02)	Recent long period only 30.10% (.02)	Constant drought only 3.41% (.01)	Constant drought & long period 6.93% (.01)
		Percentages % (SE)				
Distress (K10)	Low	64.15 (.01)	63.02 (.03)	64.09 (.02)	69.09 (.04)	70.00 (.04)
	Moderate	21.34 (.01)	19.65 (.02)	21.57 (.02)	19.32 (.03)	16.11 (.03)
	High	10.43 (.01)	15.17 (.02)	11.15 (.01)	7.58 (.02)	11.52 (.02)
	Very high	04.08 (.02)	02.17 (.01)	3.19 (.01)	3.99 (.02)	2.37 (.01)
Age	15 – 25 years	14.94 (.01)	18.73 (.03)	18.12 (.01)	14.30 (.03)	14.22 (.03)
	26 – 39 years	09.57 (.01)	12.68 (.03)	9.60 (.01)	10.05 (.03)	15.58 (.03)
	40– 55 years	32.42 (.01)	23.07 (.03)	34.12 (.02)	34.21 (.04)	29.13 (.03)
	56 – 65 years	19.10 (.01)	23.21 (.03)	16.91 (.01)	14.73 (.03)	23.53 (.03)
	66 – 79 years	18.46 (.01)	17.41 (.02)	15.44 (.01)	20.74 (.04)	15.16 (.03)
	80+ years	05.51 (.01)	04.90 (.01)	5.80 (.01)	5.98 (.04)	2.37 (.01)
Male %		.4731 (.01)	55.06 (.02)	50.58 (.01)	49.79 (.03)	50.59 (.04)

Table C. continued. Descriptive characteristics across the 5 clustered dryness conditions

Measures		Dryness conditions				
		Zero to moderate 47.26% (.03)	Very dry 12.30 % (.02)	Recent long period only 30.10% (.02)	Constant drought only 3.41% (.01)	Constant drought & long period 6.93% (.01)
		Percentages % (SE)				
Ethnicity	Indigenous/Torres Strait Islander Australian %	01.53 (.003)	00.48 (.003)	01.51 (.01)	0	1.64 (.01)
	English-speaking immigrant %	10.84 (.01)	10.15 (.02)	07.94 (.01)	7.47 (.02)	9.99 (.02)
	Non-English-speaking immigrant %	12.62 (.02)	23.36 (.04)	18.39 (.03)	7.51 (.02)	10.79 (.03)
Left school at15 years or younger		59.79 (.01)	69.61 (.03)	65.45 (.02)	62.55 (.04)	61.94 (.04)
Education	Year 11 or less	42.08 (.01)	28.9 (.03)	37.24 (.02)	39.37 (.05)	34.48 (.04)
	Year 12	13.47 (.01)	17.25 (.02)	14.92 (.01)	12.02 (.02)	17.51 (.03)
	Certificate or diploma	28.22 (.01)	27.75 (.02)	30.10 (.02)	31.71 (.04)	30.64 (.04)
	Tertiary degree	9.72 (.01)	13.67 (.02)	9.35 (.01)	5.00 (.02)	11.10 (.02)
	Higher degree	6.50 (.01)	12.39 (.03)	8.39 (.01)	11.90 (.04)	6.27 (.01)
Married %		57.42 (.02)	52.84 (.03)	58.64 (.02)	58.72 (.04)	56.23 (.05)
Divorce/Separated %		18.78 (.01)	14.00 (.02)	12.30 (.01)	16.12 (.04)	14.40 (.02)

Table C. continued. Descriptive characteristics across the 5 clustered dryness conditions

Measures		Dryness conditions				
		Zero to moderate 47.26% (.03)	Very Dry 12.30 % (.02)	Recent long period only 30.10% (.02)	Constant drought only 3.41% (.01)	Constant drought & long period 6.93% (.01)
		Percentages % (SE)				
Gross	nil-$31,199	23.79 (.02)	15.76 (.03)	16.54 (.01)[b]	21.40 (.05)	14.90 (.03)
household	$31,200 - $51,999	18.12 (.02)	16.84 (.03)	16.83 (.02)	16.84 (.04)	18.53 (.05)
income (AUD$)	$52,000 - $77,999	22.89 (.02)	18.14 (.03)	25.22 (.03)	20.24 (.05)	21.45 (.04)
	$78,000 - $114, 399	20.34 (.02)	16.59 (.03)	25.26 (.02)	27.34 (.06)	24.69 (.06)
	$114,400 +	14.87 (.01)	32.66 (.05)	16.15 (.02)	14.18 (.05)	20.43 (.06)
Pensions/allowances > 30% of income		34.02 (.02)	22.60 (.03)	28.41 (.02)	25.98 (.05)	23.94 (.06)
Health condition		32.55 (.01)	29.97 (.03)	26.60 (.01)	38.64 (.04)	33.26 (.04)
Mental health condition		4.20 (.01)	1.82 (.01)	3.28 (.01)	2.46 (.01)	2.94 (.01)

Table C. continued. Descriptive characteristics across the 5 clustered dryness conditions

Measures	Dryness conditions				
	Zero to moderate 47.26% (.03)	Very dry 12.30 % (.02)	Recent long period only 30.10% (.02)	Constant drought only 3.41% (.01)	Constant drought & long period 6.93% (.01)
			Means (SE)		
Satisfaction with local community (range 0-10)	7.01 (.09)	6.71 (.24)	7.05 (.07)	7.48 (.19)	6.95 (.19)
Dryness intensity measure	5.75 (.11)	10.23 (.11)	4.59 (.12)	4.71 (.24)	3.64 (.10)
Nº months in recent count index dryness	1.71 (.27)	2.830 (.63	14.99 (.18)	0	16.84 (.31)
Months in both kinds of drought	12.23 (.32)	8.919 (.37)	17.01 (.38)	24.03 (.62)	22.75 (.30)
Months in sum drought	12.35 (.32)	9.025 (.36)	17.07 (.37)	24.12 (.60)	22.82 (.34)
Months in count drought	18.19 (.40)	15.84 (.45)	23.24 (.35)	30.43 (1.17)	29.58 (.29)
Cycles in sum drought	3.83 (.09)	4.01 (.13)	2.47 (.08)	3.49 (.18)	2.68 (.11)
Cycles in count drought	2.53 (.06)	4.74 (.09)	3.75 (.08)	3.93 (.24)	3.77 (.12)