Response for the anonymous referee #1

Comment: The reviewer's major concern about this manuscript is the section 4.2. This section should be the focus of this manuscript. Presentation in this section does not reveal how to apply the results such as Figures D1 and D2 as the management tool for ecosystem rehabilitation planning at different locations.

Response: We agree with your comment and we will include a new section (4.3) which includes a new table (Table 3) in the discussion to describe how the results of the design drought method can be used as a management tool for ecosystem rehabilitation.

4.3 Application of design droughts to rehabilitation planning

Table 3. Management actions for addressing specific kinds of drought characteristics identified with SDF curves for the southern hemisphere.

Management domain	Management actions	Type of drought
Plant species selection	Drought tolerant species	LS, LP, SP, SS
	Quickly germinating species	SS
	Species with physical/chemical dormancy	LS, LP
	Shade tolerant species on southern aspects	LS, LP
	Light tolerant species on northern aspects	LS, LP, SP, SS
	Annual grasses	SS, SP
	Perennial grasses	LS, LP, SP, SS
	Trees	LS, LP
Planting/seeding regime	Trees require repeated establishment	LS, LP
	Annual/perennial grasses are successful after rain events	SS, SP
Soil characteristics	Deep top soil	LS, LP, SP
	Amendments of silt/clay	LS, LP
	Gentle slopes	LS, LP
	Mulching	SS
Irrigation method	Regular irrigation	LS, LP
	Seasonal irrigation	SS, SP
	Critical stage irrigation	LS,LP,SP,SS
	Drainage system	LS, LP

SS – High recurrence of short time scale (3 month) severe droughts
SP – High recurrence of short time scale (3 month) prolonged droughts
LS – High recurrence of long time scale (12 months) severe droughts
LP – High recurrence of long time scale (12 months) prolonged droughts

One of the major outcomes of this study is to support land managers and/or rehabilitation practitioners to make fundamental decisions on appropriate management actions in the context of drought frequency. For rehabilitation to be successful in the face of severe and prolonged droughts, there are a range of management domains and management actions that need to be considered in response to recurrence intervals, drought severity, and drought duration (Table 3). These management actions can be categorised into four domains: plant species selection, planting/seeding regime, soil characteristics, and irrigation method.

Selection of suitable plant species based on drought type is one of the key management actions for successful rehabilitation. Some management actions can be applied to all drought types (LS, LP, SS, SP in Table 3). These include (i) planting of drought tolerant species (e.g., *Acacia* spp., *Banksia* spp., *Casuarina* spp.), at (ii) northern aspects to address drier conditions that result from higher solar radiation causing increased evaporation (Sternberg and Shoshany, 2001), and (iii) planting of perennial grasses (*Eragrostis* spp., *Themeda* spp. (Bolger et al., 2005)), which may not be affected by long-term water deficits. At locations with frequently recurring long-term (12 month time scale) droughts of high severity and durations (LS, LP in Table 3), such as Mount Isa and Quilpie, seeding of species with physical/chemical dormancy may increase the probability of germination during favourable periods (Hilhorst, 1995; Arnold et al., 2014b). Additionally, a southern aspect may require drought tolerant species to increase survival of plant communities (Sternberg and Shoshany, 2001). However, these species need to be shade tolerant as southern aspects get less solar radiation in winter. At locations with frequently recurring short-term (3 month time scale) droughts of high severity but short duration, with rainfall throughout the year (SS in Table 3), such as Wagga Wagga, annual grasses and seeds with short germination periods may be suitable.

Soil characteristics play a critical role for plant available water and a number of strategies may need to be employed to make soil more favourable to plant establishment. Except for mulching, all of the management actions within the soil characteristics management domain can be applied to locations with high recurrence of long-term, severe, and prolonged droughts (LS, LP in Table 3), such as Quilpie and Mount Isa. For locations with high recurrence of short-term, and prolonged droughts (SP in Table 3), such as Melbourne, increasing the depth of topsoil can increase water holding capacity (Audet et al., 2013; Bot and Benites, 2005). Similarly, by mixing silt and clay soil in the topsoil and reducing slope gradients may facilitate infiltration and increase soil water retention capacity (Audet et al., 2013). For tropical locations with high recurrence of short-term (3 month time scale), severe, and prolonged droughts (SS, SP in Table 3), such as Cairns and Weipa, ground cover such as mulch and planting fast growing cover (e.g., Buffel grass) may reduce evaporation and maintain soil moisture to allow for the establishment of drought sensitive and slow growing species (Blum, 1996).

Utilising irrigation methods for specific site characteristics is a cost effective strategy for any rehabilitation plan. Regular irrigation with proper drainage systems that distributes water is an effective strategy in locations with high recurrence of long-term, severe, and prolonged droughts (LP, LS in Table 3). For locations with high recurrence of short-term, severe, and prolonged droughts (SS, SP in Table 3), with seasonal rainfall (e.g. Brisbane, Sydney, Kingaroy, Brigalow), seasonal irrigation and irrigation at critical stages of plant growth (Blum, 1996), such as germination, and root or pod development periods are efficient actions to ensure plant survival throughout drought spells.

Comment: Many results are relating to Table 3 as the authors stated in pages 10 (lines 15, 17, 20), 11 (line 5), and 12 (lines 12, 18, 24). But this manuscript does not contain Table 3. The authors should check whether the wrong table number is used or Table 3 is missing in this manuscript.

Response: Thank you for catching this; we used the wrong table numbers. We revised the references to table 3 accordingly.

Comment: Does the Appendix C stated in pages 11 (line 25) and page 13 (lines 2 and 5) mean Figures C1 and C2 (pages 38 and 39)?

Response: Yes, we added titles of appendices C and D throughout the manuscript.

Comment: The Conclusion section (page 17) should be more specific to include the obtained results of the Eastern Australia.

Response: We agree and added two sentences about our results in the beginning of the conclusion (existing text in italics).

The study revealed site specific patterns of recurrence intervals of short-term and long-term droughts across Eastern Australia. Severe and prolonged short-term droughts recurred most often in tropical climates and temperate Wagga Wagga, while severe and prolonged short-term droughts recurred most often in arid conditions and temperate Melbourne. *Design droughts can be applied to quantify the frequency of drought events – characterised by* *severity and duration – at different time scales. This is a critical step forward to consider drought in risk assessments for rehabilitation of post-mining ecosystems. Together with design rainfalls, design droughts should be used to assess rehabilitation strategies and ecological management based on drought recurrence intervals, thereby minimising the risk of failure of initial ecosystem establishment due to ignorance of fundamental abiotic and site-specific environmental barriers.*

Comment: Page 7, line 15. RDI3, the I should not be typed as a subscript.

Response: Thanks for catching this! The typo was corrected.

Comment: Page 13, line 24. “Hodgkinson and Flagship, 2010” should be “Hodgkinson et al., 2010”

Response: We revise the reference accordingly.

References

Arnold, S., Kailichova, Y., Knauer, J., Ruthsatz, A. D., and Baumgartl, T.: Effects of soil water potential on germination of co-dominant Brigalow species: Implications for rehabilitation of water-limited ecosystems in the Brigalow Belt bioregion, Ecological Engineering, 70, 35-42, http://dx.doi.org/10.1016/j.ecoleng.2014.04.015, 2014.

Audet, P., Arnold, S., Lechner, A., and Baumgartl, T.: Site-specific climate analysis elucidates revegetation challenges for post-mining landscapes in eastern Australia, Biogeosciences, 10, 6545-6557, 2013.

Blum, A.: Crop responses to drought and the interpretation of adaptation, Plant Growth Regulation, 20, 135-148, 1996.

Bolger, T. P., Rivelli, A. R., and Garden, D. L.: Drought resistance of native and introduced perennial grasses of south-eastern Australia, Australian Journal of Agricultural Research, 56, 1261-1267, http://dx.doi.org/10.1071/AR05075, 2005.

Bot, A., and Benites, J.: The importance of soil organic matter: key to drought-resistant soil and sustained food and production, FAO, 2005.

Hilhorst, H. W.: A critical update on seed dormancy. I. Primary dormancy, Seed Science Research, 5, 61-73, 1995.

Sternberg, M., and Shoshany, M.: Influence of slope aspect on Mediterranean woody formations: Comparison of a semiarid and an arid site in Israel, Ecological Research, 16, 335-345, 10.1046/j.1440-1703.2001.00393.x, 2001.

Response for the anonymous referee #2

General comments

Comment: It is not clear what is meant by “design” in the context of ecosystems restoration. It needs to be defined with clear criteria. How will the drought assessment alter the rehabilitation measures for a post-mining landscape? I suggest that the title of the paper should reflect this by eliminating the term “design drought” and by introducing the term “risk assessment” or “risk framework”, or alternatively, rework the paper to quantitatively define the design issue and within this context the term “design drought” Either way, I suggest the title and contextual focus to be changed accordingly.

Response: Similar to the concept of Intensity-Frequency-Duration (IFD) design rainfall, which aims to quantify the recurrence interval if rainfall events based on their intensity and duration, we apply the same concept to quantify the recurrence intervals of periods of water deficit (droughts) based on their severity and duration, and refer to this concept as Severity-Duration-Frequency (SDF) design drought. While IFD design rainfalls are a well-established tool in civil engineering and hydrology to assess the risk of infrastructure failure (e.g., buildings, bridges, water damns, flood levee), we believe SDF design drought could be used in a similar way to assess the risk of ecosystem rehabilitation failure due to droughts.

We see how “design drought” in the title can be confusing as it needs to be defined first in the text, and therefore changed the title to “Severity-Duration-Frequency curves of droughts: An early risk assessment and planning tool for ecosystem establishment in post-mining landscapes”.

We have also added extra text describing how the method proposed in this paper could be used in the context of ecosystems restoration in accordance with the other referee’s comment on the lack of information describing implications for ecosystem rehabilitation. The new section that we have added is section 4.3. This includes table 3:

4.3 Application of design droughts to rehabilitation planning

Table 3. Management actions for addressing specific kinds of drought characteristics identified with SDF curves for the southern hemisphere.

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Soil characteristics	Deep top soil	LS, LP, SP
	Amendments of silt/clay	LS, LP
	Gentle slopes	LS, LP
	Mulching	SS
Irrigation method	Regular irrigation	LS, LP
	Seasonal irrigation	SS, SP
	Critical stage irrigation	LS,LP,SP,SS
	Drainage system	LS, LP

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Comment: Paper will have a wider readership if the description of the methodology includes a clear statement of the assumption made as well as a clear statement of its limitations.

Response: We elaborated possible limitations of our study in section 4.3 (now 4.4) "Future research". Regarding the assumptions made to estimate the SDF curves, we added the following paragraph to the beginning of the methodology (section 2):

"Estimating SDF curves involves some uncertainties associated with the length of the observed rainfall data, the applied drought index, the probability distribution functions used to fit the observed severity and duration, and the estimated copula parameter (Hu, Liang et al. 2014). To overcome these uncertainties we tested the applicability of drought indices for locations in different climatic regions by calculating the correlation of three selected drought indices. Likewise we used the best fitted probability distribution functions and copula for each site (Fig. 2)."

Detailed Comments

Abstract

Comment: 4810/4 is water the stressor or the lack of water, Clarify

Response: Thanks for pointing this out. Of course the lack of water is the primary abiotic stressor for (agro)ecosystems across eastern Australia we altered the text in the following way "For some of the agro-climatic regions in Eastern Australia lack of water is the primary abiotic stressor.."

Comment: 4810/17 not clear why evaporation plays a minor role

Response: Here we refer to the tropical locations (Weipa and Cairns), where rainfall is equal or exceeds annual evaporation and therefore evaporation does not critically affect the output of the drought indices RDI and SPEI.

Comment: 4810/24 vague statement, specific mentioning of what those "environmental barriers" are?

Response: We agree and added "[…] site-specific environmental barriers such as *flood and drought events*"

Introduction

Comment: 4811/18 …The relevance water stress during rehabilitation is reviewed here. Can this be resolved in more detailed perhaps in the discussion section such that quantitative criteria could be derived?

Response: In the revised manuscript, and in accordance with the other referee's comments, this is addressed in section 4.3 and table 3.

Materials and Methods

Comment: 4816/22-24 Notation of eq. 1 not clear. Shouldn't it be… for I_i < 0 without the negative sign and the absolute value within the summation?

Response: That's correct, thanks for pointing that out. Equation 1 should read as:

$$\boldsymbol{S} = \sum_{\boldsymbol{i}=\boldsymbol{1}}^{\boldsymbol{D}} |-\boldsymbol{I}_{\boldsymbol{i}}|$$

Comment: 4818/15-20 Table 3 doesn't exist.

Response: Thank you for catching this; we used the wrong table numbers. We revised the references to table 3 accordingly.

Comment: 4819/2 Fig. 7 is mentioned before Fig. 5 and 6. Correct sequence.

Response: We revised the figure numbers accordingly.

Implication

1. 4822/26-28 Good example of vague statement: Why can't you be specific and provide an example with mentioning the species, the duration values and then use your method to make a well-informed assessment of the risk of rehabilitation failure. If we don't have that type of information available, than the method proposed is useless.

   Response: As described above we addressed this in the new section 4.3 of the revised manuscript.

2. 4823/16-29 This section is a good example of the use of the indices. The issue of simplification and the use of surrogate information should be presented earlier in the paper to justify why you go through the statistical analysis of correlating your different indices.

Response: We added two sentences to the introduction (4812/18). “In many parts of the world evaporation data are unavailable or incomplete and simple rainfall indices are most commonly used. In this study we compare indices incorporating evaporation (SPEI and RDI) with the simple rainfall index SPI in order to determine the accuracy of using SPI across different climatic regions.”

Future

3. 4824/23-26 The statement that the analysis in not predictive should be presented earlier in the paper (introduction). As mentioned above, list all assumption of the method (for example assumption on independence etc.) before you introduce the method and then clearly indicated limitations based on that.

Response: In the revised manuscript, we moved the statement to the introduction.

“While uncertainty is associated with any step in figure 2, a detailed uncertainty analysis is beyond the scope of this study. Yet, given that we have applied more than one probability density function and copula to fit the observed severity and duration, we believe uncertainty is minimised to an acceptable level. We are confident that further research, as outlined in section 4.3 of the old manuscript, can address these uncertainties.”

References

Hu, Y.-M., Z.-M. Liang, Y.-W. Liu, J. Wang, L. Yao and Y. Ning (2014). "Uncertainty analysis of SPI calculation and drought assessment based on the application of Bootstrap." International Journal of Climatology: n/a-n/a.