Biogeosciences Discuss., 12, C1090–C1105, 2015
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Biogeosciences Discussions
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Interactive comment on "Primary productivity and its correlation with rainfall on Aldabra Atoll" *by* J. Shekeine et al.

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Received and published: 8 April 2015

Author's response to Reviewer 1

We thank the reviewer for careful reading and consideration of our manuscript. Below, we outline in a point-by-point response how we will address the raised concerns through additional data analysis and refocussing of the research question. Regarding main changes to the data analysis, we will 1. add a rainfall variability and anomaly analysis to the current rainfall trend analysis (see details in response 3), and 2. address start and end of season rainfall-vegetation activity correlations separately (see details in response 13).

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Point 1: General comment (C176)

Although the subject of this study is very interesting and merits large scientific/societal interest, the analyses are poor (see my specific comments) and never support any causal relationship between changes in productivity due to changes in rainfall. Moreover, the study draws several conclusions that are not supported by the results. Finally, I believe that the study is little innovative (e.g. Vicente-Serrano et. al. (2013) have done something very similar but with a global focus and not zooming in on the atoll). Consequently, I recommend not to accept the paper. Only when the authors manage to adapt their paper, which basically would require to rewrite it completely with several additional analyses, I think it could be published eventually.

Response 1 :

We are pleased that the reviewer finds the study subject interesting and acknowledges its large scientific/societal interest. The importance of our study lies in the detailed analysis of vegetation activity, its seasonal dynamics and correlation to rainfall at a spatial scale that captures vegetation communities important to the giant tortoise population of the atoll. The paper mentioned by Reviewer 1 (Vicente-Serrano et. al., 2013) excludes small oceanic islands as it focusses on global biome to biome comparisons and is based on a drought severity index dataset of 0.5° spatial resolution which, by design, cannot capture oceanic islands the size of Aldabra (0.31° long, 0.12° wide). While we acknowledge the importance of global studies, we lack current information on the seasonality of vegetation activity and its correlation with rainfall on Aldabra Atoll, at a spatial scale that captures the various vegetation communities (e.g. tortoise turf versus areas dominated by evergreen or deciduous shrub) and over multiple years. These vegetation communities provide seasonally shifting foraging and shade sources for the giant tortoises. The seasonal dynamics of the vegetation activity derived in this study will be used in future analyses, for example, to test whether it influences tortoise migratory behaviour. Additionally, we used an atoll-specific rainfall data set that was not available to earlier studies. We are aware that the previous version of the manuscript

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might not have been explicit enough and we will formulate the specific aim of the study more precisely in the introduction and adapt the discussion correspondingly.

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Point 2: MODIS GPP Vs NDVI (C176)

Title: “Primary productivity” is the main word in the title, whereas the paper never mentions primary productivity in the main text (except when discussing the work of others in the introduction (p983,L24) or to introduce the tree ring results (p984,L20), which later appear useless to study productivity trends). I believe the use of the MODIS GPP product would provide much more insight in the primary productivity than the NDVI, which is only a proxy of greenness.

Response 2 :

Reviewer 1 noted correctly that we used NDVI as a proxy for primary productivity, while we did not make any attempt to convert our results to productivity. As the main focus of the study lies in the identification of the seasonality of vegetation activity for different vegetation communities and its relation to rainfall, we will adapt the terminology in the entire manuscript and replace ‘primary productivity’ by ‘vegetation activity’, a term often used in the context of NDVI phenological analysis. Specifically, the title will be changed to ‘Seasonality of vegetation activity and its correlation to rainfall on Aldabra Atoll’. We carefully evaluated the choice of satellite data used in the study (GPP versus NDVI). The MODIS GPP product (MOD17A2) is designed for global to biome scale monitoring of vegetation productivity (http://datamirror.csdb.cn/modis/resource/doc/MOD17_UsersGuide.pdf). More specifically, MOD17A2 - has a spatial resolution of 1km, 4x lower than MOD13Q1 used in our study which will increase the contribution of water from the sea and lagoon area to the overall signal. Such pixels would have to be excluded from the analysis, cutting out important areas of interest. - depends on the MODIS global land cover product MOD12Q1 which is designed for global scale land cover monitoring and has a low

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accuracy in areas of complex vegetation (MOD17A2 User guide: 3. Dependence on MODIS Land Cover Classification (MOD12Q1)). We evaluated MOD12Q1 for Aldabra and it does not adequately represent the vegetation patterns of ecological interest. - claims that MODIS GPP products are better suited for ecological studies than the NDVI have to be considered against the challenges of validating MODIS GPP products in different vegetation types and especially in the tropics (see Pettorelli, 2013 (The Normalized Difference Vegetation Index, ISBN-13: 978-0199693160, under " 11.4.2 NDVI Versus MODIS-based NPP and GPP"). Considering the above points and the focus of the study on seasonality rather than absolute values for productivity, we are convinced that NDVI is the most suitable product currently available.

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Point 3: (C176)

Abstract: L4 Not only the trends are important. The variability is much more important from an ecological perspective (C176)

Response 3 :

We agree that the main focus of the study lies on the seasonality and the variability between years, not the overall trend. We will add a variability analysis as recommended; whereby we will focus on the identification and characterization of anomalously dry periods based on the Standardized Precipitation Index (SPI).

The introduction is lacking information to put the study into context (C177) We will refocus the introduction and include more context information as recommended (see also response 1).

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Point 4: Conversion of rainfall to drought index (C177)

Response 4 :

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We agree that lack of rainfall is not a direct measure of water stress or drought. We will therefore add an anomaly-based index or indices that relate more closely to drought conditions. Specifically, we plan to include the Standardized Precipitation Index (SPI).

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Point 5 (C177)

I think that by putting so much focus on the aim to use tree ring data, which later are useless, the paper gives a false impression to the reader.

Response 5 :

We will move the detailed methods description of the tree-ring analysis to the supplementary material. We originally intended to exclude the tree-ring analysis from the manuscript. It is however important to communicate the outcome to the scientific community as the cross-section material looked promising (showing rings, while a detailed analysis was needed to test if the rings are annual). Further, a recently initiated analysis of monthly pinned samples from the atoll revealed exceptionally low cambial growth in O. ciliata for 2013 (a very dry year) even in comparison to Mediterranean trees, indicating that tree growth is indeed limited under such dry conditions on Aldabra. Finally, we are convinced that it is good practice to communicate results that did not fulfil expectations, to prevent tree cutting for similar studies, especially for a protected site such as Aldabra. Indeed, if all negative results just sit in the file drawer, then a rather biased picture of science will emerge!

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Point 6 (C177)

p988,L16-21: Uncertainties in the SOS and EOS can have large consequences for the later analyses. Was any sensitivity analysis performed to assess the effect of different TIMESAT setting on later analyses? I think it is important to analyse and mention the uncertainties as a result of this.

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Response 6 :

The methodology used in extracting the seasonality parameters is documented in the literature (Jönsson & Eklundh, 2004: doi:10.1016/j.cageo.2004.05.006), widely applied in land surface phenology studies of water limited ecosystems in Africa (Hemann et al, 2007: doi:10.1016/j.rse.2006.11.025, Wessels & Steenkamp, 2011: doi:10.1111/j.1654-109X.2010.01100.x, Bachoo & Archibald, 2007) and represents the state of the art in land surface phenology (Hird & McDermid, 2009: doi:10.1016/j.rse.2008.09.003).

The parameterization of TIMESAT influences the results in two ways: a) the choice of representation (Gaussian, logistic, etc.) may influence how accurately the observations are being modelled, especially around the inflection points and the peak of season; b) the choice of SOS definition (midpoint, maximum, increase, etc.) may influence the phenological metrics and, to a much smaller extent, the magnitude of the trend. We adopted a commonly used configuration that is anticipated to be least sensitive to these effects, following recommendations in mentioned papers. We have not performed additional sensitivity tests because these are subject of a different field within the land-surface phenology and beyond the scope of our study. A visual quality check of the fit to the raw data and quantitative analysis of the RMSE between the raw and smoothed curves was thus used to select the best smoothing algorithm and parameters. Being a local smoother, the Savitzky-Golay outperforms, in terms of RMSE, global smoothers such as logistic or Gaussian.

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Point 7 (C177) p988L21 (C177): What is the best result? Was there any objective criterion for that? Or was it just visual inspection?

Response 7 : See Response 6

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Point 8: p988L21 (C177)

I am not completely convinced about the absolute accuracy of the method. E.g. in Fig4 the minimum albedo in winter 2006-2007 seems largely overestimated as the downward 'outliers' do not seem clouds (in comparison with the other NDVI values).

Response 8 :

The smoothing function was configured to adapt more strongly to higher NDVI values since lower values (especially abrupt, low values) are usually indicative of cloud contamination. For our study, whether dry season NDVI minima are "largely overestimated" is of little consequence because the smoothed NDVI time-series (or minima) are only used to calculate the timing of SOS and EOS. Apart from the SOS and EOS timing, none of the analyses are based on the smoothed NDVI values (p989, L4-L7) e.g.: a) our observation about Aldabra's dry season NDVI minimum being high during the dry season (p994, L3) is based on the raw NDVI data (see Fig. 4), not on the smoothed data. b) seasonal NDVI means and maxima were calculated from the raw NDVI data (See p989, L10-L11 of the paper). c) cross-correlation analyses of rainfall and NDVI time-series were based on the raw NDVI time-series, not on the smoothed data. Therefore the noise in the raw NDVI is accounted for in the calculation of the test statistic in Figure 5. Looking at Figure 4, all SOS and EOS points of the NDVI time-series lie where we would conceptually expect them according to our definition of NDVI SOS and EOS (p989, L4-L7). Finally, the seasonal variation in our NDVI data shows strong agreement with previous studies on the vegetation phenology of the atoll's terrestrial flora (doi:10.1098/rstb.1983.0050) and our knowledge of the atoll. It is therefore reasonable to assume that the TIMESAT derived seasonality metrics reflect actual vegetation phenology events on the ground.

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Point 9: p988L21 (C178)

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the effect of noise can have strong effects on the later cross-correlation analyses (eg. Lhermit et. al. http://dx.doi.org/10.1016/j.rse.2011.06.020.) Understanding the noise is therefore also important to understand the uncertainties and its effect should be included as an uncertainty in the analyses.

Response 9 :

Seasonality metrics computed by TIMESAT are determined based on the de-noised NDVI time-series, not the raw data (Jönsson & Eklundh, 2004: doi:10.1016/j.cageo.2004.05.006). The reason for smoothing the data is to remove the noise and its potentially disruptive effects on SOS and EOS detection. (see Section 5.2. Importance of knowledge of time series characteristic and Lhermit et al. 2011, paragraph 3). The Lhermit et al. 2011 study is not on the effects of residual noise in smoothed time-series onto the seasonality metrics (note the title: "A comparison of time series similarity measures for classification and change detection of ecosystem dynamics"). However, the Lhermit et al. 2011 paper is indeed relevant for our study as it assessed the effect of noise and other time-series characteristics on correlation-based measures between time-series. According to Lhermit et al. 2011 (p3144), noise depresses cross-correlations between time-series. Therefore, noise might have led to an underestimation of the cross-correlation between vegetation activity and rainfall in our study, Fig. 5. We will include a corresponding sentence in the manuscript.

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Point 10: (C178)

p988L26: Was TIMESAT fit on all individual pixels? Or was it fit on the mean of all pixels? The paper should do the former as otherwise the final NDVI is just mixing all different ecosystems dynamics into one signal.

Response 10 :

TIMESAT was not fit on the mean of all pixels (see p988, L3-L20). Stratification of

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pixels into sites is done based on the dominant plant functional types, separating the dynamics of different vegetation communities.

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Point 11: (C178)

p989L12-17 : Does it make sense to fit a smoothed curve on the rainfall series?

Response 11 :

The spiky nature of the rainfall series, despite being part of the "signal" itself (unlike in the NDVI series where abrupt dips and spikes are due to quality issues), poses the same problem as noise with respect to SOS and EOS determination. To quantitatively determine the rainfall SOS and EOS, it is necessary to smooth the rainfall time-series, as exemplified in other studies (e.g. Guan et al, 2014. doi:10.1002/2013JG002572). Note that we are interested in the year to year variation in the length of the rainfall season and its effects on vegetation activity, so a constant definition of wet and dry season for all years would not be satisfactory. The inaccurate detection of the 2006 and 2007 rainfall EOS is acknowledged and addressed in the paper (p993, L15).

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Point 12 (C178)

p989L20: Was the correlation calculated between the raw NDVI and rainfall series? Or between the TIMESAT smoothed curves? I would strongly recommend the former as otherwise the TIMESAT uncertainties will be taken along.

Response 12 : Time-series cross-correlation functions were calculated based on the raw NDVI and raw rainfall time-series. We will make this more explicit in the revised version.

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Point 13 (C178-C179)

Section 2.5: By calculating the cross-correlation on the complete time series it is implicitly assumed that the vegetation response to rainfall in the beginning of the growing season is similar to the response at the end of the growing season. This is, however, clearly not the case. For example in Fig.4 it is clear that the green-up after the first rains is much quicker and direct than the senescence phase at the end of the rain season. This difference in response, however, is never take this into account, but this will have strong consequences for the interpretation of the response of vegetation to rainfall.

Response 13 :

We agree that vegetation activity might show different lags with respect to rainfall at the start and end of the growing season. With regard to Figure 4, we think that the claimed effect is not apparent but we will assess it in out revised analysis. NDVI shows responses to rainfall during the senescence phase as well i.e. the senescence rate appears to slow if some rain falls during the senescence phase (e.g. 2001). This behaviour is in accordance with Guan et al, 2014's (doi: 10.1002/2013JG002572, Page 1654) observation of the opportunistic nature of most grass species in arid ecosystems in Africa i.e. they will make use of water whenever it is available. We will address start and end of growing season correlations between rainfall and vegetation activity by two separate statistical analyses, where we will choose the timing of the minimum of the smoothed NDVI curve and the peak of growing season as temporal separation points between green-up and senescence phases.

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Point 14 (C179)

Section 3.1 The downward trend of -6mm/yr is very small relative to the inter-annual variability, which seems in the order of 400-500mm/yr. Therefore, I have my severe doubts that the slow trend will be determining the future of the endemic species. I don't

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think that species response is related mean rainfall. They will be much more affected by extreme dry years or the sequence of dry/wet years than by a relatively small trend. The paper, however, does not discuss or analyze any of these variability effects and bases all its conclusions on a mean trend.

Response 14 – see Response 3

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Point 15 (C179) p992L7: these minima are very sensitive to the accuracy of the TIMESAT method. See my earlier comment, where I don't trust the minima in the winter 2006-2007 in Fig.4

Response 15 : See Response 8

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Point 16 (C179)

I think the interpretation of these lags is very doubtful if there is no discrimination between the greening response (which is much faster) and the browning response (which is slower).

Response 16

We will address this, see Response 13

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Point 17 (C179)

p992L22: 'and their sensitivity to water stress'. I don't agree. Rainfall is not water stress!

Response 17 : See Response 4

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Point 18 (C179-C180)

p992L25: 'suggesting the tortoise turf are particularly sensitive to changes in rainfall'. I don't agree. The NDVI of tortoise turf is more strongly correlated to rainfall, which is logical as it is a more deciduous. There is however no clear sign of a causal relationship (i.e. still low R2).

Response 18 :

Tortoise turf dominated areas, acting as crucial seasonal food resource for giant tortoises on Grand Terre East, show the highest correlations with rainfall compared to other vegetation communities. Magnitude and statistical significance of rainfall-NDVI correlations only indicate the possibility of a causal relationship between the two variables (not proof) hence the cautious statement: "...suggesting the tortoise turf are particularly sensitive to changes in rainfall" in the article. The fact that a significant correlation between rainfall and NDVI derived lengths of season occurs only in the site (GTE) with the highest proportion of deciduous plant functional types is ecologically sensible, relating to the soil properties in this area (p996L12-20). The rainfall-NDVI relationship might be stronger than reported correlations due to the effects of other growth-limiting factors; as discussed in Section 4.2 (p995). The primary production of the tortoise turf is correlated more closely with rainfall when grazing effects of the tortoises are taken into account (doi:10.1098/rstb.1983.0050), which could explain the rather low correlations in Fig. 5. We are addressing this research question in an ongoing long-term study with tortoise exclosure plots.

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Point 19 (C180)

Moreover, other vegetation types may be more sensitive to rainfall, but perhaps it is not shown by their NDVI as a large NDVI response is not necessarily an indicator of sensitivity.

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Response 19 :

No part of this paper has even remotely implied that a large NDVI response is an indicator of sensitivity. Given the practical meaning of Equation 2 (p990, L2), if a plant functional type "X" is more sensitive to rainfall compared to the tortoise turf then: a) whether X's NDVI responses are large or small in absolute terms is irrelevant when assessing how sensitive the NDVI of X is to changes in rainfall by means of a correlation statistic. b) the correct expectation is not a "large NDVI response" in X but rather, greater consistency in the nature of this response (no matter how small in absolute terms) with variation in rainfall.

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Point 20 (C180)

p994: How accurate are the minimum NDVI analyses if uncertainties are already apparent in Fig.4?

Response 20 :

No minimum NDVI analyses based on smoothed data (Fig. 4) were used in the manuscript (Response 8). P994, L3-L8 refers to the raw NDVI minima.

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Point 21 (C180)

p994L5: given the low correlations and lack of any proof of causal relationship, I think this evidence is very small.

Response 21 : See response 18. We will change 'clear evidence' to 'clear indications'.

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Point 22 (C180)

p994L20-p995L9: I agree that there must be concern, but I really doubt that a small

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trend in mean rainfall will determine the future of the tortoise population. Several other factors (interannual variability, etc.) are much more important, but the paper fails to address all of these. This also shown by Bourn et. al. who mention that two consecutive dry years are strongly responsible for the decline in tortoise population. This is something completely different than a small decline in mean rainfall! Therefore, I do not agree with any of the papers conclusion on the future of the tortoise population.

Response 22 :

We will include interannual variability in rainfall and consecutive dry years in the analysis (see response 3) and adapt the discussion section correspondingly.

The Bourn et al (1999) paper would fall very short of reviewer's 1 high standards for evidence! That study is based on only two time points: the first conducted over several months in 1973 to 1974 and the second over two months in 1997. Because the methodologies used at these two time points are so different, various unspecified 'adjustments' were made to the later dataset. The apparent 'crash' in the population is therefore highly disputable, and indeed, we find it highly suspect that the data apparently support so strongly their pre-conceived beliefs. Certainly, attributing a crash which apparently occurred over a twenty year period to two dry years in this period is extreme speculation. Hence it seems entirely reasonable to us to report a downtrend in rainfall that might indeed impact the atoll and its inhabitants. To want to ignore this possibility on the grounds that this reviewer 'knows what factors are much more important for the future of the tortoise population' (providing only one concrete suggestion with interannual variability) seems to us entirely irresponsible.

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Point 23 (C181)

p995-23-p996L11: I think most of this information is not relevant in relation to the paper's analyses and highlights the very limited contribution of this paper to under-

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standing the effective response of vegetation on the Atoll to water stress (rainfall, not drought; raw data, no anomalies; all year data, no difference between start/end growing season).

Response 23 :

As correctly mentioned by Reviewer 1, the correlation might not be causal and other growth-limiting factors need to be discussed to relate results to earlier studies on growth-limiting factors of the vegetation on Aldabra Atoll. The other concerns mentioned in this comment have been addressed in responses 4 and 13.

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Point 24 (C181)

p996L15-21: The 'strong' correlation does not explain anything about causal relationships (certainly not if 1 of 12 years was removed and the other one should have been removed as well; or both not). Moreover, this correlation is not that strong (only significant at one of the four study areas).

Response 24 :

We will update the wording according to the reviewer's suggestion. Regarding causality, see Response 18.

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Point 25 (C181)

p997L6: strong coupling. I don't see this strong coupling. By looking at mean and maximum NDVI the paper does not assess at the coupling of dry periods, but only at wet periods, whereas Bourn et. al. have highlighted the importance of consecutive dry periods.

Response 25 : See Response 13

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Point 26 (C181)

p997L14: tortoise are not sensitive to mean annual rainfall. To understand the vulnerability the paper should investigate the importance of changes in extremes and variability.

Response 26 :

Once again, the reviewer simply does not know this. However, we will include a rainfall variability analysis and a corresponding section in the discussion.

Interactive comment on Biogeosciences Discuss., 12, 981, 2015.