# Peer review history for:

Riddin T, Van Niekerk L, Strange F, Adams JB. Habitat changes in response to pressures in the Verlorenvlei estuarine lake, South Africa. S Afr J Sci. 2024;120(7/8), Art. #16868. https://doi.org/10.17159/sajs.2024/16868

**HOW TO CITE:**
Habitat changes in response to pressures in the Verlorenvlei estuarine lake, South Africa [peer review history]. S Afr J Sci. 2024;120(7/8), Art. #16868. https://doi.org/10.17159/sajs.2024/16868/peerreview

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**Reviewer A: Round 1**
**Date completed:** 24 January 2024
**Recommendation:** Accept / Revisions required / Resubmit for review / **Decline**
**Conflicts of interest:** None

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|---|
| Does the manuscript fall within the scope of SAJS? |
| **Yes**/No |
| Is the manuscript written in a style suitable for a non-specialist and is it of wider interest than to specialists alone? |
| **Yes**/No |
| Does the manuscript contain sufficient novel and significant information to justify publication? |
| Yes/**No** |
| Do the Title and Abstract clearly and accurately reflect the content of the manuscript? |
| Yes/**No** |
| Is the research problem significant and concisely stated? |
| Yes/**No** |
| Are the methods described comprehensively? |
| Yes/**No** |
| Is the statistical treatment appropriate? |
| Yes/No/**Not applicable**/Not qualified to judge |
| Are the interpretations and conclusions justified by the research results? |
| Yes/**Partly**/No |
| Please rate the manuscript on overall contribution to the field |
| Excellent/Good/Average/**Below average**/Poor |
| Please rate the manuscript on language, grammar and tone |
| Excellent/Good/**Average**/Below average/Poor |
| Is the manuscript succinct and free of repetition and redundancies? |
| **Yes**/No |
| Are the results and discussion confined to relevance to the objective(s)? |
| **Yes**/No |
| The number of tables in the manuscript is |
| **Too few**/Adequate/Too many/Not applicable |
| The number of figures in the manuscript is |
| **Too few**/Adequate/Too many/Not applicable |
| Is the supplementary material relevant and separated appropriately from the main document? |
| **Yes**/No/Not applicable |
| Please rate the manuscript on overall quality |
| Excellent/Good/**Averag**e/Below average/Poor |

Is appropriate and adequate reference made to other work in the field?

**Yes**/No

Is it stated that ethical approval was granted by an institutional ethics committee for studies involving human subjects and non-human vertebrates?

Yes/No/**Not applicable**

If accepted, would you recommend that the article receives priority publication?

Yes/**No**

Are you willing to review a revision of this manuscript?

**Yes**/No

Select a recommendation:

Accept / Revisions required / Resubmit for review / **Decline**

With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.

**Yes**/No

**Comments to the Author:**

While there is a good deal of potential value in this paper, and the overall conclusions are probably justifiable, the paper lacks structure and would need considerable further development if it were to be considered publishable. There is rather too much 'anecdotal' information and substantial amounts of data that are either missing (not collected) or taken for granted.

It seems the authors have done some valuable mapping work on the range of habitats in the Verlorenvlei using remotely sensed imagery supported by some field observations. The key figure and table are provided in Figure 3. If we take the identification of these habitats at face value, these are important data – but they represent 'snapshots' and it really would have much more impact had several other years been subject to the same analysis. That way, way more could be done with the data – including an analysis of how the rainfall fluctuations impact on these habitats. Having gone through the effort of identifying these communities, I would suggest taking a year in each of the decades (1960s, 70s – based on aerial photos) and 80s, 90, 2000s and 2010s (based on Google Earth) would really reinforce the arguments here and applying the same methodology. Some simple statistical analysis on the resulting spatial changes (% increase/decrease etc.) would be highly instructive. As it stands – the aerial photo in Fig. 3 is rather unhelpful/unclear. The discussion on factors underlying the pattern of pH in sediments and water seems more reliable, but it is based on very few sample points. All in all, there is not much 'original' data here beyond two vegetation maps, several sediment analyses of pH and quite a lot of photographs and visual interpretation – too much speculation for my liking. And the writing and referencing lack precision.

As it stands, I do not believe the paper can be published. I set out some more specific points below (constrained by the absence of line numbers on the ms):

Title: Should surely include the dates 1942-2021 (or 2023?)

Abstract (and in several other places). There is reference to 'important peat beds' and in other places the impression is given that 'peat' is widespread in the lake and surrounding floodplain. This is a complete overstatement. There are relatively small patches of 'more organic' sediments, particularly associated with sprints (for example at Klaarfontein). The 'peats' are neither 'peat' (which suggests very high organic matter) or widespread. Verlorenvlei does have some organic accumulations, but I doubt it could be described as 'an important peatland'.

Introduction: what is the source of the statement that: "Only 4% of South African estuaries are estuarine lakes, yet they cover more than 60% of the country's estuarine habitat area"? Many other sources missing throughout the text, which therefore lacks credibility as a scientific analysis. Would be useful to give other examples of such coastal lakes (Lake St Lucia, Wilderness, for example – both of which are much larger).

Irrigation is mentioned only once – but I think it is likely to be a major factor in water supply to the lake (arguably more than direct water extraction). Whatever, it warrants much more detailed consideration (the centre-pivot fields could, for example, be mapped).

My version of the ms had a number of 'error! Reference source not found. This needs to be resolved of course.

Materials and methods: Last paragraph – what is the source of the information about opening/closure of the mouth.

Present and past habitat distribution: What is CDNG? 50cm resolution? Surely impossible.

"Although humans have inhabited the area since the 1600s". What absolute nonsense. Who do you think was responsible for the paintings at EBC? Indeed, the discussion of longer-term changes in and around the Verlorenvlei is weak – with key references missing (e.g. Stager et al. Climates of the Past).

The word 'data' is plural – therefore 'data are…'

Results and Discussion:

I think separating 'results' from 'discussion' would better clarify the contribution of the study (which is limited to the 2021 mapping and 1942 interpretation plus a few sediment samples) and highlight better what is really needed to justify the conclusions drawn.

It's presence – should be 'Its presence'

140 what? Units?

150000cm3 (really, this is not a lot of water) Changes in habitat in response:
Rainfall data (from which location? – the water level probably responds more to changes in the catchment, not local rainfall). This warrants discussion – and more data.

Human pressures: Sources of (anecdotal?) information about obstructions (para 1), fire (para 2) and 'peat swamps' are not stated, or not sufficiently detailed.

Future outlook: 'future climate change' is vague, and taken for granted – but how about looking at some of the published model outputs – at least for SA as a whole?

**Author response to Reviewer A: Round 1**

While there is a good deal of potential value in this paper, and the overall conclusions are probably justifiable, the paper lacks structure and would need considerable further development if it were to be considered publishable. There is rather too much 'anecdotal' information and substantial amounts of data that are either missing (not collected) or taken for granted.

AUTHOR: The manuscript has been revised to provide the necessary structure. Our analysed "data" consists of mapping the habitat within the estuarine functional zone (EFZ) to determine the present status. This is a step in the application of the Estuarine Health Index, a method used by Department of Water Affairs and Sanitation and South African National Biodiversity Institute (SANBI) in the National Biodiversity Assessment to assess ecological health of estuaries. Available long-term data are used to make these ecological health assessments. Unfortunately, there is limited if any, long term data for the majority of South Africa's estuaries and the use of anecdotal data for the last 100 years are used to describe the past or non-impacted estuary state. To improve our "data collection" in this revised version of the article we have mapped estuary habitat cover for additional years and linked these changes in areal extent to rainfall and

water level data. Rainfall data are only available from the 1960s, the patchy data sets hamper any statistical analyses. While anthropogenic pressures cannot be empirically linked to habitat changes, we have a good understanding of the changes that have taken place in the Verlorenvlei Estuary their drivers. We have assessed over 40% of South Africa's estuaries using the Ecological Flow Requirement methodology (Adams et al. 2002) along with partaking in National Biodiversity Assessments since 2011 (Van Niekerk et al. 2011, 2018).

Adams JB, Bate GC, Harrison TD, Huizinga P, Taljaard S, Van Niekerk L, et al. A method to assess the freshwater inflow requirements of estuaries and application to the Mtata Estuary, South Africa. Estuaries. 2002;25(6b):1382-93.

Van Niekerk L, Turpie JK. South African National Biodiversity Assessment 2011: Technical Report. Volume 3: Estuary Component. Pretoria: South African National Biodiversity Institute. Stellenbosch: Council for Scientific and Industrial Research.

Van Niekerk L, Adams JB, Lamberth SJ, MacKay CF, Taljaard S, Turpie JK, et al. South African National Biodiversity Assessment 2018: Technical Report. Volume 3: Estuarine Realm. CSIR report number CSIR/SPLA/EM/EXP/2019/0062/A. South African National Biodiversity Institute, Pretoria. Report Number: SANBI/NAT/NBA2018/2019/Vol3/A.

The text has been revised as follows on page 12, line 303:
*"This article serves as a collation of available knowledge and published data on the Verlorenvlei Estuary so that its present habitat status (2021) and changes over time could be assessed. Unfortunately for many of South Africa's estuaries long-term data are lacking and any local sources of information are invaluable in understanding changes over time. For this reason we have made use of a variety of data sources from aerial photographs, repeat photography, rainfall records and anecdotal data to gain an understanding of macrophyte changes in Verlorenvlei. This information can be used in ecological water requirement studies (EWRs) being marked as low, medium or high confidence depending on data available, and from this monitoring and data requirements are specified in the study to improve future assessments. These EWR studies of the Department of Water Affairs and Sanitation are a national requirement in the management of South African estuaries and encompass ecohydrological and ecosystem-based concepts(31) (19, 32). To date the study approach has been applied to 40% of South Africa's estuaries with the majority (68%) of studies completed as low confidence desktop or rapid level assessments(19, 33)."*

It seems the authors have done some valuable mapping work on the range of habitats in the Verlorenvlei using remotely sensed imagery supported by some field observations. The key figure and table are provided in Figure 3. If we take the identification of these habitats at face value, these are important data – but they represent 'snapshots' and it really would have much more impact had several other years been subject to the same analysis. That way, way more could be done with the data – including an analysis of how the rainfall fluctuations impact on these habitats. Having gone through the effort of identifying these communities, I would suggest taking a year in each of the decades (1960s, 70s – based on aerial photos) and 80s, 90, 2000s and 2010s (based on Google Earth) would really reinforce the arguments here and applying the same methodology. Some simple statistical analysis on the resulting spatial changes (% increase/decrease etc.) would be highly instructive.

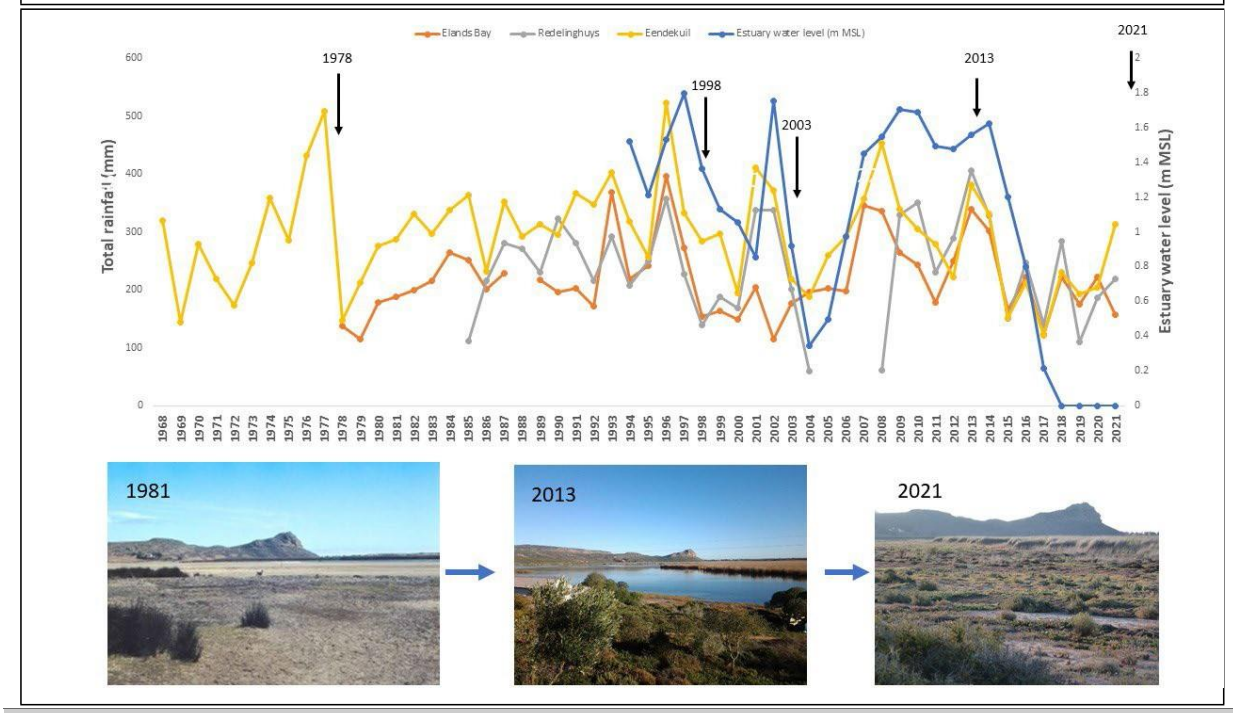
AUTHOR: Thank-you for the input, the article has been revised to include habitat mapping for additional years as shown in Figure 4 of the revised manuscript. Additional mapping of estuary habitats for 1978, 1998, 2003 were completed. These years were chosen based on availability and quality of aerial images that clearly indicate habitat. The changes in the estuarine lake are then described in relation to rainfall and water level, where relevant data exists. Figure 6 (water level and rainfall) has been edited to include these additional years. Simple statistics, % increases and decreases, have been added in the Results.

Page 8 line 195:
*"Open water area decreased by 64% from a mean of 1113 ± 27 ha (SE) before the drought to 421 ha (Figure 4)."*

Page 6 line 220:

*"Reeds and sedges appear to be stable in extent over the last few decades with only a 6% increase from 1942 to 2021 with a mean area of 704 ± 28.9 ha (SE) (Figure 4)."*


| | 1942 | 1978 | 1998 | 2003 | 2013 | 2021 |
|---|---|---|---|---|---|---|
| Degraded / developed | 124 | 236 | 304 | 304 | 254 | 487 |
| Floodplain/ecotone/terrestrial | 240 | 156 | 64 | 64 | 244 | 686 |
| Open water | 1069 | 1030 | 1150 | 1146 | 1170 | 421 |
| Reeds and sedges | 724 | 795 | 719 | 722 | 579 | 688 |
| Sand and mudbanks | 0 | 0 | 0 | 0 | 2 | 193 |
| Salt marsh | 125 | 77 | 22 | 22 | 4 | 3 |
| Submerged macrophytes | 321 | 309 | 345 | 344 | 351 | 126 |




As it stands – the aerial photo in Fig. 3 is rather unhelpful/unclear.

AUTHOR: Figure 3 has been removed from the revised article.

The discussion on factors underlying the pattern of pH in sediments and water seems more reliable, but it is based on very few sample points. All in all, there is not much 'original' data here beyond two vegetation maps, several sediment analyses of pH and quite a lot of photographs and visual interpretation – too much speculation for my liking. And the writing and referencing lack precision.

AUTHOR: The article has been rewritten to improve precision. The Verlorenvlei Estuary is in a critical acidic state; it is important that available data are used to highlight the current condition so that a detailed monitoring and reporting programme can follow for this important Ramsar (Wetland of international importance) site. This article provides an historical account of changes in habitat in response to rainfall and

water level changes in a data poor environment and relies heavily on all available anecdotal data. While the pH data are invaluable in describing the present acidic state, a larger dataset form part of a separate manuscript that is in preparation.

As it stands, I do not believe the paper can be published. I set out some more specific points below (constrained by the absence of line numbers on the ms):

Title: Should surely include the dates 1942-2021 (or 2023?)

AUTHOR: The title has been changed to "The present status and habitat changes between 1942 and 2021 in response to pressures in Verlorenvlei, an estuarine lake on the west coast of South Africa."

Abstract (and in several other places). There is reference to 'important peat beds' and in other places the impression is given that 'peat' is widespread in the lake and surrounding floodplain. This is a complete overstatement. There are relatively small patches of 'more organic' sediments, particularly associated with sprints (for example at Klaarfontein). The 'peats' are neither 'peat' (which suggests very high organic matter) or widespread. Verlorenvlei does have some organic accumulations, but I doubt it could be described as 'an important peatland'.

AUTHOR: This section has been rewritten to focus on Grundling et al.'s (2021) description of peats. His works recognises the Verlorenvlei as one of 20 important peatlands in South Africa where peat is defined as *"an area with or without vegetation with a naturally accumulated peat layer at the surface", where peat is "sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material with depth at least 300 mm."*

Grundling PL, Grundling A, Van Deventer H, Le Roux JP. 2021. Current state, pressures and protection of South African peatlands. Mires and Peat 27, 26:25.

The new text reads as follows on page 3, line 67:
*"A number of freshwater springs facilitated the proliferation of the current wetland species during this period of sea level regression and the permanence of the reed swamps resulted in the formation of large peat beds associated with Verlorenvlei, where peat is defined as "an area with or without vegetation with a naturally accumulated peat layer at the surface", where peat is "sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material with depth at least 300 mm" ([2, 9])".*

Introduction: what is the source of the statement that: "Only 4% of South African estuaries are estuarine lakes, yet they cover more than 60% of the country's estuarine habitat area"? Many other sources missing throughout the text, which therefore lacks credibility as a scientific analysis. Would be useful to give other examples of such coastal lakes (Lake St Lucia, Wilderness, for example – both of which are much larger).

AUTHOR: This section has been rewritten as follows and the necessary citations have been included on page 2, line 52:
*"Only 4% of South African estuaries are estuarine lakes (of which there are 13), yet they cover more than 60% of the country's estuarine habitat area([1]). Their high-water retention results in a sensitivity to the influence of in situ processes such as low flushing rates and slow remineralization of nutrients more than other estuary types, making them less resilient to change and more vulnerable to catchment land-use and development pressures, as well as climate change. This is particularly true in shallow estuarine lakes such as Verlorenvlei. Not surprisingly, more than 84% of South Africa's estuarine lake area are in a poor ecological state([1]). The Verlorenvlei is particularly important because despite being small in comparison to other estuarine lakes, it is an ecologically and socio-economic source of freshwater on an arid coastline([10])".*

Irrigation is mentioned only once – but I think it is likely to be a major factor in water supply to the lake (arguably more than direct water extraction). Whatever, it warrants much more detailed consideration (the centre-pivot fields could, for example, be mapped).

AUTHOR: Additional information has been included on abstraction of water for irrigation in the new Discussion section as per the below extract on page 14, line 372:
"Agricultural activities have expanded in the catchment of Verlorenvlei with over 50% of the catchment already under cultivation prior to the 1990s. Commercial agricultural activities include potato farming, rooibos plantations (Aspalathus linearis), vineyards and orchards. Centre-pivot irrigation, a method which uses rotational cropping and the clearing of large areas, the use of fertilizers to enhance nutrient poor soils

and groundwater abstraction have all increased to boost production([10, 15]). Agriculture accounts for more than 90% of the total registered groundwater use in the Sandveld, with potato farming accounting for 20% of the annual groundwater recharge([15, 36]). Over abstraction of groundwater not only threatens the deep baseflows of the large secondary aquifer which feeds and sustains the wetlands of Verlorenvlei, particularly during the dry seasons, but also increases salinisation of groundwater resources([37]). There is a disagreement amongst groundwater specialists to the degree to which Verlorenvlei is dependent on groundwater versus surface water to maintain lakes levels([36, 38]), both ultimately contributes to the total flow into Verlorenvlei and lake levels. Over the last 90 years baseflows alone have decreased by 50% and lake levels by 33 cm([10]).”

My version of the ms had a number of ‘error! Reference source not found. This needs to be resolved of course.

AUTHOR: Our apologies for this, we hope this is resolved with the next revision.

Materials and methods: Last paragraph – what is the source of the information about opening/closure of the mouth.

AUTHOR: The paragraph has been rewritten as follows with the necessary citation added on page 4, line 115:

*“A recent study on the estuarine lakes of South Africa showed that Verlorenvlei alternates between four abiotic states, in response to local climate and rainfall(1). Historically drought cycles occur every 10 to 20 years and the mouth breaches every two to three years, remaining open for between 1 and 2 months after breaching. Under closed mouth conditions the estuarine lake can either be in a very low water level state (a drought state where waters can either be brackish or progress to acidic), or a low water level and fresh state, or a high-water level and fresh state, fed by rainfall and a large groundwater recharge from a secondary aquifer([2]). During the closed mouth state back flooding of the floodplain during high inflow periods causes high water levels that inundate large parts of the wetlands in the upper reaches, which in turn can result in the illegal practice of artificial breaching, for example in 2014. The fourth state is one where the mouth is open and water levels are declining due to outflow. At the time of this assessment in November 2021 the mouth was closed and the water level below 0.5 m MSL with hypersaline conditions in the lower mouth region, and large parts of the main basin exposed and acidic (pH in Lower reaches > 8, Middle reaches < 3 and Upper reaches between 6 to 7.5) ([10]) and vegetation was dying back as a result (Figure 2).”*

Present and past habitat distribution: What is CDNG? 50cm resolution? Surely impossible.

AUTHOR: CDNGI has written out as the Chief Directorate National Geo-spatial Information (CDNGI). Their recent images (in our case 2016) are aerial images of 50 cm resolution.

“Although humans have inhabited the area since the 1600s”. What absolute nonsense. Who do you think was responsible for the paintings at EBC? Indeed, the discussion of longer-term changes in and around the Verlorenvlei is weak – with key references missing (e.g. Stager et al. Climates of the Past).

AUTHOR: The sentence has been edited to read as colonial settlers in the following places: Page 3, line 75:
*“In the last 2 000 years pollen analysis shows a decline in grass species probably due to the increased presence of grazers([11, 12]), further exacerbated by colonial occupation in the area from 1741 and the introduction of wheat and corn production, and cattle([3])”.*

Page 5, line 140:
*“Although colonial settlers have inhabited the area since the 1600s, earliest images to assess vegetation distribution were only available for 1942; and represent a near natural state with little human pressure”.*

Page 14, line 369:
*“The decline in grass pollens from 1900 BP in sediment cores suggests the impacts of pastoralists, colonial and post-colonial disturbance of the vegetation. In the 350 years of colonial occupation, disturbance has been the greatest in the last few decades due to agri-business”.*

The authors recognize the presence of hunter-gatherers and pastoralists in the fourth paragraph of the Introduction and have cited important anthropological and paleontological work that includes the Elands Bay Caves, page 10, line 276:. “*Hunter-gathers and pastoralist have been intermittently present in the area*

*over the last 20 000 years([5, 11, 12, 14]).”*

Estuary health assessments for DWS and the Nationally Biodiversity Assessment typically consider changes in the system over the last 100 years.

Information from Stager et al. (2012) has been incorporated, thank you.

The word ‘data’ is plural – therefore ‘data are…’

AUTHOR: This has been corrected thank you.

Results and Discussion: I think separating ‘results’ from ‘discussion’ would better clarify the contribution of the study (which is limited to the 2021 mapping and 1942 interpretation plus a few sediment samples) and highlight better what is really needed to justify the conclusions drawn.

AUTHOR: Results and Discussion have been separated during the major revision that has taken place.

It’s presence – should be ‘Its presence’

AUTHOR: This has been corrected, thank you.

140 what? Units?

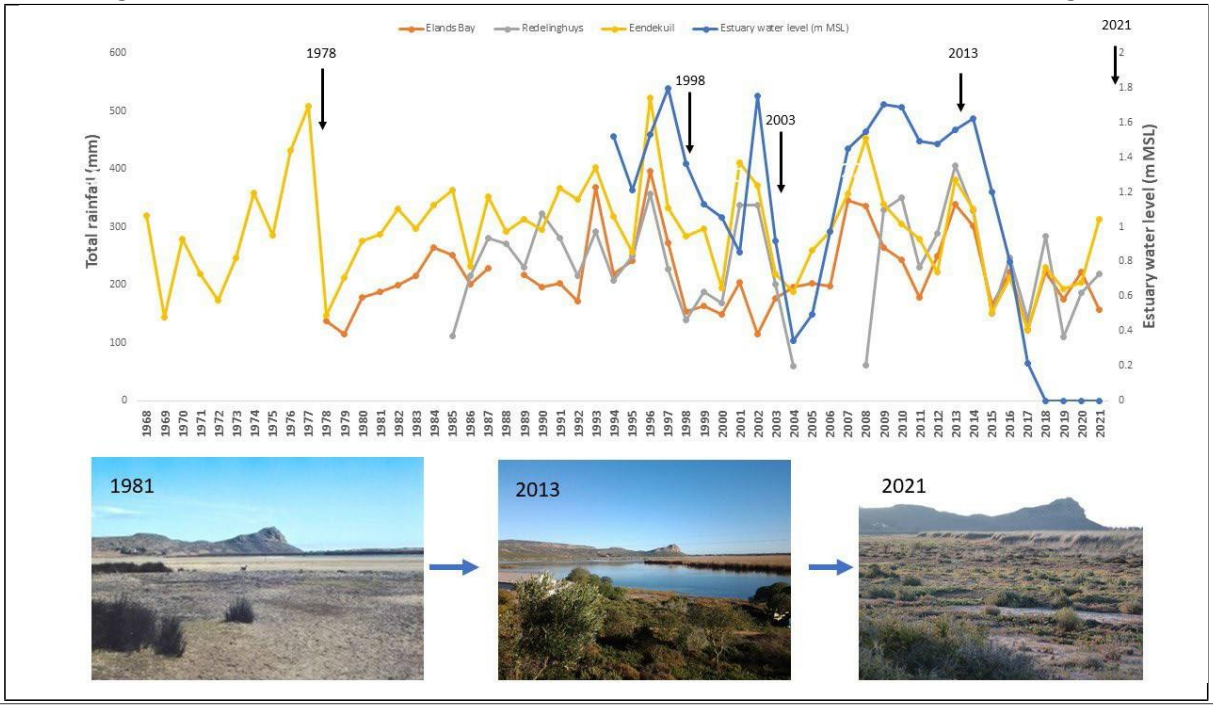
AUTHOR: The present measure of salinity according is dimensionless, as per the Journals request. Although the previous sentence refers to salinity preference of Phragmites australis, the word salinity has been included to remove any confusion on page 9, line 246:
*“During the field trip surface water salinity was found to be over 140 in the lower reaches, but at sediment depths between 30 cm to 1.5 m groundwater was 10.”*

150000 cm3 (really, this is not a lot of water)

AUTHOR: Our apologies, this should read 150 000 m3. The text has been corrected.

Changes in habitat in response: Rainfall data (from which location? – the water level probably responds more to changes in the catchment, not local rainfall). This warrants discussion – and more data.

AUTHOR: Additional rainfall sites from Agricultural Research Centre (ARC) have been added as shown in the revised Figure 6 below. The data sources are listed in Table 1 and stations are shown in Figure 1.




Human pressures: Sources of (anecdotal?) information about obstructions (para 1), fire (para 2) and ‘peat swamps’ are not stated, or not sufficiently detailed.

AUTHOR: A table has been included on page 6 line 151 showing the various data sources and the years for which they were available.

Table 1: Available data used in the assessment of habitat changes over time in Verlorenvlei.

| Data | Period | Source |
|---|---|---|

| | | |
|---|---|---|
| Aerial imagery | 1942, 1978, 1998, 2013, 2016, 2021 | Chief Directorate National Geo-spatial Information (http://www.cdngiportal.co.za/)<br><br>Google Earth |
| Oblique imagery | 1981, 2013, 2021 | Jenny Day, Dimitri Veldkornet, this study |
| Rainfall data | Elands Bay 1978 to 2021<br>Redelinghuys 2008 to 2021 | South African Weather Services<br><br>Agriculture Research Institute |

Future outlook: 'future climate change' is vague, and taken for granted – but how about looking at some of the published model outputs – at least for SA as a whole?

AUTHOR: Thank you for bringing this to our attention. We have added the work of Stager et al. (2012), Archer et al. (2009), Tadross et al. (2005) and Meadows and Baxter (1991, 2006) and discussed their findings with respect to future habitat changes. The Future Outlook section has been rewritten as follows on page 15, line 407:

*"With the recent extreme low water level in the Verlorenvlei, exposure of acidic soils and die back of vegetation, what does the future hold for Verlorenvlei where climate change predicts more extreme weather events (greater droughts and floods), increased temperature, greater aridity and sea level rise? Since this study in 2021 the lake water level declined further by 88% to 52 ha in May 2023 with water only occurring in the Middle reaches. Despite a 1:20 year flood in June 2023 which raised lake water level, both sediment and water showed continued acidic conditions (article in preparation). This acidic state has had cascading effects on the lake biota as well as on surrounding livestock and farm animals. Freshwater invertebrates were in the past present throughout the lake but under this new acidic state, no life occurs in the Lower and Middle reaches([10]). Partial drying out and flooding are natural cycles in lakes due to their large surface area and shallow nature, and this study has reported on these fluctuations. Under climate change this cycling is expected to occur more frequently with greater extremes. Increased aridity, increased extreme weather events (droughts, floods), increased temperatures, increased wind, decreased rainfall (especially during critical growing months for agriculture), increased mouth closure, increased evaporation, will result in lower lake levels and increased acidification is expected([10, 15, 16, 41]), with the build-up of hyper-sulfidic sediment potentially remaining for decades([42]). What effects this will have on the long term storage of seeds in the sediment, as well as recovery of vegetation and aquatic communities is unknown due to limited literature([43]). Mean annual runoff has been predicted to further decrease from the current 30% to 50%([10]), putting more pressure on groundwater abstraction for commercial agriculture irrigation in particular. The additional pressure of land use practises and existing human pressures needs to be considered if Verlorenvlei is to maintain its current RAMSAR status. This can be achieved through compulsory water use licensing, a reduction in water abstraction, a reduction in inorganic nutrient input from the catchment, prevention of illegal artificial breaching of the mouth, restoration of hydrological connectivity, protection of resources and buffer zones (reduced reed burning, grazing of salt marsh) and promulgation as a formally protected area with agreements on the freshwater requirements of the downstream estuarine lake ([10])."*

**Reviewer C: Round 1**
**Date completed:** 19 January 2024
**Recommendation:** Accept / **Revisions required** / Resubmit for review / Decline
**Conflicts of interest:** None

Does the manuscript fall within the scope of SAJS?

**Yes**/No

Is the manuscript written in a style suitable for a non-specialist and is it of wider interest than to specialists alone?

**Yes**/No

Does the manuscript contain sufficient novel and significant information to justify publication?

**Yes**/No

Do the Title and Abstract clearly and accurately reflect the content of the manuscript?

**Yes**/No

Is the research problem significant and concisely stated?

**Yes**/No

Are the methods described comprehensively?

**Yes**/No

Is the statistical treatment appropriate?

Yes/No/**Not applicable**/Not qualified to judge

Are the interpretations and conclusions justified by the research results?

**Yes**/Partly/No

Please rate the manuscript on overall contribution to the field

Excellent/**Good**/Average/Below average/Poor

Please rate the manuscript on language, grammar and tone

Excellent/**Good**/Average/Below average/Poor

Is the manuscript succinct and free of repetition and redundancies?

**Yes**/No

Are the results and discussion confined to relevance to the objective(s)?

**Yes**/No

The number of tables in the manuscript is

Too few/Adequate/Too many/**Not applicable**

The number of figures in the manuscript is

Too few/**Adequate**/Too many/Not applicable

Is the supplementary material relevant and separated appropriately from the main document?

**Yes**/No/Not applicable

Please rate the manuscript on overall quality

Excellent/**Good**/Average/Below average/Poor

Is appropriate and adequate reference made to other work in the field?

**Yes**/No

Is it stated that ethical approval was granted by an institutional ethics committee for studies involving human subjects and non-human vertebrates?

Yes/No/**Not applicable**

If accepted, would you recommend that the article receives priority publication?

Yes/**No**

Are you willing to review a revision of this manuscript?

**Yes**/No

Select a recommendation:

Accept / **Revisions required** / Resubmit for review / Decline

With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.

**Yes**/No

**Comments to the Author:**

This study details the habitat changes within and around Verlorenvlei over the last few decades, with a specific focus on dramatic changes over the last decade. It is certainly appropriate in terms of scope and content for publication in SAJS and overall the study is well executed and presented.

Please see, and address, the edits and comments made directly to the word document.

In addition to the more detailed comments on the document, I have three more general comments:

1) I feel a fuller, more detailed description of the land use within the area is needed, especially in terms of agricultural activities (e.g. types of crops, changes in types of crops, livestock farming etc),

also tourism activities.

2) What seems to be missing are details on what mitigation actions can be taken to help restore / conserve Verlorenvlei's natural habitats.
3) 3) Figures: The maps combined with time series imagery are nicely done, just make sure that they are large enough for the reader to see the details such as site labels and numbers. One further suggestion is that you include a few photographs of the key vegetation types per habitat type as SI material.

***[See Appendix 1 for Reviewer C's comments made directly on the manuscript]***

**Author response to Reviewer C: Round 1**

This study details the habitat changes within and around Verlorenvlei over the last few decades, with a specific focus on dramatic changes over the last decade. It is certainly appropriate in terms of scope and content for publication in SAJS and overall the study is well executed and presented.

Please see, and address, the edits and comments made directly to the word document.

AUTHOR: Where the original text has remained, these have been attended to with the comments included in the document, thank you.

In addition to the more detailed comments on the document, I have three more general comments:

1)I feel a fuller, more detailed description of the land use within the area is needed, especially in terms of agricultural activities (e.g. types of crops, changes in types of crops, livestock farming etc), also tourism activities.

AUTHOR: This has been addressed in the revision under the new Discussion page 14, line 372:
*"Anthropogenic pressures have intensified over the last 100 years as agriculture, road and rail development have increased. These have led to competition for water resources, and land practices such as burning and clearing of reed swamps and have fast-tracked land cover change in the area. This increased abstraction has led to a reduction of 50% in baseflow and together with a reduction in mean annual rainfall in the last 90 years, has led to a reduction in lake water level by 33 cm([10]). These natural and anthropogenic pressures pose a serious threat to the ecological health of the Verlorenvlei and therefore to its current RAMSAR status. Agricultural activities occupy over 50% of the catchment prior to the 1990s. Commercial agricultural activities include potato farming, rooibos plantations (Aspalathus linearis), vineyards and orchards. Centre-pivot irrigation, a method which uses rotational cropping and the clearing of large areas, the use of fertilizers to enhance nutrient poor soils and groundwater abstraction have all increased to boost production([10, 15]). Agriculture accounts for more than 90% of the total registered groundwater use in the Sandveld, with potato farming accounting for 20% of the annual groundwater recharge([15, 36]). Over abstraction of groundwater not only threatens the deep baseflows of the large secondary aquifer which feeds and sustains the wetlands of Verlorenvlei, particularly during the dry seasons, but also increases salinisation of groundwater resources([37]). While there is a disagreement amongst groundwater specialists to the degree to which Verlorenvlei is dependent on groundwater versus surface water to maintain lakes levels([36, 38]), both ultimately contributes to the total flow into Verlorenvlei and lake levels."*

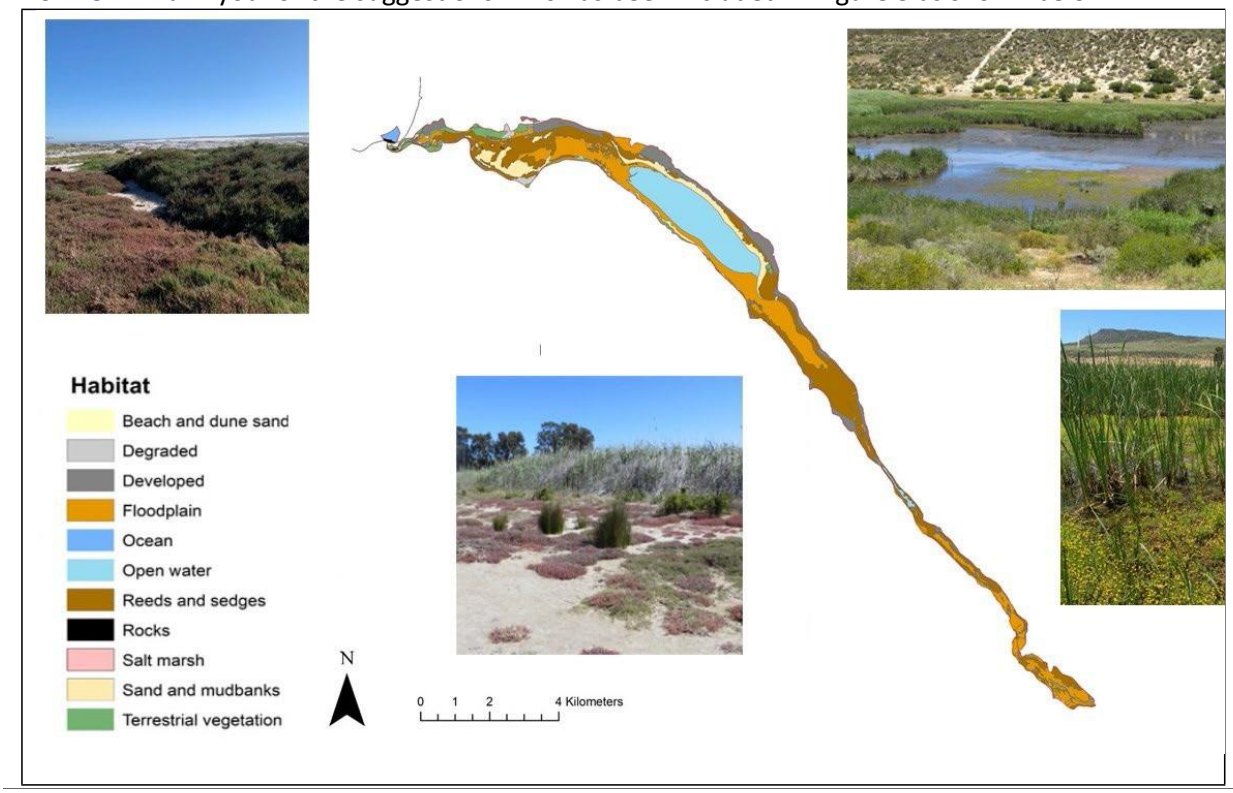
2)What seems to be missing are details on what mitigation actions can be taken to help restore / conserve Verlorenvlei's natural habitats.

AUTHOR: This has been addressed in the revision under the new Discussion and Future Outlook, page 15 line 426:
*"The additional pressure of land use practises and existing human pressures needs to be considered if Verlorenvlei is to maintain its current RAMSAR status. This can be achieved through compulsory licensing, a reduction in water abstraction, a reduction in inorganic nutrient input from the catchment, prevention of illegal artificial breaching of the mouth, restoration of hydrological connectivity, protection of resources and buffer zones (reed burning, grazing of salt marsh) and promulgation as a formally protected area with agreements on the freshwater requirements([10])".*

3)Figures: The maps combined with time series imagery are nicely done, just make sure that they are large enough for the reader to see the details such as site labels and numbers. One further suggestion is that you

include a few photographs of the key vegetation types per habitat type as SI material.

AUTHOR: Thank you for the suggestions. This has been included in Figure 3 as shown below.




**General Response to Reviewers Round 1**

Reviewer A stated that the manuscript does not contain sufficient novel information, nor that the Title, Abstract and research question is accurate and concise. The Reviewer also stated that the methods were not described comprehensively and that there were too few figures and tables. In response this we have mapped additional years with a total of 6 periods and included basic statistical analysis of habitat change over time (% increases/decreases). Reviewer C stated that the manuscript contained sufficient novel and significant information and figures to justify publication. We hope that the revisions provided will fulfil the expectations of Reviewer A and for both reviewers, specific comments have been addressed below in blue. Reviewer C provided changes within the original manuscript using track changes and these remain showing their markup in blue.

**Reviewer A: Round 2**
**Date completed:** 25 April 2024
**Recommendation: Accept** / Revisions required / Resubmit for review / Decline
**Conflicts of interest:** None

Does the manuscript fall within the scope of SAJS?

**Yes**/No

Is the manuscript written in a style suitable for a non-specialist and is it of wider interest than to specialists alone?

**Yes**/No

Does the manuscript contain sufficient novel and significant information to justify publication?

**Yes**/No

Do the Title and Abstract clearly and accurately reflect the content of the manuscript?

**Yes**/No

Is the research problem significant and concisely stated?

**Yes**/No

Are the methods described comprehensively?

**Yes**/No

Is the statistical treatment appropriate?

Yes/No/**Not applicable**/Not qualified to judge

Are the interpretations and conclusions justified by the research results?

**Yes**/Partly/No

Please rate the manuscript on overall contribution to the field

Excellent/**Good**/Average/Below average/Poor

Please rate the manuscript on language, grammar and tone

Excellent/**Good**/Average/Below average/Poor

Is the manuscript succinct and free of repetition and redundancies?

**Yes**/No

Are the results and discussion confined to relevance to the objective(s)?

**Yes**/No

The number of tables in the manuscript is

Too few/**Adequate**/Too many/Not applicable

The number of figures in the manuscript is

Too few/**Adequate**/Too many/Not applicable

Is the supplementary material relevant and separated appropriately from the main document?

Yes/No/**Not applicable**

Please rate the manuscript on overall quality

Excellent/**Good**/Average/Below average/Poor

Is appropriate and adequate reference made to other work in the field?

**Yes**/No

Is it stated that ethical approval was granted by an institutional ethics committee for studies involving human subjects and non-human vertebrates?

Yes/No/**Not applicable**

If accepted, would you recommend that the article receives priority publication?

Yes/**No**

Are you willing to review a revision of this manuscript?

Yes/**No**

Select a recommendation:

**Accept** / Revisions required / Resubmit for review / Decline

With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.

**Yes**/No

**Comments to the Author:**

Thank you for attending to the comments made on the initial submission. The ms is substantially improved.

**Reviewer C: Round 2**

**Date completed:** 18 April 2024

**Recommendation: Accept** / Revisions required / Resubmit for review / Decline

**Conflicts of interest:** None

Does the manuscript fall within the scope of SAJS?

**Yes**/No

Is the manuscript written in a style suitable for a non-specialist and is it of wider interest than to specialists alone?

**Yes**/No

Does the manuscript contain sufficient novel and significant information to justify publication?

| |
|---|
| **Yes**/No |
| Do the Title and Abstract clearly and accurately reflect the content of the manuscript? |
| **Yes**/No |
| Is the research problem significant and concisely stated? |
| **Yes**/No |
| Are the methods described comprehensively? |
| **Yes**/No |
| Is the statistical treatment appropriate? |
| Yes/No/**Not applicable**/Not qualified to judge |
| Are the interpretations and conclusions justified by the research results? |
| **Yes**/Partly/No |
| Please rate the manuscript on overall contribution to the field |
| Excellent/**Good**/Average/Below average/Poor |
| Please rate the manuscript on language, grammar and tone |
| Excellent/**Good**/Average/Below average/Poor |
| Is the manuscript succinct and free of repetition and redundancies? |
| **Yes**/No |
| Are the results and discussion confined to relevance to the objective(s)? |
| **Yes**/No |
| The number of tables in the manuscript is |
| Too few/**Adequate/**Too many/Not applicable |
| The number of figures in the manuscript is |
| Too few/**Adequate**/Too many/Not applicable |
| Is the supplementary material relevant and separated appropriately from the main document? |
| **Yes**/No/Not applicable |
| Please rate the manuscript on overall quality |
| Excellent/**Good**/Average/Below average/Poor |
| Is appropriate and adequate reference made to other work in the field? |
| **Yes**/No |
| Is it stated that ethical approval was granted by an institutional ethics committee for studies involving human subjects and non-human vertebrates? |
| Yes/No/**Not applicable** |
| If accepted, would you recommend that the article receives priority publication? |
| Yes/**No** |
| Are you willing to review a revision of this manuscript? |
| Yes/**No** |
| Select a recommendation: |
| **Accept** / Revisions required / Resubmit for review / Decline |
| With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author. |
| **Yes**/No |
| **Comments to the Author:**<br>*No comments provided.* |

**Appendix 1:** Reviewer C comments on manuscript

# Habitat changes in response to pressures in ~~the~~ Verlorenvlei, an estuarine lake on the west coast, ~~-~~ of South Africa

## Abstract

~~The~~ Verlorenvlei is a large freshwater estuarine lake on the arid west coast of South Africa. It has nationally important peat beds and was awarded RAMSAR status in 1991 as a globally significant ~~important~~ birding site and area of high biodiversity. However, drought and competition for water has resulted in extremely low water levels. Using historical data in the form of aerial and satellite imagery, rainfall amounts? Totals?, and water level/s? data?, we provide a clear ~~understanding~~ overview of habitat changes ~~of habitat~~ within the estuarine functional zone of the Verlorenvlei Estuarine Lake. Since 1942 the lake fluctuated in surface water area by almost 50% due to decadal rainfall cycles. However, an extended drought from 2016 until 2023 resulted in a 95% decline in open water area, hypersaline conditions (> 100) , ~~and~~ acidic water (pH < 3) and exposed sediment. Localized increase of reeds has occurred due to sediment and nutrient input from surrounding farming practices, but also due to the long period of exposed lakebed. Additional pressures such as fires have reduced above ground biomass, potentially altering surface morphology and reducing stored carbon. In June 2023 flooding occurred in the catchment area, the water level increased but the lake remained in an acidic state (3.9 to 4.3). Under future climate change scenarios which predict more frequent extreme weather events, similar extreme conditions are likely to occur for longer and more regular periods with low pH remaining for an unknown length of time. Monitoring is needed to confirm rate of change and improvement in conditions.

**Significance:**

This article assesses vegetation change in ~~the~~ Verlorenvlei – an estuarine ~~Lake~~ lake on the arid ~~West~~ west ~~Coast~~ coast of South Africa. Estuarine lakes are scarce in the country and an extended drought has impacted on water level in the Verlorenvlei and the biota as a result. Additional impacts such as competition for water from agriculture has resulted in extremely low water levels ~~with~~ and the exposure of acid soils. Subsequent

**Commented [A1]:** Over what time period? / since when?

**Commented [A2]:** And besides monitoring, any recommendations in terms of mitigation of the effects of current and future impacts of extreme weather events / climate change etc

**Commented [A3]:** Just veg change?

**Commented [A4]:** rephrase

heavy rains have been slow to buffer lake acidity and the impacts thereof serve as warning for the management of similar ecosystems and their ecological water requirements, especially under Climate Change where extreme weather conditions and competition for water becomes a reality.

**Keywords**: Estuarine Lake, anthropogenic impact, vegetation response, drought, lake acidification

## Introduction

Estuarine lakes are particularly susceptible to anthropogenic pressures due to their shallow nature, large surface area, weak connectivity with the sea and low flushing rate[1]. ~~The~~ Verlorenvlei is the only freshwater lake being fed by surface, river and several springs on a very arid ~~coastline~~ west coast of South Africa. ~~and it~~It has historically been an important source of freshwater for early humans, later becoming the focal point of settlements and agriculture and in the last few decades, an important agribusiness region[2-4]. ~~The estuarine lake~~ Verlorenvlei is also an important bird area providing feeding, nesting and resting facilities, for up to 20 000 birds at a time; for these reasons it achieved RAMSAR status in 1991 (no. 525). It also represents an important national peatland due to the buildup of organic matter over centuries[5] (~~as this is a rare habitat type~~peatlands are rare in South Africa). Ecologically ~~the~~ Verlorenvlei is located in an area that forms a transition between Strandveld and Fynbos biomes[6], supporting many rare and threatened species. This collectively makes it an estuary of high conservation importance, albeit with no statutory protection[1, 7].

Only 4% of South African estuaries are estuarine lakes, yet they cover more than 60% of the country's estuarine habitat area. Estuarine lakes have large surface area: volume ratios, comparatively low mean annual runoff, and intermittent connectivity to the sea. Their high water retention results in a sensitivity to the influence of *in situ* processes more than other estuary types, making them less resilient to change and more vulnerable to catchment land-use and development pressures, as well as climate change. This is particularly true in shallow lakes like ~~the~~ Verlorenvlei. Not surprisingly, more than 84% of South Africa's estuarine lake extent are in a poor ecological state[1].

**Commented [A5]:** Isnt this the case already?

**Commented [A6]:** Strandveld is not a biome - more a bioregion or veg type

I would change this to: a transition between fynbos and karroid vegetation types (Meadows et al 1996)

Estuarine habitats in general fluctuate~~s~~ naturally over time, and this is particularly evident at ~~the~~ Verlorenvlei, where changes have taken place since the Holocene (the last X years) [3, 8-10]. Fossil pollen analysis conducted on sediments from Verlorenvlei show that the ~~area~~ dominant vegetation type within the vicinity of the lake shifted ~~switching shifted~~ between ~~drought~~ drought-resistant woody shrubs and salt marsh vegetation (REF/REFS) ~~that occurred over 15 km inland~~. ~~This change~~These shifts took place on several occasions over the last XX years largely in response to changing sea levels [3, 4, 8, 9]. The present ecotonal mix of ~~Strandveld~~ strandveld and f~~F~~ynbos vegetation was established ~~grew~~ around 1900 BP in response to lowered sea level (REF). A number of freshwater springs facilitated the proliferation of the current wetland species during this period of regression and the permanence of the reed swamps resulted in the large peat beds associated with ~~the~~ Verlorenvlei[7, 11].

**Commented [A7]:** Changes surely took place since the system came into being, but we only have records covering the changes of the Holocene

**Commented [A8]:** Sea level regression? Rephrase to be more clear

Interwoven with global climatic drivers, human presence and their pressures, are also at play locally. Archaeological studies from ~~the~~ Elands Bay Cave, situated south of ~~the~~ Verlorenvlei's mouth show intermittent human presence ~~for~~ over the last 20 000 years[4, 12]. In the last 2 000 years pollen analysis shows a decline in grass species probably due to the increased presence of grazers[8], further exacerbated once colonial farmers settled in the area in 1741, bringing with them wheat and corn production, along with cattle[2]. Anthropogenic pressures have intensified over the last 100 years as agriculture, road and rail development have increased. These have led to competition for water resources, and land practices such as burning and clearing of reed swamps have fast-tracked land cover change in the area. A recent protracted drought together with a competition for freshwater between farmers and the estuarine habitat, has led to drying out of the lake and extended periods of low water level[13]. These natural and anthropogenic pressures pose a serious threat to the ecological health of the Verlorenvlei and therefore to its current RAMSAR status.

Given the importance of ~~the~~ Verlorenvlei, this study describes the extent of changes in the macrophyte habitat and their drivers over the last 80 years, when anthropogenic pressure resulted in the greatest change. The study makes use of historical aerial and satellite imagery, repeat photography, and historical abiotic data in a data poor environment to gain an understanding of these changes. The implications of these changes

under future climate change scenarios where rainfall patterns are expected to be more extreme and anthropogenic pressures more likely are also evaluated.

## Materials and Methods

### *Study site*

Verlorenvlei lies approximately 180 km north of Cape Town with a surface area of approximately 198 000 ha and an average depth of between 2 to 3 m [(1)] (Figure X?). The lake can be divided into three distinct reaches - Lower, Middle and Upper[(14)]. The Lower reach near the mouth has a small shallow channel (~2.6 km) that connects the larger lake basin (Middle reach) to the sea. There is very little free water exchange between the sea and the lake, mostly being closed by a sandbar during the dry summer months overlying a rocky sill. A migrating barrier dune has pushed the mouth progressively south. During the winter months when rainfall is maximum, the sandbar is breached and limited tidal interaction occurs. During high spring tides and stormy conditions seawater can enter the perched estuarine portion through overtopping. The Lower reach is separated from the main lake basin (Middle reach) via a causeway and rocky sill. The lake basin has an average depth of between 2 and 3 metres with a maximum depth of 5 metres[(15)]. The Verlorenvlei River feeds the estuarine lake system through a series of wetlands at Redelinghuys into a shallow upper reach – refer to a figure here.

A recent study on the estuarine lakes of South Africa showed that ~~the~~ Verlorenvlei alternates between four abiotic states, in response to local climate and rainfall[(1)]. Under closed mouth conditions it can either be very low water level (a drought state that can either be brackish or progress to acidic), low water level and fresh, or high-water level and fresh, fed by rainfall and a large groundwater recharge from a secondary aquifer[(11)]. The fourth state is one where the mouth is open and water levels are declining. Historically drought cycles occur every 10 to 20 years and the mouth breaches every two to three years and remains open between 1 and 2 months after breaching. At the time of the study the mouth was closed and the water level below 0.5 m MSL with hypersaline conditions in the lower mouth region, and large parts of the main basin were

**Commented [A9]:** Refer to a figure here?

exposed and acidic (pH in Lower reaches> 8, Middle reaches< 3 and Upper reaches between 6 to 7.5)[14]. The Ecological Flow Requirement study found that natural breaching frequency has decreased from the original natural state due to freshwater abstraction[14]. This together with the number of obstructions (bridges, footpaths, causeways) in the main channel have altered the hydrodynamic connectivity, resulting in the system being disconnected under low water level. During the closed mouth state back flooding of the floodplain during high inflow periods causes high water levels that inundate large parts of the wetlands in the upper reaches, which in turn can results in the illegal practice of artificial breaching. For example, the system was artificially breached at lower than natural levels in 2014 due to backflooding from good rains in 2013.

## *Present (2021) and past (1942) habitat distribution*

The present habitat within the estuarine functional zone (EFZ) (represented by the 5 m contour) was mapped manually by digitizing in ArcMap 10.6.1 ~~with~~ aerial imagery obtained from CDNGI (http://www.cdngiportal.co.za/cdngiportal/). These orthorectified images are of 50 cm resolution and they were used in conjunction with Google Earth imagery to map present areal extent. Estuarine habitat was categorized into the following subcategories: freshwater reeds and sedges, salt marsh, terrestrial vegetation, and open water which represents microalgal habitat[16]. Also mapped were degraded habitat (where original vegetation and biodiversity remain along with some ecosystem) and developed habitat (where complete transformation has taken place, usually represented by hard structures like roads, railways and the built-up environment, along with agriculture). To verify these habitat ground truthing took place on 8$^{th}$, 9$^{th}$ and 10th November 2021 during which time geotagged images assisted with the identification of habitat type. During the field trip random depth to groundwater and groundwater salinity measurements were taken to understand the location and extent of habitat and their drivers.

The past / natural state of Verlorenvlei was determined using the earliest available aerial image, in this case 1942, also obtainable from CDNGI. Intermediate years were also obtained for 1960, 1971, 1978, 1986, 1994, and 1993 were analysed to build a better understanding of habitat fluctuations. Clear Google Earth imagery is only available from 1985 onwards.

Although humans have inhabited the area since the 1600s, the 1942 images were assumed to represent a near natural state with little human pressure. These early images have low resolution and poor quality, making digitizing habitat challenging. Confidence in areal extent is therefore medium to low. Historical oblique photos, unpublished literature, social media and local conservancy group ("Friends of Verlorenvlei") were widely sourced to gain an understanding of the spatio-temporal changes of vegetation at the local scale especially. Where available, repeat photography from previous research on the estuary was used (1981, 2013 and 2021). This method of historical ecology analysis provides an accurate, practical tool to document vegetation changes, especially when used together with other historical information like long-term fire and rainfall data. It is also invaluable as a method of comparing predicted climate change scenarios with actual changes[17-19].

**Commented [A10]:** You mean European settlers? Evidence for Hunter-gatherers and pastoralists ~2000 years ago

Rephrase in terms of calling the 1942 the "natural" state. Rather the baseline for this study

From historical Google Earth imagery the two states identified by Van Niekerk et al.[14] could be clearly identified; Closed with very low water levels, and Closed with high water levels, occurred in 2013/4 and in 2021 respectively. Habitat extent was mapped for these two periods. Changes in the catchment were assessed using the South African National Landcover Data https://egis.environment.gov.za/sa_national_land_cover_datasets) and raster data on the rates and patterns of habitat loss which cover four periods, 1990, 2014, 2018 and 2020[20]. These images were clipped using the catchment and the EFZ polygons of the Verlorenvlei.

### *Drivers of macrophyte change (rainfall, water level, human pressures)*

Two important drivers influence habitat extent in the Verlorenvlei Estuary, namely rainfall/water level and human pressure. Monthly rainfall data was obtained for Elands Bay from the South African Weather Services for the period 1978 to 2021; no data prior to 1978 exists. This data along with historical aerial imagery were used to identify when the different abiotic states identified by Van Niekerk[14] occurred and identify how this influenced habitat extent. The ~~Closed~~closed, very low water level state was clearly seen in 2021 images which represented the present state. The Closed…? with high water level state occurred in the 2013/4 Google Earth imagery -rephrase / expand to make sense.

Water level data in the estuary was supplied by the Department of Water and Sanitation, station number G3T001. The gauge is located near Uithoek Farm 11 kms from the mouth within the reed beds (Figure X?). Data was obtained for the period 1994 to June 2017, after which the lake bed dried at the monitoring point and no further measurements could be recorded. Salinity is closely linked to vegetation distribution and species composition in estuaries[16, 21], but since no historical data exists, known species tolerance ranges were used to assess temporal changes.

Historical accounts were used to assess the change in human pressures over time. Local knowledge regarding the fire history was sourced from the Friends of Verlorenvlei, a conservancy group and other available data such as the Estuary Management Plan[6].

In November 2021 sediment pH was analysed at six sites (Figure 2) by an accredited laboratory (give the name of the lab), and pH of standing water (either the water column or standing pools of water) were assessed using a YSI ProDSS multiparameter meter. Due to the low lake level sampling stations were limited by water availability. During a follow up field trip on 25 March 2023 and mid June 2023 additonal sediment and water pH was recorded at the same sites. Results on sediment and water quality data including metal analysis, dissolved oxygen, salinity and temperature are to be reported on in a separate article.

## Results and Discussion

### *Present (2021) and past habitat distribution (1942)*

The main habitats associated with the Verlorenvlei are open water, reeds and sedges, sand and mudflats, and floodplain (Figure 3). Due to a drought between 2016 and 2023, water level dropped exposing large areas of sand (189 ha) in the main basin (Middle reaches) and Upper

reaches. On Google Earth imagery these beds appeared orange in colour in places. The open water supports submerged and floating aquatic macrophytes, but this habitat could not be mapped and ground truthed in November 2021 due to limited access as a result of the low water level. It was estimated that these macrophytes covered an approximate 30% of the open surface water area (126 ha). The open water in the Middle and Upper reaches were connected, but not the limited water in the Lower reaches. No water occurred in the Lower nor Upper reaches. Submerged and floating aquatic macrophytes were represented by freshwater species. The naturalized exotic submerged aquatic *Myriophyllum spicatum* was not observed during the field trip nor in the satellite images despite being prolific in the 1980s[2]. It's presence in the past was suggested to be in response to nutrient runoff from surrounding agricultural activities. However large beds of floating *Crassula natans* occurred together with *Cotula coronopifolia* and *Aponogeton distachyos*, in the Middle and Upper reaches in 2021.

At the mouth the water was hypersaline (> 100) and no aquatic plants were observed. However, reeds and sedges occurred in the Lower and Middle reaches despite high surface salinity. *Ad hoc* augured holes found the groundwater to be at 10 to 30 cm depths with a salinity of 10. These freshwater seepage areas maintain these plants in this area as they grow best at a salinity of below 15. This groundwater source is of significance as the water column salinity in the Lower reaches was hypersaline (mean 143). Most of the reeds and sedges (*Phragmites australis*, *Scirpus maritimus, Schoenoplectus scirpoides, Typha capensis* and various other *Cyperus* species), occur in the Middle and Upper reaches (688 ha). Beds can either cover the width of the system (Middle and Upper reaches) or can occur on the dry exposed lakebed intermingled with salt marsh and terrestrial species forming an ecotone. In the Upper reaches the reeds and sedge habitats rely on the Verlorenvlei River which feeds the system through a series of wetlands at Redelinghuys and appear to have ~~persistent~~ persisted? since 1942 despite the absence of water at times (Figure 3), probably due to the groundwater input from a large secondary groundwater aquifer[11] as well as the permanent inflow of river water at the head. Reeds and sedges appear to be stable in extent over the last 79 years with only a change of 36.2 ha from past to present. With the low water level there has been localised increase in reed and sedge extent in the Middle as well as in the Upper reaches (Supplementary material: Figure 1). This increase is probably linked to increased sediment and nutrients brought in from the agricultural activities in the catchment. Although these reeds are an effective nutrient and sediment filter, the increased plant organic plant matter could possibly lead to an increase of inorganic nutrients through remineralization. Cyanobacterial blooms in the basin (Middle reaches), and also at times in the Upper reaches (especially during

spring and summer when temperatures are higher and residence times longest) supports this hypothesis[1]. Reeds can expand into the dry riverbeds at a rate of 1.4 ha per year taking about 14 to 19 months to return to previous extents.

Cape Arid Estuarine salt marsh and saline grasses (4 ha) occurred in the Lower reaches around the mouth with species such as *Salicornia* spp., *Bassia diffusa, Sporobolus virginicus, Cynodon dactylon, Paspalum vaginatum, Triglochin* spp., *Cotula* spp. as well as *Juncus kraussii*. Salt marsh remains relatively constant (3 to 4 ha) and on the large floodplain above 2.5 m MSL (168 to 588 ha), terrestrial species such as *Mesembryanthemum crystallanum*, various Aizoaeceae and other ecotonal terrestrial species intermingle with *Salicornia* and *Juncus* spp. and *Phragmites australis*. The large salt marsh area in the lower reaches in 1942 (125 ha) would be a mix of ecotonal species' terrestrial and salt marsh intermingled. Other habitat like rocks (habitat for epipelic microalgae) and beach and dune sand also occur within the EFZ but to minor extents. Terrestrial vegetation consists of Lambert's Bay Strandveld, ~~Saldanah~~Saldanha Flats Strandveld and Leipodltville Sand Fynbos (99 ha)[6].

Despite the lack of physico-chemical data other than rainfall and estuary water level, it was possible to infer environmental conditions based on habitat and the salinity preferences of the dominant macrophytes. *Phragmites australis* indicates freshwater conditions even in the presence of hypersaline surface waters as was found in the Lower and Middle reaches[22]. During the field trip surface water was found to be over 140 in the lower reaches, but at depths between 30 to 1.5 m groundwater was 10. Analysis of historical aerial imagery shows the presence of reeds and sedges in the exposed lakebed even under low water level.

Development within the EFZ already covered 124 ha (5%) in the earliest aerial images of 1942 and has since increased to 12% (267.3 ha) in 2021 due to agriculture, roads, railway line, gravel roads and various footpaths. As development increased so did the presence of invasive species; for example *Eucalyptus* stands occur around farmsteads. Cattle grazing, trampling, and footpaths have degraded habitat, mostly at the

expense of floodplain and terrestrial vegetation. Almost 50% of the catchment has been transformed to either agriculture or development (47%), most of which occurred prior to 1990 (44%). Post 1990 changes account for 9% of the catchment. However, competition for water resources by farming, nutrient and sediment input arising from the various land use practises in the catchment particularly related to freshwater abstraction are further pressures on the ecological health of the estuary.

**The Present 2023 state indicates a further decline in ecological health.** Since the detailed study in 2021 the water level declined further by 88 % with water only occurring only in the middle of the Middle reaches only (*circa* 51.6 ha) in May 2023. Under the low water state reeds and sedges and terrestrial species were expanding into the exposed areas. However, in mid June 2023 heavy rains (1:20 year flood) along this stretch of the coastline resulted in flooding in many parts and ~~the~~ Verlorenvlei filled up. A local dam in the catchment also burst, adding additional 150 000 $cm^3$ water. Despite the large inflow of water, water pH remains low – can you explain/hypothesise as to why this is the case.

## *Changes in habitat in response to rainfall, water level and human pressures*

### Rainfall and lake water level

Analysis of rainfall data for the Elands' Bay area showed that over the last 43 years there have been alternate wet and dry cycles (Figure X?), with a duration of three to ten years. Estuarine habitat shifts between low and high-water state as a result. Above average / wet years were experienced between 1993 to 1998, 2007 to 2011 and 2012 to 2015. Drought years occurred between 1978 to 1983, 1998 to 2006 and 2015 to 2020. Although the estuary water level gauge only began recording in 1994 and stopped in July 2017 due to exposure of lakebed, it still shows the response of the water level to rainfall, especially the time lag between rainfall and increased water level at times only two weeks later. The

floods in June 2023 resulted in filling up of the lake to pre-drought conditions. Repeat photography has shown that variability in water surface area in the Verlorenvlei is part of a natural decadal cycle, associated with rainfall and water level.

These large changes in water level affects open water extent and the associated submerged and floating aquatic macrophytes, varying between 420.8 ha in the low water state and 1169.9 ha in the high-water state (~~Supplementary:~~ Supplementary Figure ~~Supplementary Figure~~ 2). With inundation, previously exposed sand banks (193 ha) are reduced to 1.5 ha. Although salt marsh is not widely represented in the predominantly freshwater system, extent varies between 1 to 3.7 ha. Under low water levels, terrestrial species such as *Mesembryanthemum crystallanum* intermingle with *Salicornia* and *Juncus* spp. on the exposed lake beds.

The field visit in November 2021 showed that large, exposed sand banks (61.1 ha) around the main basin (Middle reaches) appeared orange in colour. This colouration was evident in February 2019 (190.9 ha) and December 2020 (61.1 ha) on past Google Earth imagery, as well as in the March 2023 field trip (Supplementary:

Supplementary Figure 3: Large exposed sandy areas appear orange as water level recedes during low inflow (left). By November 2021, the exposed sands were oxidised, acid sulphate soils with yellow and orange mottling from jarosite and iron oxide minerals (right).

Supplementary Figure 3: Large exposed sandy areas appear as orange as water level recedes during low inflow (left). By November 2021, the exposed sands were oxidised, acid sulphate soils with yellow and orange mottling from jarosite and iron oxide minerals (right).

3).

The receding water exposed extensive areas of organic ~~sulfide~~sulphide? soils/peats along the lake margins which previously had been submerged. Natural ~~sulfate~~sulphate reduction processes in aquatic sediments can result in an accumulation of ~~sulfide~~sulphide minerals such as pyrite ($FeS_2$). Upon exposure to air, pyrite can oxidise to produce sulfuric acid and dissolved ferrous iron. Thus, strongly acidic conditions can form upon rewetting (by rainfall or lake refill) of the exposed organic-rich sediments[23]. Sediment and water analysis showed this is now a persistent and ongoing process in Verlorenvlei (Figure 2) with negative effects on the overlying vegetation (Supplementary~~:~~ Figure 3). A similar process of lake acidification occurred in the Murray-Darling Basin of Australia where a two-year drought resulted in the exposure of more than 200 $km^2$ -Reference?. Upon rewetting of the sediments, surface water had a pH of between 2 to 3 and high concentrations of dissolved metals were mobilised[23]. This acidity persisted in the lake sediment and the water for several years after the drought broke and surface water management was a long and costly process to return water pH levels to biologically acceptable. In the case of ~~the~~ Verlorenvlei, partial rewetting from small rainfall events has produced standing pools of water with pH below 3 in the Middle reaches. This has not changed much despite the increased inflow of fresh river water following the recent heavy rains of 2023.

Together with extended very low water states and exposure of large sand areas (189 ha), the build-up of sand through wind erosion leads to altered morphology further restricting water flow and connectivity. A recent dust study showed that the main source of windblown sediment in the area was from the exposed lakebed, Verlorenvlei catchment and surrounding agriculture sector[24].

**Human pressures: fires and over allocation of surface and groundwater**

Analysis of historical literature have shown the presence of humans around the Verlorenvlei since the early 1700s (Supplementary: Figure 4). Land cover changes first took place in the early 1700s when loans were granted by the governing Dutch East India Company for grazing and wheat production. By the 1800s settlements were well established in the area. Agricultural activities continued with further clearing of land especially when the area became electrified in the 1960s, promoting the use of centre pivot irrigation for cultivation of seed potatoes. Vines and orchards are

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the other main forms of agriculture in the catchment. Since the 1960s several major obstructions have altered tidal exchange in the Lower Zone. A rocky sill at the mouth (that used to be a causeway); a causeway below the Sishen-Saldana railway bridge and the road crossing to Elands Bay. In addition to the constrictions in the lower estuary, there are also two causeways in the Upper Zone at Grootdrift and Redelinghuys that also pose a constraint to circulation, separating the zones and reducing biological connectivity.

Commented [A13]: And i
dominant crops / agriculture
a shift from potatoes to vine

Irregular fire practises have also impacted the Verlorenvlei habitats in the lower to middle reaches in the past 10 years. Some of these were due to lightning strikes (1 February 2020), others through illegal burning to clear the reeds by local farmers (13 May 2013, 6 April 2016, 8 March 2017, January 2018) (Supplementary: Figure 5). One such out of control fire at Bonteheuvel began on 6 April 2016 and continued to smolder until 18 June. The fire residue was still evident on Google Earth imagery in October 2018. The most recent fire on 1 February 2020, caused by a double lightning strike, burnt until 23 April 2023. However, the below ground biomass (peat) continued to smolder for a few months, finally being extinguished on 23 April 2020.

The important peat swamps in the Verlorenvlei are at risk of being lost as a result of the current exposure and occurrence of regular fires. Although the above ground biomass only burns for a few days, the below ground biomass can continue to smoulder for a few months as happened in 2016 and 2020. In the nearby Wadrif Estuary, a reed and sedge swamp similar to those in the Verlorenvlei existed for many years. The original swamps and resulting thick peat layers were fed by a freshwater spring[25]. However, these springs were targeted as a water source by the government. As a result, the water table lowered, saline water intrusion occurred, and vegetation began to dry out and die. An electrical fire in the late 1990s resulted in a fire which continued to smoulder for two years due to the 2 m thick desiccated peat layer. These peat swamps cannot be recovered, neither their ecological service of acting as nutrient filters and carbon stores (5). Peatlands are among the world's largest carbon sources and loss of potentially 688 ha of reeds swamps in the Verlorenvlei could have serious local ecological consequences, but also through the release of carbon into the atmosphere, have a more wider impact. Clearing of peatlands by fire have estimated a release of 88 t C $ha^{-1}$ [26].

**Surface water usage** from 1954 to 2018 showed a notable increase in usage from the onset of the 1980s (~1.8 million $m^3$ /year in 1980) until the most recent available data records in 2018 (~13.3 million $m^3$ /a) [13]. The increase in surface water use is attributed to the expansion and increased intensity of commercial agriculture. Historical data from 1954 to 2018 also showed a total of 29.17 million $m^3$ /a groundwater allocated for use, abstracted from boreholes and springs via 212 registered users. The dominant groundwater use sector is also for agriculture (99.8% of the total registered groundwater use).

Due to the complex and fractured catchment geology there is disagreement amongst groundwater specialists on the degree to which Verlorenvlei is dependent on groundwater versus surface water to maintain lake levels[13, 25]. However, literature has demonstrated that the various rivers have considerable groundwater baseflow components, which ultimately contributes to the total flow into Verlorenvlei[13]. Extensive regional groundwater over-abstraction can thus potentially reduce this groundwater baseflow component, reducing total flow into Verlorenvlei (particularly during summer). The extensive and ever-increasing groundwater abstraction both adjacent to the lake, and on a greater regional extent, has a cumulative negative impact on water levels within ~~the~~ Verlorenvlei. The unregulated surface and groundwater abstraction in the catchment is certain to continue in the future as increased extreme? weather events (e.g. droughts and increased? temperatures) are likely under ~~Climate~~ climate ~~Change~~change. In addition to this the construction of the causeway /s?, bridges, electrification of the surrounding area, have decreased the mean annual inflow by almost 30%, with a further increase to 50% likely under future climate change scenarios[14].

## Future outlook

It is anticipated that under future climate change scenarios of more extreme temperature and fluctuations in rainfall, the lake will dry out more regularly and remain in the acidic state for longer periods, especially if present levels of water abstraction are maintained. This acidic state has had cascading effects on the lake biota as well as on surrounding livestock and farm animals. Freshwater invertebrates were in the past present throughout the lake but under this new acidic state, no life occurs in the Lower and Middle reaches[14]. The persistent low water pH in the middle and upper zones prior to the June 2023 floods filling up of the lake are likely to continue for some time as

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317 occurred in the Murray-Darling acidification[23]. What the effects this will have on the long term
318 storage of seeds in the sediment, as well as recovery of vegetation and aquatic communities is
319 unknown due to limited literature[27].

320

321 The decrease in freshwater inflow has led to salinization and desiccation of the macrophyte habitats
322 due to extended periods of zero inflow; with a 95% reduction in open water area from 421 ha (2021)
323 to 52 ha in June 2023 and a disconnect between different water bodies. The low water level and
324 nutrient input from surrounding agricultural activities promoted the growth of reeds and sedges in
325 the middle reaches. Despite the filling up of the lake following heavy rains, the extreme low lake level
326 is likely under higher temperatures and an increase in winds that will lead to a further increase in
327 evaporation, lower water levels and salinization. Groundwater input will decrease negatively
328 influencing the reeds and sedge areas. The influence of land use practises and other existing human
329 pressures (such as XX) needs to be considered if ~~the~~ Verlorenvlei is to maintain its current RAMSAR
330 status.

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actions can be taken

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## List of Figures

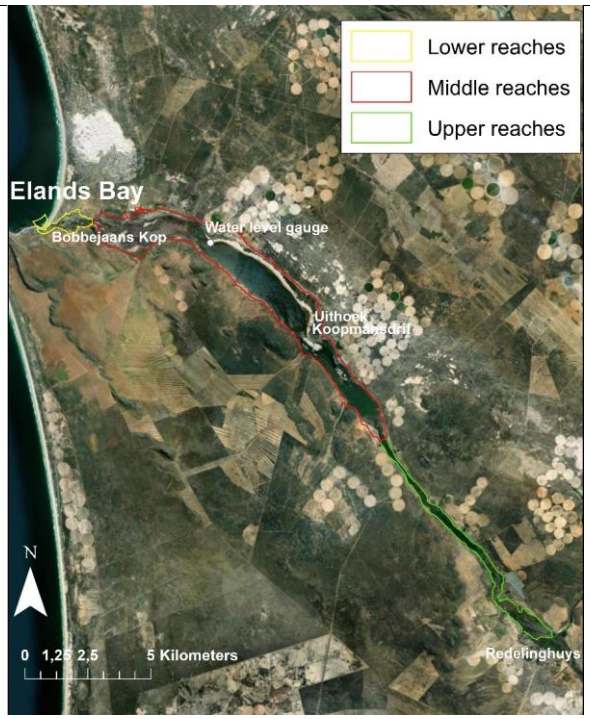
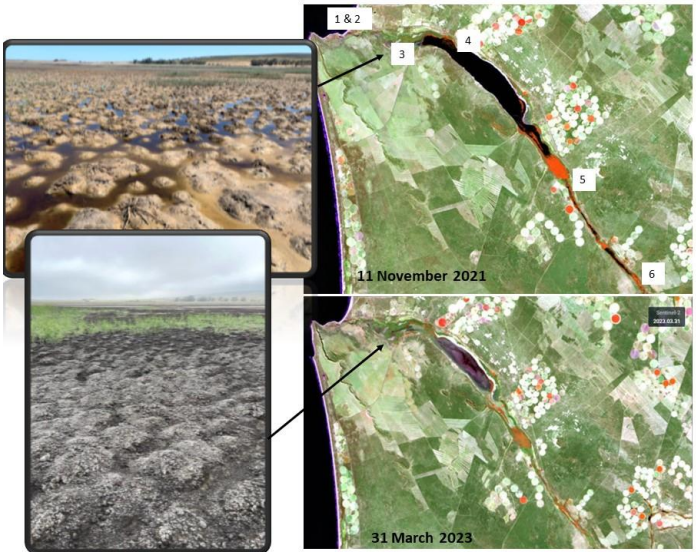


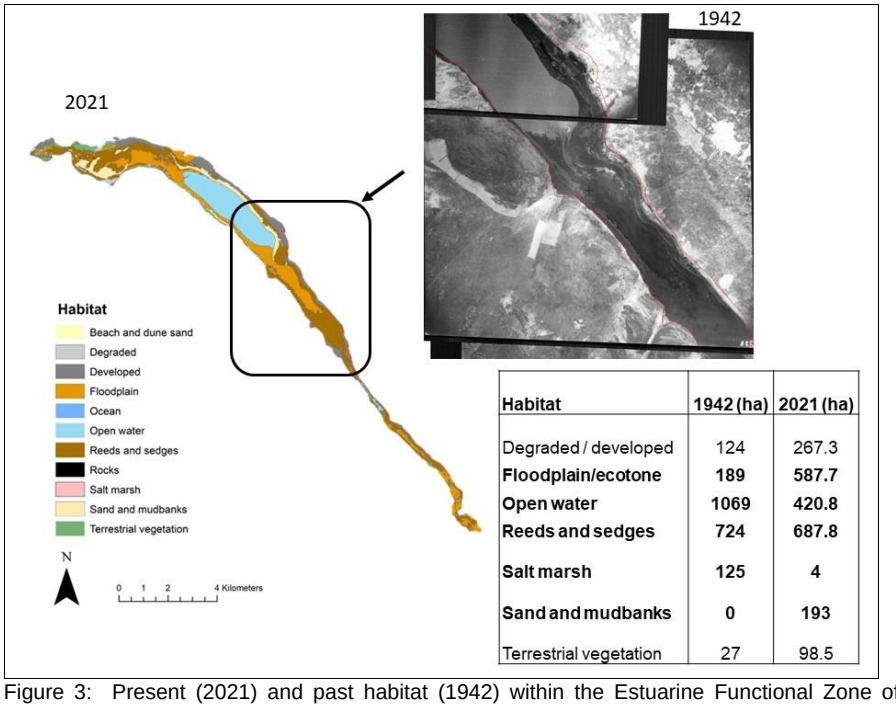

Figure 1: Locality of the Verlorenvlei Estuarine Lake, along with places of interest mentioned in the text (Image source: Google Earth).




| Sediment pH | 2021 | 2023 |
|---|---|---|
| 1 | 7.0 | 8.0 |
| 2 | ND | 7.8 |
| 3 | 3.6 | 4.0 |
| 4 | 6.0 | 4.4 |
| 5 | 6.2 | 6.1 |
| 6 | 2.9 | 3.6 |

| Water column pH | 2021 | 2023 |
|---|---|---|
| 1 | 8.7 | 7.2 |
| 2 | 8,7 | 7,4 |
| 3 | 3,4 | ND |
| 4 | 3.4 | 3.6 |
| 5 | 7.4 | 3.7 |
| 6 | 7.3 | 4.4 |

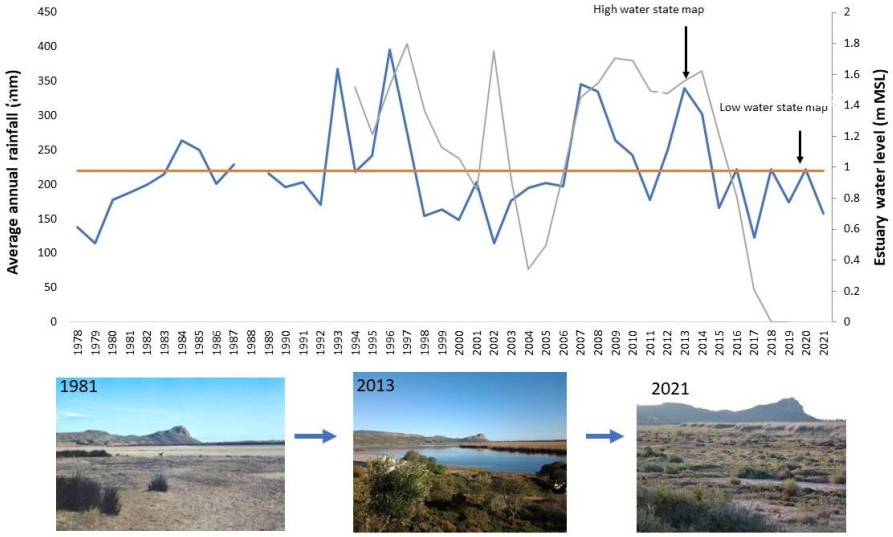
Figure 2: Sample sites for soil collection in November 2021 and March 2023.




| Habitat | 1942 (ha) | 2021 (ha) |
|---|---|---|
| Degraded / developed | 124 | 267.3 |
| **Floodplain/ecotone** | **189** | **587.7** |
| **Open water** | **1069** | **420.8** |
| **Reeds and sedges** | **724** | **687.8** |
| **Salt marsh** | **125** | **4** |
| **Sand and mudbanks** | **0** | **193** |
| Terrestrial vegetation | 27 | 98.5 |

Figure 3: Present (2021) and past habitat (1942) within the Estuarine Functional Zone of the Verlorenvlei Estuarine Lake. The 1942 image represents the boxed area showing persistence of reeds since Reference state.

436







437

438 Figure 4: Annual rainfall for Elands Bay from 1978 to 2021 (SA Weather Service) and estuary
439 water level as recorded at the DWS gauge G3T001 (blue = rainfall, grey = estuary water level,
440 orange = expected annual rainfall). No water level data after July 2017 as gauge site dried out.
441 Arrows indicate the years used for mapping low and high-water states.

442

# Supplementary material

Figure 1: Large exposed beds in middle reaches near the DWS gauge (top left) and upper zones (top right) where localised increases of terrestrial vegetation and reed expansion occurred under low lake levels (bottom).

Figure 2: Vegetation distribution for low (2021) and high (2013) water states in the Verlorenvlei Estuarine Lake with repeat photography.

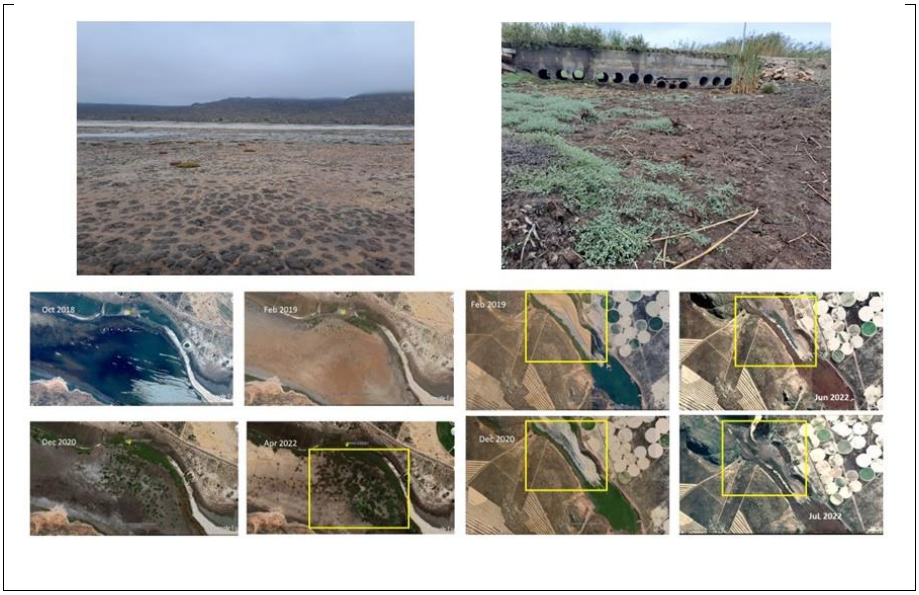
Figure 3: Large exposed sandy areas appear as orange as water level recedes during low inflow (left). By November 2021, the exposed sands were oxidised, acid sulphate soils with yellow and orange mottling from jarosite and iron oxide minerals (right).

Figure 4: Timeline of anthropogenic changes in the Verlorenvlei area from 1652 until 2023.

Figure 5. Uithoek fire in 2017 (left) and the aftereffects of the prolonged burn at Koopmansdrif 2020 (right) (image: Sara Louw); black square indicates the area where reeds burnt (image: Tiaan Carstens).

**Habitat changes in response to pressures in the Verlorenvlei estuarine lake**

458

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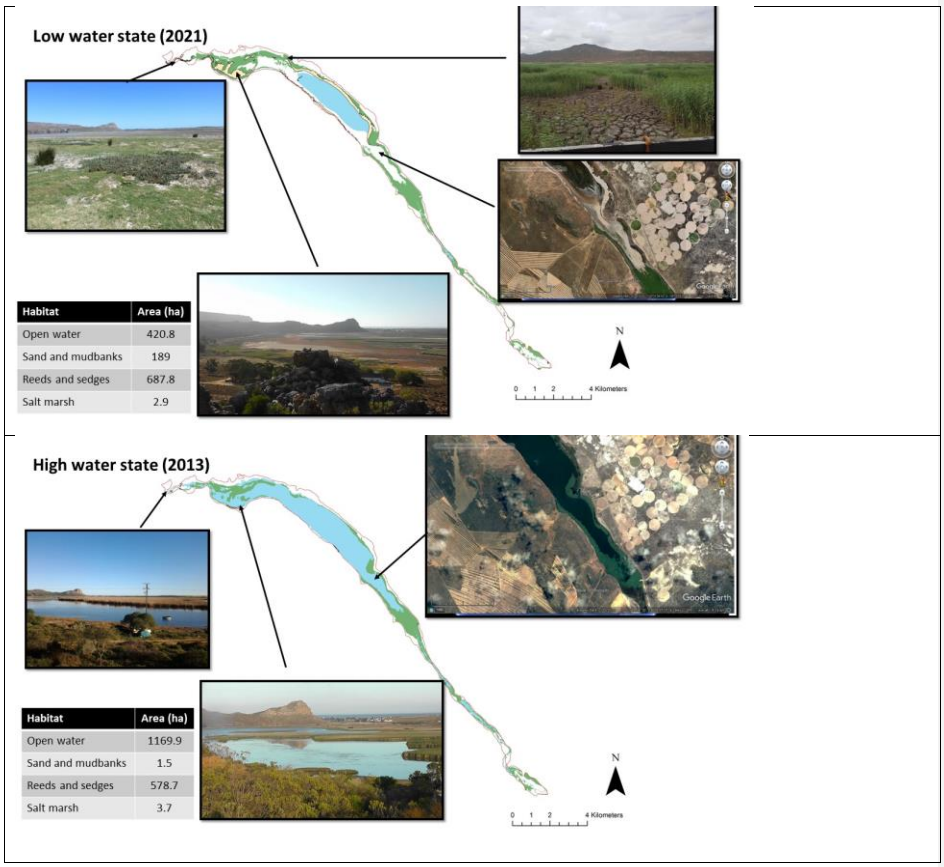
**Habitat changes in response to pressures in the Verlorenvlei estuarine lake**




Supplementary Figure 2: Vegetation distribution for low (2021) and high (2013) water states in the Verlorenvlei Estuarine Lake.

**Habitat changes in response to pressures in the Verlorenvlei estuarine lake**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**Habitat changes in response to pressures in the Verlorenvlei estuarine lake**

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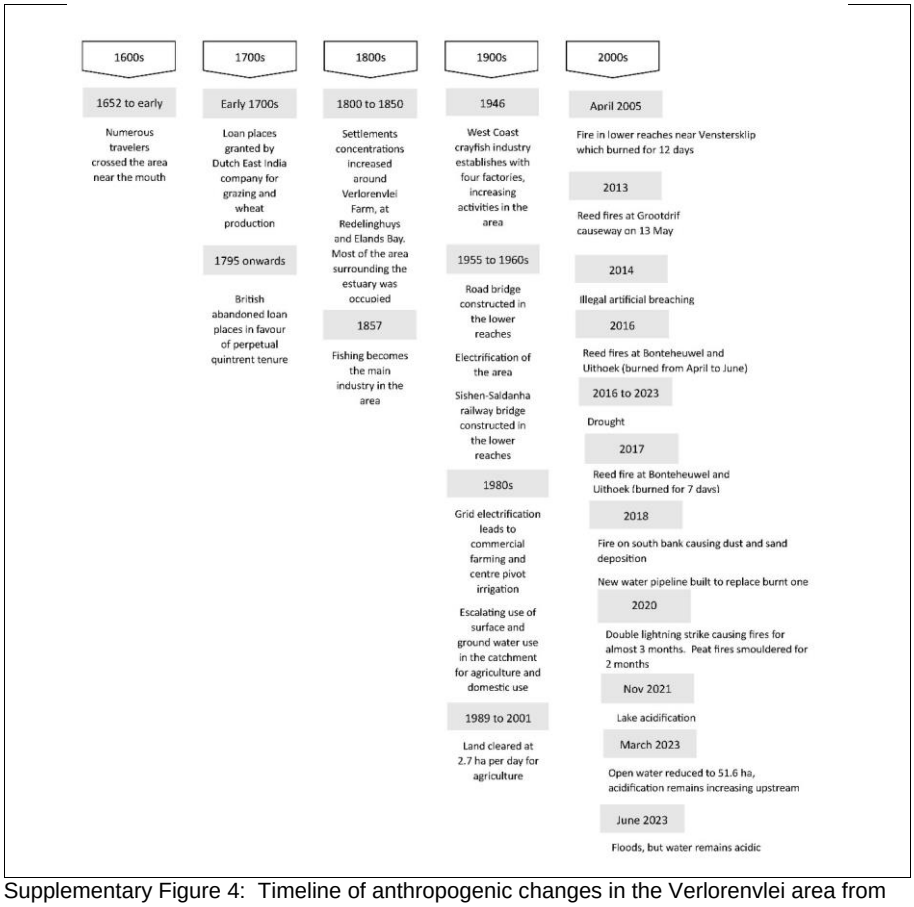


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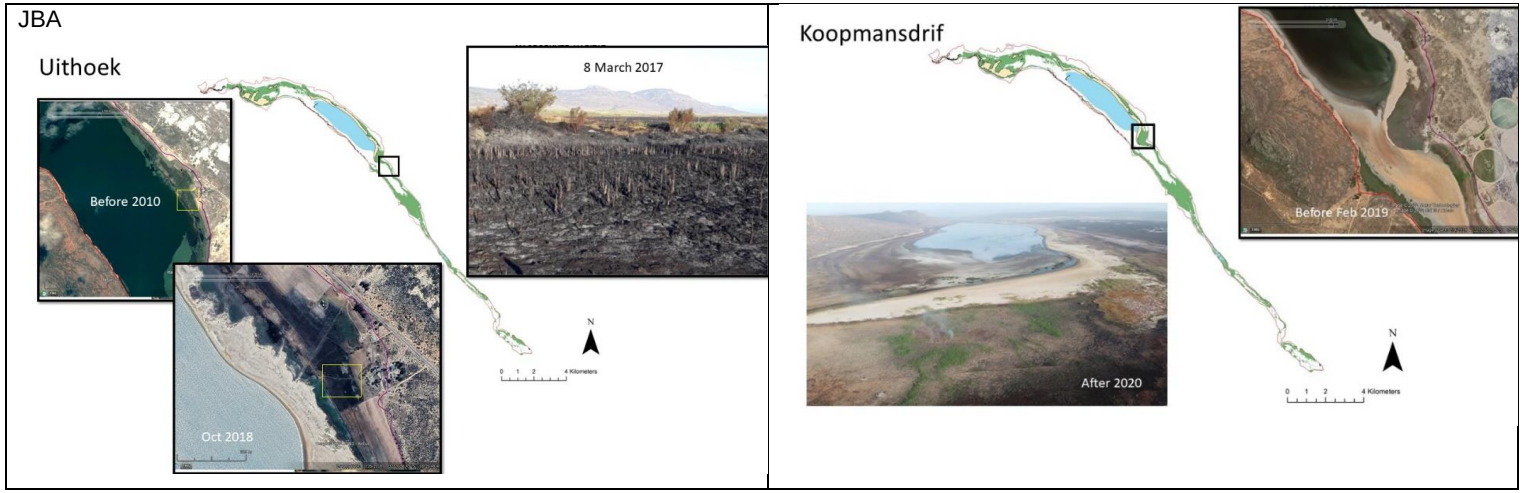
**Habitat changes in response to pressures in the Verlorenvlei estuarine lake**

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