

Regional emperor penguin population declines exceed modelled projections

Corresponding Author: Dr Peter Fretwell

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Attachments originally included by the reviewers as part of their assessment can be found at the end of this file.

Version 0:

Decision Letter:

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Dear Dr Fretwell,

First of all, please allow me to apologise for the delay in sending a decision on your manuscript titled "A fifteen-year assessment of emperor penguin breeding populations from the Bellingshausen to Weddell Sea from VHR satellite imagery" has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised.

Specifically, for publication in Communications Earth & Environment to be appropriate, we would need you to
* provide a compelling quantitative update of trends in Emperor penguin populations in Antarctica, including a full discussion of caveats, uncertainties and limitations, for example associated with the short record, compared to the typical lifetime of the penguins
* discuss possible causes for the trends, including other environmental drivers than sea ice, much more comprehensively.

Please highlight all changes in the manuscript text file.

Please submit your point-by-point responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:

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We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Heike Langenberg, PhD
Chief Editor
Communications Earth & Environment

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and also in our style and formatting guide [Communications Earth & Environment formatting guide](https://www.nature.com/documents/commsj-phys-style-formatting-guide-accept.pdf).

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Please refer to our data policies at <http://www.nature.com/authors/policies/availability.html>.

REVIEWER COMMENTS:

Reviewer #2 (Remarks to the Author):

This study by Fretwell et al. provides a regional update of the Emperor penguin population trend in one sector of Antarctica. The study is based on high-resolution satellite imagery, a method that has been previously used and validated in several other studies. The main findings is that the Emperor population in this sector may have declined by 22% between 2009 and 2023. This decline is apparently not linked to sea-ice changes.

I enjoyed reading this well-written study and believe the results presented here are important. I have, however, a few comments.

- (1) There is a very strong focus on sea-ice in this work (as in most work about emperor penguins) both in the introduction and in the discussion. Even though I am not arguing the importance of sea-ice for emperor penguins, I don't understand why there is such a strong focus to explain penguin population trends? Indeed, several previous studies showed that emperor penguins have been declining (at least in some sectors of Antarctica) while there was no detectable long-term changes in sea-ice conditions. So it seems that a decline in sea-ice extent and/or a shorter sea-ice season may not necessarily be the main drivers behind the decline in emperor penguins? I think the study would benefit from explaining more clearly the link between sea-ice changes and penguin population decline, and may also benefit for mentioning potential other environmental drivers (if any are suspected?). In the discussion, author acknowledge that emperor population changes do not fit with changes in sea-ice but no alternative explanation is provided to explain the potential decline.
- (2) The emperor penguin is a long-lived species and to detect population trends, long-term data are needed. Reproduction skipping and/or reproductive failure is common in such species and may not affect the long-term growth rate. However, including such seasons of very poor reproduction may affect the apparent population trend when the analysis is based on a relatively short series. In this study, complete reproductive failures may have happened in the period of record-low sea-ice (2020-2023) which could in theory have led an apparent population decline in period 2009-2023. However, such an apparent decline would not reflect the real trend of the population but it would only reflect a few bad reproductive years. Such bad years are not uncommon for long-lived species (cf. examples of complete breeding failures in Adelie penguins, Antarctic petrels, or ivory gull, commong guillemots...) but may not be associated with a negative long-term decline. Such scenario is not what the authors have observed in their study (the last few years were actually not bad in terms of population size) but it indicates that the overall justification of the study may need to be revised: updating the status of a population based on a short series that includes a few extreme years may lead to misleading results.
- (3) As acknowledged by the authors, there is a large variance in the estimates of population sizes based on satellite image analyses. Combined with the brevity of the study period that limits the ability to detect trends and with results that are marginally significant (using the classical 5% threshold), I would suggest the authors to tone down their conclusions (especially in the abstract and conclusion). I don't think the study "demonstrates" a 22% decline as stated but rather suggests a potential decline.

Minor comments/suggestions:

Line 36: you could be more explicit and explain this discrepancy with the IPCC projections

Line 54: you could also add references showing the detrimental effects of flipper ringing? Gauthier-Clerc et al 2004 PRSB, Jackson and Wilson 2002 Func Ecol, Wilson 2011 Nature...

Line 62: single sites surveys are of limited use not only because of immigration/emigration. Even in the absence of such processes, environmental variations and/or difference in age structure for examples may differ between populations leading to different trends (e.g. Frederiksen et al Oikos 2005, Tavecchia et al 2008 Ecology, Descamps et al 2021 Div and Distr, Frederiksen et al 2021 MEPS...for a few examples on seabirds).

Line 99: any specific reason for focusing on this region?

Abstract and line 264: I don't understand this 1.47% decline? The 2.25% decline per year of the $\log(\lambda)$ makes sense but I am not sure to understand this 1.47%?

Reference list: references are ordered by number while they are presented by name in the text.

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The authors used a multivariate supervised classification and statistical model similar to that previously published by LaRue et al. (2024) to update records of emperor penguin population trends over an additional five years (2009–2023) in the Antarctic. However, this study focuses on selected breeding colony locations in the sector between 0° and 90°W, covering the period of sea-ice loss from 2020 to 2023. It reveals a 22% population decline over the entire study period, equivalent to an annual reduction of 1.47%. This decline surpasses earlier predictions based on high-emission scenarios. The work provides critical insights into the impact of climate change on emperor penguins and underscores the urgency of expanding research efforts.

The population trends examined in the analysis are based on methods developed and refined by various scientific groups over many years. These methods are considered robust and represent the best possible practices for the available data, as presented by the authors.

One of the key merits of the analyses is their potential contribution to protecting the Antarctic ecosystem from threats posed by climate change and fisheries management in Southern Ocean waters. The results could support the activities of the Commission for the Conservation of Antarctic Marine Living Resources and provide a valuable tool for adaptive

conservation planning in the changing Southern Ocean. This is particularly relevant to the ongoing Weddell Sea Marine Protected Area project. The manuscript describes a modern approach to applying advanced remote sensing studies of polar areas and presents the latest findings, making it of interest to readers of Communications Earth & Environment.

However, before the manuscript is published, I suggest the following improvements:

Methodology: The authors mention supervised classification of "very high-resolution imagery," but this is not explained in detail. Please provide specific information about the classification methodology and the data sources used. Furthermore, it is unclear whether image enhancement techniques, such as noise reduction and the filling of missing data, or algorithms for the detection of objects were employed. Even in suboptimal conditions, there is the potential to enhance the quantity of usable images and to improve the representation of all identified colonies.

Acronyms: Define acronyms when they first appear, e.g., IPCC (line 32) and IUCN (line 322).

Figures: Improve the figure's layout for clarity. In Figure 5, ensure the sections labeled "a" and "b" are clearly identified and described, as referenced in line 274 (Fig. 5a and Fig. 5b).

Supplementary Material and References: The presentation of results in the Supplementary Material and the editing of the References are currently unsuitable for publication. Both require further elaboration and refinement.

Editorial Corrections: Correct the double bracket on line 266.

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Version 1:

Decision Letter:

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Dear Dr Fretwell,

Your manuscript titled "A fifteen-year assessment of emperor penguin breeding populations from the Bellingshausen to Weddell Sea from VHR satellite imagery" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

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Senior Editor, Communications Earth & Environment
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REVIEWERS' COMMENTS:

Reviewer #2 (Remarks to the Author):

The authors have done a very good job in revising their study and I do not see any major issue now preventing its publication. I only have a few minor comments, easy to take into account.

-a 22% decline over 15 years does not equal a 1.47% annual decline. Given that the population has declined by 22% in 15 years, we have: $N_{15} = (100 - 22) \times N_0 = \lambda^{15} \times N_0$, which gives $\lambda = 0.984$, meaning an annual decline of ca. 1.6%

-in the abstract, I would remove the text "although other sectors... loss" lines 22-23. There is no clear link between sea-ice loss and penguin dynamics so this does not seem necessary nor appropriate to stress the sea-ice changes here?

-when it comes to the sensitivity of emperor penguin population dynamics to changes in breeding success, the authors would ideal need to provide stronger references (i.e. work quantifying the sensitivity or elasticity of the lambda to the breeding success parameter). The arguments provided are not very convincing. Jenouvrier et al 2009 OIKOS quantified that changes in breeding success can have a strong effect on EMPE growth rate - this could be a relevant reference but there might be others?

Congratulations to the authors for this work!

Reviewer #3 (Remarks to the Author):

I appreciate the opportunity to review this manuscript and would like to provide my comments and recommendation below. The crucial comments on methodology were addressed, and now it is clear. I have no further objections. Although I don't understand why the authors decided not to define the acronym IUCN as the International Union for Conservation of Nature, especially since they stated in their responses that they did. In my opinion, the acronym should be expanded, but this is a minor comment that does not affect the high value of the paper, so I leave it to the authors and the editorial decision. I recommend this manuscript for publication in Communications Earth & Environment journal. It provides a valuable update on data regarding the Emperor penguin population and contributes to the discussion on conservation issues.

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Response to reviewers

We would like to thank and reviewers for their comments. We truly feel that they are excellent points and addressing them makes the work a better and more robust scientific paper. We have addressed all comments, adding extra detail, one whole new paragraph and caveating statements to ensure correct and balanced understanding of the paper. Our responses are highlighted in blue below.

REVIEWER COMMENTS:

Reviewer #2 (Remarks to the Author):

This study by Fretwell et al. provides a regional update of the Emperor penguin population trend in one sector of Antarctica. The study is based on high-resolution satellite imagery, a method that has been previously used and validated in several other studies. The main findings is that the Emperor population in this sector may have declined by 22% between 2009 and 2023. This decline is apparently not linked to sea-ice changes.

I enjoyed reading this well-written study and believe the results presented here are important. I have, however, a few comments.

(1) There is a very strong focus on sea-ice in this work (as in most work about emperor penguins) both in the introduction and in the discussion. Even though I am not arguing the importance of sea-ice for emperor penguins, I don't understand why there is such a strong focus to explain penguin population trends? Indeed, several previous studies showed that emperor penguins have been declining (at least in some sectors of Antarctica) while there was no detectable long-term changes in sea-ice conditions. So it seems that a decline in sea-ice extent and/or a shorter sea-ice season may not necessarily be the main drivers behind the decline in emperor penguins?

We agree with the reviewer that this fact is worth expanding upon and have added an extra section on the possible causes of population decline other than sea ice. We have strongly caveated this with the observation that scientific work has yet been done on these potential impacts and suggested that further study on these implications is urgently needed (see new paragraph "Why have emperor populations declined?").

I think the study would benefit from explaining more clearly the link between sea-ice changes and penguin population decline, and may also benefit from mentioning potential other environmental drivers (if any are suspected?). In the discussion, author acknowledges that emperor population changes do not fit with changes in sea-ice but no alternative explanation is provided to explain the potential decline.

We agree with the reviewer. To this end we have added a new section on why emperor populations have declined. It is worth pointing out that for many of the potential drivers of emperor penguin population the drivers are poorly quantified, so this paragraph may seem un-supported. To add extra weight to this we bring in several examples of what has

happened to Adelie penguins – the other Antarctic ice-obligate species, for which the consequences of rising temperatures have been studied. We caveat this section with a strong message that, for emperors, we urgently need to understand better the drivers of population change, especially in regions where warmer temperatures may be impacting breeding success.

(2) The emperor penguin is a long-lived species and to detect population trends, long-term data are needed. Reproduction skipping and/or reproductive failure is common in such species and may not affect the long-term growth rate. However, including such seasons of very poor reproduction may affect the apparent population trend when the analysis is based on a relatively short series. In this study, complete reproductive failures may have happened in the period of record-low sea-ice (2020-2023) which could in theory have led an apparent population decline in period 2009-2023.

However, such an apparent decline would not reflect the real trend of the population but it would only reflect a few bad reproductive years. Such bad years are not uncommon for long-lived species (cf. examples of complete breeding failures in Adelie penguins, Antarctic petrels, or ivory gull, common guillemots...) but may not be associated with a negative long-term decline. Such scenario is not what the authors have observed in their study (the last few years were actually not bad in terms of population size) but it indicates that the overall justification of the study may need to be revised: updating the status of a population based on a short series that includes a few extreme years may lead to misleading results.

Whilst we agree with the reviewer that many species of birds suffered years of poor breeding success and long-lived species can often cope with such fluctuation, the implications for emperor penguins are much more severe. Unlike other penguins Aptenodytes can only ever have one egg per year. To compound this, low juvenile survival rates mean that adult emperor penguins have to breed nearly every year to keep the population stable. Tagging studies at Pointe Géologie (Jenouvrier et al 2005) have shown that adult emperor penguins breed almost every year and breeding success plays a much more critical role in population dynamics than other long lived birds such as the snow petrel. Every year is important. The implications of this are that although the 15 year time series is relatively short, it is more illustrative to the demographics of emperor penguins than probably any other bird species. We agree that this explanation was not in the original paper so to highlight this we have added this text into the paper:

(in the intro) “Years of low breeding success due to sea ice failure are critical for emperor penguin populations. Many other seabirds can abstain from breeding when conditions are poor, but this is not an option for adult emperor penguins who have been shown to breed almost every year (Jenouvrier et al. 2005). Emperor penguins only produce one egg per season and have low juvenile survival rates (Le Scornec et al. 2019), therefore multiple years of poor breeding success can be critical to population trends.”

(in the discussion) “Although the 15 period of our study is relatively short for a long-lived species, it does approximately represent one breeding lifetime of the emperor penguin, which on average lives 20 years and first breeds at around 5 years of age. As previously mentioned, annual breeding success for this species is more critical than most other birds and skipping breeding in poorer years is not an option. Therefore, the relatively short times series shown here is more relevant than most other avian species.”

(3) As acknowledged by the authors, there is a large variance in the estimates of population

sizes based on satellite image analyses. Combined with the brevity of the study period that limits the ability to detect trends and with results that are marginally significant (using the classical 5% threshold), I would suggest the authors to tone down their conclusions (especially in the abstract and conclusion). I don't think the study "demonstrates" a 22% decline as stated but rather suggests a potential decline.

We concede that there is a large variance in the methodology, and therefore have caveated all relevant statements to reflect this. We still believe that we need to give the best fit estimate of our analysis, but we have added a clause into the introduction to highlight the high variance in the model: "Our findings indicate a significant reduction in emperor penguin numbers, **variance in the methodology is relatively high**, but estimate with a best fit estimate of a 22% decline over the whole period equating to a reduction of 1.47% per year.

We have also toned down the claim in the discussion to "this study suggests a decline in emperor penguin populations, **although there is significant statistical variance all possible results show a decline**, with a best fit of -22% over the 15 years period, equivalent to an absolute decline of 1.47% per year (or a log-linear annual rate of change of -2.25% per year)."

In the conclusion we now add in a clause about the high variance in the model; "**Although there is significant variance** in the model the best fit results suggest a 22% decline over the 15-year period"

Minor comments/suggestions:

Line 36: you could be more explicit and explain this discrepancy with the IPCC projections

Added the comment and reference where most models predict a steady decline in sea ice extent (Meredith et al. 2019).

Line 54: you could also add references showing the detrimental effects of flipper ringing? Gauthier-Clerc et al 2004 PRSB, Jackson and Wilson 2002 Func Ecol, Wilson 2011 Nature...

Added

Line 62: single sites surveys are of limited use not only because of immigration/emigration. Even in the absence of such processes, environmental variations and/or difference in age structure for examples may differ between populations leading to different trends (e.g. Frederiksen et al Oikos 2005, Tavecchia et al 2008 Ecology, Descamps et al 2021 Div and Distr, Frederiksen et al 2021 MEPS...for a few examples on seabirds).

Good point. We have amended the text to reflect this comment and added two of the references.

Line 99: any specific reason for focusing on this region?

This region contains various areas that span the whole range of environments and climatic threats that emperors breed in, from the marginal fast changing areas of the West Antarctic Peninsula and Bellingshausen Sea, to areas less affected by climate change like Dronning Maud Land and the Weddell Sea. I Had added this qualifier into the text.

Abstract and line 264: I don't understand this 1.47% decline? The 2.25% decline per year of the $\log(\lambda)$ makes sense but I am not sure to understand this 1.47%?

This is a fifteen year, not a ten year record. 22.5% divided by $15 = 1.47\%$

Reference list: references are ordered by number while they are presented by name in the text.

Changed as noted.

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However, before the manuscript is published, I suggest the following improvements:

1. Methodology: The authors mention supervised classification of "very high-resolution imagery," but this is not explained in detail. Please provide specific information about the classification methodology and the data sources used. Furthermore, it is unclear whether image enhancement techniques, such as noise reduction and the filling of missing data, or algorithms for the detection of objects were employed. Even in suboptimal conditions, there is the potential to enhance the quantity of usable images and to improve the representation of all identified colonies.

To address this comment we have added extra detail to the methods section. In the "Satellite Imagery" section we have added "Imagery was pan-sharpened using ArcGIS, and enhanced using a "Standard Deviation" histogram stretch." To explain image enhancement techniques

to get the most from the imagery. We have also added more detail about the training data of the multivariate classification: “These training data were chosen manually by experienced observers and usually equated to between 50-200 examples from each class, depending upon the homogeneity of the background image. Once the classes have been identified the multivariate classification algorithm divides the image into the available classes, one of which will be penguins. This process is iterative and usually training data needs to be refined multiple times before an acceptable confidence (>95% agreement between manual and automated observations) is reached.”

We have also added on the data sources “Additional information of image ID and scene quality is contained in Supplemental table 5.”

2. Acronyms: Define acronyms when they first appear, e.g., IPCC (line 32) and IUCN (line 322).

Added.

3. Figures: Improve the figure's layout for clarity. In Figure 5, ensure the sections labeled "a" and "b" are clearly identified and described, as referenced in line 274 (Fig. 5a and Fig. 5b).

Amended as suggested. Note that we have tweaked two other figure legends for clarity and added potential error bars onto figure 2.

4. Supplementary Material and References: The presentation of results in the Supplementary Material and the editing of the References are currently unsuitable for publication. Both require further elaboration and refinement.

We have amended the references to reflect the main text and the journal format. We will discuss with the editorial team the suggested format of the supplemental material.

5. Editorial Corrections: Correct the double bracket on line 266.

Amended

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REMOVED

-when it comes to the sensitivity of emperor penguin population dynamics to changes in breeding success, the authors would ideal need to provide stronger references (i.e. work quantifying the sensitivity or elasticity of the lambda to the breeding success parameter). The arguments provided are not very convincing. Jenouvrier et al 2009 OIKOS quantified that changes in breeding success can have a strong effect on EMPE growth rate - this could be a relevant reference but there might be others?

We have added the reference: Jenouvrier, S., Barbraud, C., Weimerskirch, H. and Caswell, H. (2009), Limitation of population recovery: a stochastic approach to the case of the emperor penguin. Oikos, 118: 1292-1298. <https://doi.org/10.1111/j.1600-0706.2009.17498.x>

We agree that this is a good additional reference, but are not aware of any other ones other than those already cited. Thankyou to the reviewer for pointing this out.

Congratulations to the authors for this work!

Reviewer #3 (Remarks to the Author):

I appreciate the opportunity to review this manuscript and would like to provide my comments and recommendation below. The crucial comments on methodology were addressed, and now it is clear. I have no further objections. Although I don't understand why the authors decided not to define the acronym IUCN as the International Union for Conservation of Nature,

We have now defined this acronym, apologies, this was an oversight.

especially since they stated in their responses that they did. In my opinion, the acronym should be expanded, but this is a minor comment that does not affect the high value of the paper, so I leave it to the authors and the editorial decision. I recommend this manuscript for

publication in Communications Earth & Environment journal. It provides a valuable update on data regarding the Emperor penguin population and contributes to the discussion on conservation issues.