We thank the editor and the two reviewers for their constructive feedback on our manuscript entitled ***Towards individual-based floral biology: Automatic tracking of life histories of individual flowers.* We appreciate the opportunity to improve the manuscript based on the comments as well as the invitation to resubmit the manuscript to Methods in Ecology and Evolution.** We have carefully revised the paper on the basis of the comments given and here resubmit an improved version. Below we give responses to each comment made and describe the revisions we have implemented to improve the manuscript based on the remarks.

1-please follow the guidelines for code and especially code testing detailed in the instructions to authors on MEE's webpage; although these were tailored for application papers, your work relies a lot on coding and make it stable over the long-term is essential;

Response

Thank you for referring us to these guidelines. We very much agree on the importance of stable and reproducible code. We have taken this opportunity to improve the structure and readability of the code accompanying the manuscript. The code repository includes an overview of programming language and version, dependencies, and a guide for installation. The repository also contains a requirements.txt file that can be used for installation of dependencies. Further, we have implemented a code test to ensure that the tracking, filtering, and evaluation algorithms are functioning as intended after installation. We include a filled-out code checklist with this submission.

2-please add a figure (which can become the first of the paper) synthetizing the does and don't + the logic behind individua-based pollination ecology and how automatic tracking add a piece to the puzzle. This will not only help users see the value and the steps of your approach but put it in a wider context. These types of figures are usually good features of our papers and attract a wide range of ecologists to try new methods;

Response

Thank you for this suggestion. We have added a figure (fig. 1) that visualizes the input and output of individual flower tracking to help the reader develop an understanding of the suggested method and its value.

3-Add a larger context in the discussion about automation and how this help solve some of the actual and future shortcomings of pollination ecology and life-history tracking + how to do you see your method blossom in the near future and how it can be even more expanded.

Response

We have adapted and expanded the discussion to put the concept of automated ecological data collection and our particular method in a wider context and underline the future potential of such methods.

This is a simple and logical algorithm to track individual features which move between successive pictures. This tracking goes beyond the tracking of immobile features, such as plants. In this sense, your algorithm is a novel feature which could be of interest to ecologists in general.

Response

We thank the editor for noting the potential of individual object tracking within ecology. We agree that tracking based on displacement of objects between frames is a generic method relevant for many object types and ecological systems.

I share reviewer 1's main concern that it is unclear how well your algorithm works in a general setting – for example, in communities with taller vegetation where the chance of overlap among flowers is higher. This is an important concern: if this algorithm is to reach as many people as possible, it is necessary to understand for what type of vegetation it a useful tool. How much work is needed to adapt this algorithm to other datasets? This is a relevant question, because you only have data for two, similar species (both from the genus Dryas). Do you have other datasets to address this concern? If not, would it make sense address this using simulation (e.g. looking at how the three parameters of the algorithm can accommodate specific issues in datasets)? If not, why is this dataset an example of general relevance? You also indicate your algorithm needs be adapted to different datasets.

Response

Thank you for bringing this concern to our attention. We agree on the importance of understanding the general applicability of our method. Tracking based on displacement between centroids of objects is a generic approach which has been implemented for objects other than flowers (Bjerge et al. 2021; Rahman et al., 2020) (references also included in manuscript). The approach benefits from its simplicity and is easy to test on other data. However, tracking of flower can be considered a special tracking challenge especially owing to their fixed anchor point. In the manuscript, we intend to first demonstrate the feasibility of flower tracking using simple centroid tracking and, second, to present potential solutions that can mitigate the specific challenges of flower tracking. The user-adjusted parameters added to the algorithm was designed with flower tracking in mind but can be relevant for other object types. To present the algorithm and the associated parameters in a more general way, we have followed the suggestion and included examples based on simulated data. The examples demonstrate the use of each tracking parameter as well as the importance of frame rate versus movement for reliable tracking, which is an important consideration ´as high frame rate/low movement eases the task of associating instances of an object between frames, while, on the other hand, Low frame rate/high movement makes this task difficult. The code and data for this added section is also made available for the reader.

Reviewer 1 also urges you not conflate the concept of individual flower phenologies with individual plant phenologies (e.g. L 80-86, 95-104, 425-426). This is a subtle, but important point.

Response

Thank you for noting this very important caveat. We have edited the text at the specified lines to make it explicit that we are talking about individual floral phenology.

Reviewer 2 suggests emphasizing the indirect applications of this algorithm – please see attached PDF for details.

Response

We have taken the comments in the PDF into account and implemented changes accordingly where relevant. Please see overview below.

Somewhat related to the main concern of reviewer 1, you should justify the use of this algorithm with respect to other options. Could this tracking be accomplished, in principle, using machine learning or AI? If yes, why is this algorithm advantageous/necessary?

Response

As we describe in the introduction, methods do exist that use deep learning methods to augment object tracking, for example by recognition of an object between frames. However, the low variation in appearance between individual flowers means that this is not a reliable approach for flower tracking. We are not aware of any methodology for object tracking fundamentally based in deep learning nor how this would be achieved. The benefit of the presented method is its simplicity, which means that it is readily testable on other data, without e.g. training of neural networks. For specific use-cases – e.g. tracking easily distinguishable objects - other and more advanced methods may be preferable. In the present paper, we intend to make the point that it is feasible to track individual flowers in image time-lapse series, which opens up new possibilities for studies of floral biology.

What is the relationship between this article, and Mann et al. 2022? You cite Mann et al. 2022 only once in the article. How is this work related to this, and how do they complement each other? I only skimmed Mann et al. 2022, but I understand that that article uses flower detection, rather than flower tracking. If so, state it clearly. Also, state that Mann et al. 2022 would be a first step in a pipeline that 1) identifies flowers in every picture, 2) tracks these flowers (IF and only IF, this is correct; this is what I have understood). Emphasizing difference between Mann et al. 2022 and the present manuscript is also relevant in the introduction, where your emphasis on "tracking" versus image detection should be much more clear (lines 87-104). In the current manuscript, I expect that readers will get confused between these two topics. Your algorithm "tracks" individual flowers, rather than simply identifying them. While this is relatively straightforward in plants whose base is fixed, flowers can move quite a bit through their petioles (Interestingly, an algorithm to track plant individuals has been just published in Methods in Ecology and Evolution; Stears et al. 2022).

Response

The reviewer is correct in his/her understanding of the difference between Mann et al. 2022 and the current manuscript. Mann et al. 2022 demonstrates the potential of automated flower detection in images using deep learning. The output of these detections, and object detection models in general, is information about the location of the detected object in the image. In the current manuscript, we demonstrate that specifically flowers in images from automated monitoring of flower plots can be individually tracked in order to derive individual floral phenology. We understand the potential for confusion and have taken the suggested steps to clarify the differences.

Thank you for raising our attention to Stears et al. 2022. In Stears et al., 2022, tracking is based on maps in the shapefile format for example derives from historical maps, while in our case it is based on distances between point-positions. Our reasoning for this is the direct compatibility with the output from deep learning object detection models, which allows us to move towards an automated pipeline of flower plot monitoring at the level of individuals. We appreciate the similarity of the methods and some of the suggested tracking parameters and consider this a strengthening of our paper and have included Stears et al. 2022 as a reference in our manuscript.

In the methods, I feel it would be helpful to immediately provide an overview of the most common tracking errors. In line 198 you talk about “a tracking error known as fragmentation”. It would be nice to have an overview of all the most important tracking errors, in order to set up the language for the two tracking errors you present in Figure 4.

Response

A good understanding of the potential tracking errors is important and, as suggested, we have provided a description of these errors. Further, we have restructured the section so that the methods section starts with the paragraph *Common* tracking *errors and evaluating tracking performance* includes both an overview of the tracking errors as well as the description on how to measure tracking performance. Finally, note that the now added figure 1 also aids the reader in understanding the reasons behind tracking errors.

Finally, in the section "Identifying the most reliably tracked flowers" (line 311): this section and its link in the introduction should be clarified. In line 312, you need to explain once again that some flowers cannot be reliably tracked by the algorithm, but that some flowers will be tracked almost perfectly. This filtering is needed to identify the flowers that can be tracked with certainty or near-certainty. Regarding the above, you explain this part of your analysis in lines 132-138: however, this section should go right after "We describe three user-defined parameters to help optimize tracking of flowers in particular", to clearly emphasize the limitations of the algorithm.

Response

We agree with the points made and have revised the introduction and the methods section according to the suggestions to in order to clarify the limitations of the tracking algorithm.

MINOR COMMENTS

71 Remove "B. D." from this citation, and all subsequent citations.

Response

Done.

111: "violate" rather than "violates"

Response

Done.

294-298: The sentence is too long; please split this up in at least two sentences. Also, the sentence is unclear: if you mean that you have no false positives/negatives, because you do not work on CNN data, then state it.

Response

Thank you for bringing this to our attention. We have revised the sentences for improved readability.

317: "two points. we": remove the dot.

Response

Done.

321: what do you mean by "collinear" points?

Response

“Collinear” is the geometric term for points lying on the same straight line. We have added a definition in the text to clarify this.

384-385: Should be "The y-axis shows the track IDs". Talking about the "correct" track ID, would imply a legend for the different color (which will presumably refer to correct and incorrect track ID).

Response

Here, correct” means the track ID assigned through manual tracking, i.e. the ground truth. The colors of the bars signify IDs assigned by the tracking algorithm, but the specific IDs are random and should and will not correspond to the ground truth ID. Therefore, no legend is shown. The goal of automated tracking is that one such ground truth track (the whole track and only that track) is assigned a unique ID by the tracking algorithm. For example. Ground truth track A could correspond to algorithmic track 1 – if all points in A, and only those points, have been assigned to 1 by the algorithm, this is correct tracking. We have revised the wording in the figure caption to better reflect this.

571-586: Discussion section on pollination has not been tested. It is therefore mostly speculative.

Response

Thank you for noting this point. In this revised edition, we have removed most of this paragraph. Further, we have included a relevant reference (Nagai et al., 2022) to our point on the potential of flower tracking in pollination ecology. Finally, we have revised the title of the manuscript to better reflect the scope of the presented method.

Figure 3: Please plot the jittered data points over the boxplots. This is good practice by allowing to see raw data points.

Response

Good point. Done.

723 The formatting of the DOI link is incorrect

Response

Thanks for bringing this to our attention. We have ensured correct formatting of all DOI links.

Reviewer comments in text:

Abstract: “Flower phenology”: the proper term here would be "floral biology.

Response

We have corrected this term throughout the manuscript.

Line 137: “floral biology” suggested instead of “phenology at the level of individual flower”.

Response

We have corrected this and revised the title of the manuscript to better reflect the relevance of our method for floral biology.

Line 144: “using time-lapse cameras”: how many?

Response

Here, we argue that the relevant number is how many time-lapse image series were included in the study which is given in the paragraph. A given camera could have been used in both study years for the Narsarsuaq site, but the image series are unique.

Line 440: “More important than the duration of the flowers are the changes that occur during this period, such as the moment of anther opening/pollen release, stigma receptivity, among others.

Is this "tool" effective in this type of sampling?”

In the revised version of the manuscript, this paragraph has been removed. However, we have included a point about the potential of detection of these phases in the text: “Owing to the limited resolution of the cameras used in the present study, it is unlikely that detailed information about anther opening or pollen release can be recorded from these images, but with increased image quality, this may be possible.”

Lines 557-559: I agree with "at logistically challenging sites". I disagree with "at large scale". I think about the cost of using cameras, especially in tropical countries with few resources.

Response

Thank you for raising this important point. We have revised our wording to clarify the meaning: “Our results show that it is feasible to collect and analyse individual floral phenology in high detail at logistically challenging sites, which is a significant contribution towards automatic and efficient phenology data collection.”

Lines 571-586: There are a lot of "guesses" here, but has the proposed tool been tested in this regard? It would be interesting to see results of these tests.

Response

Thank you for this point. In the revised version, this paragraph has been removed. Instead, we describe the potential of coupling induvial flower monitoring with pollinator information in the two first paragraphs of the section Automated monitoring of ecology and give relevant references. We agree that the potential results this tool could output in the regard of pollen limitation would very interesting indeed, but such studies have been out of scope of the presented work.

Lines 613-615: Other perspectives on this technique/method (with "adjustments"): in the tropical region this tool would be important in the study of floral biology and of nocturnal floral visitors (e.g. bats, sphingids, marsupials).

Response

Thank you for bringing these exciting applications of our method to our attention. We very much agree on the extended potential of the presented method in the mentioned regards. Although, with the word count of the manuscript in mind, we have decided not to make further additions to the paragraph.

REFERENCES

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