In this document please find our responses to the reviewers and an associated summary of changes made to the manuscript stemming from the reviews. In addition to the changes made in response to the reviewers, the following changes have been made since the responses were submitted on April 14:

Lines 39-48:
Original: While dune height change is an important metric to consider when measuring storm impacts (e.g., Long et al., 2014), other measures of dune erosion, such as volume loss (e.g., Durán et al., 2016; Larson et al., 2004), may 40 better describe the overall change in morphology by accounting for changes in height as well as width (Figure 1). Understanding how the relative value of height divided by width, or aspect ratio, in foredune morphology will affect storm-induced erosion and impacts to coastal communities is important, especially because pre-storm dune shape is affected by both environmental and anthropogenic processes.

New (italicized): While dune height change is an important metric to consider when measuring storm impacts (e.g., Long et al., 2014), other measures of dune erosion, such as volume loss (e.g., Durán et al., 2016; Larson et al., 2004), may better describe the overall change in morphology by accounting for changes in height as well as width (Figure 1). *While the role that dune height plays in assessing dune erosion has been well studied, the role played by the width of the dune is less clear. The dune aspect ratio metric, which we analyze in this paper, allows us to quantify how dunes erode under persistent scarping conditions (related to the width of the dune) while still considering the susceptibility of the dune to overwash (related to the height of the dune).* Understanding how the relative value of height divided by width, or aspect ratio, in foredune morphology will affect storm-induced erosion and impacts to coastal communities is important, especially because pre-storm dune shape is affected by both environmental and anthropogenic processes.

Lines 46-49:
Original: Understanding how the relative value of height divided by width, or aspect ratio, in foredune morphology will affect storm-induced erosion and impacts to coastal communities is important, especially because pre-storm dune shape is affected by both environmental and anthropogenic processes.
New: Deleted the sentence as the previous lines leading up to it explain the importance now and any additions made here would be better suited at other locations in the introduction

Lines 61-67:
Original: None
New: Changing environmental conditions may also drive shifts in the range of dominant dune grass species, for example Goldstein et al. (2018) found that there is a northern shift in the range of *U. paniculata* along the east coast of the United States consistent with latitudinal temperature trends. This may cause a shift in dunes along the northeastern United States to take on a taller but narrower morphology (i.e., higher aspect ratio). Similar to changing dune morphologies in the PNW driven by changes in dune grass species, it will be important to understand how these dunes will impact coastal erosion given that they may be more protective from overwash but more likely to be severely eroded via scarping.

Lines 319-324:
Original: This suggests that a dune which is more resistant to the effects of collision may offer the greatest degree of protection so long as it is not overtopped, especially given that the dune will likely be experiencing collision for a longer time under longer duration storm events.

New (italicized): This suggests that a dune which is more resistant to the effects of collision may offer the greatest degree of protection so long as it is not overtopped, especially given that the dune will likely be experiencing collision for a longer time under longer duration storm events. *To this end, the role of the dune width in mitigating hazard exposure has been qualitatively explored (Davidson et al., 2020; Leaman et al., 2020) however this has not been assessed quantitatively. Further, the relative role of the dune morphology (height and width) versus the beach width in limiting exposure to coastal hazards has been identified as a necessary avenue for future research (Davidson et al., 2020) which we are able to assess from the findings of this study.*

Lines 254: High aspect ratio dunes are closer to the angle of repose than low aspect ratio dunes so they tend towards avalanching with sediment piling up at the dune toe. While the low aspect ratio dunes lose more volume than the high aspect ratio dunes the sediment is lost offshore during the storm.

Changed to (italics): High aspect ratio dunes are closer to the angle of repose than low aspect ratio dunes so they tend towards avalanching with sediment piling up at the dune toe. While the low aspect ratio dunes lose *less* volume than the high aspect ratio dunes, the sediment *tends to be* lost offshore during the storm.

Lines 361-366:
Original: Across simulations in which the beach width varied (i.e., the crest-aligned and heel-aligned scenarios), there is a clear relationship between the amount of erosion prevented (relative to the toes-aligned scenarios) and the width of the beach (Figure 10), wider beaches lead to less sediment loss from the dune and a more seaward shift in the dune toe position.

Changed to (italics): Across simulations in which the beach width varied (i.e., the crest-aligned and heel-aligned scenarios), there is a clear relationship between the amount of erosion prevented (relative to the toes-aligned scenarios) and the width of the beach (Figure 10), Wider beaches lead to less sediment loss from the dune and *more progradation of the dune toe*.

Lines 443-453:
Original: Given the challenges of achieving such a foredune morphology in the face of rising sea level and within resource limitations (i.e., sand availability, cost, etc.), our findings suggest that the greatest increase in short-term protective service can be achieved by widening beaches, regardless of the frontal dune morphology. Although our work demonstrates that widening beaches through nourishment may provide more protection from flooding in the near-term than artificially constructed dunes, it is costly and may be infeasible over the long-term in the face of sea level rise and shoreline erosion. Alternative strategies for widening beaches would also have a similar protective effect (e.g., managed retreat; , Cutler et al., 2020; Gibbs, 2016). Further,

dune building initiatives, such as the emplacement of sand fences, that increase the width of the dune, likely offer the greatest protection against longer storms. Though wider dunes do not necessarily decrease the likelihood of overwash, given that wave collision is a common and frequent mode of dune erosion (e.g., Brodie et al., 2019), a wider dune does provide protection from the most commonly experienced mode of erosion. Though potentially beneficial in the short-term, widening beaches and reducing overwash through the emplacement of tall dunes can also have negative long-term consequences because they reduce overwash flux, which is essential for barrier islands to maintain elevation as sea level continues to rise (i.e., Lorenzo-Trueba & Ashton, 2014; Magliocca et al., 2011; Rogers et al., 2015). Ultimately, pairing wide dunes and wide beaches to provide protection from the most common storm scenarios may balance the need for protection from most storms, but this must be considered against a longer-term need for the island to rollover and maintain a subaerial surface via overwash processes lest it risk drowning.

Changed to (italics): Given the challenges of achieving such a foredune morphology in the face of rising sea level and within resource limitations (i.e., sand availability, cost, etc.), our findings suggest that the greatest increase in short-term protective service can be achieved by widening beaches, regardless of the frontal dune morphology. *However, although our work could be used to demonstrate that widening beaches through nourishment may provide more protection from flooding in the near-term than artificially constructed dunes, we note that this is costly, may be infeasible, and is irresponsible over the long-term given that these management initiatives reduce overwash flux, which is essential for barrier islands to maintain elevation as sea level continues to rise (i.e., Lorenzo-Trueba & Ashton, 2014; Magliocca et al., 2011; Rogers et al., 2015). Alternative strategies for widening beaches would also have a similar protective effect (e.g., managed retreat; Cutler et al., 2020; Gibbs, 2016) while allowing for more of the natural processes to occur that allow an island to evolve and persist in the face of rising sea levels. Ultimately, pairing wide dunes and wide beaches to provide protection from the most common storm scenarios may balance the need for protection from most storms, but this must be considered against a longer-term need for the island to rollover and maintain a subaerial surface via overwash processes lest it risk drowning.*

We have also included an additional figure (Figure 2) showing the study area and the location of the different transects used in this study:

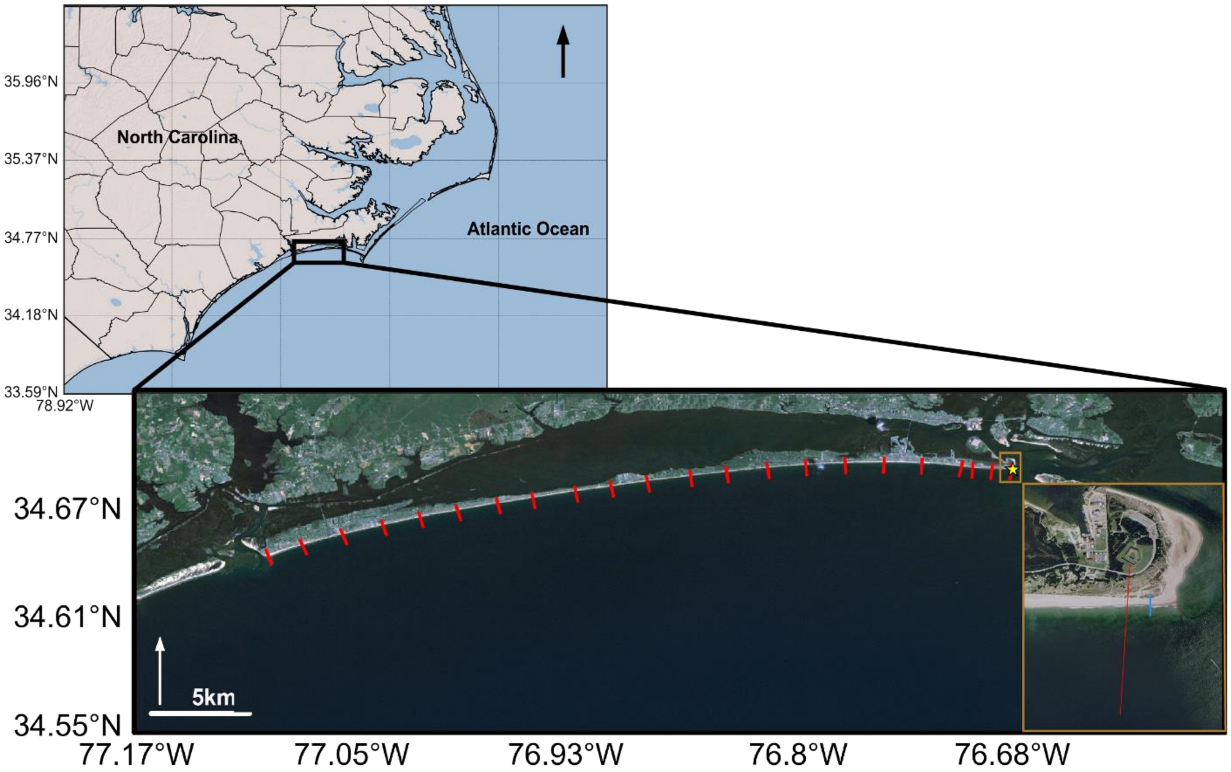

Figure 2: Map of Bogue Banks, North Carolina showing the locations of the field transects used in this study (red) and the location of the LiDAR profile (yellow star) used to construct the synthetic dune profiles used in this study. The inset image shows the eastern half of Fort Macon State Park with the LiDAR profile location in blue. Figure modified from Itzkin et al. (2020).

Note that the Figure numbers in the reviews here have been updated to reflect this change to the manuscript (i.e., Figure 8 is now Figure 9).

Finally, numerous minor edits have been made to improve the flow and clarity of the manuscript.

Reviewer 1

We appreciate this reviewer's thoughtful comments, which have assisted us in improving the manuscript. In what follows, we respond (in non-bold text) to reviewer's comments (shown in bold text). New or revised manuscript text is italicized. We found it simplest to revise the manuscript at the same time that we prepared our response to reviewer comments. Thus, the line numbers refer to the submitted version unless otherwise noted and indicate where new text has been inserted. Note that all revised Figures referred to throughout the response can be found at the end of this document.

Here, we provide a brief summary of the major changes we have made in response to Reviewer 1: We now more carefully control for the effects of dune aspect ratio and beach width in our analyses. We also clarify our goals and approach with respect to these points throughout the manuscript. To accomplish this, we have reframed our presentation, restructuring the results section and reorganizing the discussion section to highlight that 1) We isolate the effects of dune aspect ratio on dune erosion through analysis of our toes-aligned simulations (in which beach width is held constant). These scenarios allow us to also examine the effects of storm duration and storm surge level on dune erosion as a function of dune aspect ratio. 2) We then isolate the effects of beach width on dune erosion by subtracting the effect of dune aspect ratio on dune erosion as determined from the corresponding toes-aligned simulations, and 3) Our fenced-aligned simulations then provide additional insights into how dune erosion is influenced by emplacement of sand fences as a function of storm duration and surge level. We also propose to change our title from “The influence of dune aspect ratio, beach width and storm characteristics on dune erosion for managed and unmanaged beaches” to- “The relative influence of dune aspect ratio and beach width on dune erosion as a function of storm duration and surge level.” Consistent with this revised and more clarifying approach, we adjusted the figures and their presentation in the following way:

- Figure 8 now only shows results from the toes-aligned simulations (instead of all four configurations). There are now three columns (one for each surge scenario), and the top row shows the volume loss, the middle row shows dune toe migration, and the bottom row shows the wave energy reaching the dune (these are new metrics provided in response to comments from Reviewer 2). We include equivalent figures (Figures 9, 10, 12) for the crests-aligned, heels-aligned, and fenced simulations but with the influence of beach width removed by subtracting the toes-aligned results. We have removed original figures 9 and 10.
- A new figure (Figure 11) now shows the volume loss for the crests- and heels-aligned simulations minus the volume loss from the equivalent toes-aligned simulations. These data were plotted versus the initial beach widths of the crests- and heels-aligned simulations to demonstrate the volume loss that was prevented as a function of the varying beach width for these simulations.

Below we respond to specific points in the review although we note the key changes to the manuscript to address the review have been summarized above.

The manuscript under discussion here has as major purpose to analyse dune erosion as a function of dune aspect ratio (i.e., dune height versus dune width) for storms of varying intensity and duration by simulating hydrodynamic processes, sediment transport, and morphologic change. For that, the authors create a series of synthetic dunes to run a series of sensitivity analysis.

The manuscript is well organized, easy to read and clearly presents its objectives. However, I am afraid that the outcomes from the author’s experiments do not actually support their conclusions, and more important, are not the best to address the original objective. The conclusions reached by the authors overlap very well grounded facts, namely the importance of the beach width as a major control of dune erosion, stated by several earlier works; e.g. review works (Davidson, Hesp and Miot da Silva, 2020) and works based on field observations (e.g. Burroughst and Tebbens, 2008; Charbonneauet al., 2017; Claudino-sales et al., 2008; Crapoulet et al., 2017; Galiforni Silva et al.,2019; Héquette et al., 2019; Itzkin et al., 2020; Keijsers et al., 2014; Pye and Blott,2016), making it difficult to

understand what is the actual contribution of the manuscript tother than calling our attention to the fact that dunes may erode over time (usually not by a single storm), reducing their capacity to prevent overwash and inundation, depending not only on their elevation but also on their width.

We appreciate that the reviewer found the manuscript well organized, easy to ready and to clearly present its objectives—thank you for this positive feedback. We note that the major changes made to the manuscript and summarized on page one of this response improve the connection between objectives stated in the paper, the experiments and the results. In the comment directly above, the reviewer provides several citations to papers that discuss the role of beach width in dune erosion. However, in our reading of these papers while they suggest or state the importance of beach width, they do not quantitatively demonstrate its importance. Not only does our work show that beach width plays a role in dune erosion, it also demonstrates the relative roles of dune morphology (height and width, quantified as the aspect ratio) and beach width in determining how a dune will erode under various storm conditions. Storm impact studies focus on the role of dune morphology (typically just height) but here we quantitatively show, through the use of numerous XBeach simulations, that dune morphology is secondary to beach morphology in predicting storm-induced dune erosion.

Regarding the concern that we are demonstrating something that has already been shown, in the review paper by Davidson et al. (2020)—the most recent of the papers cited by the reviewer— beach width is mentioned as a factor that regulates foredune scarping, and the paper concludes with a statement that calls for just the type of study we have conducted stating that "Further research is required to determine the relative importance of some of the controls on the degree of scarping detailed here, and future investigations on what constitutes the most vulnerable beaches and dune systems, and why, is required" (Davidson et al., 2020) . The paper by Davidson et al. (2020) also states "observations and tests that record the difference in the magnitude or degree of scarping occurring on reflective versus intermediate versus dissipative beaches under the same storm and offshore swell conditions would be very useful". In our revised manuscript wee determine, after incorporating the suggestions from the reviewers, the relative importance of the various controls (TWL, dune height/width, beach width/slope, and storm duration) on dune erosion. Further, while we do not explicitly reference reflective/intermediate/dissipative beaches, we do simulate erosion across a wide spectrum of beach morphologies using "the same storm and offshore swell conditions." Thus, our paper specifically contributes to the further research that Davidson et al. (2020) call for.

The reviewer also suggests that the main message of the paper is that that "dunes may erode over time (usually not by a single storm), reducing their capacity to prevent overwash and inundation, depending not only on their elevation but also on their width." We think this is an oversimplified statement of our study. In response, we have reviewed the text carefully and made changes that we believe helps better communicate our findings to the reader (revised manuscript lines 77-86 and 437-439 respectively):

"The main goal of the work presented here is to assess how dunes erode during a single storm, as a function of dune aspect ratio (i.e., the combined measure of height and width), beach width, and management efforts that led to the formation of an artificial dune (i.e., sand fences). While previous studies of storm impacts on dunes have primarily focused on dune height (e.g., Long et al., 2014; Sallenger, 2000; Stockdon et al., 2007), recent studies suggest that the dune

width may also be a key predictor for how much dune erosion will be experienced (Leaman et al., 2020). *Additionally, although beach width has been posited as a strong predictor of dune erosion (e.g., Burroughs and Tebbens, 2008; Claudino-Sales et al., 2008; Itzkin et al., 2020; Silva et al., 2018) quantifying and understanding the relative role of beach width in dune erosion processes requires further investigation* (Davidson et al., 2020)*."*

"In this study we analyzed how coastal foredunes erode during a storm as a function of their aspect ratio (height and width), beach width, and the presence of management interventions (i.e., sand fencing and beach nourishment)."

I believe that it would make more sense to me to call our attention to the fact that the shape of the dune, not only the aspect ratio as that might be a bit limiting indicator as the shape of a dune can vary very much, turning it very important to consider indicators that inform about the volume, in addition of course, to the elevation, as that is the key parameter that determines the impact regime, the impact can shift to overwash or inundation if a particular height is maintained over a certain width of the dune, but this is not informed by the aspect ratio. So, I would say that additional information other than only the aspect ratio would be needed to actually understand if a particular dune can cope with the impact of one or several storms if the shoreline is retreating (or if the dune is being eroded) the aspect ratio of the dune may also change, as they are all but very irregular features.

We agree that there are many different metrics which can be used to describe the shape of the dune beyond the aspect ratio such as the dune face slope, dune height, or dune width. When we constructed the set of synthetic dune shapes, we set all the dunes to a similar volume so as to compare volume loss among the dunes as a consequence of their shape. To control for volume, we had to adjust both the height and width of the synthetic dunes (as described in the methods section of the manuscript). The aspect ratio metric takes into account both the height and the width of the dune and thus it describes the shape of the dunes we used due to the manner in which the synthetic profiles were constructed. Additionally, as a consequence of the manner in which we constructed the synthetic profiles, the dune face slope is directly related to the aspect ratio of the dunes and so all the results presented as a function of aspect ratio could be interpreted the same way as a function of the dune face slope given that these two parameters are not independent of each other in this study. To address this concern, we have added the following table into the methods section as a complement to Figure 3 detailing shape parameters we use to more fully describe the dune shapes used in this study:

	Aspect Ratio (-)	Volume (m3/m)	Dune Height (m)	Dune Width (m)	Dune Slope (m/m)
1.6X	0.25	52.75	5.68	49	0.15
1.4X	0.2	50.64	4.95	50	0.13
1.2X	0.15	51.76	4.29	53	0.12
1.0X	0.11	53.27	3.69	56	0.1
0.8X	0.07	53.45	2.9	60	0.08
0.6X	0.04	53.25	2.18	67	0.06

0.4X	0.02	53.29	1.47	82	0.04

For clarification we have also modified the caption for Figure 3 to highlight that the "#.#X" values refer to the percent increase (decrease) in dune height (width) relative to the base profile (1.0X) as described in the methods section of the manuscript to maintain a constant initial volume. We have also added the following lines to the section on synthetic dune profiles to address the limitations of these shapes (revised manuscript lines 132-134):

"We modify the dunes to have a similar volume to more easily compare volume loss across different aspect ratios. For completeness in describing the dune shapes, the initial dune shape parameters (i.e., steepness, height, width) can be found in Table 1."

In this line, the authors state that the amount of dune erosion or the vulnerability of coastal dunes does not only depend on dune height but also on its width, as dunes can also erode by collision regimes, and thus, an aspect ratio that includes both dimensions should be used instead of only the elevation. In addition, they also state that dune erosion might be influenced by this aspect ratio. In general, I do agree with the hypothesis stated by the authors, however, I cannot fully agree with the approach used to support their statements and reinforce my concern regarding the originality of the contribution from this work. My main concern is linked to the experiments chosen by the authors, namely to the synthetic dunes used and the way the authors have decided to create the four different configurations, which ended up having dunes with different morphologies (symmetric, non-symmetrical and with changing front dune slopes) and different distances to the shoreline that cannot be easily compared. In fact, the results suggest other factors might be more important than the dune aspect; namely the beach width, which determines the level of impact of the storm over the dune

We appreciate the reviewer's concern that the role of the beach width is critical in understanding how dunes erode during a storm and we have revised the paper (in the ways described on page one of this review) to clarify and strengthen this point. In addition to the changes made, we have kept the numerous instances in which we did refer to the importance of beach width in the original submitted version of the manuscript.

I will try to synthesize my concerns focusing on some statements from the abstract of the manuscript and mainly linked to the results of the experiments or simulations.

The authors state in the abstract that "low aspect ratio (low and wide) dunes lose less volume than high aspect ratio (tall and narrow) dunes during longer storms, especially if they are fronted by a narrow beach". Regarding the first part of the sentence and looking at Figure 7, where the results from the simulations are presented, it is not so obvious this affirmation as low aspect ratio dunes only erode less when using the fixed dune toe configuration (narrowing the size of the beach).

In response to comments from Reviewer 2 (described below), we ran new simulations with improved parameterizations for simulating erosion with XBeach (after Palmsten & Holman, 2012; Palmsten & Splinter, 2016; Splinter & Palmsten, 2012) to better replicate scarping and prevent XBeach from overestimating erosion (see response to Reviewer 2 comments for details). As such, our results are now more physically grounded and they also demonstrate a clearer distinction between how high aspect ratio dunes erode versus low aspect ratio dunes. Our updated Figure 8 (as described on page one in this response) shows a 10-40m^3/m difference in volume loss between high and low aspect ratio dunes, depending upon storm conditions. We have added text to the manuscript to better explain and quantify this revised result (Lines 213-233 in the revised manuscript):

"Simulations with the dune toes aligned have profiles that all share the same beach width (and slope) for the different dune aspect ratios included in this study, thus decoupling aspect ratio from beach morphology. Simulations with the dune toes aligned showed that there was greater erosion for the high-aspect ratio dunes compared to the low-aspect ratio dunes (Figure 8A, B, C). The increased erosion was especially pronounced during low intensity storms where there was a ~10 m^3/m (~19%) difference in volume loss between the high and low-aspect ratio dunes. For the most intense storms, the difference in volume loss between the high and low-aspect ratio dunes was ≤10 m^3/m (~19%). As expected, increasing the duration of the storms led to an increase in the amount of overall erosion experienced, especially for high-aspect ratio dunes. While none of the dunes were completely inundated in our simulations, the dunes (all aspect ratios) lost a significant amount of sediment (>30m^3/m, >60%).

Although the tall/narrow dunes lose the greatest amount of sediment compared to the low/wide dunes, the dune toe experience less erosion regardless of the storm scenario. While the dune toe for the low/wide dune retreated up to 10m during the longest and most intense storms (Figure 8F), the dune toe for the tall/narrow dunes never retreated more than ~5m (Figure 8D) and actually moved seaward by up to ~12m (Figure 8F). For a given storm duration and intensity, the dunes of different aspect ratios are impacted by a comparable amount of wave energy (Figure 8G, H, I) and the beach morphology is the same for all simulations, so the style of erosion is purely being regulated by the morphology of the dune. High aspect ratio dunes are closer to the angle of repose such that they avalanche with sediment piling up at the dune toe. In contrast, low aspect ratio dunes lose more volume than the high aspect ratio dunes but the sediment is lost to the surf zone. For example, during a shorter (+10 hours) storm with low surge, dunes with an aspect ratio of 0.1 and 0.2 both lost equal amounts (~5m^3/m) of sediment (Figure 7A) and were impacted by an equal amount (~500Nm/m^2) of wave energy (Figure 8G) during the storm. However, the sediment for the lower aspect ratio dune experienced dune toe erosion while the higher aspect ratio dune experienced dune toe progradation."

The higher aspect ratios in this case are related to dunes with very steep seaward slopes resembling scarped dunes. As the authors state, and following Hesp 1988, these dunes can be more un-stable and have greater probabilities of crest collapse, is all the sediment from the col-lapsed dune removed by the waves? Having in mind the main principles of dune/beach erosion, the amount of volume eroded should not be very different or dependent on the dune shape, but on the volume of sand that needs to be eroded as it is a response to adjust the beach profile to more energetic waves.

We agree that wave energy impacting the dune plays a critical role in describing how the dunes erode and also that sediment may be deposited at the dune toe or transported towards the surf zone depending upon the mode of erosion. In our simulations we are able to quantify the cumulative energy impacting the dune in each simulation. We have also quantified the change in dune toe position following comments from Reviewer 2 (a metric which relates to where sediment is deposited during the storm). We have added a description of these new metrics in the methods section (Lines 99-109, new text in *italics*):

"To track changes in dune and beach morphology throughout our simulations, the following morphometrics are calculated at every model time step: dune aspect ratio, dune volume, overwash volume, beach width, *dune toe erosion, and wave energy reaching the toe of the dune*. The dune aspect ratio was calculated as the height of the natural dune from D_{high} to D_{low} divided by the width of the dune from D_{heel} to D_{low} (Figure 1). The dune volume is calculated by integrating over the portion of the profile contained within the original cross-shore location of the dune (D_{low} to D_{heel}) in the first-time step and above the D_{low} elevation (0.59 m, NAVD88). The overwash volume is similarly calculated as the change in volume of the profile landward of the initial D_{heel} position. Beach width is calculated as the cross-shore distance between MHW and D_{low} at every time step. Given that pre-storm D_{low} was held constant across all simulations, the beach slope is inversely proportional to the beach width in our simulations (i.e., beach slope decreases as beach width increases). *Dune toe erosion was measured as the final minus initial position of the dune toe. Wave energy is counted as the cumulative amount of wave energy at the dune toe throughout the simulation."*

We have also included new metrics throughout the results section and in the new figures described above. From this analysis we find that, for a given storm condition (surge and duration), there is little difference in the energy impacting the low versus high aspect ratio dunes (when the toes are aligned) however the high aspect ratio dunes have a seaward shift in the dune toe position (sediment piling up at the base of the dune following scarping) while low aspect ratio dunes had a negative shift in dune toe position (sediment being carried offshore). This result would suggest that differences in volume loss are related to the dune aspect ratio as every other factor was controlled for in the toes-aligned simulations and there was minimal difference in the wave energy impacting the dunes. We have incorporated these findings into the results section for toes-aligned dunes, which can also be found on page **6** of this response.

Further, this comment by the reviewer is grounded in the assumption that the beach achieves an equilibrium profile during the course of the storms. Given that an equilibrium profile is not necessarily reached during the course of a storm, this would affect the volume of sediment lost and may be regulated by the aspect ratio. To explain this we have added the following sentences to the discussion section (revised manuscript lines 362-367):

"Additionally, the dune aspect ratio may determine the rate by which the profile achieves equilibrium during a storm. If equilibrium is achieved than volume loss would be equal for both the low and high aspect ratio dunes. However, given that erosion is a time dependent process and is also dependent upon the levels of wave energy during the storm. It is possible that when the dune is scarped (a process which is more associated with the high aspect ratio dunes in our simulations) more sand is moved into the surf zone which will help the profile achieve equilibrium more quickly compared to a low profile dune where there is less sand moving into the surf zone."

It is not so obvious from these results that low ratio dunes erode less, as the authors change the shape of the dunes and their distance to the shore, and therefore, they cannot be easily compared any-more.

The distance to the shore only varies between the different profiles in the crests-aligned and heels-aligned configurations. For these simulations, the beach width increases with the dune aspect ratio such that higher aspect ratio dunes are fronted by wider beaches (note that this is more pronounced in the heels-aligned setup as seen in Figures 3B and 3C). Because we only compare results within each configuration (i.e., Section 3.3.1 compares results from the toes-aligned simulations), and the dune and beach morphology are consistent across runs within each configuration, we believe the within configuration comparisons are valid. We only compare results *across* configurations to evaluate the effectiveness of the fenced dune in mitigating erosion (Section 3.2). However, with the changes to the structure of the paper described above we have made sure to more effectively and clearly distinguish the erosion attributable to the dune aspect ratioand the erosion attributable to differences in beach morphology.

In this regard, I would imagine that a more synthetic dune would help and allow direct comparisons. By a more synthetic dune I imagine something that preserves the slopes (shape) changing the ratio (even though not so realistic, a cube would make it easier). In fact, when looking again at figure 7, the lower ratio dunes are eroding more for all cases but the toe fixed one, which is due to a change in the seaward slope of the dune and not merely to a change in the ratio, as those have very very gentle slopes that do not make easy to identify which is the actual location of the dune toe (or transition to the beach). So, from what is shown here, high ratio dunes are not "specially" losing more volume of sand when the beach is narrow as the authors state, but "only" when the beach is narrow, otherwise they almost don't lose sand.

We agree with the reviewer's comment that different dune face slopes may lead to variability in how the dunes erode. We also made this point in the discussion section (lines 377-379) where we pointed out that the higher aspect ratio dunes have dune face slopes that are closer to the angle of repose and thus may more readily experience avalanching/scarping.

The latter results from the fact that the other configurations (fixed crest and heel) present wider beaches and so, they may enter the collision regime later, or not at all. The authors also suggest that this affirmation mostly applies to longer storms. However, from figure 7f, j, g, k, we see that the erosion increases over time also for low aspect dunes if the configuration of the dune is different, so, again, the problem of comparing dunes with different shapes and distance to the shore does not help interpreting the outcomes of this work, and to assess the role of the ratio.

We agree that the results within the crests and heels-aligned configurations need to factor in the role of dune aspect ratio and beach width, which is why we have restructured this analysis to more clearly present erosion as a function of dune aspect ratio (Section 3.1 and Figure 7) and beach width (Section 3.3 and Figure 8). Additionally, we have added the following statements to clarify this distinction by explaining a) that the toes-aligned simulations control for beach width and thus we can attribute differences in erosion to differences in dune morphology and b) that by subtracting out the erosion from toes-aligned simulations from the crests- and heels-aligned simulations (as described above) we are able to isolate the effect of varying beach width between the dunes in these simulations. These additions are on Lines 209-214, 219-221, 264-268 in the revised manuscript, and shown in order below:

- *"Additionally, the four different dune configurations presented in our analysis (i.e., toes-aligned crest-aligned, heels-aligned, and fenced) allow us to isolate the amount of erosion attributable to the dune morphology (aspect ratio) and the amount of erosion attributable to the beach morphology (width and slope) by establishing a baseline level of dune erosion in the toes-aligned simulations before introducing variations in the beach width in the crests- and heels-aligned simulations and management interventions in the fenced simulations"*
- *"Simulations with the dune toes aligned have profiles that all share the same beach width (and slope) for all of the different dune aspect ratios included in this study; Because of this we are able to isolate the effect of dune aspect ratio on dune erosion from these results because the only difference between the simulations was the dune morphology."*
- *"To isolate the effect of beach width we subtract the amount of erosion from the dunes in the toes-aligned simulations (which control for beach width) from the amount of erosion in the crests- and heels-aligned simulations."*

Also in the abstract, the authors affirm: "During more intense storms, low aspect ratio dunes experience greater erosion as they are more easily overtopped". I see again a problem when comparing dunes with different shapes and distances to the shoreline. The affirmation sounds totally logic to me as the amount of volume needed to erode depends on the magnitude of the storm, and as stated by previous authors: "one of the most significant factors affecting the magnitude of spatial and temporal change to a foredune during an erosion event is the height of the mean water level during the storm(Davidson, Hesp and Miot da Silva, 2020 and references therein)", and in fact this is the main factor that the authors assess when changing the magnitude of the event, the water level. However, when looking again at figure 7 (namely 7i), high and low aspect ratios share maximum volume loses, and in fact the main difference with fig.7e, is the fact that a higher water level reaches the low aspect ratio dune crest more easily than low water levels. Conversely, low aspect ratio dunes for the configurations other than the fixed toe one, are more vulnerable because their toe is closer to the shoreline when compared to the high aspect dunes, which are far from the shore in the crest and heel fixed configurations, which in turn makes it difficult to compare volumes of erosion

The changes described in our responses above better isolate the effect of varying beach width in our simulations. Specific to this comment, a new figure (Figure 11) now shows the difference in volume loss between the crests- and heels-aligned simulations and their equivalent toes-aligned simulations as a function of beach width. This shows a strong relationship between the amount of volume loss and the increase in beach width relative to the toes-aligned simulations. For example, we now show that for heels-aligned simulations with a ~68m wide beach there was a 15-30m^3/m decrease in volume loss (greater decrease in volume loss for longer storms) compared to the equivalent toes-aligned simulations which had an equally narrow beach for all dune shapes. In addition to the new figure, we have added an explanation for this relationship in lines 261-264 in the revised manuscript:

“Combining results from all simulations (Figure 11), we observe a proportional relationship between pre-storm beach width and volume loss (relative to the equivalent toes-aligned simulation). We also find that the erosion mitigated by wider beaches is even greater under longer and stronger storms (Figure 11).”

Still in the abstract, the authors state that in managed scenarios (by managed dunes, they refer to those sites where a fenced dune is constructed seaward of the existing natural dune) a fenced dune effectively prevents the natural dune behind from experiencing volume loss. Again, this is what should be expected as having a fenced dune implies in their case that the shoreline is again seaward and distant from the toe of the natural dune, resembling a wide backshore. Yet, the authors mention that the volume loss can be reduced up to 50%, which is a number that depends on their experiments, as if they have built a larger fenced dune it would be greater, also if instead of using the toe fixed they had used the crest or heel fixed configurations, that % would increase. So, again, it is not clear the point/contribution of the authors as these are well grounded ideas/facts usually used for the managers to design the actions to take

While our simulations show a reduction in volume loss of up to 50% with the new XBeach parameterization between the fenced and toes-aligned simulations, we fully expect the modeled volume loss to vary based on both the parameters used with XBeach and the configuration of the synthetic profiles. We have added this point in an explanation clarifying that the specific amount of volume loss related to how our dunes eroded are a function of XBeach parameterization but that we expect the trends and relationships identified in this work to hold true in all instances given that any of these changes related to model setup would be applied uniformly to all simulations and would thus impact them all equally (Lines 209-211):

“We note that while the specific amount of volume loss relating to dune erosion and wave energy are a function of model setup, the setup is applied uniformly to all simulations such that the trends will remain constant regardless of how the dune shapes are formulated and how the model parameters are set.”

Regarding the shoreline positioning in the fenced dune simulation, the shoreline is in the same location as it is in the toes-aligned simulations; The only difference is that part of the beach has been turned into the fenced dune. While this scenario may not be entirely realistic, it allows us to directly quantify the role that the fenced dune plays in mitigating dune erosion by allowing for a comparison between the fenced and toes-aligned simulation as the only difference between the two is the presence of the fenced dune. If the fenced dune were placed in the crests-aligned or heels-aligned simulations, the issue of the varying beach widths would still be present as the distance from the shoreline to the toe of the fenced dune would vary between the different dune profiles. While the role of sand fences on dune growth has been studied before (e.g., Anthony et al., 2007; Charbonneau & Wnek, 2016; Itzkin et al., 2020; Mendelssohn et al., 1991), a quantitative assessment of how much natural dune erosion is prevented during a storm by the presence of a fenced dune has, to our knowledge, not been previously addressed. To explain why we have configured the fenced simulations in this manner we have added the following sentence to the results section (revised manuscript lines 284-287):

"We performed a suite of simulations using the same dune profiles as the dune toes-aligned scenarios but with a portion of the beach replaced by a fenced dune (Figure 1D). The placement of the fence on the beach allows us to compare with the non-fenced simulations without changing the beach width. By comparing the results from these simulations with those from the toes-aligned simulations (Figure 11) we are able to quantify the effectiveness of artificial dunes (formed via the emplacement of sand fences) under varying storm scenarios."

We have also modified the following sentences in the discussion section (revised manuscript lines 393-394 and 416-420 respectively):

"The key dynamic in this case (regardless of actual storm duration), was that the fenced dune was sufficiently high to protect the natural dune until the peak of the storm had passed. The foredune behind a fenced dune is not impacted until the fenced dune is eroded away, making the aspect ratio of the foredune secondary to the morphology of the fenced dune in providing protection to back-barrier environments *(a taller fenced dune would offer even greater protection)."*

"The strong inverse relationship between beach width and dune erosion (Figures 10 and 11) suggests that regardless of the aspect ratio of a foredune, widening the beach can be sufficient for preventing overwash during most storms and will be a more effective strategy for increasing coastal protection than re-building the dune or installing sand fences; *although pairing sand fences with a wide beach via nourishment would offer the greatest overall reduction in natural dune volume loss."*

In this line, the authors also state: "a wide beach offers the greatest protection from erosion in all circumstances regardless of dune morphology or storm characteristics". This is again, the expected result, so, are the authors trying to convince the readers that XBeach can simulate erosion? And yet, this is again something that many examples in the literature have demonstrated. Finally, and yet in the abstract, the authors end saying: "in maintaining wide beaches and dunes, the protection offered in the short-term must be considered against long-term detrimental effects of potentially limiting overwash fluxes, which are critical to maintaining island elevation as sea level rises". This idea is developed at the end of the discussion section. From what I understand, a nourished beach, if using the adequate sediments, could provide the needed sediments for the dune to cope with sea-level rise as that is the regular mode dunes grow vertically. The authors claim that maintaining large beaches would prevent rollover and thus, the natural adaptation of the barrier to sea-level rise. Here, I cannot agree with the authors because barriers, if sediment input is enough (so they maintain their beach, even if artificially) can adapt by adapting the vertical elevation of the dune feed from the abundant sediments of the beach, and not only

through rollover, right? I see more the problem of being able of maintaining large beaches with the adequate sand and in terms of costs. In this context, if sea level rises, so will the nourished beach berm and thus the dune, unless winds are not efficient anymore, which seems not to be the case in the future. Therefore, I would recommend the authors to better explain what the actual message is that they try to highlight here and to state what is their opinion about the possible coupled adaptation of the dune in that context.

At the end of the discussion section (Lines 477-485) we point out that the limited overwash flux in managed locations can have long-term implications for barrier island survival under sea level rise. Barrier island rollover under SLR and how it may be modulated by development is a process that is well-studied (see citations in the paper). Our work ties into this process because we show that wide beaches and higher aspect ratio dunes will be more resistant to erosion and therefore less frequently overwashed. Rollover is the cumulative effect of numerous overwash instances and previous studies show that reduction in overwash volumes can hasten island drowning (e.g., Magliocca et al., 2011; Rogers et al., 2015). If dunes (or structures) reduce the volume of overwash from reaching the island interior and back-barrier, island elevation decreases, and nourishment on the front side will not prevent drowning from the bay side. Further, while it is true that continuous nourishment can promote resilience to barrier drowning (i.e., Masselink and Lazarus, 2019), this is not a realistic long-term solution. Resource limitations, pointed out on line 500 and by the reviewer, will not allow for continuous nourishment indefinitely. We have revised the wording on these points at the end of the discussion to clarify (revised manuscript lines 421-430):

"*It is important to recognize that although management initiatives such as widening beaches and building dunes with particular aspect ratios can be effective at mitigating erosion, these actions may have effects that are undesirable in the long-term. For example, overwash facilitates barrier rollover—a process that is necessary if islands are to maintain subaerial exposure as sea level rises (e.g., Leatherman, 1979; Moore et al., 2010; Lorenzo-Trueba & Ashton, 2014; Rogers et al., 2015). Thus, constructing dune and beach systems that reduce the amount of overwash that would otherwise naturally occur may inhibit rollover, thereby increasing the likelihood of eventual barrier drowning (e.g., Magliocca et al., 2011; Rogers et al., 2015). This lack of overwash is a concern even in the presence of expected ongoing beach nourishment because overwash-induced increases in island interior, and back-barrier elevations are necessary to prevent drowning from the backside and because it is not feasible to continue beach nourishment indefinitely along all developed barriers.*"

More specific comments: Regarding the introduction, I would expect here that the authors present the main factors controlling the magnitude of dune erosion by storms, as this will be the main point of discussion, also considering the scales of change, from a single storm to a series of storms or the time-scale of relevance for managing would be interesting. In relation to the methods, they mention that the effect of the configuration of the beach, namely the beach slope, will be also assessed, however, this is not thereafter clearly evaluated. In line 281, I would add here the importance of the width of the dune to the impact of storm groups also.

We see the confusion here, perhaps introduced by our objectives which state that the third question we will address is “How does the morphology of the beach (i.e., width and slope) affect volumetric dune erosion independent of dune aspect ratio?” As we explain in the methods section (2.1, Lines 94-96), because the dune toe elevation is the same (0.59m) for all the dunes considered, the beach width and beach slope (calculated between MHW and the dune toe) are directly proportional to one another. For this reason, we only consider beach width in our analyses because additional analyses on the beach slope would be redundant. We address this concern by modifying the statement of our third objective (Lines 93-94) as follows (new text italicized): “How does the morphology of the beach (i.e., *width/slope*) affect volumetric dune erosion independent of dune aspect ratio?” We have also added a statement to the methods (Lines 106-108) explaining that beach slope and beach width are directly related in these simulations to further clarify this issues.

Additionally, we have included the following sentences to the introduction to clarify that the focus here is on a single storm and the specific metrics we analyze in the paper which can be found on page **3** in this review and lines 77-86 in the revised manuscript

We have also modified the following sentence in the discussion section to address the effects of multiple storms on the dunes as described in our comments on page 11-12 of this response.

Reviewer 2

We would like to thank Reviewer 2 for their thoughtful comments and suggestions which are much appreciated and have helped to strengthen our manuscript. Note that all the revised figures referenced throughout the response can be found at the end of this document.

Overall, I found the paper well written and quite succinct. From a point of view on was there a substantial increase in our fundamental understanding into dune erosion, I was less convinced. Not much in the paper surprised me or told me something I didn’t know, but more reaffirmed my understanding/observations/past work. That’s not to say that more couldn’t be presented to improve the paper and provide further understanding that I think is unique to modelling work as you have high resolution results that you can interrogate more than you have presented here. By presenting more and digging more into the results I think you could better answer your three objectives above. For example: Your dune profiles were very different and in XBeach, erosion occurs if a cell is determined to have been ‘wet’ so since your higher aspect ratio dunes had more sand closer to the dune toe, they would expect to have more erosion volumes by the nature of the model and not necessarily by a physical meaning. XBeach dune erosion is purely ad-hoc. If a cell is wet, it compares it to your wet slope and erodes it if it’s above this critical value. Realignment can also take place if dryslp is exceeded. None of this is really based on physics of dune erosion. Dunes hold much larger scarps under active erosion (See Palmsten and Holman paper for examples but many others as well including work by Erikson and Hanson -> dune notching paper , Larson Erikson and Hanson (2004) and all the work on dune impact models (Overton et al) all show this). The sand is typically (from my experience using XBeach) also immediately moved offshore (to keep the wetslp low) so the feedback mechanisms we’d see in real erosion are not there where slumped sand protects the dune toe. The model has

limitations and I can accept those but I think you need to acknowledge them a bit more here and realize what we can (and cannot) learn from these results. Consider the very different dune aspect ratios you are considering and the distribution of sand in the cross-shore, it would be good to see dune toe recession presented as well as you refer to volumes (which I also think are needed) but when you align toe,
heal, center, and with each of the aspect ratios you change the distribution of the volume in the dune. So small events will erode a lot when the toe is aligned because there is a lot of sand up close, but dx (dune toe erosion) might be similar and this is a key variable of interest to engineers/managers. The model is a grid so you are 'eating away' at the dune 1 grid point at a time as a function of the predicted TWL. Default dry slopes in XBeach are also quite flat compared to what would be capable in active dune erosion (see for example lab studies of Palmsten and Holman 2012,https://www.sciencedirect.com/science/article/pii/S0378383911001633; Palmsten and Holman 2011, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011JC007083;Palmsten and Splinter 2016, https://www.sciencedirect.com/science/article/pii/S037838391600017X- this latter one explicitly looked at XBeach and my memory is that to match the lab data they used dryslp almost 4x the default value to allow for near vertical scarping)

Reviewer 2 suggested that we conduct additional analyses to better understand changes to the dune and beach morphology as a function of the dune aspect ratio. Following these suggestions, as well as those of Reviewer 1, we now include wave energy (directly outputted from XBeach) in our revised paper because it is related to impact hours (which were suggested by Reviewer 2), but provides more insight into the amount of erosion found in our simulations. We have also included analyses for the change in dune toe position as a function of dune aspect ratio and storm duration, as suggested by the reviewer. We do not include changes in beach width (suggested by reviewer 2) because it is independent of dune toe position. However (following our response to Reviewer 1), we have more clearly isolated the role that varying beach widths play in mitigating dune erosion (see page one of this response for details). Each of the analyses presented in the revised paper have been conducted using updated and improved parameterizations to XBeach following comments and suggestions by Reviewer 2. Details on this are provided in the responses below. Because these suggested changes are referenced throughout the review, we list the changes we have made to the paper in response to this review below:

- Updated the methods section (Lines 99-109) to describe the new metrics that we added to our analysis
- Updated the results section to include analyses of changes in the dune toe position (suggested by reviewer 2) and wave energy reaching the dune.
- Updated Figure 8 to only show results from the toes-aligned simulations where the different storm surge scenarios are presented in each column (rather than each row) and the rows each show a different metric as a function of dune aspect ratio and storm duration. In the top row we show volume loss, in the middle row we show change in the dune toe position, and in the bottom row we show the cumulative wave energy impacting the dune. Additionally, we have removed Figures and 9 from the submitted

> manuscript and replaced them with ones showing the same metrics but for the crests-aligned and heels-aligned simulations. Figure 11 shows this analysis for the fenced simulations.

These new analyses allow us to better describe not just the amount of erosion experienced by the dunes in our simulations but also the manner in which they were eroded (i.e., sediment piling up at the base of the dune via scarping versus sediment being transported offshore), adding greater depth and context to our analyses.

Here the reviewer also suggests useful papers that have indicated different XBeach parameter values, which may be more appropriate than the values we used with the simulations presented in the original manuscript. We re-ran the simulations with the new parameterization, described below and, which qualitatively confirm our original results but with some quantitative differences. The default values for wetslp and dryslp in XBeach are 0.3 and 1.0 respectively. The wetslp value we used is equivalent to that used by Palmsten and Splinter (2016) but with a dryslp of 4.0 instead of the default 1.0. To improve the model results and simulate better erosion physics with XBeach we re-ran the simulations using an improved setup with parameter values updated from those published by Splinter and Palmsten (2012) and Palmsten and Splinter (2016) The following values have either been changed from a previous non-default value or have been set from their default value:

- Changed *eps* from 0.05 to 0.1
- Changed *facSK* from 0.30 to 0.15
- Changed *dryslp* from 1.0 to 4.0
- Set *hswitch* to 0.10
- Set *hmin* to 0.01

We have added the following statement to the methods section detailing the changes we made to the parameterization and some of XBeach's limitations as detailed by the reviewer (revised manuscript lines 180-187):

"We used the XBeach (Roelvink et al., 2009) model to simulate the effects of the synthetic storms described in Section 2.2 on the profiles described in Section 2.1. We ran XBeach (version 1.23.5465) in 1D-hydrostatic mode with the break parameter set to roelvink_daly and the gamma parameter set to 0.52 to better capture the effect of swash processes on the reflective beach profiles (Roelvink et al., 2018) we also adjusted parameters related to wave breaking and dry sediment transport in order to more realistically simulate dune erosion processes given the tendency of XBeach to overestimate erosion with default settings (Palmsten and Holman, 2011, 2012; Palmsten and Splinter, 2016; Splinter and Palmsten, 2012). XBeach erodes the profile by comparing the slopes to the dryslp (if a cell is dry) parameter or wetslp (if a cell is wet) to determine how much erosion should occur to maintain these values. Palmsten and Holman (2011, 2012) show that wet sand can sustain much steeper scarps than dry sand. By using a particularly high value for the dry slope (dryslp = 4), we allow the dunes to maintain much steeper, and more realistic, scarps during the storms (Palmsten and Splinter, 2016). This realism allow us to better understand how the dune is eroding under collision when it is actively scarping during the storm by comparing dune toe migration to dune volume loss. A full listing of non-default parameters can be found in Table 2."

Can you also answer your objectives in terms of dune toe recession (as well as volume)to get a deeper understanding/picture of how dune aspect ratio effects overall erosion. One would expect that perhaps that higher aspect ratios might also have less dune toe recession as more sand is dumped onto the beach and may offer protection. I would also like to see plots of beach width change over the storm. This is some-thing you say is quite important to your results – wider beaches offer more protection. Something that other researchers have also shown to be quite important (eg. Plant and Stockdon, 2012. Probabilistic prediction of barrier-island response to hurricanes https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011JF002326;Beuzen et al.2019.Controls of Variability in Berm and Dune Storm Erosionhttps://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019JF005184) Beach width(or safe corridor width) is also a key parameter that engineers/managers are wanting. How does your beach width over a storm impact on the erosion – does it need to be completely removed or only a certain percent for the dunes are vulnerable. I think if you could present your results looking at multiple parameters (volume, dune toe retreat, beach width change, dune impact hours) then the reader would get a much richer understanding of the impacts these changes to dune aspect ratio/beachwidth/storm duration had on the study. Volumes themselves only tell a small part of the story.

The reviewer suggests considering a number of other response in our simulations to further understand how dunes are eroding. For details regarding the changes stemming from this comment please refer to the top of our response to Reviewer 2. We have included dune toe position change and cumulative wave energy (related to impact hours) to our analysis to better understand changes in dune sand volume. We considered change in beach width but found it similar to change in dune toe position so we did not include this variable, although in our re-structured manuscript (see response to reviewer 1) we have included a figure (Figure 11) that demonstrates more clearly how the beach width and dune volume loss are related regardless of dune configuration.

Other Scientific Aspects to be considered: L35: "Considering that wave runup is most likely to impact the dune face (i.e., collision; Sallenger, 2000), which is more likely to affect the width of the dune rather than the height, is the most temporally common impact regime during a storm (Brodie et al., 2019; Stockdon et al., 2007), the width of the dune is an important predictor of how much erosion a dune might experience during a storm." I find this sentence really hard to read. Consider revising. As well, width won't be a predictor so much of the amount of erosion I would think, but of the erosive vulnerability of the dune itself. This paper might be of interest to you as it looks at both dune characteristics (height/width) and beach width in terms of erosion and flooding risks in storms: Leaman et al. (preprint, under review in Coastal Eng). A Storm Hazard Matrix combining coastal flooding and beach erosion. https://eartharxiv.org/repository/view/1753/

Regarding the suggestion to line 35: To clarify this statement and address the role of dune width we have changed these sentences in the introduction to (revised manuscript lines 39-41):

"Considering that wave runup is most likely to impact the dune face, collision (Sallenger, 2000) – which is more likely to impact the width of the dune rather than the height – is the most common impact regime during a storm (Brodie et al., 2019; Stockdon et al., 2007) and thus the width of the dune is likely to be an important predictor of how vulnerable the dune is to erosion during a storm (i.e., Leaman et al., 2020)."

L171: I am a bit concerned about leaving all other XBeach parameters as default as many studies have shown this isn't appropriate outside of the highly dissipative beaches for which the model was originally designed (along the Dutch coast). Leaving all other parameters as default has implications between overwash and collision regime erosion estimates as noted by previous researchers such as Passeri et al. and Simmons et al.. Not accounting for these processes will impact on your results. Why weren't these considered?, even is the cases were limited where overwash did occur? Others have also shown sensitivity of the erosion to parameters. Eg references below(note this isn't a complete list, just ones I could think of off-hand). Passeri et al. The influence of bed friction variability due to land cover on storm-driven barrier island morphodynamics https://www.sciencedirect.com/science/article/pii/S0378383917301114Simmons et al.Calibrating and assessing uncertainty in coastal numericalmodels https://www.sciencedirect.com/science/article/pii/S0378383916303234#f0030C4 Splinter and Palmsten. Modeling dune response to an East Coast Lowhttps://www.sciencedirect.com/science/article/pii/S0025322712002034

We agree that XBeach cannot appropriately simulate behavior on reflective beaches in its default state. To account for this, we used model parameters values published in Roelvink et al. (2018) who found good agreement with field data from Duck, NC by setting the breaker formulation to "roelvink_daly" and the value of gamma to 0.52 for simulations. Additionally, our revised manuscript includes results with simulations from the updated parameterization described above (Lines 40-42, Table 1) to more appropriately simulate dune erosion. The reduction in erosion using these new parameterizations has eliminated instances of overwash from our simulations, which is consistent with the lack of overwash in our study site during the survey period of 2016-2020, so tuning the model for collision appears to be appropriate in this case.

L183: "or when dunes are located closer to the shoreline (represented by the dune toes-aligned scenarios; Figure 7)." I am a bit confused by this as the effect of beach width would be shown not when the dune toes were aligned (and all beaches had the same beach width) but instead when the dunes were aligned at their crest or heel, which then changes their beach width. Ideally you should be comparing the cases for the same dune aspect ratio at these three positions to determine if effect of beach width. And this is repeated for each of the dune aspect ratios. This would be an interesting thing to see in my opinion (same dune aspect ratio plotted for the 3 positions within your dune toe, heal, crest align) to see how BW effects erosion for the same dune. Wider beaches offer a big buffer of sand that must be eroded before the wave action can get to the dune and frictional damping of the runup would also occur, lessening the probability of a dune experiencing wave impacts. Looking at dune impact hours could be interesting and provide some good insight here.

In the revised version of the manuscript we have addressed this concern (brought up by both Reviewer 1 and Reviewer 2) by including a figure (Figure 11) that directly compares the beach widths for the crests-aligned and heels-aligned simulations to the amount of volume loss between the crests-aligned and heels-aligned simulations with their corresponding toes-aligned simulations. The toes-aligned simulations are not included in this analysis because the beach width is the same for all the profiles such that those simulations would plot as vertical line for all toes-aligned simulations. This allows us to isolate the role of the beach width and demonstrate how much erosion is prevented for a given beach width regardless of the dune configuration. Additionally, we have included wave energy into our analysis throughout the results section to consider the amount of wave action reaching the dune (more impact hours, the metric suggested by Reviewer 2, leads to more cumulative wave energy reaching the dune).

L185: "situated farther from the shoreline (dune heels-aligned)" as above, I don't see how having the dune heels aligned also indicates they are further from the shorelines as each of these cases would have a different beach width"

We agree and removed the parenthetical "(dune heels-aligned)" to make this sentence easier to understand and more accurate. The dunes that were farther from the shoreline experienced less erosion than those that were closer to the shoreline; The dunes fronted by the widest beaches are found in the heels-aligned configuration as a consequence of how the synthetic profiles were configured (Figure 3).

L241: "Additionally, the sensitivity of the dune to decreases in storm duration was inversely proportional to the beach width such that dunes fronted by wide beaches were noticeably less sensitive to increases in storm duration than dunes fronted by narrow beaches (Figure 9)." – It would be great to see figures that show beach width change over the storm.

Figure 11 in the revised manuscript shows the reduction in volume loss between the crests- and heels-aligned simulations and their equivalent toes-aligned simulations as a function of pre-storm beach width and for different storm durations. The restructured manuscript no longer includes this sentence or paragraph but in our revisions to the paper (Lines 265-310) we more clearly isolate and analyze the relationship between beach width change and dune volume loss.

Specific Minor Editorial Comments: L75: 'aspect ratio' is repeated twice

L91: replace 'Dtoe' with 'Dlow' to match figure 1 and to remove confusion as I believe that Dlow=Dtoe.

L95: "Given that Dlow was held constant across all simulations" I think should be "Given that prestorm Dlow was held constant across all simulations".

L147: remove '.' in 'approximately.'

We appreciate that Reviewer 2 also pointed out some grammatical and punctuation errors, which we have addressed in the revised version of the manuscript.

Overall, I think the paper could be improved to provide a fuller understanding of the complexities of dune erosion and how dune aspect ratio, beach width and storm duration/intensity impact on the model results. I have provided a number of example references to consider, but I'd like to acknowledge here that these are limited to what I could recall off hand rather than providing a complete list of relevant resources. Please consider these as examples and you might find more suitable ones within these papers as well

Thank you very much for the references and kind comments of our paper.

Reviewer 3

We thank Reviewer 3 for their thoughtful comments and suggestions and would also like to wish them a speedy recovery.

Note that all revised figures referred to throughout the response can be found at the end of this document.

Dear Authors,

Thank you for your patience awaiting the reviews of your manuscript. The third referee suffered an arm injury and was unable to write up a full review report but did send me via direct email a number of general comments and suggestions.

The first two review reports both identify some major limitations of the work presented here. Of key concern are the lack of novelty of the findings and inconsistencies be-tween the objectives, simulation scenarios, and conclusions. These concerns are shared by the third referee, whose comments I can paraphrase here as: /- Conclusions are stretched, and the impact of beach width on dune erosion is already well-known. Itis also obvious that dune erosion is less when an artificial dune is placed in front; the% reductions found are purely a consequence of the arbitrary geometry of the artificial dune.

This concern has been shared among the reviewers and we understand that further work was needed to clarify the conclusions and analysis presented in this paper. Reviewer 1, in particular, shared this concern and stemming from their comments we have restructured the paper to better demonstrate the relative roles of dune aspect ratio and beach morphology in determining how dunes erode under storms of varying intensities and duration. To explain how we have revised the manuscript, we present an excerpt from our response to Reviewer 1 below, which outlines the changes which have been implemented:

> We have reframed our presentation, restructuring the results section and reorganizing the discussion section to highlight that: 1) We isolate the effects of dune aspect ratio on dune erosion

through analysis of our toes-aligned simulations (in which beach width is held constant). These scenarios allow us to also examine the effects of storm duration and storm surge level on dune erosion as a function of dune aspect ratio. 2) We then isolate the effects of beach width on dune erosion by subtracting the effect of dune aspect ratio on dune erosion as determined from the analogous toes-aligned simulations, and 3) Our fenced aligned simulations then provide additional insights into how dune erosion is influenced by emplacement of sand fences as a function of storm duration and surge level. We have also proposed to change our title from "The influence of dune aspect ratio, beach width and storm characteristics on dune erosion for managed and unmanaged beaches." "The relative influence of dune aspect ratio and beach width on dune erosion as a function of storm duration and surge level." For more details, please see page one of this response for the complete summary of changes in this regard.

/- Systematic exploration of dune erosion is a good idea, but the set of scenarios is not optimal and there is little interrogation of the details of the erosion process itself.

To further analyze the erosion processes occurring in our simulations we have performed additional analyses investigating changes in dune toe position, beach width, and wave energy impacting the dune. Results from these analyses have been incorporated into our revised manuscript and can also be found in our response to reviewer 2.

/- There is thus more to be found in analysis of the simulations, perhaps also regarding the parametrisations in Xbeach. Figure 7 shows some interesting features that are not fully discussed.

This comment was also shared by Reviewer 2 and we repeat our response here:

Here the reviewer also suggests useful papers that have indicated different XBeach parameter values, which may be more appropriate than the values we used with the simulations presented in the original manuscript. We re-ran the simulations with the new parameterization, described below and, which qualitatively confirm our original results but with some quantitative differences. The default values for wetslp and dryslp in XBeach are 0.3 and 1.0 respectively. The wetslp value we used is equivalent to that used by Palmsten and Splinter (2016) but with a dryslp of 4.0 instead of the default 1.0. To improve the model results and simulate better erosion physics with XBeach we re-ran the simulations using an improved setup with parameter values updated from those published by Splinter and Palmsten (2012) and Palmsten and Splinter (2016) The following values have either been changed from a previous non-default value or have been set from their default value:

- Changed *eps* from 0.05 to 0.1
- Changed *facSK* from 0.30 to 0.15
- Changed *dryslp* from 1.0 to 4.0
- Set *hswitch* to 0.10
- Set *hmin* to 0.01

We have added the following statement to the methods section detailing the changes we made to the parameterization and some of XBeach's limitations as detailed by the reviewer (revised manuscript lines 180-187):

"We used the XBeach (Roelvink et al., 2009) model to simulate the effects of the synthetic storms described in Section 2.2 on the profiles described in Section 2.1. We ran XBeach (version 1.23.5465) in 1D-hydrostatic mode with the break parameter set to roelvink_daly and the gamma parameter set to 0.52 to better capture the effect of swash processes on the reflective beach profiles (Roelvink et al., 2018) we also adjusted parameters related to wave breaking and dry sediment transport in order to more realistically simulate dune erosion processes given the tendency of XBeach to overestimate erosion with default settings (Palmsten and Holman, 2011, 2012; Palmsten and Splinter, 2016; Splinter and Palmsten, 2012). XBeach erodes the profile by comparing the slopes to the dryslp (if a cell is dry) parameter or wetslp (if a cell is wet) to determine how much erosion should occur to maintain these values. Palmsten and Holman (2011, 2012) show that wet sand can sustain much steeper scarps than dry sand. By using a particularly high value for the dry slope (dryslp = 4), we allow the dunes to maintain much steeper, and more realistic, scarps during the storms (Palmsten and Splinter, 2016). This realism allow us to better understand how the dune is eroding under collision when it is actively scarping during the storm by comparing dune toe migration to dune volume loss. A full listing of non-default parameters can be found in Table 2."

The 'managed dune' set-up is rather limited, it should include modifications of the dune toe such as marram planting, sand ramps, and sand fencing, interventions that aim to widen an existing/eroded dune again.

The managed setup is meant only to represent the effect of a dune system that has an established fenced dune. The impetus for this project arose from an exploration on the morphologic evolution of fenced versus natural dune systems in the Outer Banks (Itzkin et al., 2020). While we do not simulate other management interventions that also effectively widen the dune, our results can reasonably apply to the interventions mentioned by Reviewer 3 given that they would result in a decrease in the dune aspect ratio while maintaining the pre-intervention dune elevation. We have addressed this issue in the paper by including the following (revised manuscript lines 399-405):

"While we do not explicitly simulate other interventions that would widen the dune (e.g., dune grass planting, sand ramps), these management strategies effectively widen the dune without adding elevation, thus leading to a lower dune aspect ratio than the pre-management condition. In this case, the results presented for sand fences likely apply to these situations as well. In all cases, if dune management actions are not paired with beach nourishment (i.e., Itzkin et al., 2020) then the wider dune will likely come at the cost of a slightly narrower beach. The amount of erosion during storms will likely decrease because of the lower aspect ratio (Figure 7), but the potential decrease in erosion will likely be offset by the erosion arising from the narrower beach (Figure 11)."

The following figures can be found in the revised version of the manuscript referred to in the responses to the reviewers. Note that figure numbers refer to their placement in the manuscript.

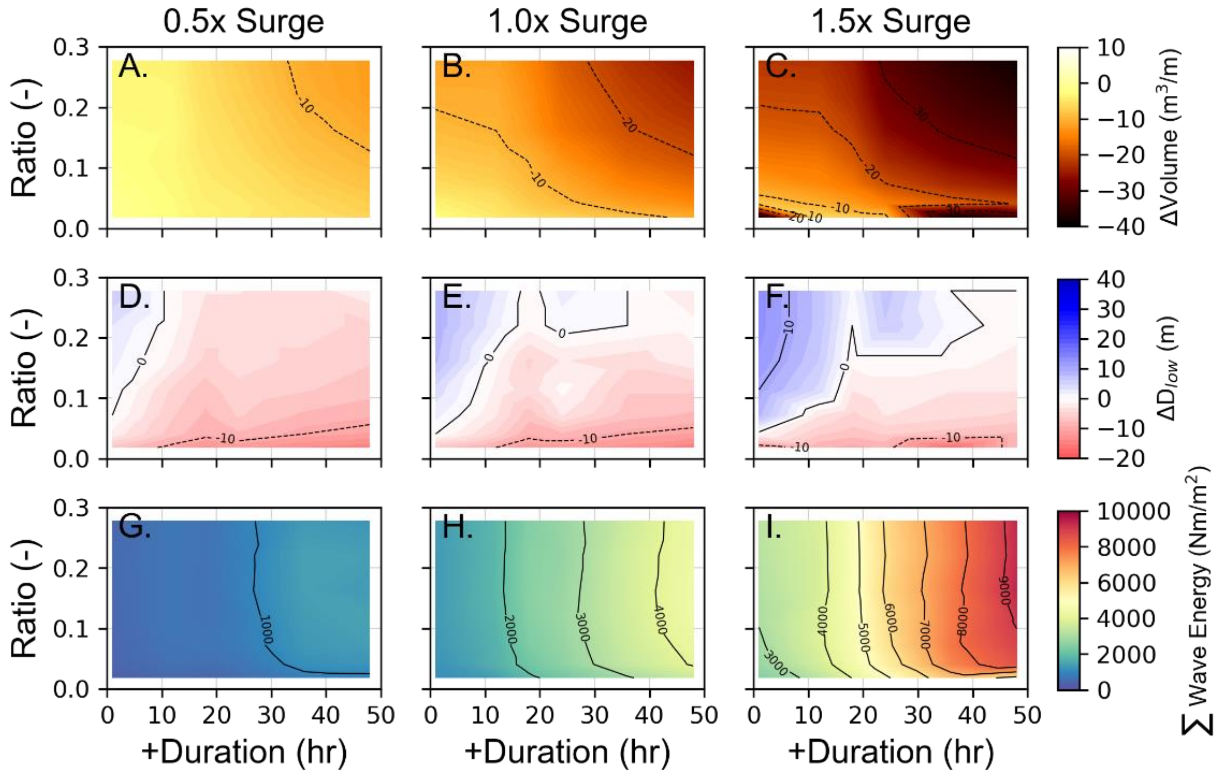

Figure 8: Dune aspect ratio versus storm duration for simulations with toes-aligned (controls for beach width/slope and initial dune volume). Each column represents a different storm surge level (increasing left to right). The top row (A, B, C) shows the change in dune volume, the middle row (D, E, F) shows the change in dune toe position (negative values indicate landward erosion), and the bottom row (G, H, I) shows the cumulative wave energy impacting the dune.

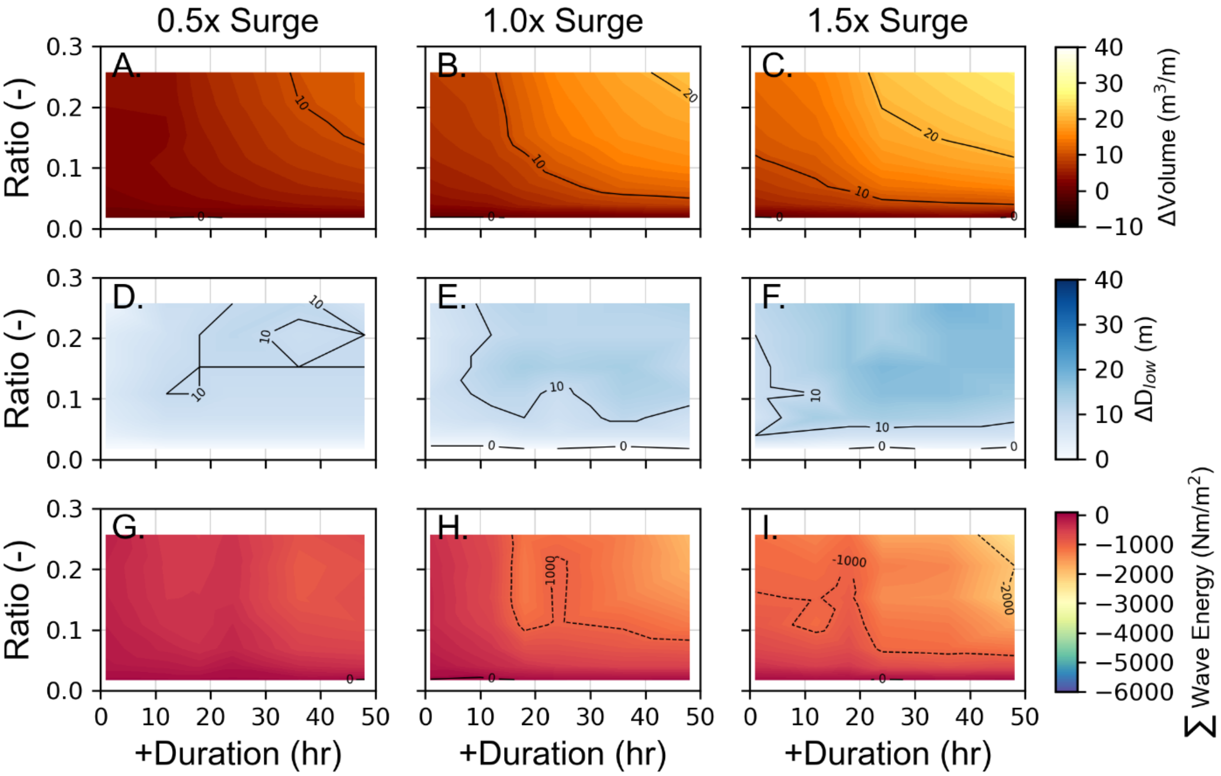

Figure 9: Dune aspect ratio versus storm duration for simulations with crests-aligned. The values from the equivalent simulations with the dune toes aligned have been subtracted from the crests-aligned simulations to highlight the influence from the varying beach widths in the crests-aligned simulations. Each column represents a different storm surge level (increasing left to right). These values represent a comparison relative to the toes aligned simulation (where beach width is controlled for) such that the top row (A, B, C) shows the amount of volume loss prevented by the wider beach in these simulations, the middle row (D, E, F) shows the additional dune toe progradation induced by the wider beach width, and the bottom row (G, H, I) shows the reduction in wave energy reaching the dune due to the wider (and thus lower sloping) beach.

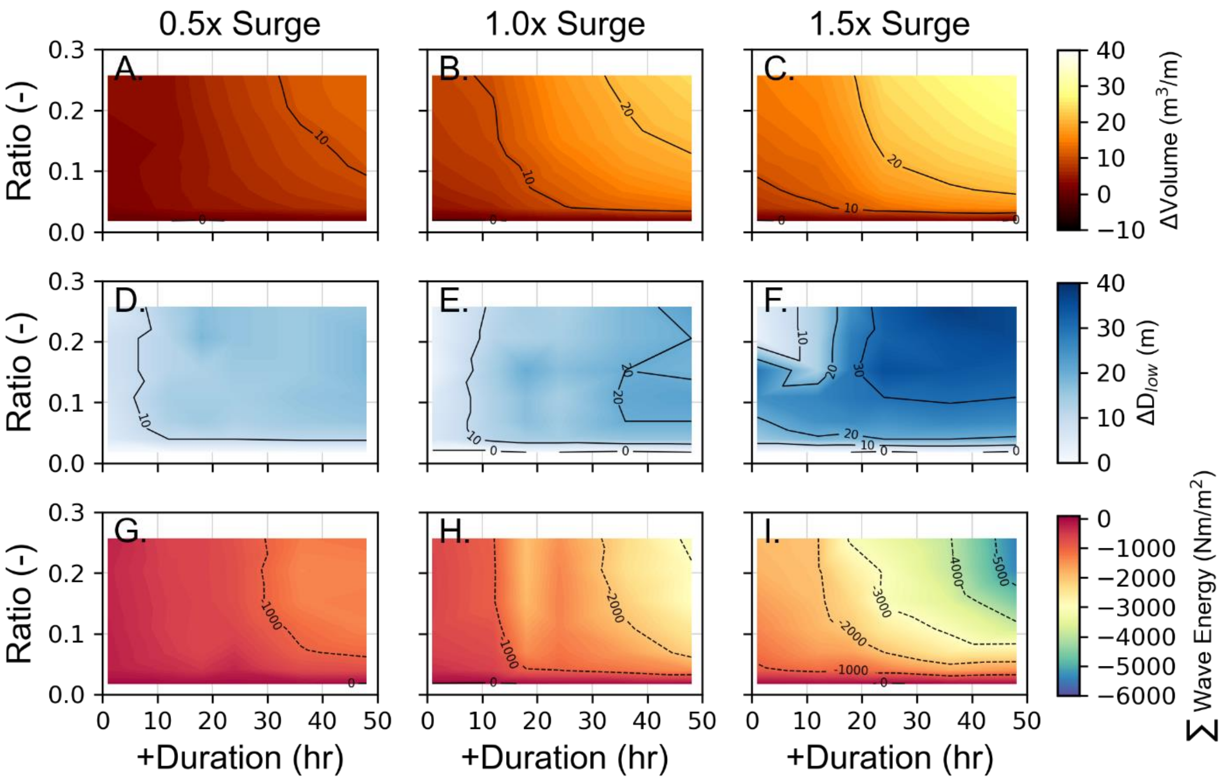

Figure 10: Dune aspect ratio versus storm duration for simulations with heels-aligned. The values from the equivalent simulations with the dune toes-aligned have been subtracted from the heels-aligned simulations in order to highlight the influence from the varying beach widths in the heels-aligned simulations. Each column represents a different storm surge level (increasing left to right). These values represent a comparison relative to the toes-aligned simulation (where beach width is controlled for) such that the top row (A, B, C) shows the amount of volume loss prevented by the wider beach in these simulations, the middle row (D, E, F) shows the increase in dune toe progradation induced by the wider beach width, and the bottom row (G, H, I) shows the reduction in wave energy reaching the dune due to the wider (and thus lower sloping) beach.

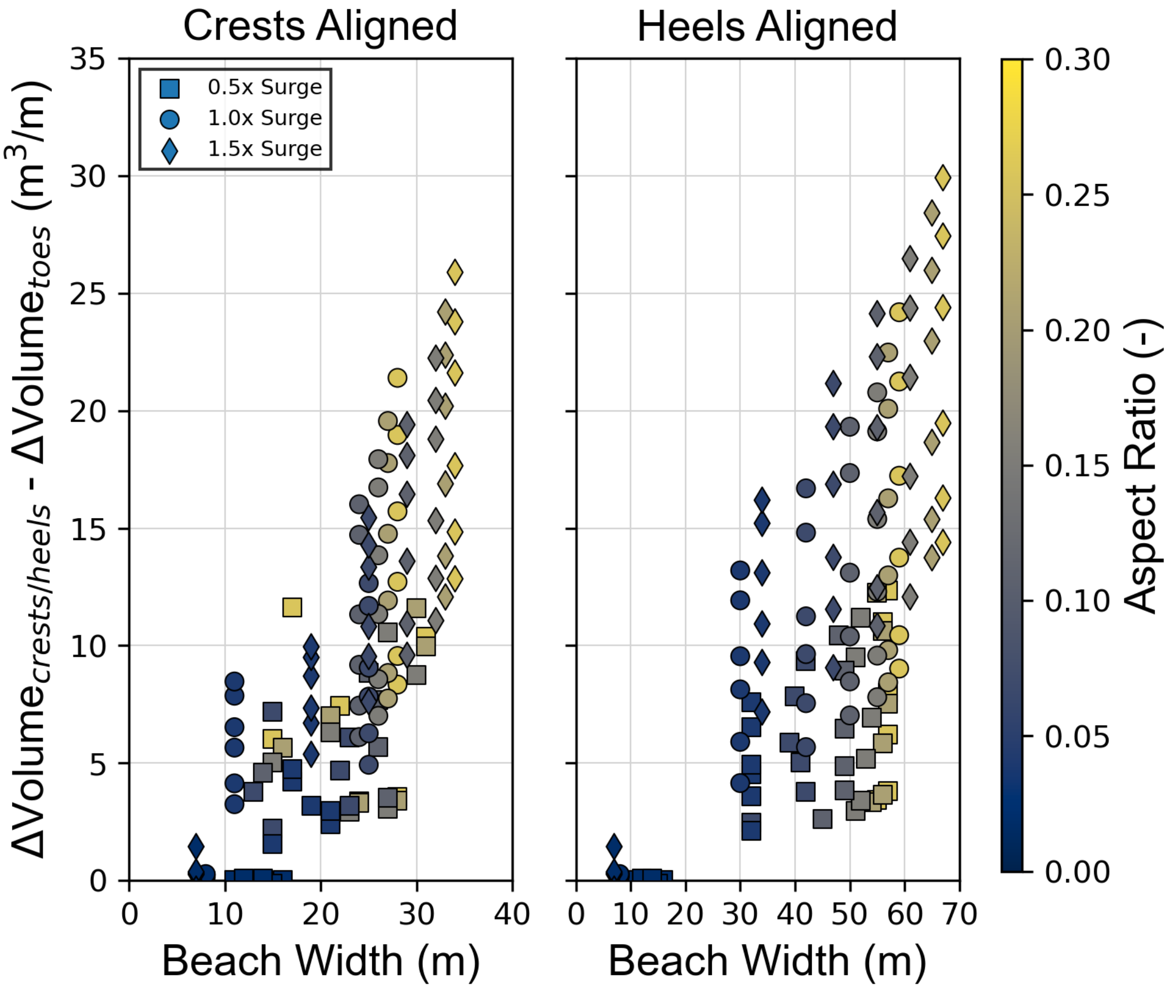

Figure 11. Volume loss from the crests-aligned and heels-aligned simulations minus volume loss from the equivalent toes-aligned scenarios versus the initial beach width for the crests- and heels-aligned simulations. The color corresponds to the dune aspect ratio and the shape corresponds to the surge level.

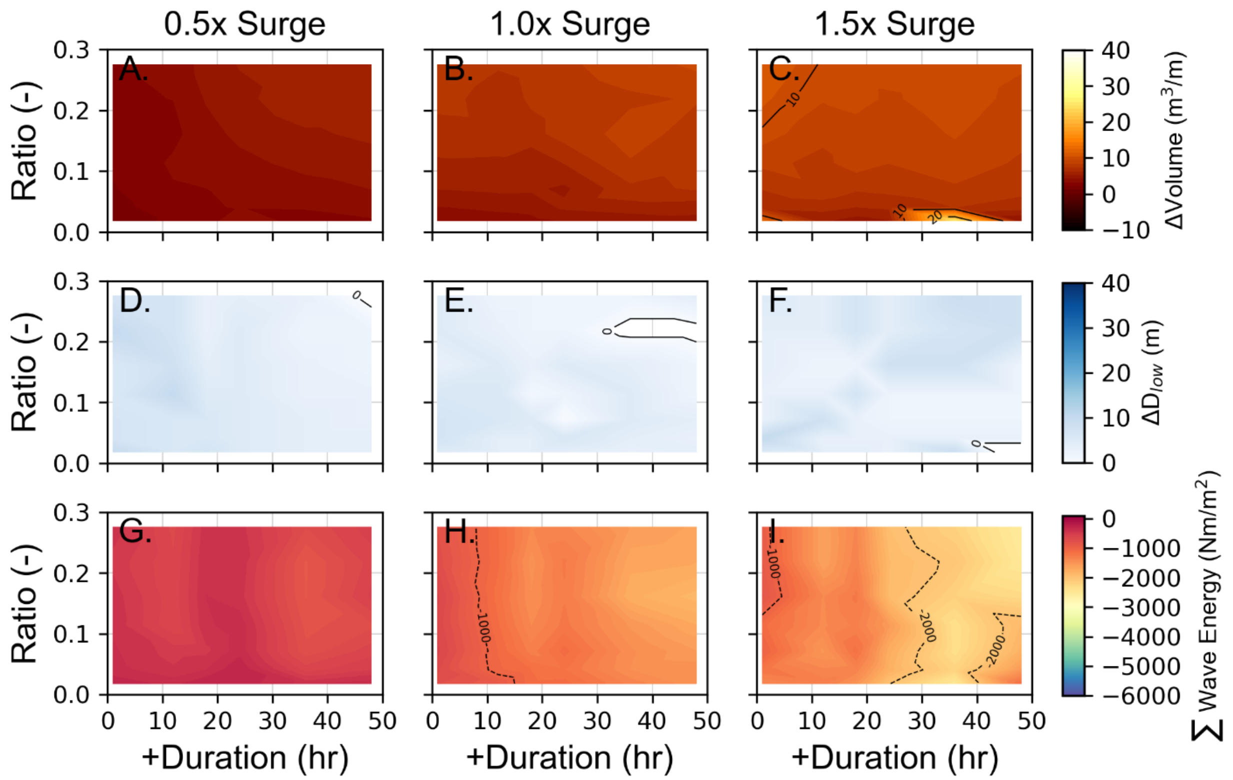

Figure 12: Dune aspect ratio versus storm duration for simulations with sand fences. The values from the equivalent simulations with the dune toes aligned have been subtracted from the fenced simulations in order to highlight the influence from the presence of the fenced dune seaward of the natural dune. Each column represents a different storm surge level (increasing left to right). These values represent a comparison relative to the toes-aligned simulation (where beach width is controlled for and there isn't a fenced dune) such that the top row (A, B, C) shows the amount of volume loss prevented by the fenced dune in these simulations, the middle row (D, E, F) shows the increase in dune toe progradation induced by the fenced dune, and the bottom row (G, H, I) shows the reduction in wave energy reaching the dune due to the fenced dune.