INVESTIGATING THE FETCH EFFECT ON AEOLIAN SEDIMENT TRANSPORT ON A SANDY BEACH

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INTRODUCTION

In aeolian environments, the fetch effect significantly influences sediment transport, particularly on narrow beaches. It describes the increase in sediment transport with increasing distance from a non-erodible boundary, affecting landform evolution. Despite extensive research, there is no consensus on the relationship between wind speed and critical fetch distance.

This new study focuses on the fetch effect on a sandy beach, examining the relationship between wind speed and critical fetch distance and the growth rate of sediment transport with distance downwind. Eight experiments were conducted under various wind conditions, offering insights into this complex phenomenon and its impact on aeolian sediment transport in sandy beach environments.

STUDY AREA

The study area, located in Oosteroever, Belgium, on the North Sea coast, features a macro-tidal beach approximately 320 m wide with a gentle slope, primarily composed of medium to fine sand (median grain size: 0.25 mm) (Figure 1). The area experiences significant tidal variations, ranging from 3.5 m to 5 m during neap and spring tides, respectively. Dominant south-westerly winds, combined with northeast tidal currents, result in a net sediment transport towards the northeast. The site is protected by a seawall called "Spinoladijk" and inland dunes. To prevent sand accumulation on the Spinoladijk, a 120x20 m² experimental artificial dune was constructed on the dry beach plateau in January 2021, featuring marram grass planting strategies (Derijckere et al., 2023).

METHODOLOGY

Eight field experiments were conducted to determine critical fetch distances, which represent the point where sediment transport is maximum for a given wind speed. These experiments occurred on various dates in March and April 2021 and were conducted during oblique onshore and longshore winds (see Figure 1).

A meteorological station was deployed to record wind speed and direction at different heights above the surface. Seven to ten Sherman-type sand traps were placed per transect, aligned with the wind direction to measure transport rates. They were spaced at varying distances based on wind speed strength. Surface sediment samples were taken along the transect at multiple locations to assess grain size variability. Surface moisture content was quantified using a Delta-T Theta ML3 probe, inserted into the upper 0.02 m of the sand surface.

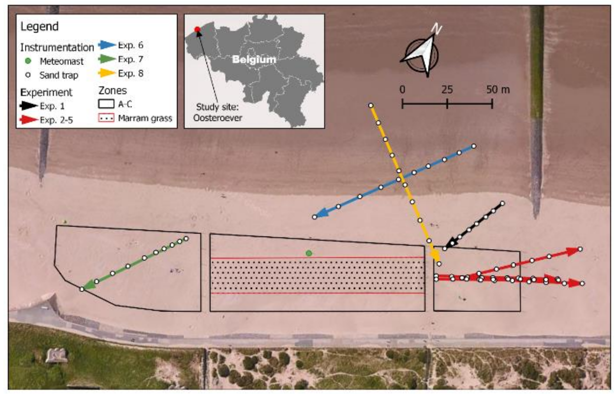

Figure 1 – Location of the study area in Oosteroever, Belgium. The eight fetch effect experiments are indicated by the colored arrows with the arrow showing the incoming wind direction. The artificial dune is located in the red rectangle.

RESULTS AND DISCUSSION

Wind direction remained stable during the experiments, with 5% fluctuations. Wind speeds ranged from 9.32 to 16.97 m/s. Experiment 2 and 3 had the strongest winds, while Experiment 1 had the weakest. Table 1 provides a summary of the main conditions during the experiments.

Table 1 - Summary of meteorological and general conditions during experiments.

Exp.	U_{10m} (m/s)	Std U_{10m} (m/s)	u_* (m/s)	Std u* (m/s)	Dir. (deg)	Std Dir. (deg)
1	9.32	0.65	0.34	0.027	24	2
2	16.79	1.96	0.67	0.092	224	5
3	16.97	1.20	0.68	0.058	231	2
4	15.70	1.31	0.62	0.061	232	1
5	13.76	1.41	0.53	0.064	233	3
6	11.48	0.74	0.43	0.032	23	2
7	11.80	0.69	0.44	0.030	21	3
8	12.54	1.95	0.48	0.087	300	11

Figure 2 displays sediment transport variability along the downwind fetch distance for all experiments. Fetch distance was defined based on upwind boundaries determined by RTK-GNSS. Critical fetch distances ranged from 23.8 to 103.5 m, with maximum transport rates from 4.1 to 77 g/m/s. Experiments 6 and 8, conducted in the intertidal zone during wet conditions, had notably higher critical fetch distances.

The results reveal increased sediment transport with fetch distance until a critical point, followed by a decrease in transport, likely due to the formation of an internal boundary layer. Future research with co-located airflow and sand transport measurements could further explore these mechanisms. Surface moisture ranged typically from below 1% to 8-14% in the intertidal area, decreasing downwind toward the upper dry beach.

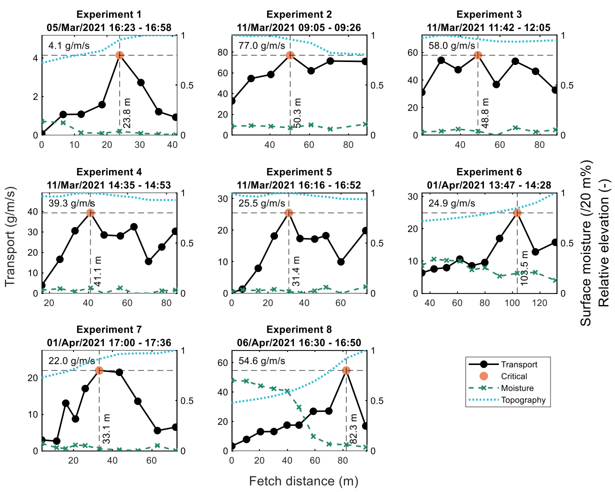

Figure 2 - Relation between sediment transport and fetch distance, with dashed lines marking the locations of maximum measured transport rates and corresponding critical fetch distances. The figure also depicts surface moisture levels and initial transect topography.

On the dry beach, a strong correlation between wind speed and critical fetch distance was observed (Figure 2). The linear trend had a high correlation coefficient of 0.89, expressed as follows:

$$F_c = 3.25 \cdot U_{10m} - 7.61 \qquad (1)$$

As wind speed increases, a longer fetch is needed to achieve equilibrium transport. This differs from Delgado-Fernandez's (2011) correlation (Figure 3), which is widely used in foredune growth prediction, indicating stronger winds are necessary for the same critical fetch distances.

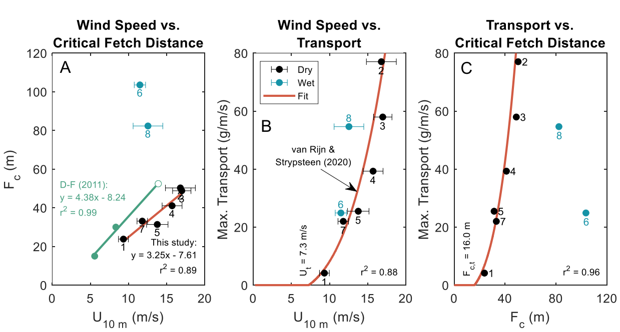

Figure 3 - Correlation between wind speed at 10 m above the surface and critical fetch distance, wind speed and maximum sediment transport, and critical fetch distance with maximum transport rate. The horizontal error-bars represent the standard deviation of the wind speed.

Experiments 6 and 8, conducted under wet surface conditions, showed different behavior. The higher critical fetch distances in these conditions are due to the elevated threshold wind speed needed for sediment transport. There was a strong correlation, described by van Rijn and Strypsteen (2020), between maximum sediment transport and critical fetch distance under dry conditions (r^2-value = 0.88). This suggests that at the critical fetch distance, saltating particles carry the full vertical wind momentum, achieving maximum transport for the given wind speed. Lastly, maximum transport exhibited a cubic increase with critical fetch distance (r^2-value = 0.96). In this site, a minimum F_c of 16 m was required for maximum transport to develop with wind speeds just above the threshold (7.3 m/s).

$$q(F) = q_s \cdot \frac{2}{\pi} \cdot \sin^{-1}\left(\frac{F}{F_c}\right) \qquad (2)$$

Bauer and Davidson-Arnott (2003) investigated four equations describing transport rate concerning fetch distance when the available fetch is less than the critical fetch distance. Among these equations, Equation 10 from Delgado-Fernandez (2010), expressed as Equation 2 here (r^2-value = 0.82), provides the best results when fetch distance and transport rate are normalized across all experiments. It exhibits a gentle initial transport increase, becoming steeper when the normalized fetch distance exceeds 0.85.

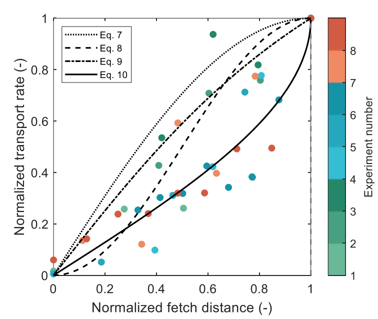

Figure 4 - Normalized transport rate with normalized fetch distance. The four popular trigonometric equations shown in Delgado-Fernandez (2010) are given as well.

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