Readme file

Data published in paper:

van Puijenbroek, M.E.B., Nolet C., de Groot A.V., Suomalainen J.S., Riksen M.J.P.M., Berendse F., Limpens, J. (2017) Exploring the contributions of vegetation and dune size to early development using unmanned aerial vehicle (UAV)-imaging. Biogeoscience

Datasets included:

1. Final dataset with data on dune growth and erosion, used for the statistical analysis
2. Dataset on the accuracy and repeatability of UAV-imaging

The RAW images, digital terrain model, digital surface model and orthomosaics are available upon request by the corresponding author (Marinka van Puijenbroek).

Methods

Study site

We monitored 8 hectares (200 m x 400 m) of a natural nebkha dune field with a large range of dune sizes at ‘the Hors’, the southern tip of the barrier island at Texel, the Netherlands, coordinates: 52°59’43.70”N, 4°43’47.53”E (Fig. 1). The Hors is a wide dissipative beach with a high degree of hydrodynamic reworking of the sand, which results in a high transport potential and opportunity for dunes to develop. In the last 5 years, between 2010 and 2015, many nebkha dunes have developed on the beach by plant species *Ammophila arenaria*, *Elytrigia juncea* or a mixture of both species. These three dunes with different species composition occur at similar distances from the sea, making this area ideal for exploring the effects of dune size and species composition on dune growth. *A. arenaria and E. juncea* differ in their vegetation characteristics: *A. arenaria* grows in dense patches, whereas *E. juncea* has a more sparse growth form. This difference in growth form probably also results into a different dune morphology: *A. arenaria* forms higher ‘hummocky’ shaped dunes, whereas *E. juncea* builds broader and lower dunes (Bakker, 1976; Hacker et al., 2012). The monitoring area is bisected by a low (maximum height of 7 m NAP, i.e. above the mean sea level near Amsterdam), continuous foredune ridge that runs parallel to the shore. The nebkha dunes that occur at the seaward side of this foredune are more exposed to the sea, while the nebkha dunes occurring at the landward side of the foredune are more sheltered from the sea, enabling us to explore whether the effects of dune size and vegetation are modified by the degree of shelter, especially since the age difference between the seaward and landward nebkha dunes is at most 5 years.

Data collection

Three UAV flights in November (2015), April (2015) and August (2016) were carried out with a rotary octocopter UAV system (Aerialtronics Altura Pro AT8 v1) and camera equipment of WageningenUR *Unmanned Aerial Remote Sensing Facility* (Fig. 1). The octocopter was equipped with a Canon EOS 700D single-lens reflex camera with a 28mm f/2.8 Voigtländer Color Scopar SL-II N objective. The camera sensor was modified to give a false colour output. The red channel of the camera had been converted to be sensitive in the near-infrared, with centre point around 720nm. The blue channel of the camera had been extended to also cover the UV region of the spectrum. The green channel was left with almost original response. The false colour modification enabled the calculation of a modified Normalised Difference Vegetation Index (NDVI), a commonly used measure for vitality and/or cover of the vegetation (Carlson and Ripley, 1997). Aerial images were acquired by auto-piloted flights at an altitude of 80 m at 4 – 5 m s^{-1} velocity. The camera was set to take one image per second. The auto-piloted flights enabled us to have the same flight paths for each of the three mapping campaigns. The flight paths ensured that images had a minimum of 85% forward and 65% side-way overlap. Four flights of 10 minutes were needed to cover the study area, yielding up to 900 RAW false colour images per mapping campaign. Five ground control points were permanently placed in the flight area and measured with a RTK-DGPS Trimble R6 Model 3 (TSC3) to calibrate our images with coordinates. During our mapping campaign, a Spectralon reference panel was measured with our camera immediately before take-off and after landing.

Radiometric calibration

In order to compare the images over the time, they were calibrated and converted from RAW to 16 bit tiff format. First, we ensured that each individual pixel within an image was comparable, by converting the RAW digital number into radiance units using a pixel-wise dark current and flat field calibration. Second, each radiance image was calibrated to a reflectance factor image in order to correct for changes in incident irradiance on different flight days. This calibration was done by using a Spectralon panel with a known reflectance factor. The radiometric calibration is described in more detail by Suomalainen et al. (2014).

The images were subsequently converted into NDVI images. Usage of the standard NDVI was not possible due to lack of red channel in the false colour modified camera. Thus we used a custom NDVI equation (Eq. 1), which was recommended by the company that modified the sensor. On their website (MaxMax.com) this equation was shown to be just as effective for green vegetation as the traditional NDVI formula (R^2 = 0.77) where the red band is taken as the absorption channel.

1) $$NDVI = \frac{(NIR + G) - (2B)}{(NIR + G) + (2B)}$$

Where NIR, G, and B are the near-infrared, green and blue bands of the false colour image respectively. For photogrammetric reconstruction, the NDVI image layer was stacked with the original green and blue bands to form a three-color image.

Photogrammetric reconstruction

The large overlap between the consecutive images was necessary for photogrammetric software to successfully process the aerial images into a 3D point cloud (Fig. 2). The 3D point cloud was generated using Agisoft Photoscan Professional (v. 1.2.6), using the Structure-from-Motion (SfM) and Multi-View Stereo (MVS) algorithms (Fonstad et al., 2013; Westoby et al., 2012). The correlated 3D points are georeferenced to match the ground control points, and contain pixel intensity values of the input imagery. From this 3D point cloud we interpolated a 5 cm pixel size digital surface model (DSM) and a 1 cm pixel size orthomosaic image. The DSM included also vegetation, which resulted in a vertical error in dune height in areas where vegetation is present. We removed the vegetation from the point cloud by identifying and removing the vegetation points. Vegetation points were removed by distinguishing vegetation from sand using k-means clustering of the 3-D point cloud with NDVI using the Hartigan and Wong (1979) algorithm in R (R Core Team, 2016). The holes in the point cloud that arose by removing the vegetation were filled by using LAStools (the tool Blast2dem) (Isenburg, 2016), which resulted in a Digital Terrain Model (DTM) without vegetation.

We checked the accuracy of the photogrammetric reconstruction by measuring the vertical error, the repeatability of the method and the degree in which NDVI predicted the biomass of the vegetation. The vertical error of the DTM was assessed during a combined mapping and flight campaign in August 2015 by measuring the elevation for 1100 points distributed over the flight area with an RTK-DGPS Trimble R6 Model 3 (TSC3) and comparing the measured point measurements with the DTM. The repeatability of the UAV photogrammetry was tested by repeating the same flight path five times in November 2015 and comparing the similarity between the five DSMs. The NDVI measurements were tested by clipping the vegetation flush with the sand surface for six *A. arenaria* and seven *E. juncea* dunes and relating the biomass of the vegetation to the NDVI values.

Defining dunes

To be able to relate dune growth to characteristics of an individual nebkha dune including its shadow dune, we first had to define individual dunes from the DTM. We followed a step-wise procedure for each of our mapping campaigns (November, April, and August) using ArcGIS 10.3 (ESRI, 2016) that resulted into different polygons in which each individual dune expanded or decreased in volume over the study period. Dune volume and growth were later calculated using the same polygons for each measurement campaign through time (see next section). To define the polygons we used the step-wise procedure described below: 1) we constructed a baseline raster by calculating the average elevation in a circle of 5m radius around each pixel in the DTM. A higher or lower radius resulted in either a too low or too high baseline. 2) We then qualified pixels of the DTM as dunes, if they were 5 cm or higher above a baseline raster, or had a slope of 15° or higher. The 5 cm threshold is the minimum that can be accurately derived from the images and corresponds with visual estimates of nebkha dune foot; a slope of 15º has been earlier identified by Baas et al (2002), as the slope for a shadow dune. From these selected ‘dune’ pixels we created dune polygons. 3) Dune polygons of consecutive campaigns were overlaid to construct the largest dune-covered area during the study period. 4) Each polygon was visually checked for minimum size and presence of vegetation: dunes consisting of only one clump of vegetation (0.4 m^2 or smaller) and dunes with no vegetation were discarded to derive conservative estimates of nebkha dune volume and growth.

Variables

For each nebkha dune and for each mapping campaign we extracted dune volume (m^3), max height (m) and horizontal area (m^2) from the dune polygons (see previous section) in the DTM. We calculated changes in dune volume, i.e. absolute dune growth (m^3/week) by subtracting the current dune volume (V_t) from the volume of the previous mapping campaign (V_{t-1}), correcting for the number of weeks between the mapping campaigns. To explore relationships irrespective of dune size, we also calculated the relative dune growth (m^3/m^3/week).

We manually identified the species composition on each nebkha dune from the orthomosaic. Species identification was verified in the field for a random subset of 100 dunes (23%) in May 2016. To this end we created 2 transects from the southwest border to the northeast border of the area, along which we determined the species on each nebkha dune. We compared the presence of species in the field with the orthomosaic, and adjusted the species composition if necessary. In our dataset, dunes have either *A. arenaria, E. juncea* vegetation, or a mixture of both species. A dune was defined as covered by a mixture of both species, when it had distinct vegetation patches of both species present. For each nebkha dune and mapping campaign we also extracted the vegetation density and the maximum plant height. To assess vegetation density we first distinguished vegetated pixels from non-vegetated pixels based on the orthomosaic using k-means classification of the NDVI using the MacQueen (1967) algorithm. Hereafter, the vegetation area (m^2) and vegetation density (NDVI/cm^2 dune) were calculated by summing the NDVI values of all vegetated pixels within the dune polygon (vegetation area) and then dividing this summed NDVI by the total number of cm^2 pixels within the dune polygon (vegetation density). The maximum plant height was calculated by subtracting the DSM (with vegetation) from the DTM (without vegetation).

Sheltering can affect the sand supply and storm erosion. We used two methods to define the degree of sheltering. Firstly, we distinguished whether a nebkha dune was seaward or landward from the foredune. Secondly we determined how much the dune was clustered with other dunes. We extracted the degree of clustering for each dune by calculating the mean height from the DTM in a 25 m radius around the dune. All data extraction from the DSM, DTM and orthomosaic were done in R (R Core Team, 2016).

Dataset: Data_final_dunes.csv, final dataset on dune growth and erosion used for statistical analysis.

Column name	**Information**	**Time of measurement**
ID	ID number dune	
Area	Area (m2) dune polygon	
NDVI_aug	NDVI presence august	August
NDVI_apr	NDVI presence april	April
NDVI_nov	NDVI presence november	November
Species	Species of dune	
big_dune	Before or after foredune 0 = before, 1 = foredune, 2 = after foredune	
Block	Block number 0 = is not in any block	
Dune_aug	Dune was a dune polygon in August	August
Dune_apr	Dune was a dune polygon in April	April
Dune_nov	Dune was a dune polygon in November	November
mid_x	x coordinate middle point	
mid_y	y coordinate middle point	
max_height_aug	Maximum height (m)	August
mean_heigth_aug	mean height (m)	August

mean_slope_aug	mean slope (degree)	August
var_slope_aug	variability slope (degree)	August
volume_aug	Volume (m3) august	August
max_pheight_aug	Maximum plant height (m)	August
mean_pheight_aug	Mean plant height (m)	August
distan_border	Distance to the border (m) of the DEM (southwest border, in the direction of the sea)	August
closest_dune	Distance to the nearby dune (m)	August
dune_grass_ndvi_aug	Sum of NDVI pixel of dune	August
grass_cover_aug	Grass cover (%)	August
buffer_volume_aug	Volume (m3) buffer area of 25 m around dune	August
area_buffer_aug	Area (m2) buffer area of 25 m around dune	August
max_slope_aug	Maximum slope (degree)	August
max_height_apr	Maximum height (m)	April
mean_heigth_apr	mean height (m)	April
volume_apr	Volume (m3) august	April
mean_slope_apr	mean slope (degree)	April
var_slope_apr	variability slope (degree)	April
max_slope_apr	Maximum slope (degree)	April
dune_grass_ndvi_apr	Sum of NDVI pixel of dune	April
grass_cover_apr	Grass cover (%)	April
buffer_volume_apr	Volume (m3) buffer area of 25 m around dune	April
area_buffer_apr	Area (m2) buffer area of 25 m around dune	April
max_pheight_apr	Maximum plant height (m)	April
max_height_nov	Maximum height (m)	November
mean_heigth_nov	mean height (m)	November
volume_nov	Volume (m3) august	November
mean_slope_nov	mean slope (degree)	November
var_slope_nov	variability slope (degree)	November
max_slope_nov	Maximum slope (degree)	November
max_pheight_nov	Maximum plant height (m)	November
dune_grass_ndvi_nov	Sum of NDVI pixel of dune	November
grass_cover_nov	Grass cover (%)	November
buffer_volume_nov	Volume (m3) buffer area of 25 m around dune	November
area_buffer_nov	Area (m2) buffer area of 25 m around dune	November
veg_dens_aug	Vegetation density dune (NDVI/cm dune)	August
veg_dens_apr	Vegetation density dune (NDVI/cm dune)	April
veg_dens_nov	Vegetation density dune (NDVI/cm dune)	November
ab_diff_volume_grow	Absolute dune growth (m3) t - (t-1)	April - August
rel_diff_volume_grow	Relative dune growth (m3/m3) = t / (t-1)	April - August
ab_diff_volume_storm	Absolute dune growth (m3) t - (t-1)	November - April

rel_diff_volume_storm	Relative dune growth (m3/m3) = t / (t-1)	November - April
ab_diff_volume_net	Absolute dune growth (m3) t - (t-1)	November - August
rel_diff_volume_net	Relative dune growth (m3/m3) = t / (t-1)	November - August
b_change_grow	Binominal growth 0 = negative, 1 = positive	April - August
b_change_storm	Binominal growth 0 = negative, 1 = positive	November - April
buffer_mheigth_aug	Mean height (m) of 25 m around dune	August
buffer_mheigth_apr	Mean height (m) of 25 m around dune	April
buffer_mheigth_nov	Mean height (m) of 25 m around dune	November

Dataset: data_accuracy_DSM.csv, compares z values of DSM with z from RTK-DGPS

Column	**Information**
	Rownumber
ID	ID number of RTK-DGPS measurement
z_dem	The z (m elevation) of the digital surface model
Actual_z	The z (m elevation) measured by the RTK-DGPS
Distance_gcm	Distance to the ground control point
Error	Vertical error (m) of digital elevation model, subtracted actual_z from z_dem

Dataset: biomass_NDVI_dunes.csv, data on the NDVI and biomass for different dunes.

Collumn	**Information**
ID_all	ID name for all the different dunes
Species	Species of each dune H = *Ammophila arenaria* and B = *Elytrigia juncea*
NDVI	The sum of the NDVI measured within this dune
Fresh_weight	Fresh biomass weight (gr) of clipped plant material of each dune
Dried_weight	Dried biomass (gr) of clipped plant material of each dune