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The impact of inundation and sandstorms on the growth and survival of the mangrove *Avicennia marina* seedlings in the southern Red Sea

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Summary: Mangroves occur in tropical and subtropical regions, including harsh arid areas. Little is known about how the environmental conditions of deserts influence the ecology of mangrove seedlings. The seedlings of the mangrove *Avicennia marina* were examined in situ in a natural stand of the southern Red Sea coast of Saudi Arabia to (1) estimate and compare the growth rate of *A. marina* between selected microhabitats with different tidal exposures, and (2) examine the influence of sandstorms on the growth and survival of the seedlings. Samplings were conducted in four zones established according to their tidal exposure: low tidal exposure (Z1), medium tidal exposure (Z2), high tidal exposure with numerous burrows (Z3), and high tidal exposure with a few or no burrows (Z4). Vertical growth and mortality of the seedlings and selected environmental variables were quantified. The results show that seedling growth rates differed significantly between the sampling zones, the highest growth being found in the high tidal regions (Z3 followed by Z4) and the lowest growth in Z1. Growth rate followed a significant decreasing pattern over time, coinciding with increasing air temperature and decreasing relative humidity. Sandstorms showed a marked increase in July, leading to massive dust deposition that caused extensive mortality of the seedlings by burial. Our study highlights that seedling growth can be affected by the extent of tidal inundation and that sandstorms act as a natural stressor.

Keywords: Jizan, burial; temperature; stressor; dehydration; conservation.

El impacto de las inundaciones y las tormentas de arena en el crecimiento y la supervivencia de las plántulas del manglar *Avicennia marina* en el sur del Mar Rojo

Resumen: Los manglares proliferan en regiones tropicales y subtropicales, incluidos los desiertos. Sin embargo, se sabe poco acerca de cómo las condiciones ambientales de los desiertos influyen en la ecología de las plántulas de manglares. Las plántulas del manglar *Avicennia marina* se examinaron in situ en un manglar natural de la costa sur del Mar Rojo de Arabia Saudita para (1) estimar y comparar la tasa de crecimiento de *A. marina* entre microhábitats seleccionados con diferente exposición a las mareas, y (2) examinar la influencia de las tormentas de arena en el crecimiento y supervivencia de las plántulas. Los muestreos se realizaron en cuatro zonas establecidas en función de su exposición a las mareas: exposición a las mareas bajas (Z1), exposición a las mareas medias (Z2), exposición a las mareas altas con numerosas madrigueras de cangrejos (Z3) y exposición a las mareas altas pero con pocas o ninguna madriguera (Z4). Se cuantificó el crecimiento vertical y la mortalidad de las plántulas, así como las variables ambientales seleccionadas. Los resultados muestran que las tasas de crecimiento de las plántulas difirieron significativamente entre las zonas de muestreo con el mayor crecimiento encontrado en las regiones de marea alta (Z3 seguida de Z4) y el crecimiento más bajo en Z1. La tasa de crecimiento siguió un patrón decreciente significativo a lo largo del tiempo, que coincidió con el aumento de la temperatura del aire y la disminución de la humedad relativa. Las tormentas de arena aumentaron en julio, causando una deposición masiva de polvo que enterró a las plántulas, desencadenando una gran mortalidad. Nuestro estudio destaca que el crecimiento y la supervivencia de las plántulas pueden verse afectados por la extensión de la inundación de las mareas y las tormentas de arena, actuando como factores de estrés natural.

Palabras clave: Jizan; entierro; temperatura; factor estresante; deshidratación; conservación.

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INTRODUCTION

Mangroves, woody plants inhabiting the interface between land and sea in tropical and subtropical regions (Chapman 1976) in more than 100 countries, cover more than 81 million ha worldwide (Hamilton and Casey 2016). They provide many ecological services, acting as nursery grounds, a thermal refuge from ocean warming and a foraging habitat for biota (Mumby et al. 2004, Giomi et al. 2019, Macreadie et al. 2019). In the last two decades, there has been a drastic decrease in mangrove cover of up to 20% globally and 50% in Southeast Asia, mainly because of massive urban development and increased land usage for aquaculture purposes (Thomas et al. 2017). One of the few exceptions to this declining trend is the Red Sea coast of Saudi Arabia, wherein mangrove cover has been increasing, mainly thanks to a series of replantation programmes (Almahasheer et al. 2016a). The diversity of mangroves in the Red Sea is limited to two species, *Avicennia marina* and *Rhizophora mucronata*, the former of which shows the widest distribution (Price et al. 2007). This low diversity of mangrove species in the region is likely driven by the extreme environmental conditions, including high temperature, high salinity and ultra-oligotrophy of the ambient seawater and the sediments (Garcias-Bonet et al. 2019, Saderne et al. 2019, Anton et al. 2020), all of which can limit mangrove survival, growth and height (Bernstein and Hayward 1958, Clarke and Hannon 1970, Burchett et al. 1984).

Mangrove seedlings are influenced by the available nutrient supply and oxygenation at the root level (Ball 1988a, Krauss et al. 2006). Concomitantly, mechanical factors such as burrows by crabs, mainly of the orders Sesarmidae and Oocypodidae (Lee 1999, Kristensen 2008), have been shown to promote seedling growth by increasing soil aeration and nutrient-holding capacity (Ridd 1996, Lee 1998, Gribsholt et al. 2003). Tidal inundation, which promotes root ventilation and nutrient availability (Ball 1988a, Krauss et al. 2006), is also a critical factor for the growth and survival of mangrove seedlings (Smith 1987). In fact, the structuring of species zonation with diverse mangrove communities is attributed to this mechanical process (Krauss et al. 2006). However, despite its significance, studies on the influence of tidal inundation in the early development of mangroves are few, both in situ in the field and under laboratory conditions (Krauss et al. 2006), and no studies have been performed to date in the Red Sea. Thus, the influence of tidal flooding on seedling growth in this region merits further investigation.

The effect of sandstorms on the growth and survival of mangrove seedlings has as yet received very little attention (Tamaei 2005), despite the negative consequences that have been shown for mangrove seedling survival, growth and tree species richness as a result of varying exposure to burial and soil accretion (Ellison 1999, Thampanya et al. 2002). In the Arabian Peninsula, sandstorms occur naturally and frequently, and one study indicates negative effects (e.g. mortality) of a sandstorm on the grey mangrove *A. marina* (Tamaei 2005). In contrast, some mangrove species are able to develop morpho-anatomical adaptations that enhance life recovery after burial exposure (Okello et al. 2020). In addition, a recent study (Cusack et al. 2020) identified that dust particles in the Red Sea were enriched in iron and phosphorus, which may provide a vital source for oligotrophic coastal mangrove stands in the Red Sea (Anton et al. 2020).

To the best of our knowledge, the only study that has been conducted so far on mangrove seedling growth on the Red Sea coasts is a laboratory study that found that the growth of mangroves in the central Red Sea is likely driven by iron limitation (Almahasheer et al. 2016b). In addition, Anton et al. (2020) indicated that the short height of adult *A. marina* trees in the central Red Sea is likely driven by nitrogen limitation in the area. The scant information on natural mangrove habitats in the Red Sea, especially at early stages, led us to carry out this study, in which we estimated in situ growth rate of *A. marina* seedlings in a relatively pristine environment in the region of Baish, Jizan, in the southern Saudi Arabian Red Sea, in relation to tidal flooding intensity and sandstorms. Specifically, this study aimed to (1) estimate and compare the seedling growth rate at different tidal exposures and in different sampling periods, and (2) investigate the effects of burial (e.g. during a sandstorm) on the early development of mangrove trees.

MATERIALS AND METHODS

Study site

The mangrove stands in the northern region of the semi-enclosed bay at Baish in the southern Red Sea (Saudi Arabia, coordinates 17.34904°N 42.32134°E; Fig. 1) have been relatively unaffected by human activities. The environment in this area is hot and arid, and dead and desiccated mangroves are commonly found adjacent to the northernmost part of the mangrove forest. This area experiences a natural gradient of tidal inundation, which is generally lower than in other parts of the bay because of its proximity to the northernmost portion (Fig. 1). The northern easterly winds expose the site to wind stress and dust deposition. Rainfall rarely occurs in the area and is usually associated with thunderstorms. Sandstorms are common in the area particularly in summer (Arishi 2021). Sabkhas (or supra-tidal flats) are found north of the site and are composed mainly of sand and mud. Seawater temperature and salinity in the study site during the study period ranged from 35°C to 37°C and 46.9 to 53.01, respectively.

Data from March to September 2019 within the vicinity of the mangrove site suggested that the mean atmospheric temperature was 38.1°C, with values ranging from 31.7°C (March) to 42.5°C (June); mean relative humidity was 88.1%, with values ranging from 85.2% (March) to 97.2% (August); mean precipitation was 29.2 mm, with values ranging from 0 to 360.6 mm (August).

Data collection

The study site was subdivided into four distinct ecological zones based on qualitative observations of tidal exposure and fiddler crab burrow density: namely,

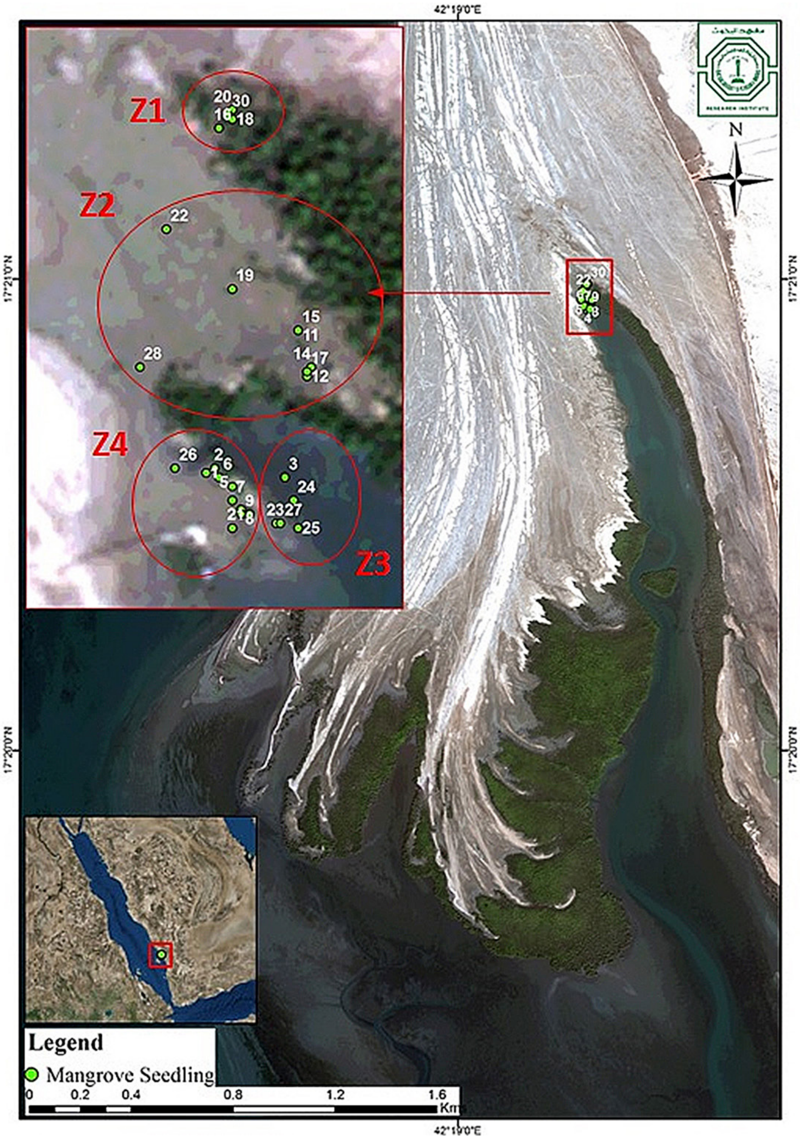

Fig. 1. – Location of the study site and seedlings assigned to four zones (rounded shapes).

Z1, low tidal exposure; Z2, medium tidal exposure; Z3, high tidal exposure with numerous crab burrows; and Z4, high tidal exposure with a few or no crab burrows (Fig. 1). The zones were qualitatively classified by tidal exposure based on their distance to the nearest tidal inundation and the observed number of fiddler crab burrows. The only vegetation on the site is the grey mangrove *A. marina*. The qualitative characteristics of the sediment varied across zones from sand (Z1), to sandy-muddy (Z2, Z3 and Z4).

Newly sprouted and naturally grown seedlings of *A. marina* from these zones, encompassing 30 sampling locations, were randomly chosen and identified with wooden markers (see Fig. 2), and all seedlings were considered for measurements. Seedling height was measured from the soil surface to the tip of the seedling for all samples (n=53) using a plastic ruler to the nearest centimetre. The study was conducted over a period of three months in the summer of 2017, from 28 April to 27 July. Measurements of seedling height and survival were performed on days 0, 14, 30, 38 and 88.

Measurements of air temperature, relative humidity, wind speed and direction, and dust concentration suspended in the air were conducted on a weekly basis at a permanent station close to the mangroves (Fig. 1). Estimates of weather conditions such as dry bulb temperature (T, °C), relative humidity (RH, %), and wind speed (WS, m s^{-1}) and direction were recorded using a Kestrel 4500 Pocket Weather Tracker. The wind direction was identified in degrees (°) measured from the north clockwise. Estimates of dust particle concentration (PM_{10} and $PM_{2.5}$) were obtained using a portable dust monitor (PC-3016A) from a fixed station with a dust meter installed near the mangrove forest (17.336617°N, 42.330517°E) at a height of approximately 1.5 m.

Data analysis

An increase in seedling height between sampling periods was used to calculate growth rates. One-way analysis of variance (ANOVA) was used to test the significance of different growth rates between the four zones across measurement periods (days 14, 30, 38, 88), survival rate and the selected environmental variables. The growth rate was calculated by the absolute difference of two height measurements divided by the number of days between two height measurements. Prior to ANOVA, data were examined for normality and homogeneity of variance. Statistical differences between specific zones and sampling periods were assessed using a Tukey post hoc test.

RESULTS

Table 1 shows the increment (cm), duration (d), growth rate (cm d^{-1}) and location of mangrove seedlings. Site Z3 showed the highest growth rate (0.34 cm d^{-1}), followed by Z4 (0.23 cm d^{-1}), Z2 (0.12 cm d^{-1}) and Z1 (0.01 cm d^{-1}) (Fig. 2A). Sampling zones differed significantly in growth rates (Table 2). Values at Z3 were significantly higher than at Z1 and Z2, but not from those at Z4 (Fig. 2A). Also, values at Z4 were significantly higher than those at Z1 and Z2 (Fig. 2A). Seedling growth rates showed a decreasing trend over time and were significantly different between sampling periods (Table 2) (Fig. 2B). The growth rate of day 14 (0.38 cm d^{-1}) was significantly different from that of days 30 (0.17 cm d^{-1}), 38 (0.1 cm d^{-1}) and 88 (0.03 cm d^{-1}) ($p<0.05$) (Fig. 2B). Furthermore, the survival rate showed a slight reduction from day 14 to day 38 but a significant reduction on day 88 (Fig. 2C, Table 2). The only seedling survivors were from Z3 (Fig. 3C) with a total of 5.6% (n=3) left from the initial samples. The significant decrease in survival was attributed to burial by sandstorm (Fig. 4).

Air temperature showed an increasing trend from May to July, rising by 2.4°C (Fig. 3A). By contrast, relative humidity showed a decreasing trend from May to July (Fig. 3B). Wind speed seemingly displayed an indistinguishable pattern, although the highest value was recorded in June (Fig. 3C). The wind consistently blows between 200° and 250° from the north (Fig. 3D). No sandstorms generally occurred between April and June, but they showed a marked increase in July (Fig. 3E, F). All the selected environmental variables showed no significant differences between sampling periods (Table 2).

DISCUSSION

Our study highlights significant aspects of the growth dynamics and fate of mangrove *Avicennia marina* seedlings, using in situ field observations in a pristine mangrove forest in the southern Red Sea of Saudi Arabia. We showed that increased exposure of seedlings to tidal inundation could increase growth performance, while a cumulative exposure of seedlings to an intense sandstorm can have a detrimental effect on their survival by burial.

The variation of seedling growth rates can be attributed to the differences in exposure to tidal inundation. This variation can be explained by (1) water and nutrient supply, (2) air temperature and (3) salinity. Firstly, tidal inundation increases water supply and enhances soil moisture and water absorption, which the seedlings need for their growth, especially in an arid environment (Bernstein and Hayward 1958, Ball 1988b). In addition, the availability of nutrients carried by the tide could be a necessary factor for seedling growth owing to the oligotrophic condition of the Red Sea (Almahasheer et al. 2016b, Anton et al. 2020). Secondly, low tidal exposure and increasing air temperature probably act towards seedling dehydration, as likely happened at Z1 (Hastenrath and Lamb 1979, Clough 1992, Rasul et al. 2015). For example, the negative growth rate observed in seedlings 16A, 20B and 30 (Table 1), which all belonged to Z1, may be attributed to dehydration resulting in the bending of the overall structure of the plant. Lastly, lower tidal inundation increases the exposure of the seedlings to high evaporation, which may tend to increase soil salinity owing to a reduced water volume and dilution. Higher salinity may force seedlings to undergo physiologi-

Table 1. – Growth measurements, increments (cm), total days of alive seedlings (day, d), growth rate (cm d^{-1}) and location of mangrove seedlings examined in Baish, Jizan, Saudi Arabia (Red Sea). ND, not determined; *, not measured; D, dead; B, buried.

Zone	Seedling	Latitude	Longitude	Shoot height (cm) 28-Apr-17	12-May-17	28-May-17	5-Jun-17	27-Jul-17	Increment (cm)	Total days of alive seedlings (d)	Growth rate (cm d^{-1})
4	1A	17.34905	42.32116	17	21.5	22	23.8	B	6.8	36	0.19
4	1B	17.34905	42.32116	18.1	22.5	23.8	25.8	B	7.7	36	0.21
4	2A	17.34906	42.32118	9.5	16.2	18.7	19.5	B	10.0	36	0.28
4	2B	17.34906	42.32118	10.7	18.4	20.7	20.8	B	10.1	36	0.28
4	2C	17.34906	42.32118	11.2	20.7	24	25	B	13.8	36	0.38
4	2D	17.34906	42.32118	13	21.9	27	28	B	15.0	36	0.42
3	3	17.34904	42.32134	12.8	15.5	18.1	19.5	B	6.7	36	0.19
4	4A	17.34902	42.32122	5.8	13	14.5	16.2	B	10.4	36	0.29
4	4B	17.34902	42.32122	8.3	13	16.5	17.2	B	8.9	36	0.25
4	4C	17.34902	42.32122	8.5	14.4	16.5	17.5	B	9.0	36	0.25
4	4D	17.34902	42.32122	9.6	15.6	17.5	18.3	B	8.7	36	0.24
4	4E	17.34902	42.32122	11.6	16.3	21	21.1	B	9.5	36	0.26
4	5	17.34902	42.32122	10.5	16.5	19	20.1	B	9.6	36	0.27
4	6A	17.34904	42.32119	8.5	7.5	10	10.5	B	2.0	36	0.06
4	6B	17.34904	42.32119	*	9.5	10	10.5	B	1.0	22	0.05
4	6C	17.34904	42.32119	*	10	13.5	14.6	B	4.6	22	0.21
4	7	17.34899	42.32122	8.5	11.6	12.2	12.2	B	3.7	36	0.10
4	8A	17.34897	42.32124	6.1	9.8	14.8	15.5	B	9.4	36	0.26
4	8B	17.34897	42.32124	6.5	12.3	15.5	16.3	B	9.8	36	0.27
4	8C	17.34897	42.32124	10.6	19.4	27.5	29	B	18.4	36	0.51
4	9A	17.34896	42.32124	4.5	9.1	9	9.5	B	5.0	36	0.14
4	9B	17.34896	42.32124	6.7	9.7	11.5	11.7	B	5.0	36	0.14
4	9C	17.34896	42.32124	13.5	19.5	19.7	20.5	B	7.0	36	0.19
4	10A	17.34896	42.32126	10	12.9	15.4	15.5	B	5.5	36	0.15
4	10B	17.34896	42.32126	11.4	16.6	20.5	21	B	9.6	36	0.27
4	10C	17.34896	42.32126	13	17.4	21	22.5	B	9.5	36	0.26
2	11	17.34936	42.32137	13	10.7	16.7	17.6	B	4.6	36	0.13
2	12	17.34926	42.32139	8	13.8	15.5	16.2	B	8.2	36	0.23
2	13	17.3214	42.32141	18	18.5	18.2	18	B	0.0	36	0.00
2	14	17.34928	42.3214	15	21	24.7	25.5	B	10.5	36	0.29
2	15	17.34936	42.32137	*	12	16	17	B	5.0	22	0.23
1	16A	17.3498	42.32119	19.3	19.3	16.2	D	B	-3.1	28	-0.11
1	16B	17.3498	42.32119	20	21	21	21.1	B	1.1	36	0.03
2	17A	17.34927	42.32139	7	9.8	11.2	11	B	4.0	36	0.11
2	17B	17.34927	42.32139	17.5	17.8	17.5	17.5	B	0.0	36	0.00
1	18	17.34982	42.32122	15	16	16	16.2	B	1.2	36	0.03
1	19	17.34945	42.32122	16.5	17.3	17.3	17	B	0.5	36	0.01
1	20A	17.34984	42.32122	7.9	8.5	*	8.7	B	0.8	22	0.04
1	20B	17.34984	42.32122	10.5	10.5	*	10.3	B	-0.2	22	-0.01
1	20C	17.34984	42.32122	22.2	22.5	*	22.5	B	0.3	22	0.01
1	20D	17.34984	42.32122	27	27	*	27.2	B	0.2	22	0.01
4	21	17.34893	42.32122	14	17.7	20.5	21.3	B	7.3	36	0.20
	22	17.34958	42.32107	6.4	6.8	6.8	D	B	0.4	28	0.01
3	23	17.34894	42.32132	15.5	24.7	27	27.5	B	12.0	36	0.33
3	24	17.34899	42.32136	*	*	30.5	36	42.0	5.5	52	0.11
3	25	17.34893	42.32137	13.7	18.7	24	26	27.6	12.3	88	0.14
4	26A	17.34906	42.32109	3.5	5	D	D	B	1.5	14	0.11
4	26B	17.34906	42.32109	5	*	D	D	B	*	0	0.00
4	26C	17.34906	42.32109	6	*	D	D	B	*	0	0.00
3	27	17.34894	42.32133	7	19.5	24.8	27	24.2	20.0	88	0.23
	28	17.34928	42.32101	7	9	D	D	B	2.0	14	0.14
1	29	ND	ND	*	6	6.4	6.3	B	0.3	22	0.01
1	30	17.34983	42.32121	5.5	4	4	D	B	-1.5	28	-0.05

Table 2. – One-way analysis of variance of the selected environmental variables.

Variables		Sum of squares	df	Mean square	F	Sig.
Growth rate by zone	Between groups	0.37205	3	0.124018	14.11	0.0000027
	Within groups	0.32519	37	0.008789		
	Total	22212.7	15			
Growth rate by period*	Between groups	0.96665	2	0.48332	32.52	0.0000
	Within groups	1.02558		0.01486		
	Total	1.99222				
Survival rate (%)	Between groups	19064.1475	3	6354.72	24.2199	0.000022
	Within groups	3148.51	12	262.38		
	Total	22212.66				
Temperature (°C)	Between groups	17.55	3	5.85	1.801	0.201
	Within groups	38.99	12	3.25		
	Total	56.54	15			
Relative humidity (%)	Between groups	513.34	3	171.11	1.664	0.227
	Within groups	1233.99	12	102.83		
	Total	1747.32	15			
Wind speed (m s^{-1})	Between groups	2.92	3	0.97	0.917	0.462
	Within groups	12.75	12	1.06		
	Total	15.67	15			
Wind direction (degrees)	Between groups	6075.50	3	2025.17	0.989	0.431
	Within groups	24576.50	12	2048.04		
	Total	30652.00	15			
$PM_{2.5}$ (µg m^{-3})	Between groups	12013.70	3	4004.57	2.71	0.092
	Within groups	17733.45	12	1477.79		
	Total	29747.15	15			
PM_{10} (µg m^{-3})	Between groups	116843.45	3	38947.82	2.446	0.114
	Within groups	191097.03	12	15924.75		
	Total	307940.48	15			

* Adjusted sum of squares for tests

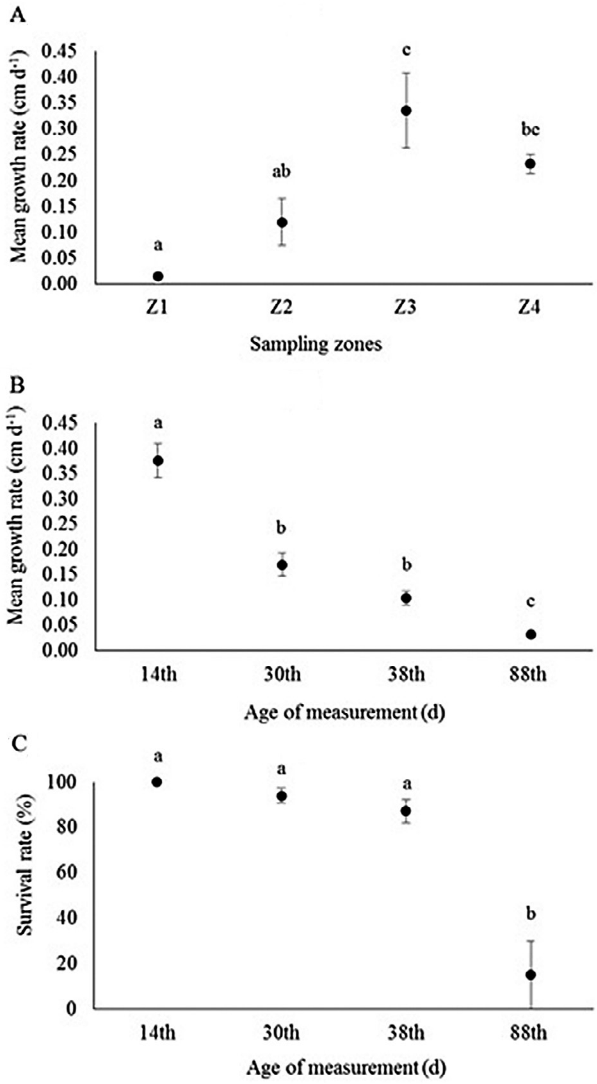

Fig. 2. – A, mean growth rate (cm/d) of *Avicennia marina* seedlings from four zones: Z1 (n=7), Z2 (n=6), Z3 (n=4) and Z4 (n=24); B, mean growth rate ± SE (cm d^{-1}) of *Avicennia marina* seedlings at Zone 4 days 14 (n=25), 30 (n=25) 38 (n=24) of sampling; C, mean survival rate (%) of mangrove seedlings between sampling periods and zones. Different letters indicate significant difference and overlapping letters indicate no significant difference ($p<0.05$; Tukey test).

cal stress, which could affect their optimal growth (Clarke and Hannon 1970, Burchett et al. 1984, Kraus et al. 2006).

Sandstorms are an environmental stressor for the mangrove seedlings, affecting the survival of the plant through burial (Balke et al. 2011). The present study warrants their inclusion in the list of previously identified natural stressors of mangroves in the Red Sea. Indeed, it has been shown that the deposition of sand results in intense burial and consequent suffocation of mangrove seedlings, probably leading to stunted growth and/or mortality (Ellison 1999). Accordingly, Tamaei (2005) enumerated sandstorms and sand accumulation as one of the leading causes of mangrove *A. marina* seedling mortality. We observed a decreasing seedling growth rate that aligned with increasing sandstorms during the course of our investigation. Since seedlings exhibit a premature root system that does not provide a strong anchorage to the ground, they are likely vulnerable to physiological stress caused by the combination of sandstorms and strong winds (Balke et al. 2011).

The higher seedling growth rate between sites Z3 and Z4 can be explained by the observed presence of burrows. Burrowing crabs may increase seedling growth by enhancing aeration of the soil (Lee 1998, Smith et al. 1991). Burrowing also creates networks for water flow below the surface, allowing diffusion

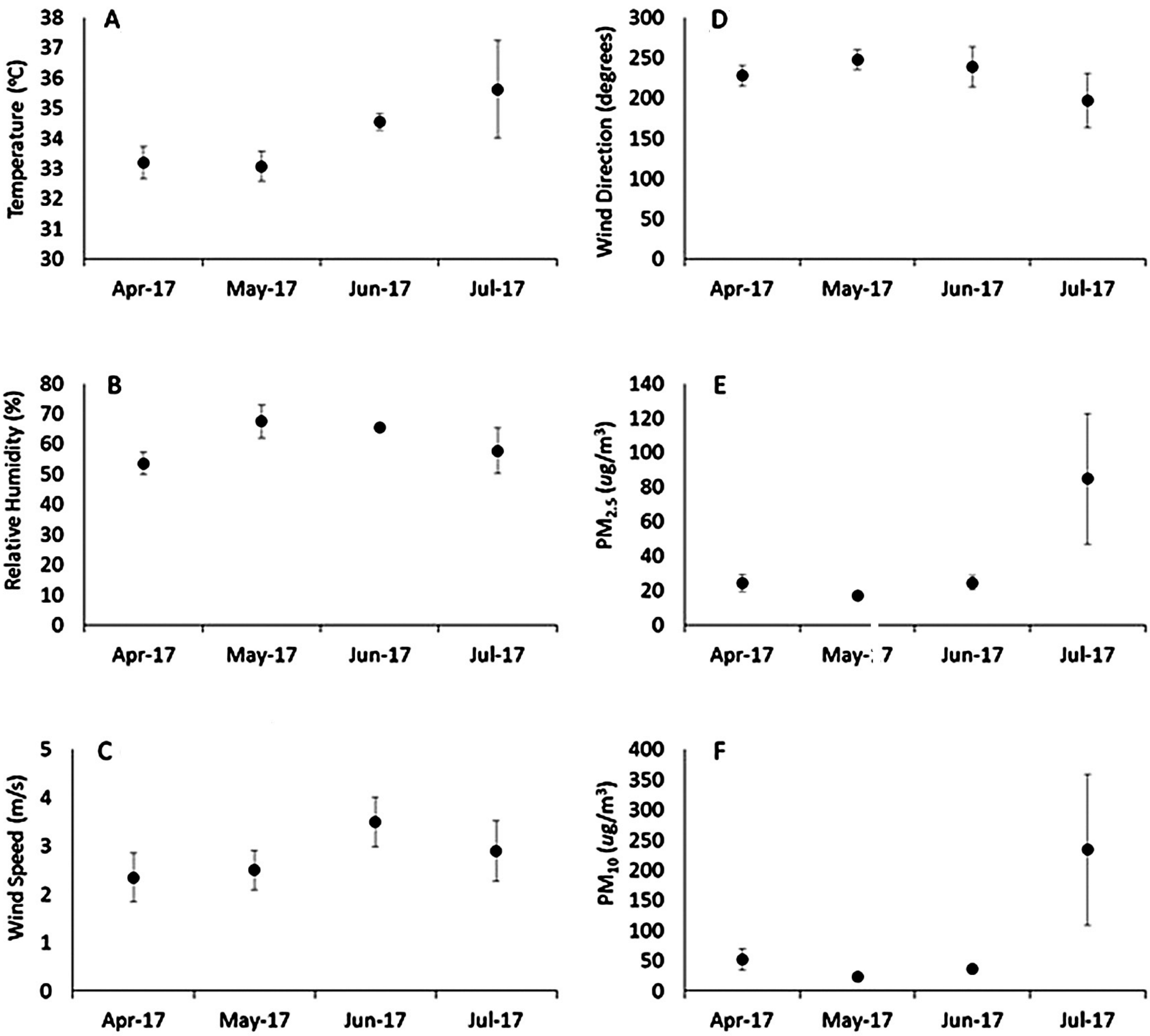

Fig. 3. – Average measurements of air temperature (A), relative humidity (B), wind speed (m s^{-1}) (C), wind direction (D); and dust concentration $PM_{2.5}$ (μg m^{-3}) (E) and PM_{10} (μg m^{-3}) (F) from April to July 2017.

of nutrients and oxygen across a swamp-bed interface (Ridd 1996). Smith et al. (2009) found that the burrowing of fiddler crabs enhances mangrove height by 27%. In our study, we found no significant differences that were due to the presence/absence of borrows, perhaps because the number of burrows at Z3 (high tidal exposure with numerous crab burrows) did not reach the minimum threshold for the burrows to make a difference in seedling growth. Unfortunately, our empirical approach was qualitative, as we did not quantify the number of burrows at Z3 and Z4, and further investigation is warranted.

The survival of Z3 seedlings could be attributed to the fact that existing mangrove trees act as a buffer against sediment resuspension and deposition caused by strong winds. The wind direction was generally 200° to 250° from the north, and all three zones except Z3 were exposed. Also, the exposure of Z3 seedlings to tidal inundation could also help reduce the impact of sediment burial by washing off the settling sediments into the seawater, especially during flood tide.

CONCLUSION

After a brief field exploration of seedlings in situ in the arid environment in the southern Red Sea, we observed that there was a correlation between growth of the seedlings and their location and growth period (age). The differences in seedling growth according to location were likely related to exposure to tidal inundation (i.e. higher growth with higher exposure to tidal inundation). On the other hand, the differences in seed-

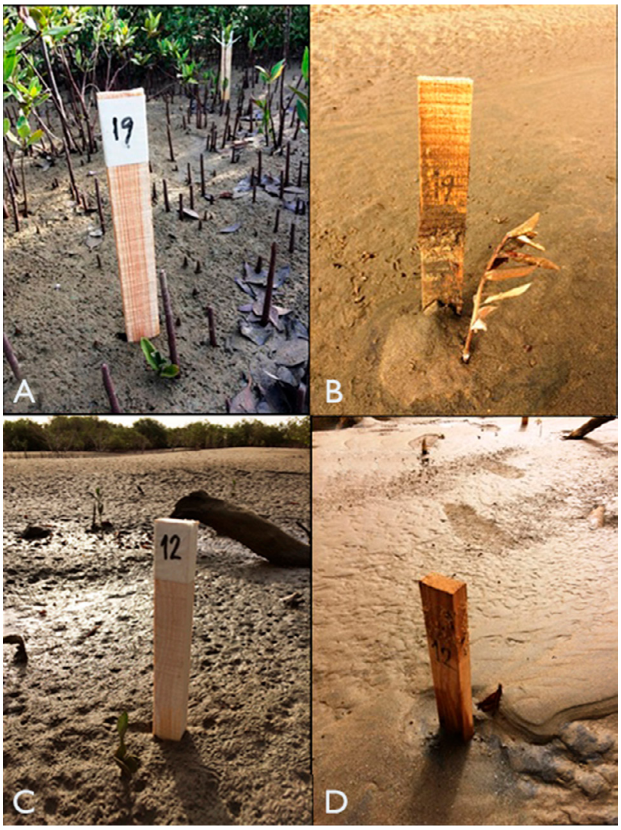

Fig. 4. – Representative seedling images of before (A, C) and after (B, D) sandstorms.

ling growth according to age, which showed a decreasing trend over the course of the study, could be related to their prolonged exposure to high air temperature, humidity and salinity. Interestingly, the severe decrease in survival of the seedlings in this area coincided with exposure to strong winds, sandstorms and dust deposition. These climatic conditions together resulted in a massive burial of the seedlings, which can be considered an important natural stressor in this area.

Therefore, while tidal exposure is important for the management of *A. marina* seedlings in arid regions such as that in the study area, the consideration of the above factors is crucial, especially for devising strategies for effective restoration and conservation of mangroves.

DECLARATION OF INTEREST

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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