Controlled trials of artificial irrigation methods to combat high sea turtle nest temperatures

Submitted to Swansea University in fulfilment of the requirements

for the Degree of MRes Biosciences

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[redacted]

MRes Biosciences

Word count: 7832

Declarations

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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Acknowledgements

I would like to first thank my supervisors, Dr. Nicole Esteban and Dr. Kimberley Stokes for their continued support and enthusiasm throughout this project. Their guidance has been instrumental in the development of this project as well as to my own personal development as a researcher.

I would like to thank Dr. Yakup Kaska and Dr. Doğan Sözbilen at DEKAMER who’s enthusiasm for the project and support at the field site made the project possible. A special mention to Emily Ward and Nathan Phillips who’s support on the day to day running at Itzuzu beach in extreme conditions kept the project running smoothly. I would also like to thank Tommy Valente-Madeira-Rodrigues for providing the sediment characteristics data and providing an excellent map of the field site.

I would also like to acknowledge Professor Graeme Hays, Dr. David Booth, and Dr. Melissa Staines for their initial consultation on this project and continued feedback throughout, sharing their time and expertise in this area of research which allowed me to develop a much broader understanding of this research topic.

Finally, I would like to thank my partner, family and friends who have had listened to me talk about this project for far too long and who’s support has been invaluable.

Contents

Abstract

Climate change-induced rises in incubation temperatures pose a threat to sea turtle reproductive success, resulting in increased embryonic mortality, skewed sex ratios, and modified hatchling phenotypes. This study evaluated the effects of three irrigation regimes (single large event, intermittent, daily) on sand temperatures at nest depths under controlled conditions and at a rookery in Southern Turkey. In controlled settings, daily irrigation decreased mean nest temperatures by up to 1.21°C compared to controls but increased diel variation by 0.84 ± 0.05 °C SE. Single applications elevated temperatures by up to 0.75°C. In the field trial, seawater irrigation led to elevated salinity at nest depth, potentially reaching lethal thresholds (16.28 ppt at 35 cm depth). Field trials conducted in extreme heat conditions (max 52.95°C) validated the effectiveness of daily irrigation, resulting in mean temperature reductions of up to 0.8°C. In extreme heat environments, sufficiently reducing temperatures to influence sex ratios is unlikely to be achievable – instead, the aim should focus on providing enough cooling to mitigate embryonic mortality.

Key words:

Artificial irrigation, embryonic development, Temperature-dependent sex determination, climate change, sea turtle conservation.

1. Introduction

The most recent climate change projections suggest global temperature increases of up to 4.4°C in the next 80 years (IPCC, 2021). These extreme shifts in temperature threaten to disrupt species phenology, life histories and reproductive success in marine environments (Cohen et al., 2018; Telemeco et al., 2013; Chen et al., 2021). Breeding environments are of considerable concern for oviparous reptiles that do not exhibit parental care, such as sea turtles, and rely entirely on ambient nest conditions for the development of their offspring (e.g., Janzen & Paukstis 1991; Pike, 2014; Beltran et al., 2021). Dependence on the ambient environment makes sea turtle eggs particularly vulnerable to the rising incubation temperatures associated with climate change (Valenzuela & Lance, 2004; Pike 2014; Montero et al., 2018).

Three climate-driven threats are commonly recognised for sea turtle reproductive success (Gatto et al., 2023). First, incubation temperatures are currently surpassing lethal thresholds of approximately 34°C (Howard et al. 2014), leading to increased embryonic mortality due to overheating at many rookeries, which has already been identified as a cause of large scale egg mortality (Turkozan et al., 2021). For example, hatchling success was 2% on Ostional Beach, Costa Rica, a mass nesting rookery for Olive Ridley sea turtles (*Lepidochelys olivacea*), during the 2008 and 2009 hatching season (Valverde et al., 2010). Second, rising incubation temperatures reduce hatchling fitness characteristics and modify offspring phenotypes (Read et al., 2013). This has been observed in Florida where the righting response of leatherback hatchlings was significantly lower in late-season, warmer nests than earlier season, cooler nests (Seaman & Milton 2023) and in the Caribbean, where leatherback hatchlings exhibited reduced body size and mass at higher nest incubation temperatures (Rivas et al., 2019). Third, sea turtles exhibit temperature-dependent sex determination (TSD), where incubation temperatures during the thermosensitive period (the middle third of incubation) determine hatchling sex ratios. Temperatures above the pivotal temperature of approximately 29°C produce a female bias, while cooler temperatures result in male-biased hatchling production (Yntema & Mrosovsky, 1980), with temperature changes as small as 0.5°C shifting the offspring sex ratio within a clutch from 1:1 to 1:0 (Hewavisenthi & Parmenter 2002). The consequence of warmer beaches is an eventual reduction of sexually mature males in populations globally (Hays et al., 2017). Other indirect threats due to climate change also pose challenges to the nesting environment such as sea level rise (Rivas et al., 2023), beach erosion (Siqueira et al., 2021) and rising water table levels (Pike et al., 2015).

Considering recent increases in incubation temperatures, a number of management strategies for sea turtle nest protection have been developed which include shading, increasing natural vegetation, and relocating nests to cooler beaches (Vindas-Picado et al., 2020; Kamel, 2013; Esteban et al., 2018 respectively). While these strategies have been effective at reducing incubation temperatures at individual nesting sites, they can be resource intensive and difficult to apply at a population wide level (Gatto et al., 2023). Extreme rainfall events have been found to provide levels of cooling at sea turtle nest depth sufficient to influence primary sex ratios (Houghton et al., 2007; Staines et al., 2020; Laloë et al., 2021), however, in addition to rising temperatures, climate change is expected to alter the patterns of severe weather events, including changes in the frequency and intensity of storms - and associated extreme rainfall events – as well as, increasing frequency of extreme heatwave events (IPCC, 2021). During warmer, drier nesting seasons, artificial irrigation has been suggested as a potential solution to reduce the warming nest environment (Laloë et al., 2021). Artificial irrigation can be applied as a potentially scalable, population-wide conservation tool, which If deployed correctly, offers a minimally invasive approach that does not require significant alterations to the natural environment (Gatto et al., 2023). However, there are a number of concerns surrounding the use of irrigation, such as nest inundation (Limpus et al., 2021) and an increase in salinity within the nest chamber if seawater is used as an irrigation medium (Bustard & Greenham 1968). Any artificial irrigation regime must therefore maintain optimal conditions within the nesting environment for embryonic development, with temperatures within the normal range (24-33 °C) (McGehee 1979; Yntema and Mrosovsky 1980), moisture content (2-10%) (McGehee 1990; Ackerman, 1997; Suss et al., 2012) and salinity (0-25%) (Bustard & Greenham 1968, McGehee 1979)

Since 2015, artificial irrigation has been tested as a strategy to decrease incubation temperatures at a range of sites including Costa Rica, Florida, and Australia (Hill et al., 2015; Jourdan & Fuentes 2015; Erb et al., 2018; Lolavar & Wyneken 2021; Matthews et al., 2021; Smith et al., 2021; Young et al., 2023). So far two limitations have been described, and these hinder the interpretation of previous research on identifying effective nest irrigation strategies. First, considerable variation in experimental design such as irrigation volume and frequency, target nest depth, timing of irrigation (i.e., morning or night) and irrigation water temperature across studies introduces significant variability in their outcomes (Gatto et al., 2023). A significant limitation in experimental design is the common practice of simply comparing irrigated nests to non-irrigated control nests, which fails to accurately quantify temperature reductions due to the high degree of spatial microclimate temperature variability inherent to beach environments (Young et al., 2023). Accounting for this baseline variability in nest thermal profiles is crucial for isolating the specific effects of irrigation regimes. Second, as all trials were conducted *in situ*, considerable variation in environmental conditions—including rainfall, solar input, beach microclimate variations, and sediment characteristics—likely influenced the effectiveness of specific irrigation regimes. These limitations make it difficult to isolate the precise effect of specific irrigation regimes and draw definitive conclusions about their effectiveness in reducing nest temperatures.

Understanding the thermal response to irrigation requires examining the heat transfer mechanisms of the nesting environment. There is substantial literature on the soil thermal regime available from agricultural research (Jury & Horton, 2004; Akter et al., 2015; Hamdhan & Clarke, 2010). There are three mechanisms that affect heat transfer within sand, radiative heat transfer (solar input), convection (transfer of heat within a fluid) and conduction (heat transfer between sand particles) (Jury & Horton, 2004). Radiative energy plays a more significant role in the heat transfer processes near the sand surface, explaining the large diurnal/ nocturnal temperature variation exhibited at the sand surface (Akter et al., 2015). However, during extreme heatwave events, there is also an increase in radiative energy reaching the subsurface. Further down the sand column, solar radiation is unable to penetrate directly. Instead, heat is transferred downwards through the process of conduction, which involves the exchange of kinetic energy between adjacent sand particles. The transfer of heat through conductive processes explains the relatively steady temperatures typically observed at greater depths compared to the more variable temperatures near the surface that are directly influenced by solar heating (Jury & Horton, 2004).

Introducing water significantly alters the thermal properties of sand. Increased moisture content in the sand column raises the specific heat capacity, requiring more energy to heat the sand (Ižvolta & Dobeš, 2014; Sharqawy et al., 2010). However, it also increases thermal conductivity, facilitating more efficient heat propagation through the moist sand column (Hamdhan & Clarke, 2010; Huber et al., 2012). The balance between these opposing effects of moisture on heat capacity versus thermal conductivity determines the overall influence of artificial irrigation on nest temperatures. Understanding these mechanisms and the environmental factors that affect them, is key to optimizing irrigation strategies for achieving targeted nest temperature reductions.

Taking these heat transfer mechanisms into account, there are two principal approaches for achieving nest cooling via irrigation: 1) cooling the clutch directly via convective heat transfer (movement of cool water past the clutch), and 2) reducing heat transfer from solar radiation by increasing the specific heat capacity of the surface sand layer through irrigation. The relative effectiveness of each approach is therefore dependent on the magnitude of solar radiative heat transfer and the target depth for cooling. For instance, a relatively small 23.3 mm water application achieved a 2.4°C mean temperature reduction at 45 cm depth in Costa Rica, but only 0.7°C at 75 cm, demonstrating the reduced effect of cooling further down the sand column (Hill et al., 2015). However, a comparable 20 mm application in Australia yielded no significant temperature decrease at 70 cm depth (Smith et al., 2021). This discrepancy likely stems from differences in the primary heat transfer mechanism. In Costa Rica, with mean nest temperatures of 31.7±0.3°C SE, there was likely substantial solar heat input, which surface irrigation mitigated by increasing the specific heat capacity of the sand. Conversely, the lower 27.0-27.8°C nest temperatures in Australia suggest lower radiative heating, such that surface irrigation had a negligible impact. Instead, the ~1.5°C cooling from a 200 mm application implies conductive heat transfer as the dominant mechanism requiring direct clutch cooling via water flow past the clutch.

Given the variations in previous experimental irrigation treatments and climatic conditions, here we set out to assess the effects of different irrigation regimes in both controlled and field conditions. We also considered mechanisms for heat transfer that are reported in soil studies (Jury & Horton, 2004). The present study aimed to advance our understanding of optimal irrigation regimes for lowering incubation temperature for sea turtles by 1) systematically assessing the thermal response of sand at nest depth to three different irrigation regimes in controlled temperature and relative humidity conditions, 2) investigating the thermal response of sand at a range of depths during water movement through the sand column, 3) comparing freshwater and saltwater as an irrigation medium, considering temperature reduction and potential increases in salinity at nest depth, and 4) recommending effective irrigation regimes to decrease sand temperature at nest depth at a loggerhead rookery.

2. Methods

2.1 Temperature controlled trials

2.1.2 Constant Temperature and Humidity (CT) room

Controlled experimental trials were conducted in the Constant Temperature and Humidity (CT) room in the Bioscience Department, Swansea University. The CT room was programmed to replicate the daily cyclic temperature fluctuations experienced during embryonic development at the target nesting site, Itzuzu beach, Dalyan, Turkey. For Trial 1, the daytime ambient temperature was set to 27.5°C and the nighttime ambient temperature to 23.5°C (the maximum temperatures that could be sustained in the CT room) representative of temperature experienced earlier in the nesting season at the target site (Turkish State Meteorological Service, 2021). In Trial 2, temperatures were adjusted to 25°C during the day and 20°C at night. The humidity settings were consistent across both trials, at 49% during the day and 55% at night. Daylight hours were set to 05:30 to 20:15 (14 hours and 45 minutes of daylight), to simulate day length at the target site, with a gradual change in temperature 2h post-dawn and pre-dusk respectively.

2.1.3 Sand chamber set up

Figure 1. a) Example of a multi-parameter probe installed at a fixed depth (30 cm) within a sand chamber to measure the effect of irrigation. b) Sand chambers (*n* = 10) set up in Constant Temperature and Humidity (CT) room, prior to installation of black card barriers and attachment of heat lamps (80W basking lamp) 18 cm above the sand surface.

The effects of irrigation on temperature, water content and salinity at nest depth (35 cm) were recorded using an array of multi-sensor probes (WET150, *n = 50*). Ten insulated cool boxes (Igloo, Bromborough, 56.2 x 52.7 x 45.2 cm) were filled to a depth of 40 cm (approximately 58,880 cm³) of oven dried (105°C for 24 h), pre-cleaned sand (Dandy's, Chester). To assess the depth profile of temperature, water content and salinity down the sand column, probes (*n* = 5 per box) were installed at 5 cm depth intervals (15-35 cm) in each box. Probes were inserted from alternating sides of the sand chamber. A heat lamp (80W Mini Mercury vapour D3 basking lamp, Arcadia, West Sussex) was positioned centrally 18 cm above the sand surface to achieve a constant target UV index of 8 (equivalent irradiance = 0.2 W/m^2 at the sand surface). Heat lamps were programmed to switch on at 08:30 h and off at 17:30 h, 3 hours post-dawn and pre-dusk respectively, to simulate gradual diel temperature fluctuation. To ensure uniform light exposure across all treatments, black card barriers were installed around the edges of each cool box.

2.1.4 Irrigation regimes

Three irrigation regimes were tested in the CT room using both freshwater and seawater. Seawater was obtained from a seawater intake pipe from Swansea Bay. Prior to irrigation, the salinity was measured at 37 ppt using a mass spectrometer. All water was stored in an adjacent CT room programmed to 20°C, for 24 h prior to irrigation, to replicate water temperatures used in a previous trial that achieved nest cooling (Young et al., 2023). Irrigation was conducted using a 0.7 L watering can that was moved in a continuous circular motion over a 28 cm diameter watering circle (irrigation area = 615.75 cm^2) to slowly irrigate the sand surface until the watering can was completely emptied. Irrigation was quantified in terms of rainfall equivalent, with measurements expressed in millimetres (mm).

Trial 1: three freshwater irrigation regimes were tested in the CT room, a single irrigation event (Single 100 mm; n = 3), a daily irrigation (Daily 20mm; n = 3), irrigation every third day (Intermittent 20 mm; n = 3), and a control (n = 1) which received a single 10 mm irrigation application to account for sand surface compression due to watering. Irrigation took place during the hottest part of the day (14:00 – 15:00 h), apart from on day 1 due to the one off Single 100 mm treatments (14:00-16:48 h), for 28 consecutive days. Irrigation was completed in a continuous process, with each treatment receiving 0.6 L applications until each treatment received the total volume of water needed (Single 100 mm: 6 L; Daily 20 mm: 1.2 L; Intermittent 20 mm: 1.2 L).

Trial 2: freshwater (Daily Freshwater 10 mm, *n* = 3) and seawater (Daily Seawater 10 mm; *n* = 3) treatments received daily irrigation at a reduced water volume. Control treatments (0 mm; *n* = 3) were distributed across the CT room to record temperature variation across the CT room. No water was applied to controls in trial 2. Irrigation method was identical to Trial 1 except time of irrigation was 07:00 – 08:00 h before sunrise (when UV lamps were switched on). Due to a heat lamp error, temperature data for trial 2 was collected for only 7 days, however salinity was measured for 12 days.

2.2 Field trial, Iztuzu beach, Dalyan

2.2.2 Study site

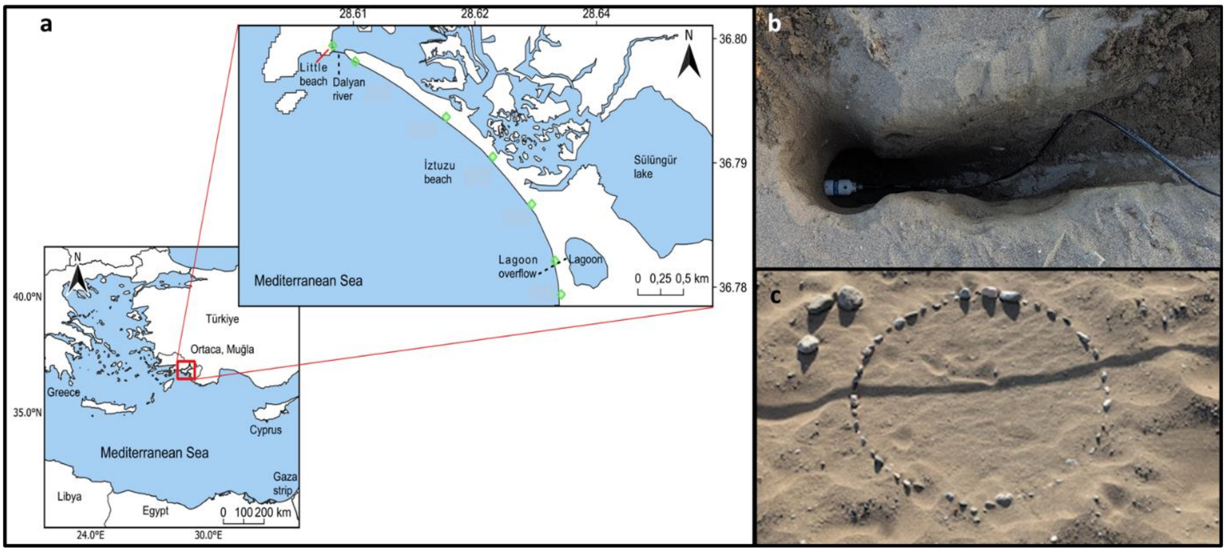

Figure 2. a) Field site location at Itzuzu beach, Dalyan, Turkey. An important loggerhead rookery in the region with 250-300 clutches laid annually (Sari & Kaska, 2015). b) Example of a multi-parameter probe installation at a fixed depth and location to measure the effect of irrigation. c) 80 cm diameter area (5027 cm^2) marked by stones where irrigation was applied.

The refined irrigation protocols identified from the controlled laboratory trials were then tested at a nesting site in Dalyan, Türkiye (36.791°N, 28.621°W). Itzuzu beach is 4.5 km long and one of the most important rookeries for loggerhead turtles in the Mediterranean region with 250-300 clutches laid annually between early May to early August with a peak in mid-June (Sari & Kaska, 2015). The sediment was analysed using Gradistat and identified as a unimodal, moderately sorted slightly gravelly medium sand.

2.2.3 probe installation

The irrigation treatment set up included 16 unshaded plots in the eastern end of Iztuzu beach so as to be in the turtle nesting zone as well as easily accessible and monitored by beach security staff. To prevent disturbance, an area (6 x 6 m) was marked out and fenced off. A 4x4 grid was established, comprising a total of 16 plots. a randomized block design with distance to the shoreline serving as the block and treatments (irrigation regimes) being randomly distributed along each block (transect). Each nest was systematically allocated a unique position within the grid to ensure a uniform distribution. The plots were arranged along four transects (Transects 1-4), oriented parallel to the shoreline, with Transect 1 being farthest from the shore and Transect 4 closest (appendix 1).

Volunteers working at the site demonstrated how nests were excavated, and this was used as a template. Within each plot, multiparameter probes (WET150, n = 3) were installed in standardized nest holes up to 50 cm depth. A trench had to be dug and refilled from the nest hole to allow for installation of cabling (Fig. 2b). Probes were installed at 15 cm depth intervals (20, 35 and 50 cm) and programmed to record every 30 minutes. An additional temperature probe (Tinytag Plus 2 model TGP-4017, Gemini Data Loggers, UK) was installed at 60 cm depth to extend depth measurements. Plots were ≥ 1 m apart. An 80 cm diameter watering circle (watering area = 5027 cm^2) was marked as a reference by using small stones. A 15 L watering can was used with a fine sprinkling rose (flow rate 1.49 L/ min), with water applied in a continuous circular motion until the watering can was emptied.

2.2.4 Irrigation regimes

Three irrigation regimes were informed by the controlled laboratory trials: single irrigation event 100 mm (Single 100 mm; n = 4), daily irrigation 20 mm (Daily 20 mm; n = 4), a reduced volume, daily irrigation 10 mm (Daily 10mm; n = 4) and control 0 mm (n = 4). Water was taken from the sea at 07:00 h daily, as the water was found to be coolest at this time. Temperature was recorded prior to irrigation. Irrigation was completed between 07:00-08:00 (local time) as informed by the controlled laboratory trials where cooling was most successful with morning applications, apart from on day 1 due to the large volume of the one off Single 100 mm treatments (07:00-10:03 h). Water was applied in a continuous process, with each regime receiving single 5 L applications until each regime received the total volume of water needed (Single 100 mm: 50 L; Daily 20 mm: 10 L; Daily 10 mm: 5 L). All treatments were exposed to sunlight during daylight hours throughout the whole of the 14 day trial period. Air and sand surface temperatures were recorded every hour from day 2 of the trial.

2.3 Data Analysis

R statistical software (R Core Team 2020) was used for all statistical analyses. The data were found to violate the assumption of normality based on the Shapiro-Wilk test ($p < 0.05$). Mean hourly temperatures, daily maximum temperatures, and daily temperature ranges were tested for statistically significant differences between the groups using the Kruskal-Wallis test. If the Kruskal-Wallis test indicated significant differences ($p < 0.05$) among the groups for a given temperature metric, Dunn's post hoc test with Bonferroni correction was performed to identify which pairwise group comparisons differed significantly.

For the first trial, a linear model was built using data from the Intermittent 20 mm regime to measure how water penetration depth affected daily temperature range, as this regime allowed slow enough water movement through the sand column to calculate the effect on diel range. For the field trial, temperature data were measured for 48 hours prior to irrigation, and a linear model was employed to assess the effect of distance from the shoreline (m) on the mean temperatures at depths of 35 cm, 50 cm, and 60 cm. All models were tested for normality. Data are presented as means ± SE and statistical significance is assumed if $p < 0.05$.

For each trial, variations in individual sand chambers or plot temperatures before irrigation were accounted for by calculating the mean baseline temperatures before irrigation. The temperature for each sand chamber or plot was then adjusted by subtracting its deviation from this mean baseline, ensuring standardized starting temperatures across treatments. To allow for easier comparison across trials, residual temperature differences were used instead, calculated as the variance between treatment and control temperatures. Owing to the high volume of data collected (lab trials every 1 min, field trials every 15 min), the smooth.spline function was employed to perform cubic smoothing spline analysis. The resulting smoothed curve was used for data visualization purposes.

3. Results

3.1 Controlled temperature trials

A total of 40,320 data points were collected over the 28 day trial period from 50 multi-sensor probes. Throughout the trial period, the CT room maintained an average daytime temperature of 26.86 ± 0.15°C and nighttime temperature of 24.82 ± 0.12°C, with a humidity of 49.13%. Over the 28 day trial period, 212.4 L of freshwater was used for irrigation, with the Single 100 mm regimes each requiring 6 L (*n* = 3), the Daily 20mm regimes requiring 33.6 L (*n* = 3), and Intermittent 20 mm regimes requiring 10.8 L (*n* = 3). Water temperature applied was an average temperature of 20.2 ± 0.03°C prior to irrigation. Mean temperatures at nest depth (35 cm) for all treatments prior to irrigation and after temperature adjustments was 25.94 ± 0.02°C.

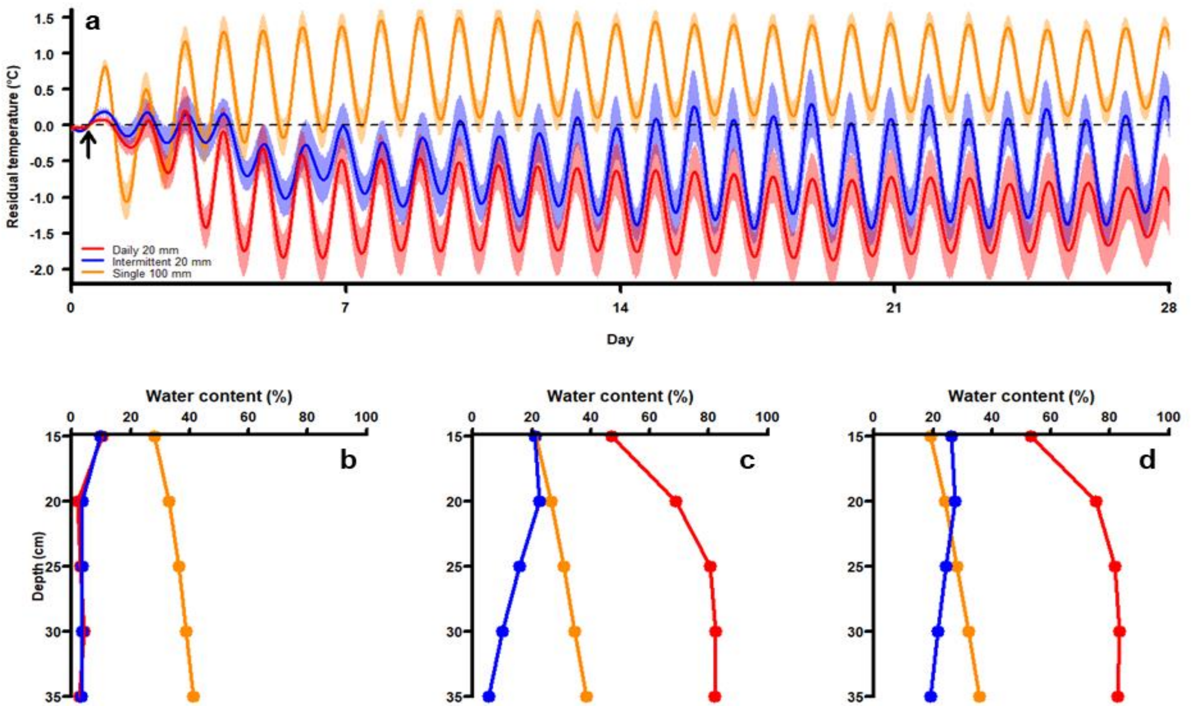

Figure 3. a) Residual sand temperature traces at 35 cm (nest depth) for three different irrigation regimes during the 28-day trial: Daily 20 mm (*n* = 3), Intermittent 20 mm (*n* = 3) and Single 100 mm (*n* = 3) compared against a single control (*n* = 1). Shaded areas indicate ± 1 SE for each regime. Vertical black arrow indicates first irrigation event at 14:00 on day 1 of the trial. Only the Daily 20 mm regime reduced both mean and maximum temperatures significantly compared to the control. b-d) Water content profiles at 15-35 cm depths on days 1, 14, and 28, showing Daily 20 mm regime led to

artificially high water content due to the limited drainage conditions (82.65 ± 0.26% SE) at nest depth (35 cm) by day 28.

Within 12 hours following irrigation, all irrigation regimes resulted in an increase in the maximum sand temperature at nest depth (35 cm), compared to the control. The highest residual sand temperatures were observed 12 hours post irrigation, with the Single 100 mm irrigation regime resulting in the most pronounced increase in mean maximum temperature (Fig. 3a; 0.94 ± 0.09 °C increase relative to the control). The Intermittent 20 mm and Daily 20 mm irrigation regimes elicited comparatively smaller temperature increases of 0.2 ± 0.03 °C and 0.09 ± 0.07 °C, respectively, compared to the control. 24 h post irrigation, all irrigation regimes resulted in a decrease in the minimum sand temperature at nest depth, compared to the control plot, with Single 100 mm regime leading to the largest reduction in temperature -1.09 ± 0.26 °C.

There were significant differences among regimes for mean sand temperature ($\chi2 = 87.23$, df = 3, $p < 0.001$). Post-hoc Bonferroni tests revealed that both the Daily 20mm and Intermittent 20 mm regimes had significantly lower mean sand temperatures compared to the control ($p < 0.001$), with the overall mean temperature at nest depth for the Intermittent 20 mm and Daily 20 mm regimes -0.5 ± 0.3 °C and -1.08 ± 0.34 °C lower, respectively, compared to the control. The Single 100mm regime had significantly higher mean temperatures ($p < 0.001$), with an overall mean sand temperature that was 0.62 ± 0.19°C higher than the control for the 28 day trial period. There were also significant differences among regimes for diel temperature range ($\chi2 = 71.46$, df = 3, $p < 0.001$). All three irrigation regimes significantly increased the diel range of sand temperatures throughout the trial period compared to the control ($p < 0.001$). The overall mean diel range increases were 1.40 ± 0.05°C, 1.13 ± 0.06°C, and 1.19 ± 0.09°C for the Single 100 mm, Daily 20 mm, and Intermittent 20 mm regimes over the 28 day trial period, respectively. The maximum sand temperature was significantly affected by the different regimes (χ2 = 79.39, df = 3, p < 0.001). The Daily 20mm regime significantly reduced maximum sand temperatures (p = 0.01), with overall mean maximum temperatures being -0.78 ± 0.03°C lower than the control. In contrast, the Single 100mm regime significantly increased maximum temperatures (p < 0.001), which were 0.76 ± 0.1°C higher than the control. The Intermittent 20 mm regime reduced daily maximum temperatures by -0.41 ± 0.03°C, however this was not statistically significant (P = 0.43).

There was a significant relationship between water penetration depth and increase in diel temperature range in the observed Intermittent 20 mm regime (Fig. 4; F=123.8, df=1,3, p<0.05, R^2=0.98). The diel temperature range increased by 0.38°C for every 5 cm the water penetrated further down the sand column.

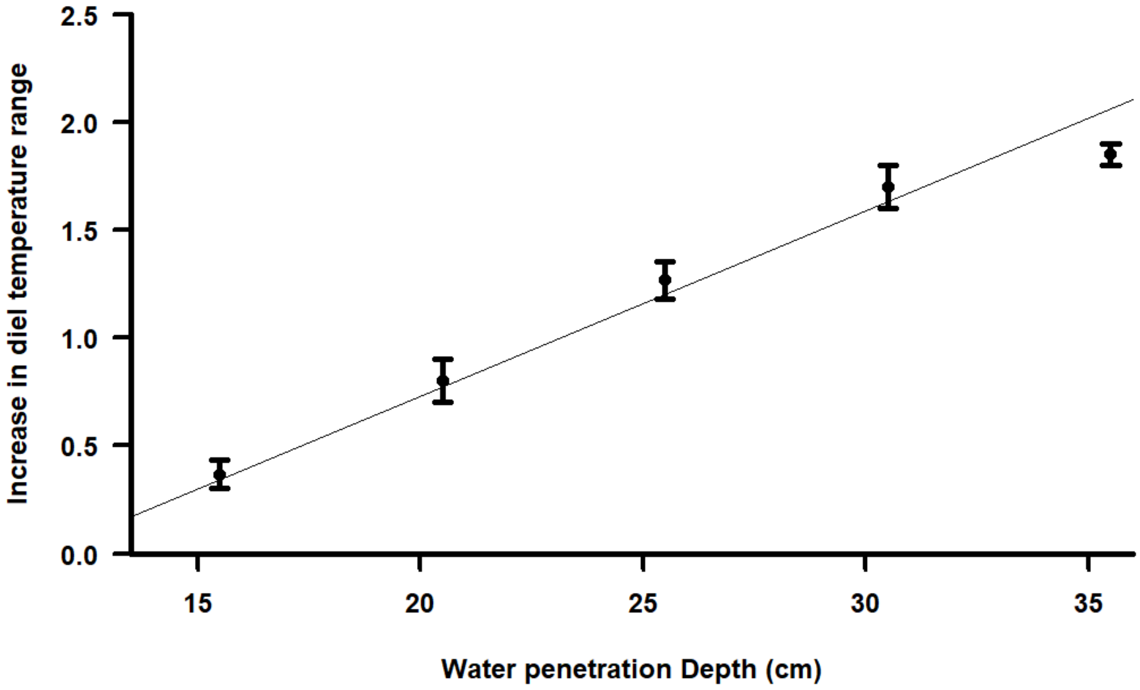

Figure 4. Relationship between water penetration depth and increase in diel temperature range at nest depth (35 cm) for the Intermittent 20 mm irrigation regime. The increase in mean diel temperature range (compared to the control) is plotted against the measured water penetration depth (15 – 35 cm) for the Intermittent 20 mm regime (*n* = 3) over a 28-day trial period, with irrigation applied every third day. Error bars represent +1 standard error (SE) of the mean. The control (*n* = 1) received a single 10 mm application at the start of the trial. Only two replicates of the Intermittent 20 mm regime reached 35 cm depth by the end of the trial.

For the Single 100 mm regime, water reached nest depth on day 1 within 3.02 ± 0.17 hours. For Daily 20 mm regimes, nest depth was reached on day 3 after 69.21 ±

6.79 hours. Two Intermittent 20 mm regimes achieved nest saturation by days 14 and 18 (385.07 ± 70.01 hours), while one reached 30 cm. Final mean nest water content varied greatly, 35.26 ± 2.64% for Single 100 mm, 19.34 ± 10.52% for Intermittent 20 mm, and 82.65 ± 0.26 % for Daily 20 mm regimes, which is an artefact of the experimental set up.

3.2 Seawater irrigation

Over the 6 day trial, 10,080 data points were collected from 45 multi-sensor probes. One Freshwater 10 mm regime was not included in the statistical analysis as water only penetrated to 15 cm depth. Throughout the experimental period, the CT room maintained an average temperature of 26.87 ± 0.62°C, and a humidity of 55.86 ± 1.55%. Over the 6 day trial period, a total of 12.6 L of freshwater and seawater was required, with each individual regime receiving 4.2 L (Daily freshwater 10mm: *n* = 3; Daily seawater 10mm *n* = 3). The same volumes of water were used in the second half of the trial when only salinity was measured. Water temperature applied was an average of 20 ± 0.00°C prior to irrigation. Mean temperatures at nest depth for all treatments prior to irrigation and after temperature adjustments was 25.35 ± 0.03°C.

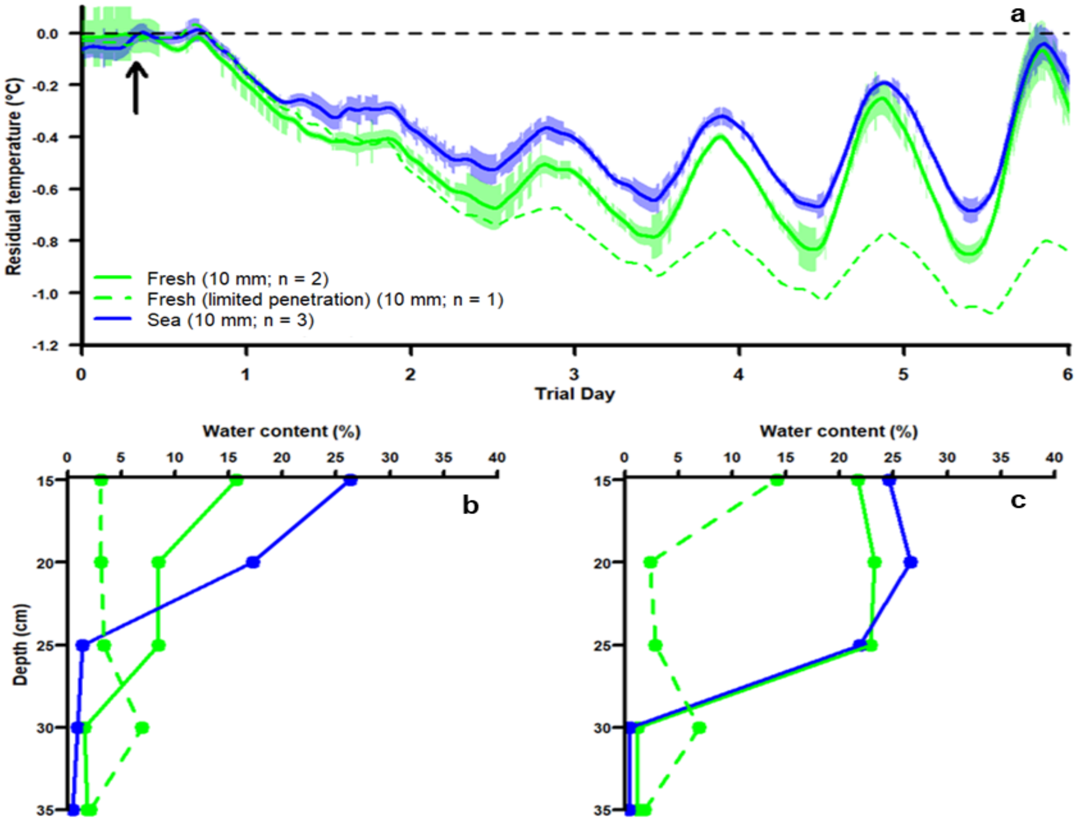

Figure 5. a) Mean residual temperatures traces at 35 cm (nest depth) for Freshwater 10 mm (*n* = 2) and Seawater 10 mm (*n* = 3) compared against a control (no irrigation; *n* = 3) over a 6 day trial. Morning applications (08:00 – 08:30 h) of both seawater and freshwater reduce mean temperatures at nest depth (35 cm), but as the water permeates down the sand column, the diel temperature range

increases and mean daily cooling effect diminishes. Shaded areas indicate ± 1 SE for each regime. A vertical arrow marks the first Irrigation event at 08:00 hours on day 1 of the trial. Irrigation events occurred at 08:00 for subsequent irrigation, preceding artificial sunrise. Water content profiles at 15-35 cm depths on days 3 (b) and 6 (c). Dashed green line indicates a single Freshwater 10 mm treatment where water did not permeate past 15 cm down the sand column during the observed period (*n* = 1).

There was no observed increase in mean maximum temperature immediately following irrigation for both Freshwater 10 mm and Seawater 10 mm regimes at nest depth, compared to the control plot. After 24 hours, both regimes exhibited a daily mean temperature reduction compared to the control (Freshwater 10 mm: -0.47±0.10°C; Seawater 10 mm: -0.36±0.10°C).

There was a significant difference between regimes for mean sand temperature at nest depth (35 cm) ($\chi2 = 120.06$, df = 2, $p < 0.001$) and diel temperature range ($\chi2 = 11.67$, df = 2, $p < 0.001$) but no significant difference on maximum sand temperature ($\chi2 = 2.81$, df = 2, $p = 0.2$) at nest depth. Post-hoc analysis revealed no significant difference between the Freshwater 10mm and Seawater 10mm regimes on mean temperatures ($p = 0.59$) or diel temperature range ($p = 0.9$). The lowest mean daily temperatures occurred on day 4 (Seawater 10 mm: -0.49±0.14°C; Freshwater 10 mm: -0.62±0.14°C). However, by day 6 the cooling effect had diminished slightly (Seawater 10 mm: -0.39±0.20°C; Freshwater 10 mm: -0.50±0.28°C) as mean temperatures increased marginally (Fig. 5a).

For both Freshwater 10 mm and Seawater 10 mm regimes, the diel temperature range at nest depth increased as water penetrated further down the sand column from day 3 (Freshwater 10 mm: 0.17 ± 0.00°C and Seawater 10 mm: 0.13 ± 0.03°C) to day 6 (Freshwater 10 mm: 0.80 ± 0.2°C and Seawater 10 mm: 0.6 ± 0.1°C). At the end of the 12 day trial period, two Seawater 10 mm irrigation regimes reached 30 cm with salinity increasing by 1.72 and 2.12 ppt, while the other reached 25 cm depth with a salinity of 2.25 ppt (Fig. 6).

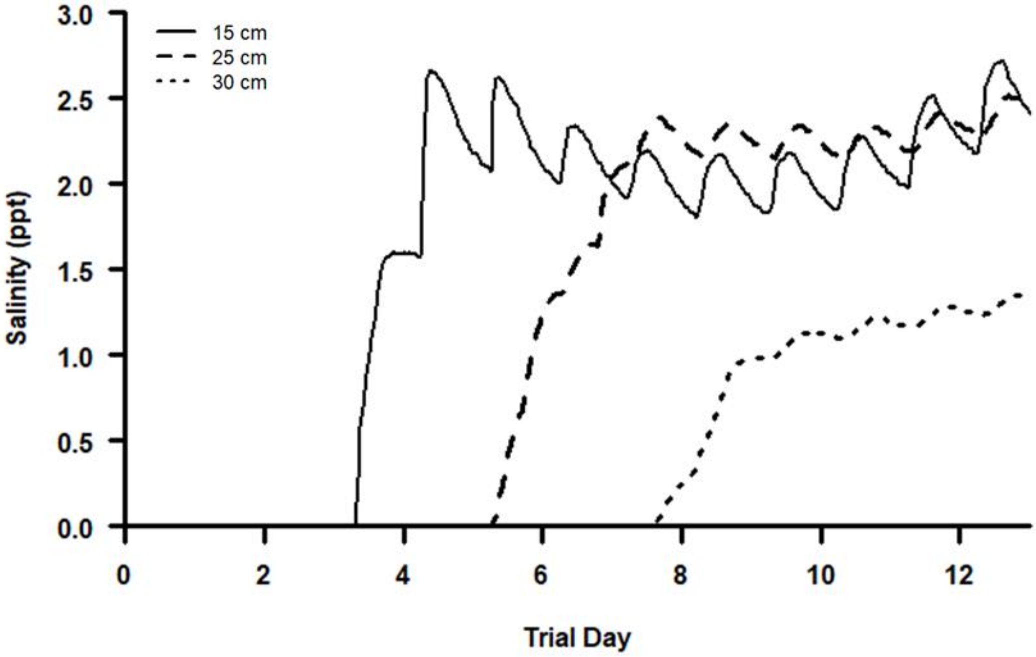

Figure 6. Mean salinity at 15, 25 and 30 cm depth for the Seawater 10mm irrigation regimes over the 12-day trial period. Over the course of the trial, salinity increased, with two Daily Seawater 10mm regimes reaching a depth of 30cm.

3.3 Field trial, Iztuzu beach, Dalyan

A total of 20,160 minutes of data was collected over the 14 day trial period from 48 multi-sensor probes. All data was collected except for one Daily 10 mm regime at 60 cm depth which ran out of battery on day 9 of the trial. Air temperature varied considerably throughout the trial, with two heatwave events, with maximum temperatures reaching 52.95°C and maximum surface sand temperatures of 62.93°C. Over the 14 day trial period, 1,040 L of seawater was used for irrigation of all nests throughout the trial period, with Single 100 mm regimes each requiring 50 L ($n = 4$), Daily 20mm regimes requiring 140 L ($n = 4$), Daily 10 mm regimes requiring 70 L ($n = 4$), and control (0 L; $n = 4$) over the 14 day trial period. Water temperature applied for Single 100 mm regimes was 24.7°C on day 1 of the trial. Average water temperature applied to Daily 20 mm and Daily 10 mm regimes was 26.61± 0.31°C over the 14 day trial period. Pre-irrigation mean sand temperatures after adjustments were 32.13 ± 0.02°C at 35 cm depth, 30.86 ± 0.01°C at 50 cm, and 29.81 ± 0.01°C at 60 cm.

Distance to the shoreline significantly influenced pre-irrigation sand temperatures at all depths measured (Fig. 7). At 35 cm depth, there was a significant positive linear relationship between distance from the shoreline and temperature ($F(1, 1502) = 2765$, $p < 0.01$, $R^2 = 0.648$). The mean temperature increased by 0.20°C ($t = 52.58$, $p < 0.05$) for every 1 m farther from the shoreline. Similarly, at 50 cm depth, distance from the shoreline had a significant positive effect on temperature ($F = 1973$, $df = 1, 1502$, $p < 0.01$, $R^2 = 0.57$), with mean temperature increasing by 0.15°C ($t = 44.42$, $p < 0.05$) per 1 m distance from the shoreline. The relationship between distance and temperature was also significant at 60 cm depth, although the effect diminished slightly ($F = 441$, $df = 1, 718$, $p < 0.01$, $R^2 = 0.38$), with a 0.11°C ($t = 21.0$, $p < 0.05$) increase in mean temperature for every 1 m farther from the shoreline.

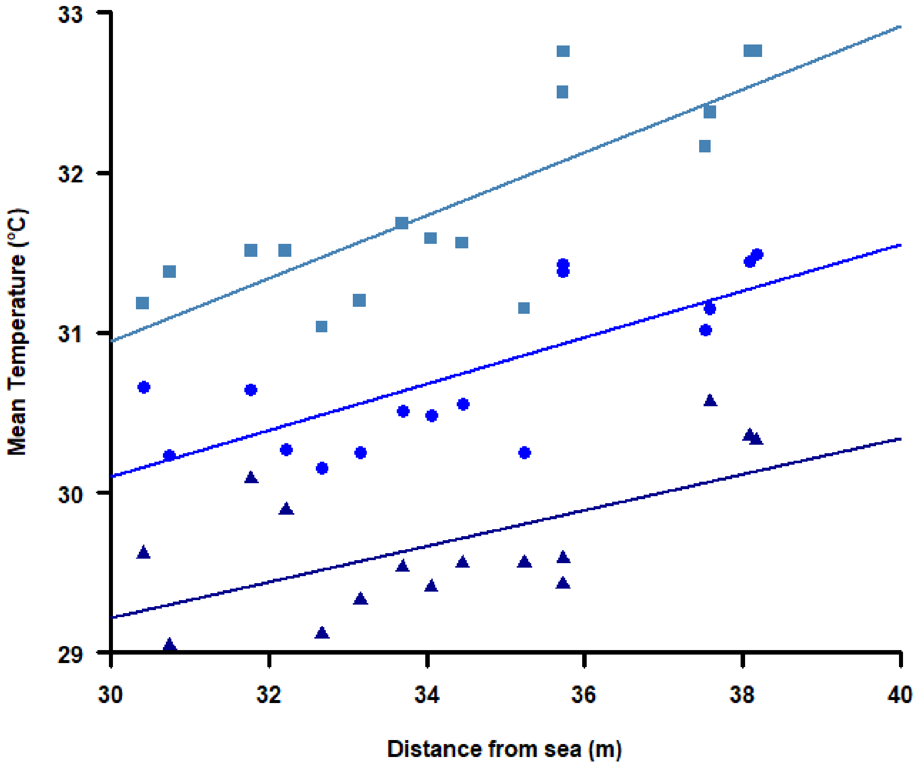

Fig. 7. The effect of distance (m) from the shoreline on mean sand temperatures at 35 cm (■), 50 cm (●), and 60 cm (▲) depth during 48-hour period prior to irrigation for all treatment plots (*n* = 48). Solid lines represent the best fit regression lines corresponding to each depth.

There was a significant difference between regimes on mean sand temperature at all depths (35 cm: χ2 = 424.81, df = 3, p < 0.05; 50 cm: χ2 = 201.1207, df = 3, p < 0.05; 60 cm: χ2 = 119.079, df = 3, p < 0.05) over the 14-day trial period. Both Daily 20 mm and Daily 10 mm regimes reduced mean sand temperatures more effectively at shallower depths compared to the control, with the cooling effect diminishing further down the sand column (Daily 20 mm: -0.81 ± 0.15 °C at 35 cm, -0.47 ± 0.09 °C at 50 cm, -0.28 ± 0.07 °C at 60 cm. Daily 10 mm: -0.72 ± 0.06 °C at 35 cm, -0.44 ± 0.03 °C at 50 cm, -0.32 ± 0.05 °C at 60 cm; Fig. 8 a-c). Bonferroni post-hoc analysis showed no significant difference between Daily 10 mm and Daily 20 mm on mean sand temperatures at all depths (P > 0.05). There was a significant difference between regimes on maximum sand temperatures at all depths (35 cm: χ2 = 18.21, df = 3, p < 0.001; 50 cm: χ2 = 11.57, df = 3, p = 0.01; 60 cm: χ2 = 9.35, df = 3, p = 0.02) however, only the Daily 10 mm regime significantly affecting maximum temperatures compared to the control at 35 cm (P = 0.01) and 50 cm (P = 0.01). The Single 100 mm regime initially decreased maximum sand temperatures at 35 cm (-0.55 ± 0.05 °C) but increased temperatures at 50 cm (0.14 ± 0.01 °C) and 60 cm (0.16 ± 0.02 °C) 24 hours post-irrigation, however, these differences were not statistically significant (P > 0.05). There was a significant difference between regimes on the effect on diel temperature range at 35 cm ($\chi2$ = 31.42, df = 3, p < 0.05) and 50 cm ($\chi2$ = 19.19, df = 3, p < 0.05) but not at 60 cm depth ($\chi2$ = 4.09, df = 3, p = 0.25). The Daily 20 mm regime significantly increased the diel temperature range at 35 cm (mean increase: 0.45 ± 0.04, P < 0.001) and 50 cm (mean increase: 0.1 ± 0.01, P = 0.001) compared to the control. In contrast, the Daily 10 mm regime had no significant effect on diel temperature range at either depth (P > 0.05).

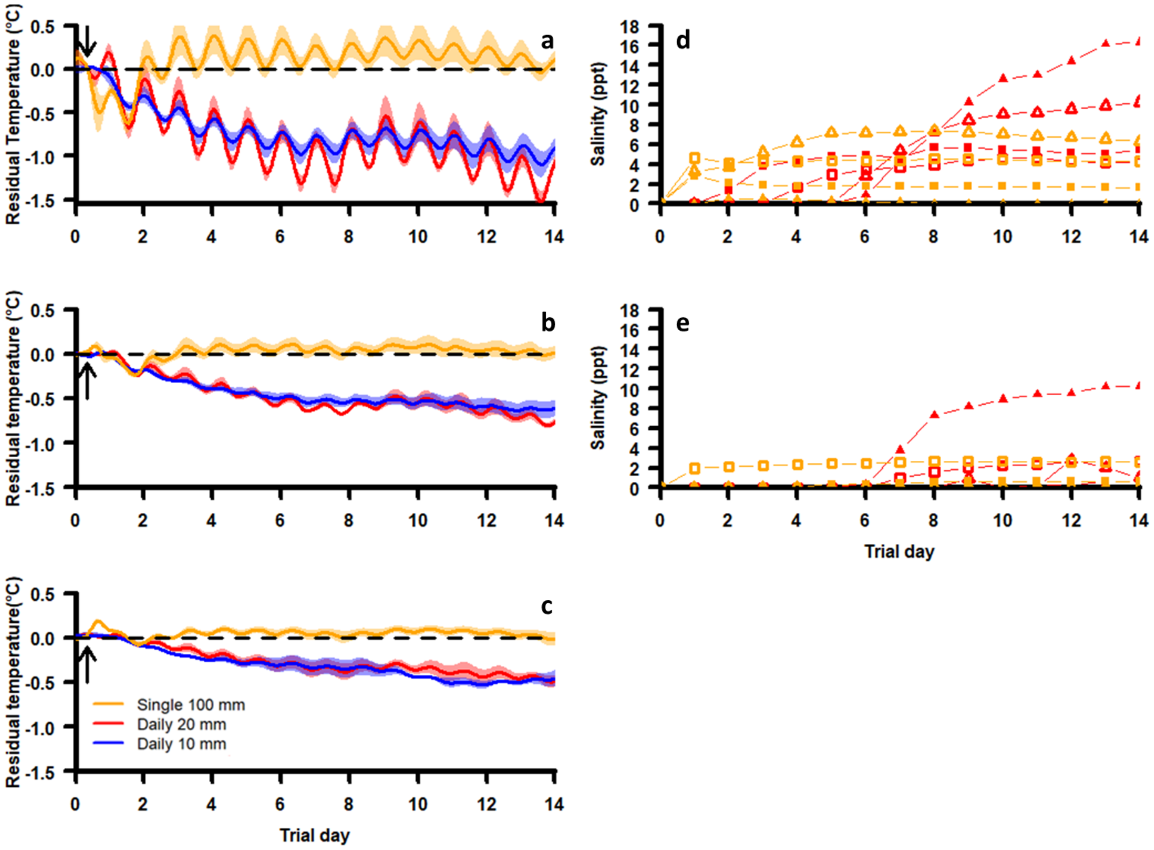

Figure. 8. a) Mean residual temperature traces for three different irrigation regimes during the 14-day trial: Single 100 mm (*n* = 4), Daily 20 mm (*n* = 4) and Daily 10 mm (*n* = 4) compared against a single control (*n* = 4) at a) 35 cm, b) 50 cm and c) 60 cm depth. Shaded areas indicate ± 1 SE for each

regime. Vertical black arrow marks first irrigation event at 07:00 on day 1 of the trial. Both daily irrigation regimes decreased mean sand temperatures at all depths whereas the large volume (100 mm) single application led to elevated temperatures. Salinity (ppt) levels for each day of the trial at d) 35 and, e) 50 cm depths. Larger volume (20 mm) daily applications led to highest salinity levels observed (max: 15.9 ppt).

The Single 100 mm regime led to an increase in salinity, although there was variability between individual regimes at 35 cm (max 6.29 ppt), with a minimal rise at 50 cm (max: 2.66 ppt; Fig. 8e). Over the trial period, the D20 regime resulted in the most significant salinity increase at both 35 cm and 50 cm depths (max 16.28 and 10.16 ppt respectively). In contrast, the D10 treatments showed no observable increase in salinity at either 35 cm or 50 cm depth.

4. Discussion

Our results demonstrate that artificial irrigation can effectively cool sand temperatures at sea turtle nest depths under controlled laboratory conditions and at a nesting site, but that wetting of the sand column to nest depth can cause increased maximum temperatures, and use of seawater for irrigation can increase sand salinity to dangerous levels. Extreme caution is therefore required to design an appropriate irrigation regime for the local conditions in order to implement this mitigation strategy effectively. During two heatwave events, the daily application of a small volume of water was most successful in lowering both mean and maximum sand temperatures at nest depth without increasing salinity or moisture content, aligning with a previous trial using a similar approach (Hill et al., 2015). In contrast, both controlled and field trials have shown that high volume, one-off irrigation regimes have the potential to increase maximum sand temperatures at nest depth, as well as increase salinity when seawater is used, both of which are known to increase embryonic mortality in sea turtles (Howard et al., 2014; Bustard & Greenham, 1968). This contrasts with previous trials that found high volume, single application treatments to be most effective at cooling (Smith et al., 2021; Young et al., 2023), however, this may be due to cooler ambient conditions during these trials with reported nest temperatures prior to irrigation at 70 cm depth between 27.0°C to 27.8°C (Smith et al., 2021) and 27.3 ± 0.1°C to 27.7 ± 0.1 (Young et al., 2023). From our trials with relatively high irradiation, we observed two effects following water penetration of the sand column to nest depth: 1) an initial spike in temperature at nest depth due to water percolating through heated layers of sand above and transferring that heat downwards, and 2) increased maximum temperatures and diurnal temperature range post-irrigation, as the wetted sand column allows more effective heat transfer down the sand column to nest depth (Hamdhan & Clarke 2010; Huber et al., 2012).

The present findings suggest that artificial irrigation should be considered separately from natural rainfall events, which are unlikely to coincide with increased solar radiation. During heatwaves and on the hottest sea turtle nesting beaches, sufficient cooling to address primary sex ratio skews is unlikely achievable using artificial irrigation. In these extreme cases, the aim should be to reduce nest temperatures to prevent embryonic overheating, which is already a cause of large-scale egg mortality (Turkozan et al., 2021). Artificial irrigation in concert with high solar irradiation carries a risk of increasing maximum nest temperatures if water reaches nest depth, necessitating localised trials to assess water penetration at proposed nest irrigation sites.

Temperature

Previous research has suggested the volume and temperature of water applied were the major factors affecting cooling from artificial irrigation (Gatto et al., 2023; Young et al., 2023). However, our findings indicate that the effect of irrigation also heavily depends on the environmental conditions at the time of irrigation and the subsequent period. Within both controlled settings and at a nesting site, a large volume of relatively cool water led to elevated daily mean and maximum temperatures at all nest depths ranging from 35 to 60 cm. In the field, the environmental context of extreme air (max 52.95°C) and surface sand (max 62.93°C) temperatures negated any potential cooling from a large volume of cool water (100 mm; 24.7°C). Unlike recent trials (Smith et al. 2021; Young et al. 2023) where ~24°C irrigation water that achieved sustained cooling of 1.5-2°C, the water here had to penetrate heated surface layers before reaching further down the sand column, facilitating downward heat transfer instead of cooling. The sustained increase in temperature after the single large irrigation events is attributable to the increased thermal conductivity of the wetted sand column, which allows more efficient vertical heat transfer (Hamdhan & Clarke 2010).

In both controlled and field studies, only the daily irrigation regime consistently reduced sand temperatures at nest depth, and this cooling effect diminishes further down the sand column. It should be noted in the first controlled trial, that the unnaturally high water content (82.65 ± 0.26% SE) observed under the larger volume (100 mm), daily irrigation regime was likely due to the limited drainage conditions in the experimental setup compared to the open beach. Our results align with previous studies identifying repeated irrigation as an effective strategy for mitigating high nest temperatures (Hill et al. 2015; Lolavar & Wyneken 2021) but emphasise the need for careful regime design in order to avoid increased vertical heat transfer through wetting sand down to nest depth.

A strong linear relationship was evident between the depth of water penetration and the increase in thermal diel range within nests. While limited research exists on the impacts of daily cyclic temperature fluctuations on sea turtle embryogenesis (Booth 2018), studies in shallower nesting freshwater and terrestrial turtles have reported varied findings on phenotype and hatching success (Micheli-Campbell et al., 2012; Georges et al., 2005; Du & Ji 2006; Lu et al., 2021). In freshwater and terrestrial species, embryos exposed to fluctuating temperatures exhibit a higher likelihood of female bias compared to constant temperatures with the same mean temperature (Raynal et al. 2022). Moreover, fluctuating temperature treatments at higher mean temperatures resulted in 67.32% lower hatching success compared to embryos developed in constant temperatures at the same mean temperature (Raynal et al. 2022). These findings underscore the need to investigate the effects of increased daily temperature fluctuations during sea turtle embryonic development on TSD response, hatchling fitness, and egg survival - which may be particularly relevant for shallower nesting species (Houghton & Hays 2001), as all tested irrigation regimes that wetted the sand to nest depth increased diel temperature range at shallower depths.

Salinity

Theoretically, sea turtle eggs incubating in a high salinity environment will experience osmotic water loss to the higher solute concentration in the surrounding saline sand matrix, which can prove lethal to the embryos. This was empirically demonstrated by eggs encased in seawater-saturated sand, which rapidly desiccated (Bustard & Greenham 1968). However, more recent research suggests the embryonic stage and duration of exposure determine whether salinity leads to mortality (Limpus et al., 2020). In our trial we were for the first time, able to directly measure *in situ* salinity over time post-irrigation. A single irrigation event moderately increased salinity up to 50 cm nest depth, supporting findings that single events at these tested volumes are unlikely to reach high salinities causing embryonic mortality (Young et al., 2023). Conversely, daily seawater irrigations that penetrated down the sand column caused salts to accumulate via evaporation and then be transported downwards by subsequent irrigations, significantly raising salinity levels at all measured depths. Daily irrigation that did not penetrate down the sand column had similar levels of cooling to larger volumes but did not increase salinity at any depth although surface sand salinity was not measured in our trials. While freshwater and seawater did not differ in cooling ability in the second phase controlled trial, further testing is needed. Our findings suggest that seawater should be used conservatively at a reduced volume for surface irrigation only, and with great caution so as not to increase salinity further down the sand column. Further work is needed to investigate the build-up of salinity in surface sand where salt water is applied during irrigation, and potential effects of high salinity surface sand on emergent hatchlings.

Beach factors

Numerous factors influence sand temperatures within sea turtle nesting environments, such as sand albedo (Hays et al., 2001), initial water content of the sand (Lolavar & Wyneken 2017), shading from vegetation (Kamel 2013), nest depth, and nest site location (Wood & Bjorndal 2000). In the current trial, spatial variability in nest temperatures was observed across a relatively small area of the beach (6 m^2) with a 3.9°C difference in mean sand temperatures between 35 cm and 60 cm depths. A relationship was also evident between increasing distance from the shoreline and higher mean sand temperatures, similar to findings from a nearby nesting beach (Kaska et al., 1998). Understanding these site-specific factors better will help inform any irrigation framework. At managed sites such as Itzuzu beach, a combination of optimal nest location (moving nests to cooler sections of the beach), increasing the depth of relocated nests, and increasing shading could improve reproductive outcomes by moderating nest temperatures, with an appropriate artificial irrigation regime being used during a heatwave event.

Conservation management

In extreme heat environments where nest temperatures greatly exceed the threshold for balanced primary sex ratios, it is unlikely that any irrigation regime will sufficiently reduce temperatures to influence primary sex ratios. In such scenarios, the aim should shift to providing enough cooling to mitigate the risk of embryonic mortality from lethally high temperatures. The present study demonstrated that small daily volumes of water can achieve a modest temperature reduction even under extreme heat conditions. However, the potential impacts of salt buildup at the sand surface on hatchling emergence ability warrant further investigation. This approach offers several advantages: 1) requiring less total water volume, 2) not relying on the specific water temperature since cooling occurs via a different mechanism, 3) minimizing risk of nest inundation, 4) avoiding increased salinity at nest depths when applied properly, and 5) does not increase the thermal diel range in the incubation environment. An improved understanding of thermal thresholds and the degree of cooling achievable through irrigation will aid in developing adaptive management strategies tailored to the specific conditions and conservation objectives.

Conclusions

Our results highlight the necessity of developing adaptive, site-specific irrigation management plans that consider local environmental conditions and specific conservation objectives. If seawater is to be used, further research is needed to investigate the effects of salinity on embryonic development, both at nest depth and on the sand surface for surface irrigation. For rookeries experiencing temperatures nearing lethal thresholds, wetting the entire sand column should be avoided, as this action increases the maximum temperatures at nest depth. Instead, surface irrigation may provide sufficient cooling at these critical temperature levels. Overall, our findings underscore the importance of tailoring irrigation strategies to the unique circumstances of each nesting site, balancing the potential benefits and drawbacks to ensure the most effective conservation outcomes.

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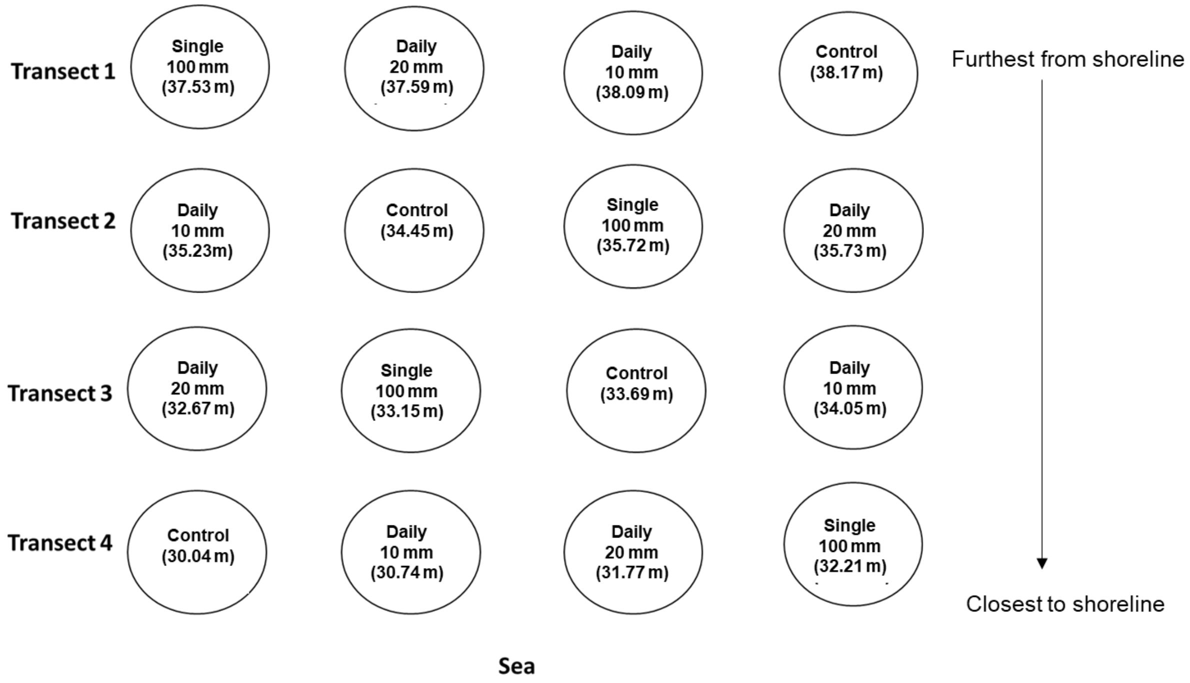
6. Appendices

6.1 Appendix A

Randomized block design with distance to the shoreline serving as the block and treatments (irrigation regimes) being randomly distributed along each block (transect).



Appendix 1. A map of plot locations at Iztuzu Beach, following a randomized block design with distance to the shoreline serving as the block. The treatments (irrigation regimes) are randomly distributed along each block (transect). The treatments are organized into four transects, labelled Transect 1 through Transect 4, parallel to the shoreline. The distances from the shoreline for each plot are marked on the map. Within each plot, probes are installed at depths of 35 cm, 50 cm, and 60 cm. A minimum distance of 1 m separates each plot from adjacent ones. The plots are arranged in order from closest to farthest from the shoreline along each transect.

6.2 Appendix B:

R Scripts used for temperature adjustments and statistical tests

#Temperature adjustment script to allow for standardized starting temperatures across treatments.

```
# Define pre-irrigation time window
prewatering_start <- as.POSIXct("2023-04-04 06:00:00")
prewatering_end <- as.POSIXct("2023-04-04 14:00:00")

# Function to calculate temperature deviations for a single trial data frame
calculate_deviations <- function(trial_data) {
  # Subset data for pre-irrigation period
  prewatering <- trial_data[trial_data$DateTime >= prewatering_start &
                            trial_data$DateTime <= prewatering_end, ]

  # Select temperature columns of interest
  temp_columns <- c("temp5", "temp10", "temp15", "temp20",
                    "temp25", "temp30", "temp35", "temp40", "temp45", "temp50")

  # Create a new dataframe with temperature data
  new_dataframe <- prewatering[, c("DateTime", temp_columns)]

  # Calculate mean temperature for each column (excluding DateTime)
  mean_temperatures <- colMeans(new_dataframe[, -1])

  # Calculate overall mean temperature across all depths
  overall_mean <- mean(mean_temperatures)
```

```
  # Calculate deviations from the overall mean for each depth
  deviations <- overall_mean - mean_temperatures

  # Update temperature data in the original trial data frame
  for (i in seq_along(temp_columns)) {
    trial_data[, temp_columns[i]] <- trial_data[, temp_columns[i]] + deviations[i]
  }

  # Return the modified trial data frame with adjusted temperatures
  return(trial_data)
}

# Apply the function to your trial data
Trial_data_adjusted <- calculate_deviations(trial_data)

# The 'trial_data_adjusted' data frame now has temperature values adjusted ready for analysis
```

 # kruskall wallis hourly mean temperature analysis example

```
# Load the dunn.test package
library(dunn.test)
mean_temperatures <- trial1[trial1$DateTime >= "2023-04-12 14:00:00" & trial1$DateTime <= "2023-05-02 00:00:00", ]
# Calculate the mean temperatures for each irrigation regime
mean_temperatures$Intermittent_20mm <- rowMeans(mean_temperatures[, c("temp11", "temp16", "temp41")])
mean_temperatures$Single_100mm <- rowMeans(mean_temperatures[, c("temp1", "temp26", "temp46")])
mean_temperatures$Daily_20mm <- rowMeans(mean_temperatures[, c("temp6", "temp31", "temp36")])

# Combine the temperature data into one column
temperature <- c(mean_temperatures$Intermittent_20mm, mean_temperatures$Daily_20mm,
          mean_temperatures$Single_100mm, mean_temperatures$Control)

# Create a group variable
group <- factor(c(rep("Intermittent_20mm", nrow(mean_temperatures)),
          rep("Daily_20mm", nrow(mean_temperatures)),
          rep("Single_100mm", nrow(mean_temperatures)),
          rep("Control", nrow(mean_temperatures))))

# Perform Kruskal-Wallis test
kw_result <- kruskal.test(temperature, group)

# Perform Dunn test for post hoc analysis
dunn_result <- dunn.test(temperature, group, method = "bonferroni")
```

#Kruskall wallis and Bonferroni post-hoc analysis Maximum temperatures examples

```
# Load the dunn.test package
library(dunn.test)
# Calculate the mean temperatures for each irrigation regime
max_temperatures$Intermittent_20mm <- rowMeans(max_temperatures[, c("IW1", "IW2", "IW3")])
max_temperatures$Single_100mm <- rowMeans(max_temperatures[, c("OW1", "OW2", "OW3")])
max_temperatures$Daily_20mm <- rowMeans(max_temperatures[, c("DW1", "DW2", "DW3")])
max_temperatures$Control <- max_temperatures$temp21

# Combine the temperature data into one column
temperature_max <- c(max_temperatures$Intermittent_20mm, max_temperatures$Daily_20mm,
              max_temperatures$Single_100mm, max_temperatures$Control)

# Create a group variable
group <- factor(c(rep("Intermittent_20mm", nrow(max_temperatures)),
           rep("Daily_20mm", nrow(max_temperatures)),
           rep("Single_100mm", nrow(max_temperatures)),
           rep("Control", nrow(max_temperatures))))

# Perform Kruskal-Wallis test
kw_result_max <- kruskal.test(temperature_max, group)

# Perform Dunn test for post hoc analysis
dunn_result_max <- dunn.test(temperature_max, group, method = "bonferroni")
```

Kruskall wallis and Bonferroni post-hoc analysis daily temperature ranges example

```r
# Load the dunn.test package
library(dunn.test)

# Calculate the mean temperatures for each irrigation regime
range_temperatures$Intermittent_20mm <- rowMeans(range_temperatures[, c("IW1", "IW2", "IW3")])
range_temperatures$Single_100mm <- rowMeans(range_temperatures[, c("OW1", "OW2", "OW3")])
range_temperatures$Daily_20mm <- rowMeans(range_temperatures[, c("DW1", "DW2", "DW3")])
range_temperatures$Control <- range_temperatures$temp21

# Combine the temperature data into one column
temperature_range <- c(range_temperatures$Intermittent_20mm, range_temperatures$Daily_20mm,
            range_temperatures$Single_100mm, range_temperatures$Control)

# Create a group variable
group <- factor(c(rep("Intermittent_20mm", nrow(range_temperatures)),
            rep("Daily_20mm", nrow(range_temperatures)),
            rep("Single_100mm", nrow(range_temperatures)),
            rep("Control", nrow(range_temperatures))))

# Perform Kruskal-Wallis test
kw_result_range <- kruskal.test(temperature_range, group)

# Perform Dunn test for post hoc analysis
dunn_result_range <- dunn.test(temperature_range, group, method = "bonferroni")
```

6.3 Appendix C

Controlled temperature and humidity trial 1 statistical outputs

Mean Temperature Analysis

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 1433.9655
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily_20	Intermittent_20
Daily_20	Mean Diff: 25.16		
	P: < 0.001*		
Intermittent_20	Mean Diff: 12.69	Mean Diff: -12.47	
	P: < 0.001*	P: < 0.001*	
Single_100	Mean Diff: -10.49	Mean Diff: -35.65	Mean Diff: -23.18
	P: < 0.001*	P: < 0.001*	P: < 0.001*

Note: Significant differences are indicated by p-values ≤ 0.05 (Bonferroni correction).

Max Temperature Analysis

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 1417.6127
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily_20	Intermittent_20
Daily_20	Mean Diff: 24.28		
	P: < 0.001*		
Intermittent_20	Mean Diff: 11.59	Mean Diff: -12.68	
	P: < 0.001*	P: < 0.001*	
Single_100	Mean Diff: -11.53	Mean Diff: -35.81	Mean Diff: -23.12
	P: < 0.001*	P: < 0.001*	P: < 0.001*

Daily Temperature Range Analysis

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 71.4606
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily_20	Intermittent_20
Daily_20	Mean Diff: -5.23		
	P: < 0.001*		
Intermittent_20	Mean Diff: -6.7	Mean Diff: -1.47	
	P: < 0.001*	P: < 0.001*	
Single_100	Mean Diff: -7.8	Mean Diff: -2.57	Mean Diff: -1.1
	P: < 0.001*	P: < 0.001*	P: < 0.001*

Linear Model: Diel Range vs Depth of Water Penetration

Call: lm(formula = IW_mean ~ Depth, data = data)

Min	1Q	Median	3Q	Max
-0.05667	-0.01000	0.07000	0.11667	-0.12000

Coefficients:

- (Intercept): Estimate = -0.73667, Std. Error = 0.18055, t value = -4.08, Pr(>|t|) = 0.02659 *
- Depth: Estimate = 0.07733, Std. Error = 0.00695, t value = 11.13, Pr(>|t|) = 0.00156 **

Model Summary:

- Residual standard error: 0.1099 on 3 degrees of freedom
- Multiple R-squared: 0.9763
- Adjusted R-squared: 0.9685
- F-statistic: 123.8 on 1 and 3 DF
- p-value: 0.001555

6.4 Appendix D

Controlled temperature and humidity trial 2 statistical outputs

Mean Temperature Analysis

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 120.0568
- df = 2
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily_Fresh	Daily_Sea
Daily_Fresh	Mean Diff: 10.35		
	P: < 0.001*		
Daily_Sea	Mean Diff: 8.29	Mean Diff: -2.06	
	P: < 0.001*	P: 0.0587	

Max Temperature Analysis

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 2.8187
- df = 2
- p-value = 0.24

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily_Fresh	Daily_Sea
Daily_Fresh	Mean Diff: 1.68		
	P: 0.14		
Daily_Sea	Mean Diff: 0.92	Mean Diff: -0.76	
	P: 0.54	P: 0.67	

Daily Temperature Range Analysis

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 11.6729
- df = 2
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily_Fresh	Daily_Sea
Daily_Fresh	Mean Diff: -3.19		
	P: 0.002*		
Daily_Sea	Mean Diff: -2.65	Mean Diff: 0.54	
	P: 0.012*	P: 0.882	

6.5 Appendix E

Field trial statistical outputs

Field trial linear model: mean temperature (pre irrigation) ~ distance from the shoreline (m) 35 cm depth

Call: lm(formula = mean_temp_35cm ~ distances_35cm)

Residuals:

Min	1Q	Median	3Q	Max
-0.82125	-0.26023	0.07151	0.22046	0.68227

Coefficients:

- Intercept (Intercept): Estimate = 25.025174, Std. Error = 0.129551, t value = 193.17, p-value < 2e-16***
- Slope (distances_35cm): Estimate = 0.197224, Std. Error = 0.003751, t value = 52.58, p-value < 2e-16***

Model Summary:

- Residual standard error: 0.3605 on 1502 degrees of freedom
- Multiple R-squared: 0.648 (adjusted R-squared: 0.6477)
- F-statistic: 2765 on 1 and 1502 DF, p-value: < 2.2e-16

50 cm depth

Call: lm(formula = mean_temp_50cm ~ distances_50cm)

Residuals:

Min	1Q	Median	3Q	Max
-0.60738	-0.19429	-0.08922	0.22261	0.50106

Coefficients:

- Intercept (Intercept): Estimate = 25.744368, Std. Error = 0.112837, t value = 228.16, p-value < 2e-16***
- Slope (distances_50cm): Estimate = 0.145132, Std. Error = 0.003267, t value = 44.42, p-value < 2.2e-16***

Model Summary:

- Residual standard error: 0.314 on 1502 degrees of freedom
- Multiple R-squared: 0.5678 (adjusted R-squared: 0.5675)

- F-statistic: 1973 on 1 and 1502 DF, p-value: < 2.2e-16

60 cm depth

Call: lm(formula = mean_temp_60cm ~ distances_60cm)

Min	**1Q**	**Median**	**3Q**	**Max**
-0.4352	-0.2638	-0.1571	0.3564	0.6665

Coefficients:

- Intercept (Intercept): Estimate = 25.845973, Std. Error = 0.183591, t value = 140.8, p-value < 2e-16***
- Slope (distances_60cm): Estimate = 0.112304, Std. Error = 0.005348, t value = 21.0, p-value < 2.2e-16***

Model Summary:

- Residual standard error: 0.3478 on 718 degrees of freedom
- Multiple R-squared: 0.3805 (adjusted R-squared: 0.3796)
- F-statistic: 441 on 1 and 718 DF, p-value: < 2.2e-16

Field Trial Temperature metrics Statistical outputs

Mean Temperature Analysis (35 cm)

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 424.8083
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	**Control**	Daily_20	Daily_10
Daily_20	Mean Diff: 14.46135		
	P: 0.0000*		
Single_100	Mean Diff: -1.397529	Mean Diff: -15.85888	
	P: 0.4868	P: 0.0000*	
Daily10	Mean Diff: 13.16430	Mean Diff: -1.297049	Mean Diff: 14.56183
	P: 0.0000*	P: 0.5838	P: 0.0000*

Mean Temperature Analysis (50 cm)

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 200.7029
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily10	Daily20
Daily10	Mean Diff: 9.392366		
	P: 0.0000*		
Daily20	Mean Diff: 9.978831	Mean Diff: 0.586465	
	P: 0.0000*	P: 1.0000	
Single10	Mean Diff: -0.627087	Mean Diff: -10.01945	Mean Diff: -10.60591
	P: 1.0000	P: 0.0000*	P: 0.0000*

Mean Temperature Analysis (60 cm)

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 118.9403
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily10	Daily20
Daily10	Mean Diff: 7.553274		
	P: 0.0000*		
Daily20	Mean Diff: 6.743005	Mean Diff: -0.810268	
	P: 0.0000*	P: 1.0000	
Single10	Mean Diff: -1.017067	Mean Diff: -8.570341	Mean Diff: -7.760072
	P: 0.9274	P: 0.0000*	P: 0.0000*

Max Temperature Analysis (50 cm)

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 118.9403
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily10	Daily20
Daily10	Mean Diff: 2.828551		
	P: 0.0140*		

Daily20	Mean Diff: 1.534020	Mean Diff: -1.294531	
	P: 0.3751	P: 0.5864	
Single10	Mean Diff: -1.152133	Mean Diff: -3.980685	Mean Diff: -2.686153
	P: 0.7478	P: 0.0002*	P: 0.0217*

Max Temperature Analysis (50 cm)

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 118.9403
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily10	Daily20
Daily10	Mean Diff: 2.920042		
	P: 0.0105*		
Daily20	Mean Diff: 1.469733	Mean Diff: -1.450309	
	P: 0.4249	P: 0.4409	
Single100	Mean Diff: 0.038847	Mean Diff: -2.881194	Mean Diff: -1.430885
	P: 1.0000	P: 0.0119*	P: 0.4574

Max Temperature Analysis (60 cm)

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 118.9403
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily10	Daily20
Daily10	Mean Diff: 7.553274		
	P: 0.0000*		
Daily20	Mean Diff: 6.743005	Mean Diff: -0.810268	
	P: 0.0000*	P: 1.0000	
Single10	Mean Diff: -1.017067	Mean Diff: -8.570341	Mean Diff: -7.760072
	P: 0.9274	P: 0.0000*	P: 0.0000*

Daily Temperature Range Analysis (35 cm)

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 31.4233
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily_20	Single_100
Daily_20	Mean Diff: -5.301673		
	P: 0.0000*		
Single_100	Mean Diff: -3.502082	Mean Diff: 1.799591	
	P: 0.0014*	P: 0.2158	
Daily_10	Mean Diff: -1.683071	Mean Diff: 3.618602	Mean Diff: 1.819011
	P: 0.2771	P: 0.0009*	P: 0.2067

Daily Temperature Range Analysis (50 cm)

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 19.1866
- df = 3
- p-value = 0

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily_20	Single_100
Daily_20	Mean Diff: -3.554021		
	P: 0.0011*		
Single_100	Mean Diff: -2.382294	Mean Diff: 1.171726	
	P: 0.0516	P: 0.7239	
Daily_10	Mean Diff: 0.032368	Mean Diff: 3.586389	Mean Diff: 2.414662
	P: 1.0000	P: 0.0010*	P: 0.0472

Daily Temperature Range Analysis (60 cm)

Kruskal-Wallis Test:

- Kruskal-Wallis chi-squared = 4.0865
- df = 3
- p-value = 0.25

Dunn Post Hoc Test (Bonferroni):

Comparison	Control	Daily_20	Single_100
Daily_20	Mean Diff: -0.608222		
	P: 1		
Single_100	Mean Diff: -0.776453	Mean Diff: -0.168231	
	P: 1	P: 1	
Daily_10	Mean Diff: 1.048212	Mean Diff: 1.656434	Mean Diff: 1.824666
	P: 1	P: 0.2929	P: 0.2042

Statement of expenditure

Controlled Experiment Expense Sheet

Date: 31/01/2023- 31/06/2023

Location: Swansea University

Table 1. Total expenses for laboratory controlled trials.

Description	Reference Code	Quantity	Unit Cost (GBP)	Total Cost (GBP)
Watering tops for plastic bottles	NA	8 pcs	£5.00	£40.00
Duracell Procell Intense Battery AA (box of 8)	212-4954	5	£6.75	£33.75
SRA3 Black Card 300 gsm	SRA3 blad	35	£0.80	£28.00
Retort Stand Rod Steel 1000mm	STR03004	5	£7.25	£36.25
Retort Clamp Cork Lined	SCL01002	4	£4.15	£16.60
SDI-12 Multi Parameter Sensor (WET150)	90278990		187	7,012.50
GP2 Data Logger	85437090		1,050.00	787.5
5-Way M12 Extension Cables (EXT/5W-01)	90278990		19	855
SDI12 T Piece for Connection to M12 Cable (STP1)	85439000		23	1,035.00
GP2 Mains Power Supply for GP2 Analyzer	85439000	1	£36.50	£36.50
Mains Lead UK Plug to IEC Connector	85439000	1	£9.15	£9.15
			Overall cost	£9,890.25

Field trial Expense Sheet

Date: 01/07/2023- 31/07/2023

Location: Itzuzu beach, Dalyan Turkey

Table 1. total expenses for field trial.

Description	Reference Code	Quantity	Unit Cost (GBP)	Total Cost (GBP)
Flights to Dalaman Field Site	NA	1	£270.50	£270.50
Field Site Accommodation (Dekamer)	NA	1	£142.00	£142.00
			Overall cost	£412.50

Statements of contribution

Fred Baggs was responsible for, data collection, analysis, software development, writing the original draft, and subsequent revision and editing. I have approved the final submitted version of the thesis and take full responsibility for the accuracy of the work and ethical conduct of the research.

Dr. Nicole Esteban provided project supervision, contributed to the study design, methodology, and revision of the thesis.

Dr. Kimberley Stokes provided project supervision, contributed to the study design, methodology, and revision of the thesis.

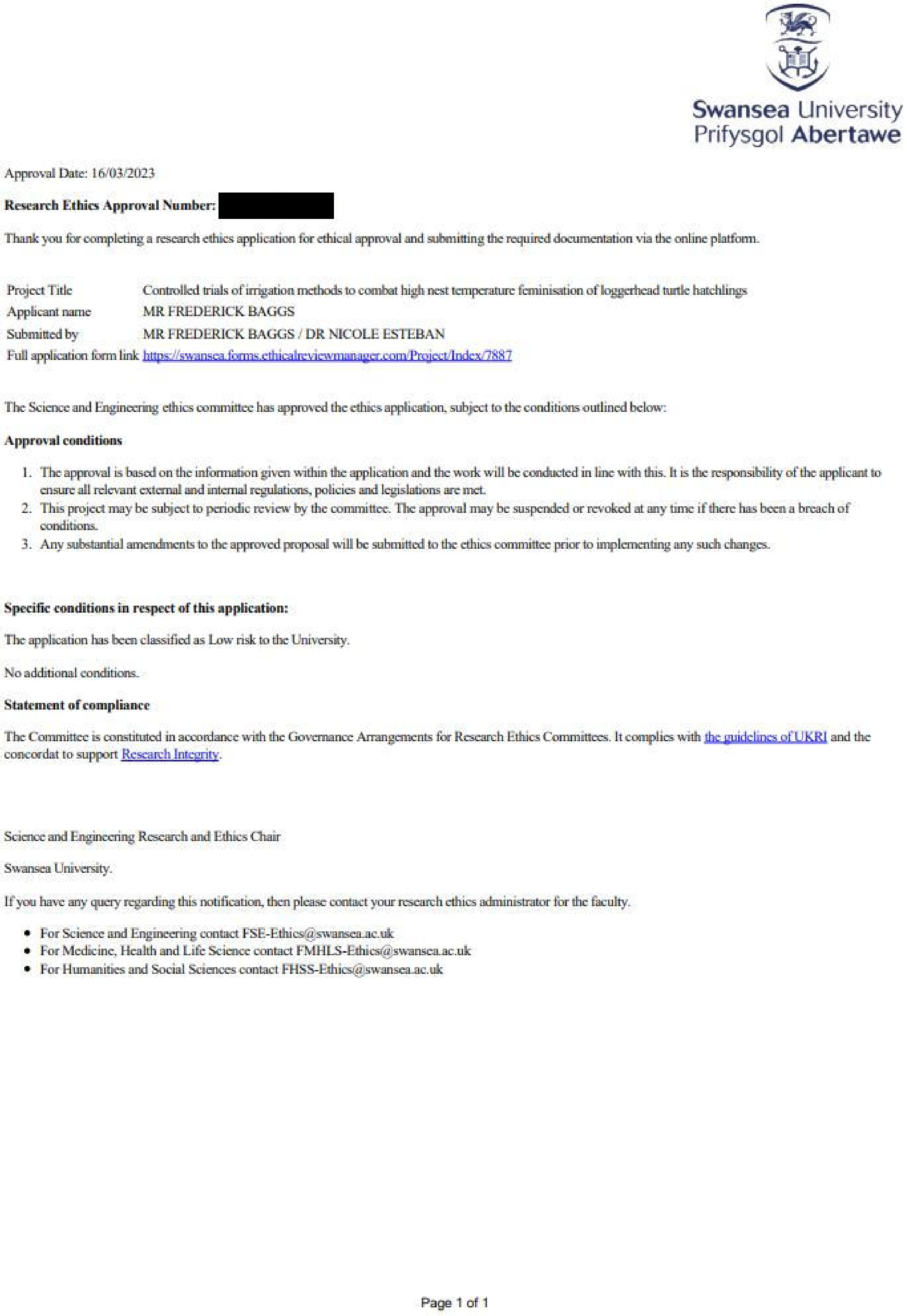
Dr. Yakup Kaska and Dr. Doğan Sözbilen at DEKAMER provided project supervision, historical meteorological weather data, contributed to the study design and supported the fieldwork project.

Dr. David Booth, Professor Graeme Hays, and Dr. Melissa staines contributed to the study design, methodology and provided feedback on initial results.

The map created in Fig. 2a was created by Tommy Valente-Madeira-Rodrigues.

Ethics approval

Controlled trial ethics approval form



Swansea University
Prifysgol Abertawe

Approval Date: 16/03/2023

Research Ethics Approval Number: [redacted]

Thank you for completing a research ethics application for ethical approval and submitting the required documentation via the online platform.

Project Title	Controlled trials of irrigation methods to combat high nest temperature feminisation of loggerhead turtle hatchlings
Applicant name	MR FREDERICK BAGGS
Submitted by	MR FREDERICK BAGGS / DR NICOLE ESTEBAN
Full application form link	https://swansea.forms.ethicalreviewmanager.com/Project/Index/7887

The Science and Engineering ethics committee has approved the ethics application, subject to the conditions outlined below:

Approval conditions

1. The approval is based on the information given within the application and the work will be conducted in line with this. It is the responsibility of the applicant to ensure all relevant external and internal regulations, policies and legislations are met.
2. This project may be subject to periodic review by the committee. The approval may be suspended or revoked at any time if there has been a breach of conditions.
3. Any substantial amendments to the approved proposal will be submitted to the ethics committee prior to implementing any such changes.

Specific conditions in respect of this application:

The application has been classified as Low risk to the University.

No additional conditions.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees. It complies with the guidelines of UKRI and the concordat to support Research Integrity.

Science and Engineering Research and Ethics Chair

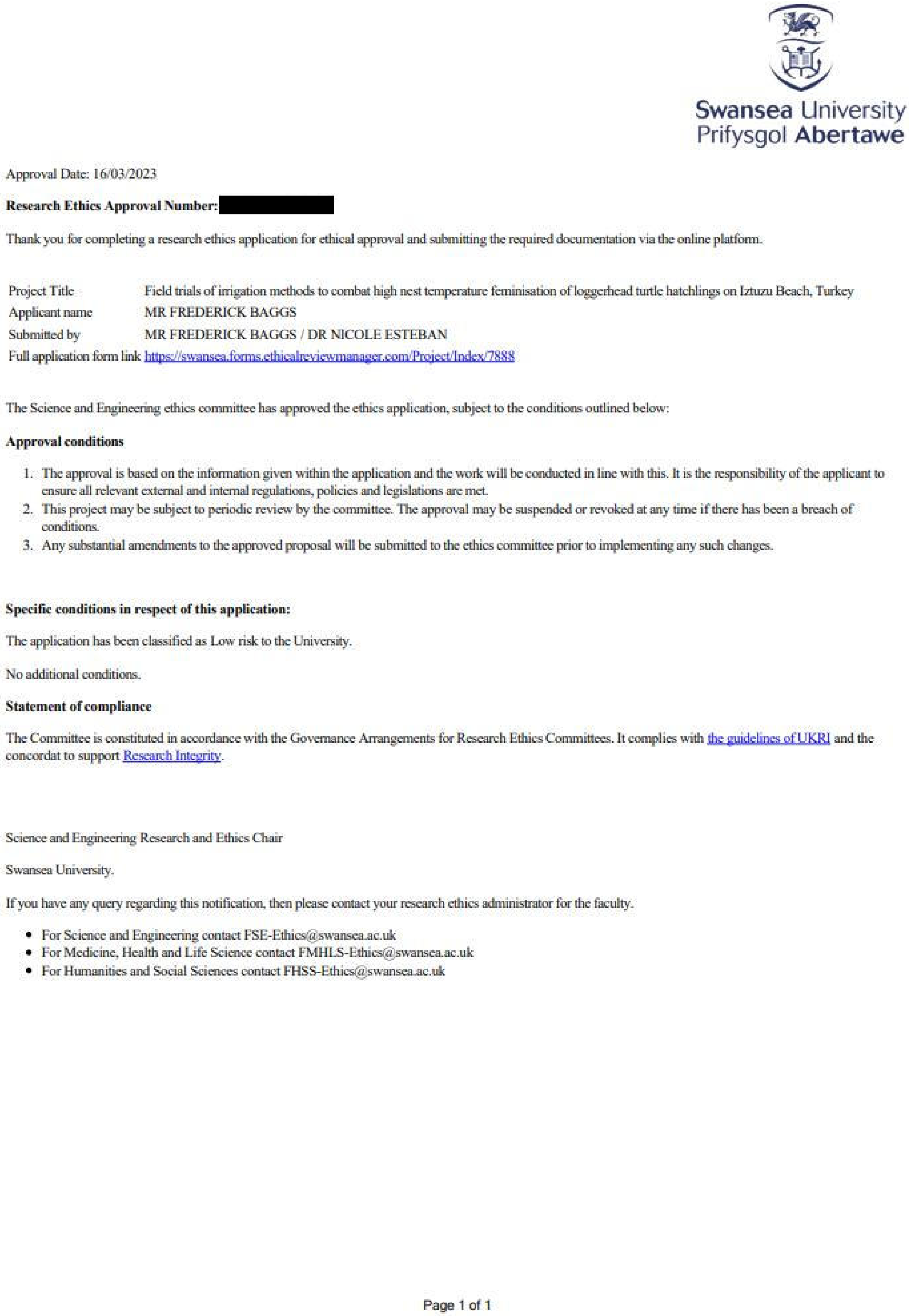
Swansea University.

If you have any query regarding this notification, then please contact your research ethics administrator for the faculty.

- For Science and Engineering contact FSE-Ethics@swansea.ac.uk
- For Medicine, Health and Life Science contact FMHLS-Ethics@swansea.ac.uk
- For Humanities and Social Sciences contact FHSS-Ethics@swansea.ac.uk

Page 1 of 1

Field trial, Dalyan ethics approval



Swansea University
Prifysgol Abertawe

Approval Date: 16/03/2023

Research Ethics Approval Number: [redacted]

Thank you for completing a research ethics application for ethical approval and submitting the required documentation via the online platform.

Project Title	Field trials of irrigation methods to combat high nest temperature feminisation of loggerhead turtle hatchlings on Iztuzu Beach, Turkey
Applicant name	MR FREDERICK BAGGS
Submitted by	MR FREDERICK BAGGS / DR NICOLE ESTEBAN
Full application form link	https://swansea.forms.ethicalreviewmanager.com/Project/Index/7888

The Science and Engineering ethics committee has approved the ethics application, subject to the conditions outlined below:

Approval conditions

1. The approval is based on the information given within the application and the work will be conducted in line with this. It is the responsibility of the applicant to ensure all relevant external and internal regulations, policies and legislations are met.
2. This project may be subject to periodic review by the committee. The approval may be suspended or revoked at any time if there has been a breach of conditions.
3. Any substantial amendments to the approved proposal will be submitted to the ethics committee prior to implementing any such changes.

Specific conditions in respect of this application:

The application has been classified as Low risk to the University.

No additional conditions.

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Page 1 of 1

Risk assessment

Field Risk Assessment			
*Grey boxes must be completed by field leader			
College/ PSU	Bioscience	Assessment date	02/06/23
Location	Dalyan, Turkey	Assessor	Nicole Esteban
Activity	Installing temperature probes on beach; Walking, lifting	Approved by	
		Review date (if applicable)	
Associated documents	• COVID Guidelines • https://www.gov.uk/foreign-travel-advice/turkey • https://www.drum-cussac.net/travel-advices/countries/tr/country/overview • Fieldwork essential information • Fieldwork participant information		

Part One: Risk Assessment

What are the hazards?	Who might be harmed?	How could they be harmed?	What are you already doing?	Do you need to do anything else to manage this risk?
Tide	Staff/students	Getting stuck	Knowledge of tides and sea conditions on shore. Everyone to be briefed about general hazards.	
Beach sampling	Staff/students	Cuts, sprains, fractures	Care required when walking along the beach and sampling. First aid kit carried.	
Snagging and tripping	Staff/students	Lacerations, fractures, serious injuries, death	All field workers should be aware of general trip hazards (and hol particularly in dense undergrowth or near steep drops/slopes. Personnel encountering trip hazards should make other team members aware and issues should be noted for repeat surveys. Any ropes and other equipment needed shall always be kept in a order and monitored to prevent snagging. Any equipment should routed in way not to create trip hazards for field workers or anyon using the site.	
Communication difficulties	Staff/students	Unable to summon first aid or assistance if required	Communication pathways shall be briefed and fully understood by everyone so that safety measures are upheld when teams are out in the field. Field team will carry mobile phones. Ensure communication devices can always be heard. Leave description of field location, expected time of return and contact details with base location (collaborators) to raise help if 'return to base' call check is not received. Protocol for buddy working to be agreed in initial meeting.	
Access	Staff/students	Cuts, sprains, fractures	Commute to study site in car and by foot, where there may be bumps and unstable terrain. Become familiar with path to study site and best routes. A first aid kit should be on person and easily accessible at all times.	
Manual handling	Staff/students	Muscular-skeletal injuries	Where equipment must be carried over a long distance, manual handling protocols should be observed. No one should carry weight over what they are comfortable with and have regular rest breaks. If the	

What are the hazards?	Who might be harmed?	How could they be harmed?	What are you already doing?	Do you need to do anything else to manage this risk?
			equipment exceeds the capabilities of the team then an additional field team member(s) should be added to ensure the task can be carried out safely.	
Driver fatigue	Staff/students	Road Traffic Collision	It is recommended drivers stop for rest breaks for 15 minutes every 2 hours. No trips will be longer than 2 hours. When combining driving and fieldwork on the same day enough time should be allowed to avoid overextending the day. If in doubt, it is recommended that personnel stay the night and travel again the following day. Parked vehicles must be parked in a safe, legal and convenient location and in a manner that does not cause and obstruction or nuisance	
Discarded needles, sharps, pathogens or disease	Staff/students	Various Health Risks	All field teams should have at least one qualified staff first aider. A first aid kit is then carried to site. Appropriate PPE will be worn at all time. Medical attention must be sort immediately in cases of suspected infection. All staff should be informed how to safely dispose of sharps and what to do if a sharps injury has been sustained.	
Adverse weather	Staff/ students	Direct injury as a result of weather e.g. lightening strike or indirect e.g. flooding, wind blown hazards	Weather forecast to be checked everyday and appropriate equipment taken to the field site. Appropriate clothing will be worn by all staff and students for the surveys they are carrying out. All staff to bring wet weather gear in case of inclement weather.	
Potentially harmful species	Staff/students	Irritation, death	Using their training and competence fieldwork leaders should always be alert to the possible presence of harmful species (e.g. mosquitos, ticks, poisonous plants, rats, bats, sharks, jellyfish). PPE should be worn as appropriate e.g. boots, long trousers, wetsuit. Use insect repellent, bed	

What are the hazards?	Who might be harmed?	How could they be harmed?	What are you already doing?	Do you need to do anything else to manage this risk?
			net and permethrin-treated clothing. If bitten by insects apply hydrocortisone cream/calamine lotion and monitor bites. More serious open wounds need to be washed immediately and seek medical attention. Check body for ticks after outdoor activity. Emergency protocols should be followed if feeling unwell. First aid kits should be carried or close by. The Fieldwork Leader should be aware of anyone who may have anaphylaxis reactions to stings.	
Use of hand tools	Staff/students	Cuts and Bruises	Care must be taken when using any tools and safe working practices followed. Appropriate PPE must be worn for the tools being used.	
Working outside	Staff/students	Hypo/hyperthermia. Heat Stroke.	In hot sunny weather team members must wear appropriate sun protection cream and a hat or head scarf during prolonged sunny conditions. Keep hydrated and maintain electrolytes. Ensure that each field team member has adequate hydration fluids and salty snacks. Wear loose, lightweight clothing. If a team member complains of effects of heat, stop work and assess the situation. If suffering from significant sunburn or from heat exhaustion stop work immediately, find shade and seek medical advice. If heat stroke is suspected, get medical help. In cold weather conditions, wear extra layers to prevent hypothermia. In wet weather suitable waterproofs should be worn. If signs of hypothermia are shown, stop work and retreat to somewhere warm and sheltered. Assess the situation. For serious hypothermia call for medical assistance.	
Hygiene	Staff/students	Sickness	When undertaking fieldwork, always clean hands before eating and drinking. Use soap and water if available or hand sanitiser. Wear protective gloves when appropriate.	
Ill health, lack of fitness	Staff/students	Fatigue	Any team members who do not feel fit to partake should alert the Fieldwork leader as soon as possible. All team members will carry their own copy of the SU travel insurance policy as proof of medically insurance. Communicate details of the insurance policy and emergency numbers to each other. Details of Next of Kin and a copy of travel insurance is provided to British Forces BIOT with AMC flight travel request.	
COVID19 measures				

What are the hazards?	Who might be harmed?	How could they be harmed?	What are you already doing?	Do you need to do anything else to manage this risk?
Contraction and spread of COVID	Staff/students	Contraction of COVID 19	Staff will take the necessary precautions before/during and after boarding fights. Students and staff are asked to download the NHS and SafeZone apps to log their visit and in case of separation from the group. Precautions include: - Maintain 2m distance between all non-household persons - Bring own food, water and equipment - Wash hands regularly for 20s (especially before eating) and avoid touching face - Wear medical grade masks - First aid kits will contain barrier ppe (Mask and gloves) in event of use. Any person, or a member of their household, who feels unwell, or has symptoms aligned to COVID 19 will not attend expedition. If anyone become symptomatic during the day, expedition will be cancelled and all members (and their household) should isolate for 14 days. All students to wear masks and sanitise hands before entry and on leaving the plane and transport. All students and staff to inform the App 'Test, trace and protect' of the incident. Respect Turkey controls for Covid-19. Follow current rules as advised on arrival at airport (currently: social distancing of 6 ft, avoid groups of people, no large gatherings). All equipment will be disinfected with disinfectant approved and issued by College of Science (Wallace Stores).	

What are the hazards?	Who might be harmed?	How could they be harmed?	What are you already doing?	Do you need to do anything else to manage this risk?
			Individuals to bring their own food and water to field surveys. Secured and unopened food and water will be carried by team and available in case of emergency. Further information can be found in the university COVID-19 guideline documents which will always be followed. NOTE TO FIRST AIDERS: RESUS council guidelines should be followed regarding CPR. Do not listen for breathing, if CPR is needed place a towel or cloth over the patient's face and use chest compressions only. Wash hands thoroughly. Please review the University Guidelines and the advice from RESUS - https://www.resus.org.uk/media/statements/resuscitation-council-uk-statements-on-covid-19-coronavirus-cpr-and-resuscitation/covid-community/	
Social Distancing	Staff/students	Contraction of COVID19	On shore: All staff and students must maintain a 2m distance from each other, with use of masks where possible. Where possible members of the same household will be allocated to activity groups.	

Actions arising from risk assessment

Actions	Lead	Target Date	Done Yes/No
Inform all staff, students and volunteers of RA and protocols and DEKAMER orientation including first aid	N Esteban	02/07/23	Yes

Actions	Lead	Target Date	Done Yes/No
Order First Aid kit	N Esteban	02/07/23	Yes
Check vaccination requirements	N Esteban	30/06/23	Yes

Risk Assessment

Travel outside of Great Britain (including destinations and transits) if:
FCDO does not advise against travel and **ALL** Drum Cussac risk ratings are **3.0 and below**.

- If you are carrying out low risk fieldwork this can be incorporated into this risk assessment (e.g., office work, attending lectures and conferencing) as defined in the university guidance.
- If you are carrying out moderate/ high risk fieldwork you will need to complete the moderate/ high risk fieldwork risk assessment (see Staff H&S Pages or PG H&S Pages).
- If the travel and/or fieldwork is arranged jointly between one or more Faculties/ PSUs, a shared risk assessment and authorisation should be undertaken.
- If travelling as a group undertaking the same activity, only one risk assessment form needs to be completed along with the Participant Declaration and Information Form.

International Travel Risk Assessor (to be completed by the solo traveller or group leader(s)).			
This should include contact details when travelling e.g., alternative mobile phone number to contact you in an emergency, if known (this can be different to Request to Travel Form).			
Name:	Frederick Baggs		
Email:	[redacted]	Phone:	[redacted]
Faculty:	FSE	School:	Biosciences
Staff ☐ PG Student ☒ UG Student ☐ Other ☐ Please specify:			
Expected Departure Date	02/07/2023	Expected Return Date	03/08/2023

Additional forms included (see Staff H&S Pages or PG H&S Pages)	
Request to Travel Form (required)	☒
Participant Declaration and Information Form (group travel only)	☐
Fieldwork Moderate/ High Risk Assessment Form (where applicable)	☐

Risk considerations

All traveller(s) must confirm that they understand the nature of the risks and the potential impact(s) and that they will take reasonable precautions as detailed below and in the associated guidance to avoid putting themselves or anyone else at risk, in particular:

- Will follow the UK Foreign and Commonwealth Office (FCDO) Travel Advice, Drum Cussac advice and University International Travel guidance.
- Provide itinerary, contact number and emergency contact to the Faculty/ PSU as set out in the guidance document.
- If travelling alone will follow Swansea University (SU) Lone Working Policy.
- Will not travel if adverse weather, natural disaster, or civil disturbance is indicated. In the event of adverse weather, natural disaster or civil disturbance whilst travelling I/traveller will contact SU and global response for advice.

- Will download SafeZone and set up Risk Monitor Traveller prior to departure.
- Will read the SU Travel Insurance Policy and confirm that I/traveller are aware of all exclusions (including higher risk leisure activities).
- If any activities are carried out in free time, outside of the low-risk activity, travellers are aware additional personal insurance may be required.
- Will plan the journey and pre-book or only use transport provided by a reputable company, to avoid unnecessary risks.
- Will use accommodation providers as per SU travel requirements and policy.
- If hiring any vehicles, will ensure the correct licence and insurance are in place to drive the vehicle. The driver/ operator must familiarise themselves with the vehicle prior to departure.
- Will follow the safety advice and guidance of the host organisation and will report any safety concerns to the host organisation and/or to my Faculty/ PSU management.
- Any travellers who have a pre-existing medical conditions/ allergies/ pregnant or new and breast-feeding parents have considered how their medical condition/ requirements will be managed and have appropriate arrangements in place.
- Individuals are not travelling against medical advice.
- Any additional needs of traveller have been discussed and considered prior to departure.
- Appropriate contingency arrangements are in place if I/travellers suffer disruption to accommodation, travel or suffer an injury, ill health.

Emergency Contact Information and Planning

Swansea University Contact This is your main contact at the university who will be available to accept any calls/ communication and manage/ monitor your agreed check-ins.			
Name:	[redacted]		
Phone:	[redacted]	Email:	[redacted]
Accommodation Details If not known, please complete prior to travelling and share with your Swansea University contact.			
Address:	[redacted]		
Phone number(s):	[redacted]		
Emergency Contact			
Swansea University Security 24/7/365:	[redacted]		
Emergency Support Global Response:	[redacted] Global Risk monitor App can be downloaded (see guidance for links)		
SafeZone App:	Downloaded Yes ☒ No ☐		
Personal Emergency Contact (Only complete for solo traveller or group leader(s))			
Name:	[redacted]		
Phone:	[redacted]	Email:	[redacted]

Declaration
International Travel Assessor(s):
By signing this document, as the Travel Risk Assessor you are confirming you: - Are satisfied that the risks of travel have been identified and appropriately controlled. - Have completed the Drum Cussac – Basic Travel Security Awareness Course and attached certificate. - Are fit to travel, are not travelling against medical advice, and not travelling to obtain medical treatment. - Have declared any allergies and sought medical advice where necessary, and appropriate measures are in place.

- Are fit to undertake the activity or reasonable adjustments have been agreed.
- All information and responses given are true and accurate to the best of my knowledge and belief.
- If group leader, will ensure the information is shared with all participants, and the Participant Declaration and Information Form is completed prior to travel.

Name:	**Signature:**	**Faculty/ PSU:**	**Date:**
Frederick Baggs	[redacted]	Biosciences	27/06/2023

Once completed, your Faculty/ PSU will give advice on the correct signatories.

Authorisation to Travel (to be completed by Authoriser)

If the international travel involves more than one Faculty/ PSU, authorisation is required for all Faculty/ PSU's involved.

Authorisation		
By signing this document, as the Authoriser(s) you are confirming you have read the International Travel Risk Assessment and are satisfied that the proposed traveller(s) are taking reasonable precautions.		
Authorisation to travel should be signed for <u>ALL</u> international travel		
Line Manager/ Supervisor of Group Leader	**Name:**	
	Signature:	
	Faculty/ PSU:	
	Date:	
	Name:	
	Signature:	
	Faculty/ PSU:	
	Date:	
	Name:	
	Signature:	
	Faculty/ PSU:	
	Date:	
	Name:	
	Signature:	
	Faculty/ PSU:	
	Date:	

Off-site project form proforma

Student name: Fred Baggs

Degree scheme: Biosciences (MRes)

Place/Institution to be visited: DEKAMER – Sea Turtle Research Rescue and Rehabilitation Center

Duration of Visit (If you intend to visit more than one place or Institution please give dates at each location):

02/07/23 to 03/08/22

Name and address of supervisor on site or sites: Prof Yakup Kazka, Denizli University, Director of DEKAMER

Tel. No: [redacted] (DEKAMER Phone Line & Fax)

Fax No: N/A

E-mail: [redacted]

Alternative contact: Dr Dogan Sozbilen, Denizli University

Tel. No: [redacted]

Swansea supervisor(s): Dr Nicole Esteban

Tel. No: [redacted]

Fax No: N/A

E-mail: [redacted]

Schedule (give details of flights, transfers and accommodation address(es) etc.):

Flights:

Easy Jet – London Gatwick to Dalaman, leaves at 06.25am arrives at 12.30pm, 02/07/22

Easy Jet – Dalaman to London Gatwick, leaves 20.50pm arrives at 23.10pm, 02/08/22

Transfers: provided by centre, 25€ each way to and from Dalaman airport

Accommodation: [redacted].

Name and address and contact number of closest relative/friend who has details of your programme:

[redacted]

I Fred Baggs understand that:

1. Students are expected to follow the safety regulations of SU (as detailed in the Department's Safety Handbook) during all project work wherever this activity occurs as well as whatever local regulations may exist.
2. Students must take out adequate medical/personal insurance for any visit.

Signature of student: [redacted]

Signature of supervisor (Swansea): Date: 31/05/2023

The completed form should be retained by the Teaching Administrative Office and a copy presented to the student.