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An experimental test of lignocellulosic fabrics for potential use in artificial habitat construction in deserts.

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A R T I C L E I N F O

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A B S T R A C T

Climate change has profound effects on drylands, where vegetation like shrubs provide microclimatic refugia for animals. However, prolonged drought and higher temperatures are reducing the resilience of vegetation. Artificial habitat constructions, such as shelters, may function similarly to shrubs in providing climatic refuge. Natural fabrics, including lignocellulosic fabrics, have gained popularity in conservation due to their biodegradability, lightweight, and strength. In this study, we tested the effects of natural fabric canopies on key desert microclimatic variables, including temperature, relative humidity (RH), and light intensity/radiation to select the best-suited fabric for microclimatic amelioration of resident fauna in future field experiments. We used 0.45 m^2 microsites of burlap, canvas, and nursery fabrics angled to the ground at three repetitions per fabric and paired them with data loggers for 30 days to record near-surface air temperature, RH, and radiation. We compared uncovered and similarly illuminated 0.45 m^2 areas to serve as the control. We saw that the control was consistently the warmest microsite, while burlap and cotton canvas were the coolest. However, burlap offered a lower amplitude of temperature variation compared to cotton canvas. The lowest mean radiation was experienced under burlap and it functioned similarly to cotton canvas when controlling light regimes. We found that nursery fabric showed the highest humidity levels with the lowest variation, while cotton canvas had the lowest humidity and the highest variation. Yet, the high variation in temperature for nursery fabrics suggests it is not ideal for deployment in the field for sheltering resident fauna. Natural fabrics for small shelters could support conservation and management, as they can be deployed, are ecologically friendly, and serve as a stop-gap solution for early restoration efforts in sites while vegetation is re-established post-disturbance.

1. Introduction

The pressures of anthropogenic change are becoming stronger and more frequent in all ecosystems around the world. Some of these changes include, but are not limited to, fragmentation due to agriculture and urbanization, the spread of invasive species, and most notably, climate change (Elmqvist, 2013; Irwin et al., 2010; Nopper et al., 2018). Human activities increase atmospheric carbon dioxide levels, mainly through the burning of fossil fuels, which in turn heat up both land and oceans (Redlin and Gries, 2021). In deserts, many species are not only sensitive to large-scale changes but also small, fine-scale fluctuations (Hadley, 1970; Shrode and Gerking, 1977). This is important because deserts support a high level of endemism and are thus key for the sustainability of global biodiversity

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(Davies et al., 2012). Climate stability is key to the continuity of plant endemism in deserts including phylogenetic endemism of vascular plants (Sosa et al., 2020). The scale at which climate is assessed is critical for the survival of species because variation in microclimates is a small-scale change that may affect species' day-to-day survival, while long-term climate patterns can influence reproduction and distribution (Bellard et al., 2012; Walther, 2010). "Microclimate" is the climate experienced in the lower 2 m of the atmosphere and the upper 0.5–1 m of the soil, while "Macroclimate" or simply climate is defined as the atmospheric situation over long periods occurring independently of local topography, soil type, and vegetation (Stoutjesdijk and Barkman, 2014). Climatic heterogeneity is an important component of environmental heterogeneity (EH), with (EH) being defined as the non-uniformities in physical and ecological landscape characteristics (Dronova, 2017). Climatic heterogeneity is crucial in deserts because these areas are shown to buffer harsh temperatures and create "tiny niches" that would enable species to behaviorally adapt (Brooker et al., 2018). Hence, the scale at which climate is assessed is critical for the survival and persistence of many species. Capacity to adapt to a changing climate is finite (Visser, 2008) and we must actively examine effective restoration and management methods that go beyond restoring the natural landscape to incorporate and directly address microclimatic challenges.

Vegetation is an integral component of many dryland ecosystems. Foundation plants including shrubs that are not necessarily always locally abundant are critical for community structure and diversity of plants and animals in many dryland ecosystems (Ivey et al., 2019; Zuliani et al., 2021). However, increased mean temperatures, extreme variability in precipitation and temperature, as well as extended drought periods, are limiting the ecological resilience of vegetation and leading to vegetation loss (Lortie et al., 2022). Restoration and management of key vegetation species are crucial to the well-being of drylands, but it is also important to examine short-term, stop-gap solutions while new vegetation grows and recovers post-disturbance. Shelters and natural or human-made architecture, are often used in deserts and are significant for a variety of ecological interactions. Furthermore, even in planting seedlings and germination trials, shelters and protective structures are often used (Oliet et al., 2012; Prinsley, 1993). Shelters or artificial structures can aid in increasing environmental heterogeneity locally. For instance, simulated solar panels have been shown to create altered microhabitats in desert landforms in turn influencing plant richness and abundance (Tanner et al., 2020). Artificial habitat structures with the aim of conservation are habitat structures that are usually deployed in degraded, disturbed, or modified environments to maintain or improve the state of individuals or populations, including their survival, growth, reproduction, and abundance (Watchorn et al., 2022). Some snakes use artificial structure to thermoregulate (Lelièvre et al., 2010), while certain birds use them for perching (Athiê and Dias, 2016). Artificial structures can be constructed in the form of shelter, such that they reduce direct solar radiation, provide more consistent temperatures throughout the day, and function similarly to natural vegetation (Ghazian et al., 2020). For instance, artificial shade can be used to reduce the nest temperature for the incubation of sea turtles, in turn mitigating the impacts of global warming and ensuring hatchling production (Esteban et al., 2018; Reboul et al., 2021). It is important however that artificial structures are monitored across relevant ecological spatial and temporal scales, and that their effects be compared to appropriate controls such that they do not serve as a greenwashing mechanism or inappropriate biodiversity offset (Watchorn et al., 2023). Thus, artificial shelters can potentially provide refuge to larger, non-burrowing animals during the hottest hours of the day, in addition to creating small or 'tiny niches' of microclimatic heterogeneity, which can allow animal species to behaviorally adapt and persist given the current paradigm of land use and changes in climate (Brooker et al., 2018). However, their effective testing and monitoring both in the field and in lab is key.

The focus of this study is a preliminary in-lab trial of different eco-friendly fabrics for later use in an artificial habitat construction experiment in drylands. Shelters built with eco-friendly covers, such as natural burlap or cotton, can be beneficial because they reduce artificial debris (waste left behind from some manipulative scientific experiments). This is a problem present in many scientific fields including astronomy (Šilha, 2019), and can apply to the field of ecology. Natural burlap or jute fibers are biodegradable and are generally treated to resist decay (Kuhns, 1997). Herein, it is important to define the term 'biodegradability'. The mechanisms of biodegradation, although important, are not the major concern of this term, instead, biodegradability refers to the environmental fate and effects of a material (Swift, 1992). Natural fibers are made up of repeating units called monomers, which when assembled turn into bigger compounds called oligomers, and eventually larger compounds referred to as polymers. For a material to be considered environmentally biodegradable, it must be able to completely break down (be mineralizable) or leave no harmful residues in the environment (Swift, 1992). When we discuss biodegradability in relation to fibers and fabrics, 'mineralization' refers to when the oligomers and monomers assimilated within the cells of a fabric are broken down and converted to CO_2 and H_2O (aerobic), and CO_2, CH_4, and H_2O (anaerobic) (Zambrano et al., 2020). In general, biologically synthesized polymers are readily biodegradable in natural environments, though the accessibility of the structure for moisture and enzyme diffusion and the capacity of the microbes and fungi in the environment to assimilate the final monomers are also important factors to consider (Arshad and Mujahid, 2011; Zambrano et al., 2020).

Most natural fabrics are made up of lignocellulosic materials, unlike synthetic fabrics which are made up of man-made materials. Lignocellulosic materials come from natural resources, such as the stems and roots of trees, and woody plants consisting of brittle and fibrous tissues and are made up of polymers of cellulose, hemicellulose, and lignin (Chen, 2015). Since cellulose is the primary carbohydrate that plants generate, it is the most prevalent organic.

polymer found in nature and is used in a wide range of products, including textiles and paper (Arshad and Mujahid, 2011). Lignocellulosic materials, including fibers, are degraded biologically because organisms reorganize the carbohydrate polymers in the cell wall, and have specific enzyme systems capable of hydrolyzing these polymers into digestible units (Ramamoorthy et al., 2019). For instance, cotton (canvas' base fiber) is a fiber made of the plant from the genus *Gossypium*, belonging to the family *Malvaceae* (Weigmann, 2023). This fiber is composed of ~87–90% cellulose, ~5–8% water, and ~4–6% natural impurities (Weigmann, 2023). The cuticle, which encircles the principal wall of the cotton fiber and is mostly made of cellulose, pectin, waxes, and proteinaceous material, is the outermost layer of the fiber (Yafa, 2005). The secondary wall, which is separated into multiple parallel layers, makes up the interior portion of the cotton fiber (Yafa, 2005). The cellulose in cotton makes it a sturdy option for short-term field studies because the fabric decays over time when subjected to tension, humidity, temperature fluctuations, and UV irradiation (Nechyporchuk et al., 2017). Biodegradable nursery fabrics are used to increase the rates of seedling establishment because they retain moisture and humidity (Wightman et al., 2001). Nursery bags are part of 'agrotextiles,' a term used to categorize the woven, nonwoven, and knitted fabrics, mesh or foil used for growing, harvesting, and storage of either crops or animals, livestock protection, shading, weed, and insect control, and extension of the growing season (Sharma et al., 2022). Non-woven, biodegradable nursery fabrics like burlap, are generally made from jute (Marasović and Kopitar, 2019). Jute comes from the jute plant consisting of cellulose and lignin coming from a few different varieties of species, including *Corchorus olitorius* (white jute), and *Corchorus capsularis* (tossa jute) (Sewport, 2023). Jute is a long, soft, shiny plant fiber from which we can spin coarse and strong threads (Arshad and Mujahid, 2011). Jute's roughness and durability make it ideal for industrial applications (Sewport, 2023). Biodegradable fibers including the ones listed above and others, are ecologically harmless, relatively strong and lightweight, low-cost, highly hydrophilic, and capable of acting as both substrate and humidity-sensitive material, and have shown great potential as structural components in automobiles, aerospace, construction, and buildings (Huang et al., 2023; Rangappa et al., 2022). Furthermore, they are generally harmless if ingested by animals as long as they are appropriately cleaned (Fynn et al., 2021).

Our objective was to quantify the extent to which cotton canvas, burlap, and nursery fabric could ameliorate, and reduce the amplitude of variation in near-surface air temperature, RH, and radiation in a lab setting, with the goal of using these data to select the best-suited fabric for shelter construction for fauna in the field in a follow-up study. We hypothesized that the lignocellulosic fabric barrier would lower the relative variation in microclimate, including near-surface temperature, relative humidity, and radiation/light intensity. We predicted that (1) the three fabrics would have different light absorption and dappling effects because of their chemical makeup, leading to different radiation regimes (Jiang et al., 2022), (2) temperature and radiation have a direct, inverse relationship, and (3) an artificial canopy increases relative humidity compared to the paired-lab control by acting as a windbreak and creating a boundary layer (Cleugh and Hughes, 2002). These in-lab trials serve as a basis for future field experiments, which are key for the effective testing of human-made constructions with the aim of conservation of endangered fauna.

2. Materials and methods

2.1. Microsite deployment

Trials were conducted under controlled lab conditions at York University, Toronto, ON (43.7730, −79.5036). In this experiment, one edge of the fabric was taped to a table and the other edge was taped to the ground such that there was a 45º angle horizontal shade created. Each fabric was approximately 0.45 m^2. We tested three environmentally-friendly fabrics including natural burlap (The Felt Store, 2021), 100% cotton canvas (Trimaco, 2021), and non-woven, biodegradable seedling nursery fabric (Endpoint, 2021), and tested their impact on understory climatic parameters. In order to create the 0.45 m^2 nursery fabrics, we had to glue smaller nursery seedling bags together to achieve the desired dimension. There were three replicates for each fabric and the adjacent open microsite, for a total of six microsites. The open was defined as the 0.45 m^2 area directly beside the angled shade. Fabrics were each tested for 30 days (one 30 day trial for each fabric triplet); however, the entire duration of the study was between March 13th – October 13th, 2021.

2.2. Abiotic measurements

Data loggers were attached to pegs using zip ties (to ensure ambient and not ground climatic parameters were recorded, they were placed ~10 cm above ground) and placed in 250 mL cups filled to ¾ with play sand (Quickrete, 2021). We placed the cups under each fabric and in the open to measure RH (%), radiation (lum/ft^2), and near-surface temperature (used interchangeably with temperature) (°C) at 1-hour intervals. OMEGA OM-91 pendant loggers were used to measure RH and temperature (OMEGA Engineering, 2021). Onset HOBO Temperature/Light Pendant (64 K) loggers were used to record solar radiation and temperature (Hoskin Scientific, 2021). 150 LED chip, 70-watt lamps provided UV for a total of 12 h/day (suggested in the manual for dryland vegetation, Likesun 2021). 60-watt heat lamps were used to create artificial heat to match the warm, dry conditions experienced in our designated dryland site in California, U.S.A during the spring-summer period, which has a mean average range of 19–32 °C between May and June ("Carrizo Plain National Monument, ", 2023). We made sure the heat lamps were set such that the temperature was always greater than 20ºC. Humidity was not manipulated; however, by increasing temperature, we decreased relative humidity considering there is a direct, inverse relationship between these two variables (Britannica, 2023). The U.S Fish and Wildlife Service Recovery Plan for Upland Species of the San Joaquin Valley (semi-arid grassland) names three key recovery sites, the largest of which is the Carrizo Plain National Monument (Williams et al., 1998). The composition and structure of the vegetation, which have been drastically impacted by land conversion, invasive non-native plant species, and shifts in shrub and herb coverings due to inter-annual climatic oscillations, have a considerable impact on local species (Stout et al., 2013). These local species include but are not limited to, the Blunt-nosed Leopard Lizard (*Gambelia sila*; federally listed as endangered (Ivey et al., 2020)), the Giant Kangaroo Rat (*Dipodomys ingens*), Kit Fox (*Vulpes macrotis*), and the San Joaquin Antelope Squirrel (*Ammospermophilus nelson*) (Zuliani et al., 2021).

2.3. Statistical analyzes

All statistics were performed using R version 4.2.2 (R Development Core Team, 2022). Code is openly published on Zenodo (Ghazian, 2022) and data are openly published on the Environmental Data Initiative (EDI) (Ghazian et al., 2022). Q-Q plots were used to examine the distribution of data and to check for normality and homoscedasticity (Schützenmeister et al., 2012). The relationship between temperature and radiation was examined using Kendall's rank correlation (non-parametric, continuous data) (Abdi, 2007). Furthermore, the relationship between temperature and RH was also examined using Kendall's rank correlation (non-parametric, continuous data). Generalized Linear Models (GLM) were used to compare temperature, RH, and radiation by microsite (Nelder and Wedderburn, 1972). GLM dispersion parameters with AIC scores were used to compare and select the appropriate family to fit models (Richards et al., 2011). Post-hoc tests were done using the function *emmeans* (Estimated Marginalized Mean) from the emmeans R package (Lenth and Herve, 2019). We explored relative variation in histograms by examining variance and used Levene's Test to check the heterogeneity of variances for temperature, RH, and radiation across microsites (Schultz, 1985). The coefficient of variation (CV) was also calculated for each shelter type and controls for each abiotic variable (Brown, 1998). The CV estimates were contrasted with the equality package (Marwick and Krishnamoorthy, 2019) using the Asymptotic test for the equality of coefficients of variation from k populations by Feltz and Miller (1996), often regarded as the 'gold test' when comparing multiple CVs.

3. Results

3.1. Near-surface air temperature effects

Near-surface air temperature significantly and positively increased with radiation at all microsites (Kendall's tau= 0.342, $p < 0.001$; Supplementary Appendix G and H). Overall, there was a significantly, positive relationship between temperature and humidity at microsites (Kendall's tau= 0.0125, $p = 0.00992$; Supplementary Appendix I and J) except for the control. The control was consistently the warmest microsite (Estimated Marginalized Mean (EMM) 21.98 ± 0.0081 °C; Table 1, Fig. 1, Supplementary Appendix A and B), while nursery fabric and canvas were the coolest microsites (EMM 21.46 ± 0.014 °C and 21.68 ± 0.015 °C, respectively). Calculated variances in temperature were significantly different between the microsites (Levene's F-value= 219.16, $p < 0.001$; Fig. 2; Supplementary Appendix F). There were significant differences between the CV calculated for near-surface air temperature for the various microsites (Asymptotic Test= 4858.663, $p < 0.001$). The lowest CV in temperature calculated was under burlap (1.81%; Table 2), while the highest was under nursery fabric (5.39%).

3.2. Light intensity and humidity effects

Not to our surprise, the control microsites experienced the greatest light radiation effects (EMM 18.20 ± 0.155 lum/ft^2; Table 1, Fig. 1, Supplementary Appendix A) and were significantly brighter than all canopied microsites (post-hoc $p < 0.001$; Supplementary Appendix D). The lowest mean radiation was experienced under burlap (EMM 1.96 ± 0.261 lum/ft^2; Table 1, Fig. 1; Supplemetary Appendix D). Burlap was significantly more shaded than nursery fabric, (post hoc $p = 0.0005$; Fig. 2) but not canvas. Variances in light radiation were significantly different between microsites (Lavene's test F-value= 838.07, $p < 0.001$; Fig. 2; Supplementary Appendix F). There were significant differences between the CV calculated for radiation at the various microsites (Asymptotic Test= 297.4007, $p < 0.001$). The coefficient of variation for radiation was the lowest for nursery fabric (103%; Table 2) and burlap (116%).

The most humid microsite was the nursery fabric (EMM 55.2 ± 0.305%; Table 1, Fig. 1) and the control (EMM 43.4 ± 0.166%). The lowest humidity was recorded under canvas (EMM 38.4 ± 0.280). Pairwise comparisons of all microsites showed to be significantly

Table 1
A summary of the GLM output for near-surface air temperature (°C), humidity (%), and radiation (lum/ft^2). Significant p-values are bolded, standard errors (SD) are given and confidence intervals (CI) provided are at the 95% level.

	Predictors	Estimates	SD (±)	CI	p-value
Temperature (°C)	Intercept	21.83	0.0136	21.80-21.85	**0.001**
	as.factor Microsite [canvas]	-0.15	0.0206	-0.19- −0.11	**0.001**
	as.factor Microsite [control]	0.15	0.0158	0.12-0.18	**0.001**
	as.factor Microsite [nursery]	-0.37	0.0196	-0.41- −0.33	**0.001**
Observations	19110				
Null Deviance	12938				
df	19019				
Humidity (%)	Intercept	40.87	0.280	40.32-41.41	**0.001**
	as.factor Microsite [canvas]	-2.43	0.396	-3.21- −1.66	**0.001**
	as.factor Microsite [control]	2.52	0.326	1.88-3.16	**0.001**
	as.factor Microsite [nursery]	14.38	0.414	13.57-15.19	**0.001**
Observations	18987				
Null Deviance	5473500				
df	18986				
Radiation (lum/ft^2)	Intercept	1.96	0.261	1.45-2.47	**0.001**
	as.factor Microsite [canvas]	0.60	0.394	-0.18-1.37	0.130
	as.factor Microsite [control]	16.24	0.304	15.64-16.83	**0.001**
	as.factor Microsite [nursery]	1.48	0.376	0.74-2.22	**0.001**
Observations	19110				
Null Deviance	5646019				
df	19109				

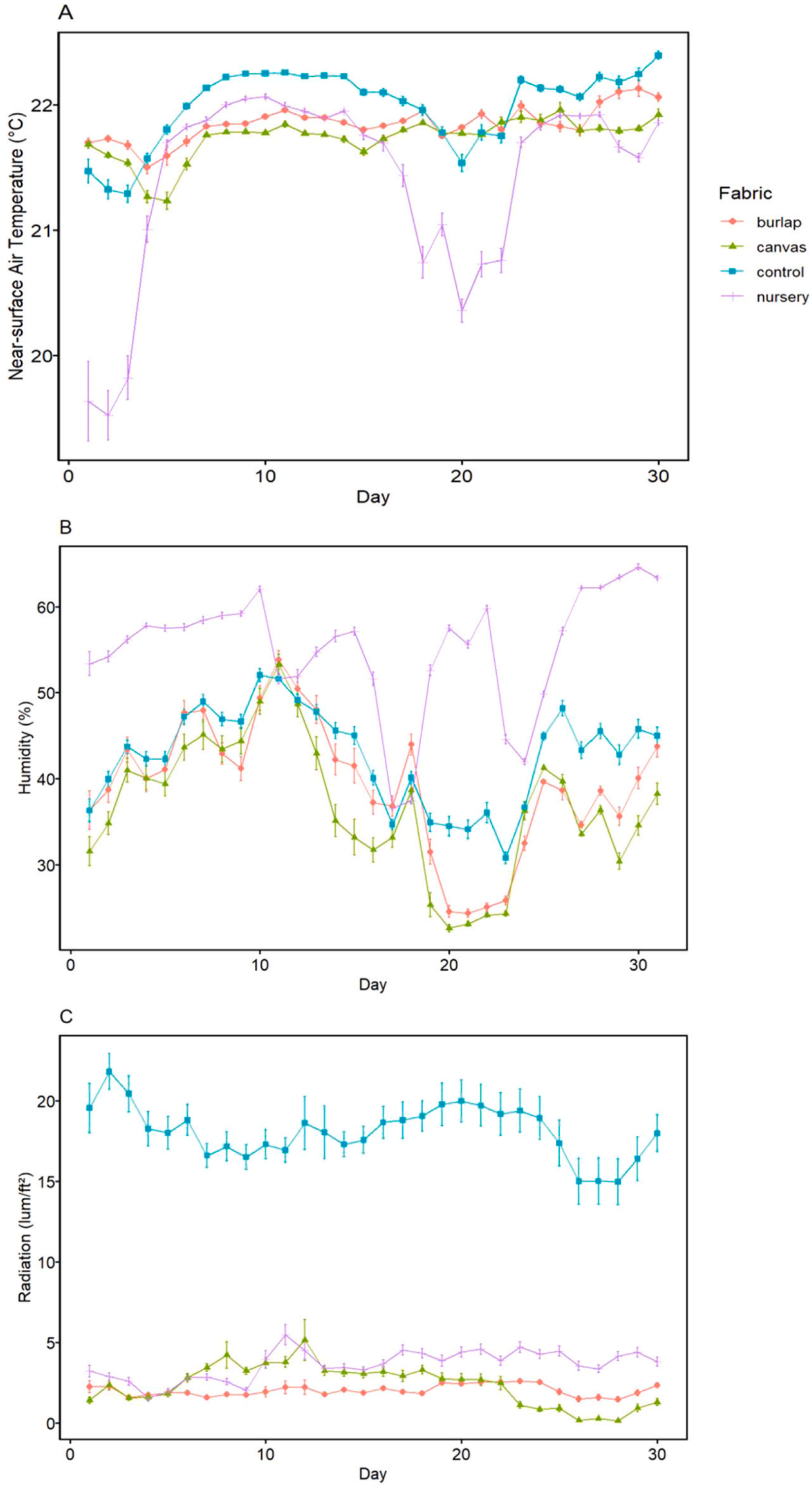

Fig. 1. Mean daily near-surface air temperature (°C) (A), humidity (%) (B), and radiation (lum/ft^2) (C) over the course of the 30-day study period recorded at each fabric and control using data loggers. Point shapes represent different microsites. Solid lines connect daily means. Errors bars are standard error (SE).

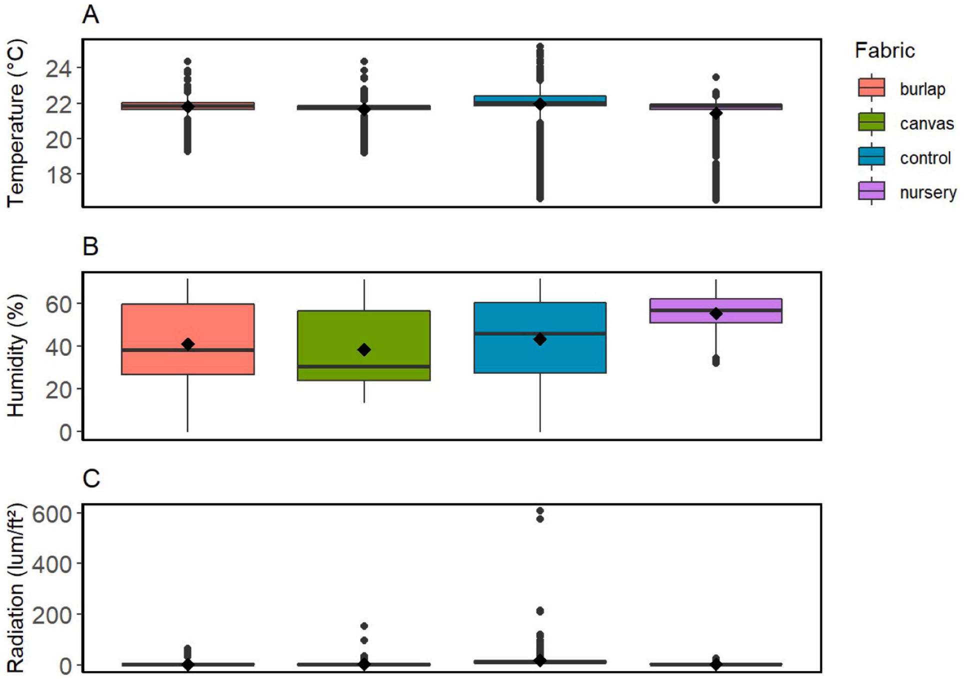

Fig. 2. Boxplots showing near-surface air temperature (°C), humidity (%), and radiation (lum/ft^2) at each fabric and control. Solid middle lines show the median of the data, whilst whiskers show 1.5 standard deviation. Solid dots are outliers > 1.5 interquartile range (IQR). Diamond dots represent the mean.

Table 2
The coefficients of variation are given as a percentage for each microsite for each climatic parameter including near-surface air temperature (ºC), humidity (%), and radiation (lum/ft^2).

Microsite	CV Temperature (%)	CV Humidity (%)	CV Radiation (%)
burlap	1.81	42.3	116
canvas	1.91	46.5	174
control	1.84	39.2	116
nursery	5.39	14.2	103

different (post-hoc $p < 0.001$; Supplementary Appendix C). Variances in relative humidity were significantly unequal between the microsites (Lavene's F-value= 838.07, $p < 0.001$; Fig. 2; Supplementary Appendix F). Calculated CVs for humidity across microsites were significantly different (Asymptotic Test= 2137.138, $p < 0.001$). The greatest variation was under canvas (46.5%; Table 2), while the lowest CV was recorded under nursery fabric (14.2%)..

4. Discussion

In drylands, heterogeneity in microclimates is important because it provides species with a variety of climatic profiles for refuge and movement (Ma et al., 2023). Critically, it is these fine-scale environments that most species experience that are inherently variable in deserts (Kotzen, 2003; Shenbrot et al., 2002) and with a changing climate even more so (Li et al., 2019). In this study, we tested the impact of natural fabrics on the understory microclimate for future use in artificial shelter construction in deserts for ecological conservation of resident animal species (Ghazian et al., 2020). The hypothesis that natural fabrics can both provide refuge from extremes and also decrease relative variation in key arid microclimatic drivers was tested. We found that microsites with fabric were significantly cooler and had a lower relative variation compared to the open controls supporting this idea that even modest, relatively small shelters can generate meaningful heterogeneity relevant to many plants and animals in deserts. Nursery fabric was often much more humid, which could benefit vegetation and mitigate against desiccation and plant death. Nursery seedling bags are generally used in germination trials because they moderate moisture and improve germination and seedling establishment (Schmal et al., 2007). Water as well as air circulate fairly well within these agrotextiles and temperatures can get really hot at times; thus, a reason for the big temperature variation may be due to the inherent nature of this fiber (Marasović and Kopitar, 2019). Hence, non-woven, biodegradable nursery fabrics may be ideal for seedling germination experiments in the field, with possible herbivore exclusion, but perhaps not for artificial habitat construction for resident fauna, which is the aim of our follow-up in field study. The goal is not necessarily to

Table 3
Keywords and definitions about materials used in this study, as well as some illustrative studies from the literature, and where the materials were purchased (if applicable).

Keyword	Description	Illustrative Studies	Where Purchased
Biodegradability	The ability of a material to be mineralizable (naturally break down) into its components, including CO_2 and H_2O (aerobic), and CO_2, CH_4, and H_2O (anaerobic) when exposed to moisture, enzymes, microbes, and fungi in the environment.	Swift (1992); Zambrano et al. (2020); Arshad and Mujahid (2011)	NA
Lignocellulose	Materials that come from natural resources, such as the stems and roots of trees, and woody plants consisting of brittle and fibrous tissues are made up of polymers of cellulose, hemicellulose, and lignin. These materials are naturally biodegradable because organisms reorganize the carbohydrate polymers in them and can digest them.	Chen (2015); Ramamoorthy et al. (2019)	NA
Agrotextile	A term used to categorize the woven, nonwoven, and knitted fabrics, mesh or foil used for growing, harvesting, and storage of either crops or animals, livestock protection, shading, weed, and insect control, and extension of the growing season.	Sharma et al. (2022)	NA
Cotton	The base for canvas, this biodegradable fiber is made of the plant from the genus *Gossypium*, belonging to the family *Malvaceae*. The cuticle, which encircles the principal wall of the cotton fiber and is mostly made of cellulose, pectin, waxes, and proteinaceous material, is the outermost layer of the fiber, while the secondary wall, which is separated into multiple parallel layers, makes up the interior portion of the cotton fiber.	Weigmann (2023);Yafa (2005)	Trimaco (2021)
Burlap	A non-woven fabric made from a biodegradable fiber jute. Jute comes from the jute plant consisting of cellulose and lignin coming from a few different varieties of species, including *Corchorus olitorius* (white jute), and *Corchorus capsularis* (tossa jute). Jute is a long, soft, shiny plant fiber from which we can spin coarse and strong threads.	Marasović and Kopitar (2019);Sewport (2023);Arshad and Mujahid (2011)	The Felt Store (2021)
Nursery Fabric	A type of non-woven biodegradable agrotextile generally used to increase the rates of seedling establishment because they retain moisture and humidity. They are used in germination trials to increase seedling establishment.	Sharma et al. (2022);Schmal et al. (2007)	Endpoint (2021)

provide the coolest shelter for mobile animals but instead a place where extremes in physical and abiotic conditions can be avoided (Schwarzkopf and Alford, 1996). This type of refugia is especially important for thermoregulatory species like lizards that now have to tolerate even longer periods of higher ambient temperature given the current paradigm of climate change (Ivey et al., 2022). In recent years, there has been increased interest in the use of biodegradable polymers that minimize the issues caused by the disposal of synthetic polymer bags (Bilck et al., 2014). In our study, we used a biodegradable nursery fabric to minimize ecological impacts and observed that it was in fact the best fabric at moderating relative humidity; however, the large spread in variation observed in temperature makes it a less-than-ideal candidate for use in artificial shelters for ecological conservation of dryland animals because you want to offer a consistency in the microsite's microclimate. Furthermore, biodegradable non-woven nursery fabrics are not available in large dimensions because they are designed for seedling germination as small bags originally (seeds are relatively small); hence, it is not optimal for shelter constructions even for small to medium-scale conservation.

Recently, ecological and environmental concerns have initiated the use of natural fibers in green technology. Despite their use in reinforced engineering, all-natural fibers have different surface morphologies and physical/chemical properties (Pai and Jagtap, 2015). Burlap is generally made from jute and hemp and is considered a 'bast' fiber (from the phloem of the plant) while canvas is made from cotton seeds (Pai and Jagtap, 2015). Because of their location of origin on the plant, these fabrics differ in properties including density, moisture content, and elongation capacity. Most natural fibers are lignocellulosic (Satyanarayana et al., 2009) and are hydrophilic, meaning they have high moisture absorption profiles (Jawaid and Abdul Khalil, 2011). In this study, we observed that burlap was more hydrophilic in profile in terms of relative humidity compared to cotton canvas and its canopy was on average more humid than canvas with less variation in humidity experienced. This property of this cellulosic fiber makes it an ideal candidate for dryland studies in the context of refugia for animals, given the prolonged periods of drought and low precipitation experienced in these regions and that drylands are mediated by rainfall (Bachelet et al., 2016). Lower near-surface air temperatures with less variation were also recorded under burlap, which many desert animals may find important for thermoregulation. Some animals may even use these shelters diurnally for their windbreak properties (Baker et al., 2021). Cellulosic fibers are relatively strong, lightweight, harmless to human health and the environment, and biodegradable (Rangappa et al., 2022). Recent advances in lignocellulosic research and our findings demonstrate their significant potential as structural components in construction.

The type of canopy impacts the quantity, quality, and distribution of the incoming light. Light is a fundamental force in nature, impacting many interactions such as predator-prey interactions (Spinner et al., 2013), thermoregulation for some species (Refsnider et al., 2018), as well as helping animals navigate their environment and interact with other organisms using eyes/light-sensitive organs (Palmer et al., 2018). Natural fibers have complex profiles consisting of cellulose, hemi-cellulose, lignin, pectin, and other proteins, waxes, and organic molecules (Truss et al., 2016). The quality and quantity of incoming light (red shift or blue shift) can be impacted through the availability of hydrogen bonds (Yamaki et al., 2005), which in turn can influence light-dappling regimes. Our data suggest that if your main goal is humidity and moisture retention for plant growth in deserts, nursery fabric is the superior option. However, for constructing artificial shade for animals while minimizing both the variation experienced in temperature and solar radiation under the shelter canopy, while controlling for moisture, then burlap is the ultimate choice. In our study, the lowest mean light intensity was measured under burlap. Burlap also showed the lowest variance for light intensity. This is important as it implies that burlap canopy can offer more consistent light regimes and thus provide more stable refugia for resident animals. The light regime measured under the burlap canopy was no different than canvas, suggesting both fabrics function similarly in controlling light variation.

5. Implications

Microclimatic variability in drylands is a critical issue because the rate of global desertification is steadily increasing. Many desert species have limited plasticity to buffer further warming (Gunderson and Stillman, 2015), hence, management actions can mitigate the potential for species loss including restoration, translocation, refuges, and seeding. Environmental heterogeneity augments the ability of organisms to inhabit different microsites (Lundholm, 2009). However, it is also likely that we need to protect abiotic heterogeneity in deserts because of increasing temperatures and decreasing precipitation (Li et al., 2019). At least in desert environments, shelters can serve a similar purpose to plants in some ways, increasing the thermal heterogeneity within the ecosystem. According to Bishop et al. (2019), ecological communities and wildfire regimes in California are changing as a result of climate change. In addition to the fact that post-disturbance vegetation recovery can take decades (Berry et al., 2016), other obstacles impeding the recruitment of native vegetation include competition and non-native invasion (Bowman et al., 2009, 2011). Artificial shelters can thus act as a stop-gap and as at least transient mechanisms to protect and even increase the microclimatic heterogeneity at fine scales in deserts (Ghazian et al., 2020). Of course, our suggestion is not to use artificial shade as a replacement for natural vegetation but instead, we argue that shelters like the ones discussed here are portable, affordable, and fill in small, critical spatial gaps locally, while natural vegetation re-grows post-disturbance. Shrubs are also under threat (García-Guzman et al., 2012) so augmenting support for animals is key because vegetation can take decades to recover post-disturbance (Berry et al., 2016) and artificial shade can mitigate the challenges that accompany re-establishment and recruitment for a short period of time. Natural fibers offer viable constituents for shelters and they can also reduce the environmental impacts of debris when damaged and are relatively low-cost to construct. The results of our study demonstrate that lignocellulosic fibers have immense potential for ecological management and conservation efforts.

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CRediT authorship contribution statement

MacDonald Suzanne E.: Conceptualization, Methodology, Writing – review & editing. **Lortie Christopher J.:** Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. **Ghazian Nargol:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Nargol Ghazian reports financial support was provided by York University. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data are public and openly accessible. They are cited in the manuscript.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2024.e02806.

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