Supporting Information Appendix

Materials and Methods

Study site

Figure S1. Typical Kalahari arid savanna

Acute exposure during extreme heat events

In brief, these measurements were made using open flow-through respirometry following the protocol described by Whitfield et al. (2015) (3). The protocol involves exposing birds to stepped increments in T_a from thermoneutral values where EWL is minimal and T_b is normothermic up to the maximum T_a each species can tolerate under conditions of very low humidity achieved by using high flow rates through respirometry chambers (3). Measurements were terminated when a bird was either a) obviously stressed (agitated jumping, pecking, wing flapping or any other escape behaviour) or b) showed signs of the onset of pathological hyperthermia such as loss of balance, coordination or dramatic decrease in EWL and/ or uncontrolled increase in T_b to > 45°C. In the latter scenario, an individual bird was considered to have reached its thermal endpoint, the T_a associated with the onset of pathological hyperthermia (3). All the studies from which we obtained data involved the same stepped heat exposure protocol and experimental conditions (4-7).

Table S1. Parameters used for modelling acute heat stress risk in desert birds. Body masses, heat tolerance limits (HTL; the highest tolerable air temperature under laboratory conditions) and the relationship between evaporative water loss (EWL) and air temperature (T_a) were obtained from the sources listed. Estimates of EWL as a function of T_a refer to whole-animal values in g H_2O hr^{-1}, except where asterisks indicate mass-specific values (mg H_2O g^{-1} hr^{-1}); these relationships were used to calculate cumulative EWL from daily T_a traces. Also shown are the maximum daily air temperature (T_{max}) associated with moderate risk of lethal dehydration; these were calculated by modelling EWL during the course of a hot day. For the latter calculations, we generated an average daily T_a profile using data from the hottest day in each year between 2000 and 2010.

Species	**Mass (g)**	**EWL ~ T_a**	**Dehydration T_{max} (˚C)**	**HTL (˚C)**	**Source**
Namaqua Dove (*Oena capensis*)	40	$0.096T_a – 3.629$	49	60	(5)
Laughing Dove (*Spilopelia senegalensis*)	100	$0.181T_a – 6.797$	52	58	(5)
Ring-necked Dove (= Cape Turtle Dove) (*Streptopelia capicola*)	153	$0.235T_a – 8.544$	52	56	(5)
Burchell's Sandgrouse (*Pterocles burchelli*)	193	$0.445T_a – 17.76$	51	50	(4)
Rufous-cheeked Nightjar (*Caprimulgus rufigena*)	53	$0.12T_a – 4.600$	54		(7)
African Cuckoo (*Cuculus gularis*)	110	$0.238T_a – 8.930$	50	50	(6)
Lilac-breasted Roller (*Coracias caudatus*)	95	$0.039T_a – 0.414$[a] $0.337T_a – 13.739$[b]	49	53	(6)
Burchell's Starling (*Lamprotornis australis*)	109	$0.231T_a – 7.110$	43	49	(6)
Scaly-feathered Weaver (*Sporopipes squamifrons*)	10	*$4.52T_a – 172$	44	48	(3)

Sociable Weaver (*Philetairus socius*)	25	$^*5.05T_a - 200$	45	52	(3)
White-browed Sparrow-weaver (*Plocepasser mahali*)	40	$^*4.02T_a - 151$	45	54	(3)

*Mass-specific evaporative water loss values

[a]Evaporative water loss at 25 °C < T_a < 44.7 °C. Lilac-breasted rollers showed two significant inflection points in the EWL versus air temperature relationship, with an upper inflection at 44.7 °C.

[b]T_a > 44.7 °C

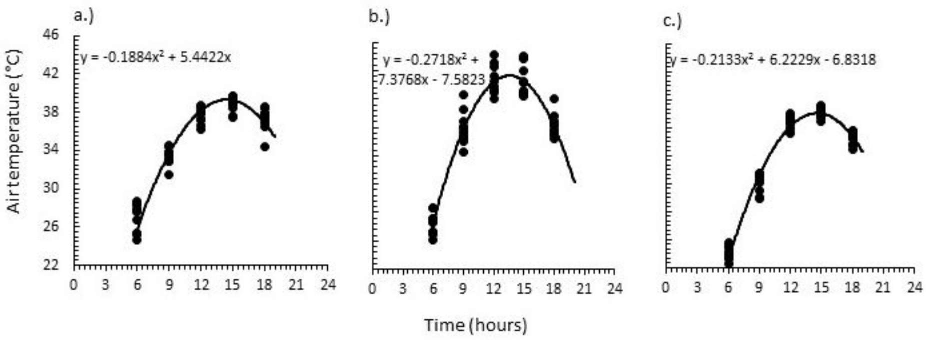

Figure S2. Three-hourly air temperature data from the hottest day of each year between 2000 and 2010 over three regions across southern Africa (a: southern Kalahari Desert, b: central Namibia and c: northern Botswana). A polynomial regression model was fitted to the data from 06:00 to 18:00.

Table S2. Processes, patterns and threshold air temperatures for chronic, sublethal fitness costs of exposure to sustained hot weather in three southern African bird species. Variables driving the changes in breeding success and body condition are indicated in bold.

Species	Process and reference	Consequence: Body condition	Consequence: Breeding success	Threshold	Significance of T_{max} > threshold
Southern Pied Babbler (*Turdoides bicolor*)	**Trade-off between foraging efficiency and heat dissipation behaviours such as panting and wing-drooping (8); reduced provisioning (9)**	Overnight mass loss versus diurnal mass gain (adults)	Nestling size and mass	Daily T_{max} = 35.5 °C	Diurnal mass gain insufficient to offset overnight loss, i.e., net 24-hr loss (adults); smaller and lighter nestlings at day 11
				Daily T_{max} = 38.5 °C	Zero diurnal mass gain (adults)
Southern Yellow-billed hornbill (*Tockus leucomelas*)	**Trade-off in breeding males between foraging efficiency and heat dissipation behaviours such as panting and shade-seeking (10)**	Overnight mass loss versus diurnal mass gain)	Shift in nest provisioning decisions	Daily T_{max} = 34.5 °C	Males spend 50 % of time panting, strong trade-offs between foraging and thermoregulation become evident [Daily T_{max} = 37.9, zero diurnal mass gain adult males]
	Effects of nest cavity thermal environment on female and nestling mass (10)		Nest abandonment, cannibalism of nestlings by female, fledging mass	Average nesting period T_{max} = 35 °C	Probability of successful breeding < 50 %
Southern Fiscal (*Lanius collaris*)	**Trade-off between foraging success and thermal properties of hunting**		Nestling growth rates	Daily T_{max} = 33 °C	Reduced fledging mass

	perches, resulting in reduced provisioning (11, 12)		Daily T_{max} = 35 °C	Delayed fledging resulting in increased nest predation risk
			Daily T_{max} = 37 °C	Reduced fledging tarsus length

Table S3. Mean summer daily maximum temperatures ("Summer") and the mean maximum temperature of the hottest day per year for three regions in the southern African arid zone under past climate (1050 – 1850 CE), present climate (2000 – 2010 CE) and a high-risk future climate scenario (RCP 8.5, 2080 – 2090 CE).

	1050 – 1850		2000 – 2010		2080 – 2090	
Region	**Summer (°C)**	**Hottest day (°C)**	**Summer (°C)**	**Hottest day (°C)**	**Summer (°C)**	**Hottest day (°C)**
Central Namibia	28.4	35.5	28.7	40.9	34.1	45.5
Northern Botswana	28.9	36.4	29.6	45.6	34.9	46.2
Southern Kalahari	28.6	35.6	29.7	40.9	35.4	45.6

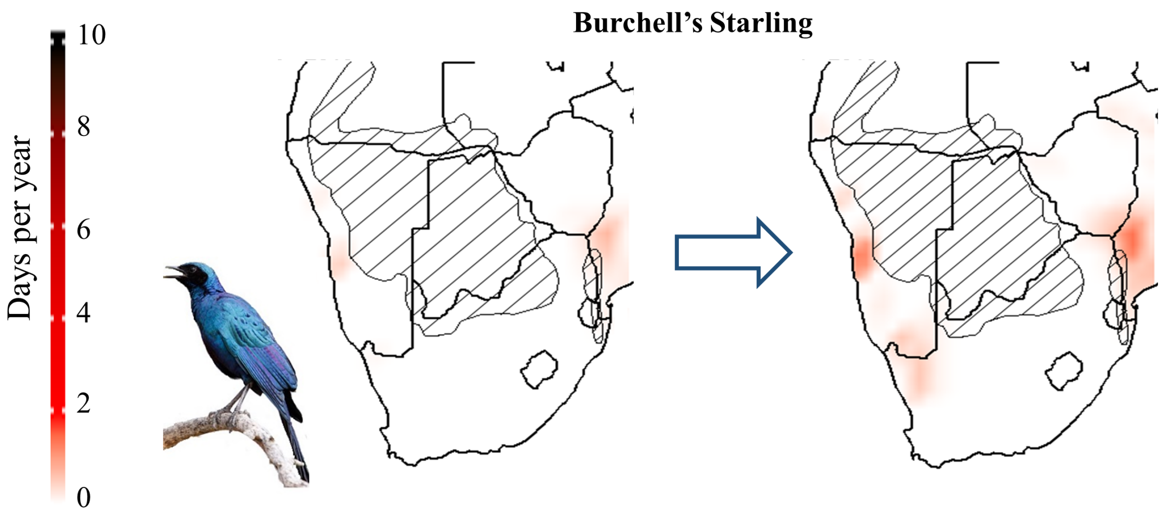

Figure S3. Average number of days per year with moderate dehydration risk (i.e., survival time of < 5 hours) across southern Africa for Burchell's Starling under current (2000 – 2010) and a moderate risk future scenario (RCP 4.5; 2080 – 2090) (2080 – 2090). Species range indicated with cross-hatching.

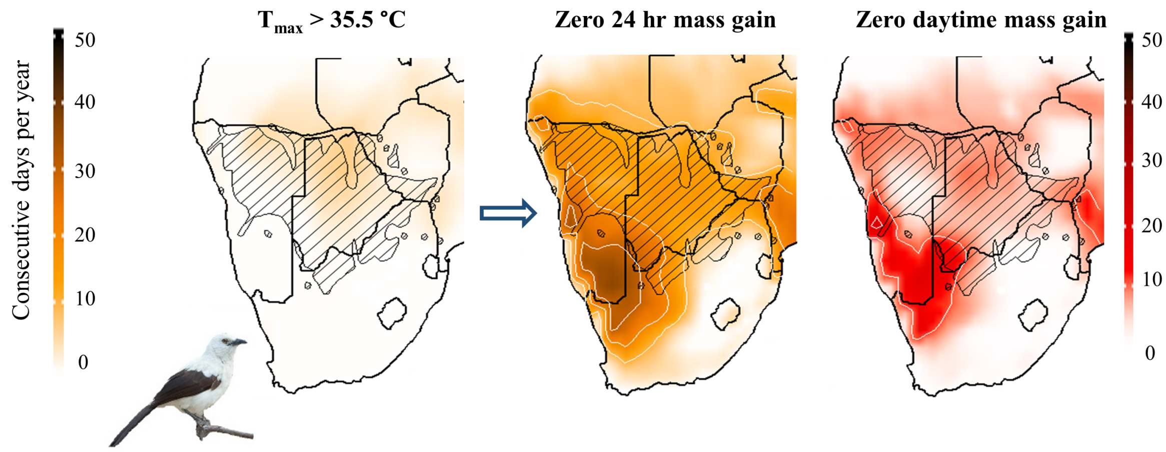

Figure S4. Average number of consecutive days per year where Southern Pied Babblers are exposed to conditions of zero 24-hr body mass gain and zero daytime body mass gain (i.e., ~ 4 % body mass loss per 24 hr)under current (2000 - 2010) and a moderate risk future scenario (RCP 4.5; 2080 – 2090). Species range indicated by cross-hatching.

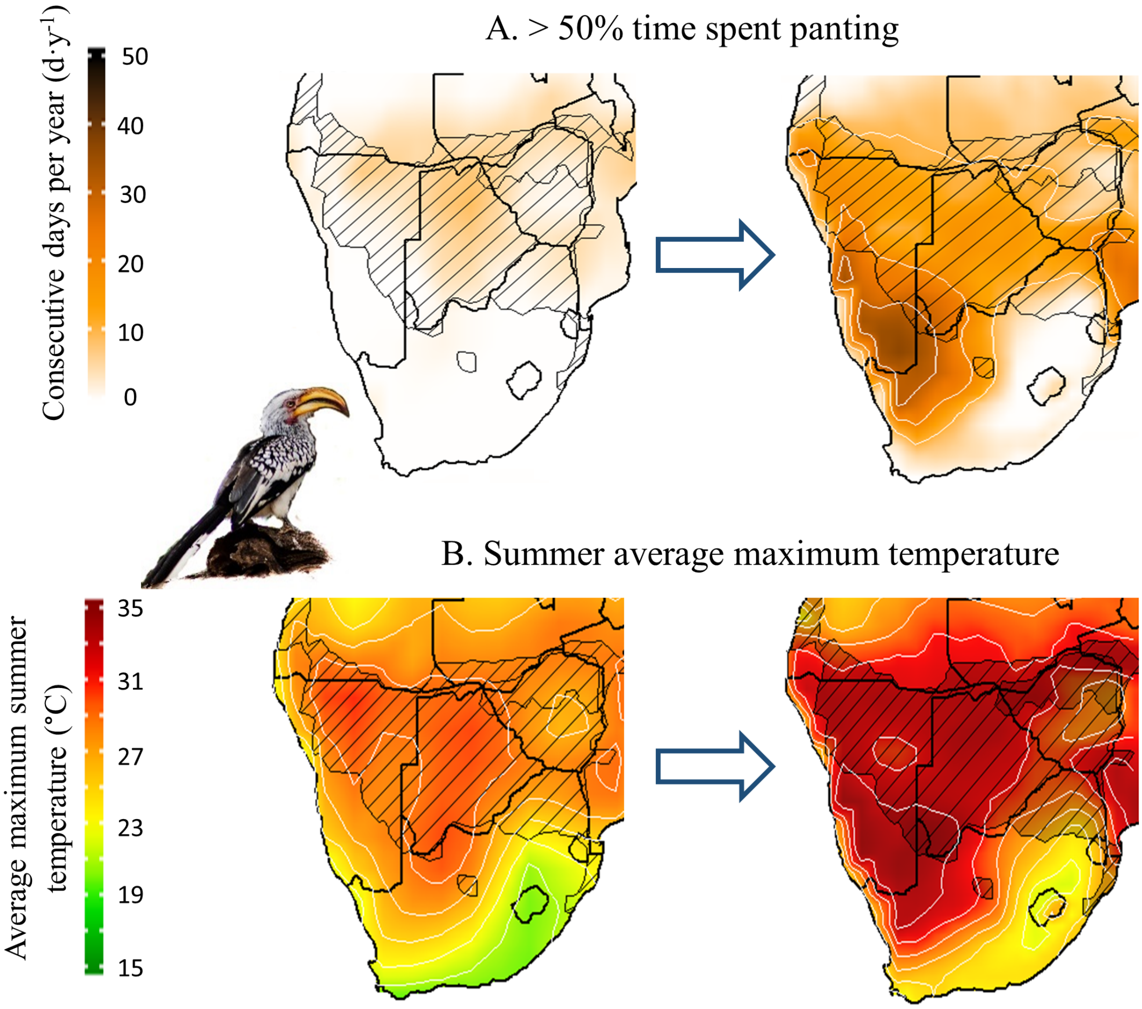

Figure S5. Average number of consecutive days pr year where Southern Yellow-billed Hornbills are exposed to conditions of chronic heat stress risk (Panel A: T_{max} = 34.5 °C, the threshold at which provisioning male hornbills spend 50 % of time panting) under current (2000 - 2010) and a moderate risk future scenario (RCP 4.5; 2080 – 2090). Panel B is the summer average maximum temperature under current and future conditions. Species range indicated with cross-hatching.

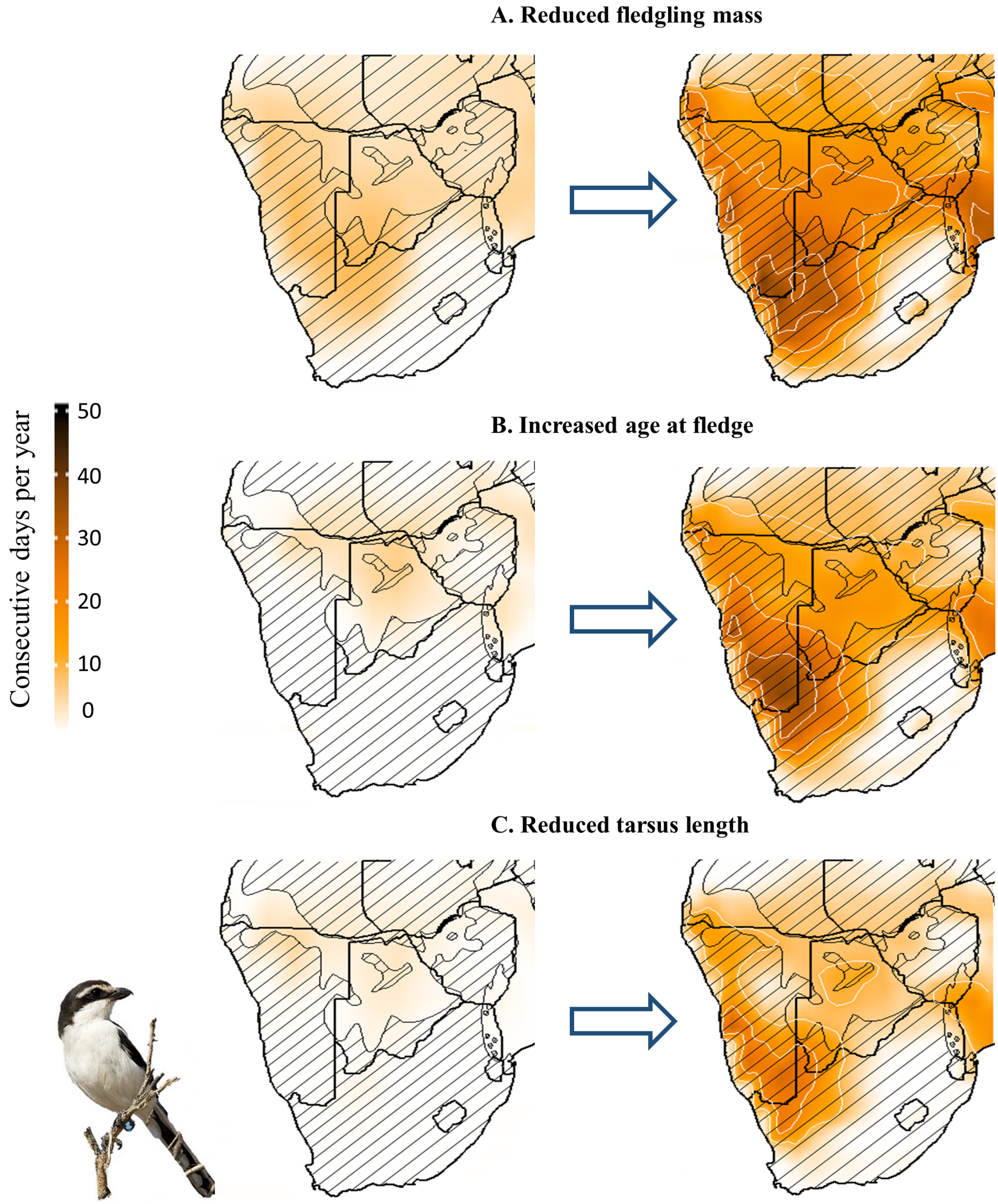

Figure S6. Average number of consecutive days per year where Southern Fiscals are exposed to conditions of chronic heat stress risk associated with reduced fledging mass (T_{max} = 33 °C), increased age at fledging (T_{max} = 35 °C) and reduced fledgling tarsus length (T_{max} = 37 °C) under current (2000 - 2010) and a high risk future scenarios (RCP 4.5; 2080 – 2090). Species range indicated with cross-hatching.

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