Measuring Thermal Tolerance

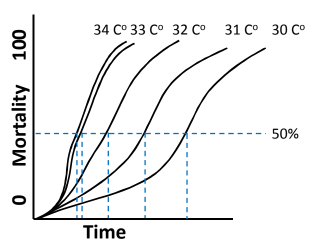
- **CT_{max}** – upper lethal temperature reached while raising temperature 1 C per minute
  - Various endpoints – muscular spasms most common
  - Why is the rate of heat increase important?
- **Ct_{min}** – lower lethal temperature
  - More difficult to measure due to lack of definitive endpoint (often a gradual reduction in activity)
  - Difficult to quantify in freeze tolerant species
- **Ecological end points**

Measuring Thermal Tolerance

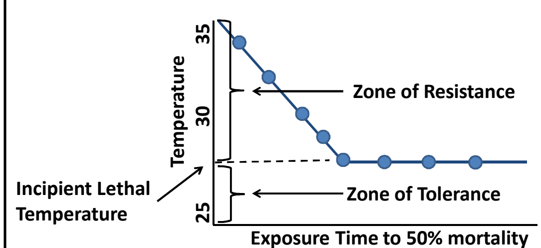
- Thermal stress has a strong temporal component
  - Thermal stress → disruption of enzymatic pathways
  - Heat hardening (HSP) and acclimation responses adjust individual physiology
  - Extended exposure to tolerable but sub-optimal temperatures can reduce fitness and eventually be fatal
  - Ct_{max} is **<u>not</u>** a measure of these sub-optimal but tolerable effects, it may be correlated

LD_{50} and UD_{50}

- Often used in tolerance studies (e.g. drug toxicity LD_{50})
- Temperature (LT_{50} or UT_{50}) at which lethal effects (50% mortality) is independent of exposure time.



Heat hardening, acclimation and measures of tolerance



Measuring Thermal Tolerance

- Variability within taxonomic groups implies strong selective pressure for tolerance
- Variety of evolutionary responses
  - Behavioral changes
  - Modifications or new enzymes to regulate reaction rates
  - Etc…

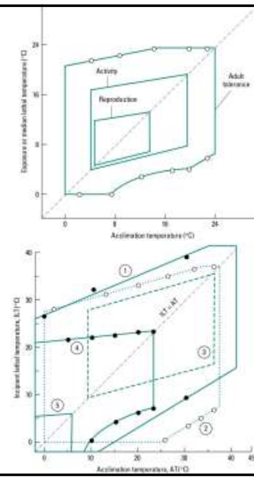
Table 8.4 Upper critical temperature (UCT) for a variety of animals from different habitats

Group	Example (habitat)	UCT (°C)
Prokaryotes	Bacteria (aquatic)	75–75
	Bacteria (thermophilic)	90–91
	Cyanobacteria	75
Molluscs	*Modiolus* (SW bivalve)	38
	Nassa (SW gastropod)	42
	[illegible] (SW gastropod)	43
Annelids	*Lumbricus* (land earthworm)	35
Echinoderms	*Asterias* (SW starfish)	32
	Ophioderma (SW brittlestar)	37
Crustaceans	*Palaemonetes* (SW/littoral prawn)	34
	Porcellio (SW crab)	39–41
	Uca (littoral/land crab)	39–41
	Armadillidium (land woodlouse)	41–42
Insects	*Lepisma* (land springtail)	35
	Thermobia (land firebrat)	48+
	Sphingonotus (land moth)	41
	Bembex (land sandwasp)	42
	Onymacris (desert beetle)	48–51
	Dasymutilla (land sandwasp)	52
	Ocymyrmex (desert ant)	51.5
	Melophorus (desert ant)	54
Arachnids	*Buthotus* (land scorpion)	45
	Leiurus (land scorpion)	47
Vertebrates Fish	*Pagothenia* (polar SW)	6–18
	Fundulus (cold SW)	35
Amphibians	Salamanders (FW/land)	29–35
	Anurans (FW/land)	36–41
Reptiles	Alligators (land/FW)	38
	Turtles (SW/land)	41
	Lizards (land/desert)	40–47
	Snakes (land)	40–42
Birds	Passerines	46–47
	Nonpasserines	45–48
Mammals	Monotremes	37
	Marsupials	40–41
	Placentals	42–44

FW, fresh water; SW, sea water.

Measuring Thermal Tolerance

- **Tolerance polygon** – a measure (in units of degrees C²) of upper and lower thermal tolerance over a range of acclimation temperatures
- Captures the thermal niche
- Theoretically centered on the **thermal optima** for a species
- Stenotherm vs. eurytherm



Thermal Tolerance

- Species thermal tolerance correlates with climate
- Why aren't all species highly tolerant?

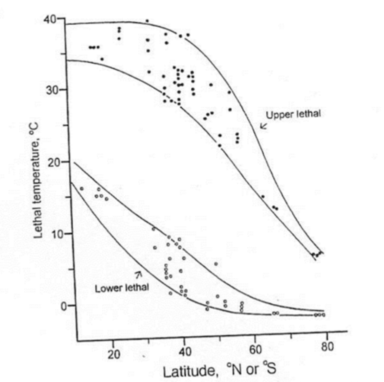
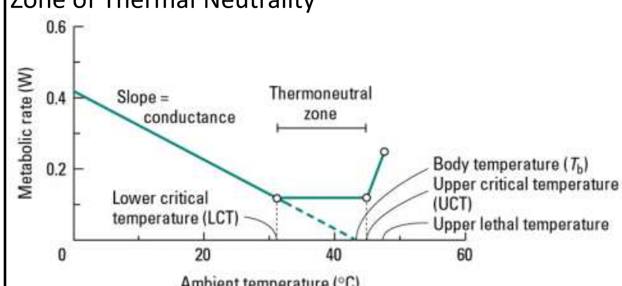


Figure 4.5 Upper and lower lethal temperatures in various fishes as a function of latitude. Source: Modified from Brett (1970).

Zone of Thermal Neutrality



- Metabolic rate-temperature patterns differ in endotherms
- Endotherm optima within thermoneutral zone

William K. Fitt · Barbara E. Brown
Mark E. Warner · Richard P. Dunne

Coral bleaching: interpretation of thermal tolerance limits and thermal thresholds in tropical corals

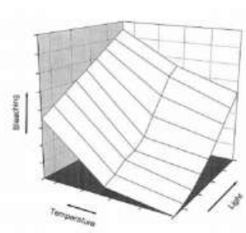
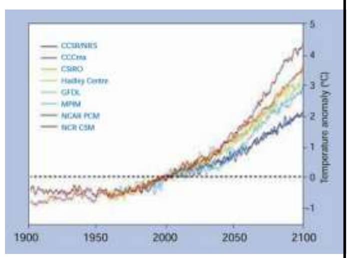
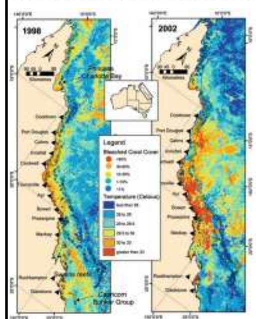


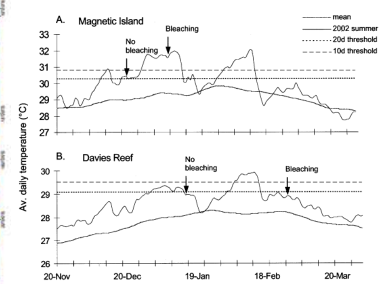
Fig. 1 Hypothetical model relating various combinations of natural light intensity and high and "normal" temperatures to bleaching of reef corals



Ray Berkelmans · Glenn De'ath · Stuart Kininmonth
William J. Skirving

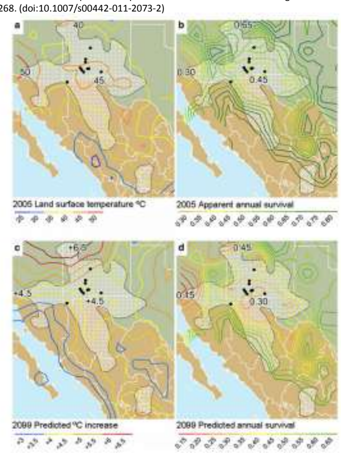
A comparison of the 1998 and 2002 coral bleaching events on the Great Barrier Reef: spatial correlation, patterns, and predictions





Moses, M. R., Frey, J. K. & Roemer, G. W. 2012 Elevated surface temperature depresses survival of banner-tailed kangaroo rats: will climate change cook a desert icon? *Oecologia* 168, 257–268. (doi:10.1007/s00442-011-2073-2)

Fig. 4 a Mean summer diurnal land surface temperature (SD_LST) during 2005 estimated from monthly Moderate Resolution Imaging Spectroradiometer (MODIS) data. b Probability of apparent annual survival (Φ) for adult *D. spectabilis* based on the highest ranked model, Φ_{A+SD_LST}. c Change in SD_LST predicted for the period from 2005 to 2099 from CCSM3 under a worst case (A2) carbon emission scenario. d Estimates of Φ based on the increase in SD_LST for 2099. Apparent annual survival was estimated by adding the change in SD_LST predicted for 2099 to that recorded in 2005 and then applying the highest ranked model (Φ_{A+SD_LST}) to estimate Φ. *Stippled area* represents the range of *D. spectabilis* (Hall 1981). *Filled circles* are the locations of the 11 populations examined in this study; at this scale, some locations are obscured



Optima and Thermal Preference

- **Preferred temperature**
- **Selected temperature**
- Eccritic or **Field Temperature**
- Thermal preferences as a measure of optima
- Dynamics and ecology of preference/optima
  - Energetics and thermal shuttling
  - Behavioral fever
  - Ecdysis
  - SDA/**Postprandial thermophile**
  - Torpor

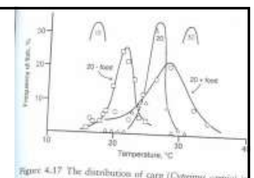


Figure 4.17 The distribution of carp (*Cyprinus carpio*) in a temperature gradient as a function of temperature, thermal acclimation, and the presence or absence of food. The numbers associated with the distributions indicate acclimation temperatures. Source: Modified from Elliott (1981).

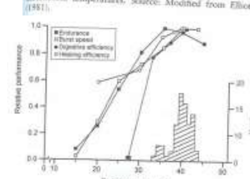
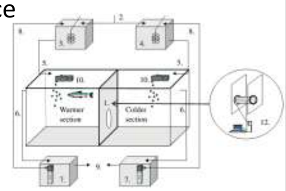


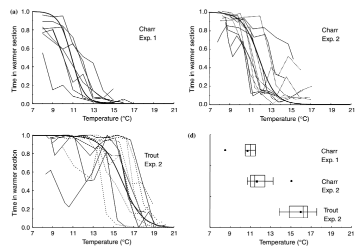
Figure 4.26 The relative performance of endurance, burst velocity, digestive efficiency, and hearing efficiency in the desert iguana (*Dipsosaurus dorsalis*) as a function of body temperature, and the frequency distribution of body temperature of *Dipsosaurus* in the field. Source: From Huey and Kingsolver (1989).

Measuring Thermal Preference

Thermal preference of Arctic charr, *Salvelinus alpinus*, and brown trout, *Salmo trutta* – implications for their niche segregation

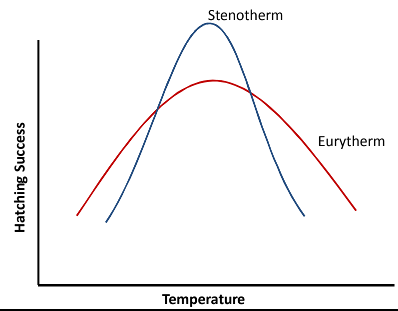


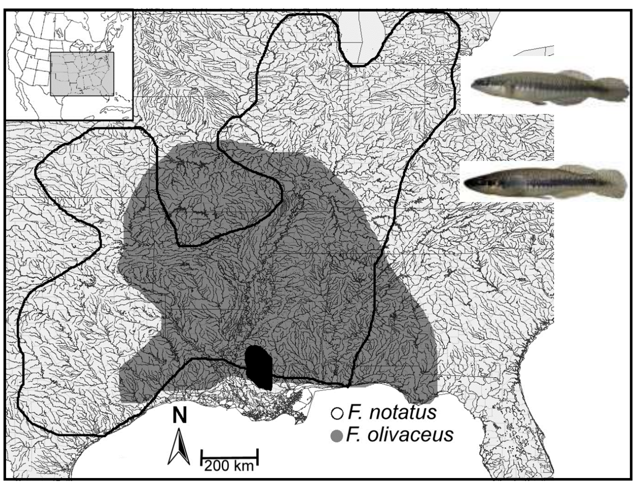
- Recall that the **setpoint** is dynamic, will change with
  - Acclimation
  - Local climate
  - Disease
  - Etc.



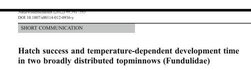
Thermal Optima and Reaction Norms

- Species fitness maximized at thermal optima
- Shape of thermal reaction norms correlated with tolerance polygon area





Performance: Hatching Success



- More broadly distributed species has a wider reaction norm (higher hatch success at extremes)
- Species optima expected to match local environments. Northern populations have lower optima.