



ISSN Print: 2664-9926
 ISSN Online: 2664-9934
 NAAS Rating (2025): 4.82
 IJBS 2025; 7(11): 92-94
www.biologyjournal.net
 Received: 25-08-2025
 Accepted: 29-09-2025

Tejas Gokhale
 Department of Ecology,
 Himalayan Institute of
 Biosciences, Dehradun,
 Uttarakhand, India

Chirag Deshpande
 Department of Ecology,
 Himalayan Institute of
 Biosciences, Dehradun,
 Uttarakhand, India

Yashwant Deshpande
 Department of Wildlife
 Ecology, Deccan College of
 Biological Sciences,
 Hyderabad, Telangana, India

Corresponding Author:
Tejas Gokhale
 Department of Ecology,
 Himalayan Institute of
 Biosciences, Dehradun,
 Uttarakhand, India

Phenotypic plasticity and adaptive responses of intertidal organisms to thermal stress

Tejas Gokhale, Chirag Deshpande and Yashwant Deshpande

DOI: <https://www.doi.org/10.33545/26649926.2025.v7.i11b.680>

Abstract

Consider a barnacle cemented to a rock in the high intertidal zone: during a single low tide on a summer afternoon, its body temperature can swing by 20 °C or more. Such thermal extremes make intertidal organisms valuable models for phenotypic plasticity research. This research examined heat shock protein expression, cardiac performance, and survival thresholds in four intertidal species—*Littorina littorea*, *Patella vulgata*, *Semibalanus balanoides*, and *Mytilus edulis*—exposed to acute thermal stress under controlled laboratory conditions. Specimens were collected from rocky shores near Dehradun-affiliated coastal field stations and subjected to ramped temperature exposures from 18 °C to 38 °C at the Himalayan Institute of Biosciences between April 2023 and July 2024. Hsp70 expression increased 3.1-to 4.5-fold under heat stress depending on species. Cardiac flatline temperatures ranged from 33.7 °C in *M. edulis* to 38.4 °C in *S. balanoides*. Survival at 48 hours post-exposure dropped below 50% at species-specific thresholds that correlated with tidal height preference. These findings show that intertidal organisms possess graded plasticity in thermal tolerance that tracks their microhabitat exposure, with implications for predicting community shifts under warming scenarios.

Keywords: Phenotypic plasticity, intertidal organisms, thermal stress, heat shock proteins, cardiac performance, *Littorina*, *Patella*, climate adaptation

Introduction

A tide pool snail clinging to sun-baked rock at noon faces thermal conditions that would kill most terrestrial insects of similar size. This example captures why the intertidal zone has become a focal system for understanding organismal responses to environmental extremes ^[1]. Intertidal species routinely experience temperature fluctuations of 15-25 °C during tidal cycles, and their capacity to tolerate these swings reflects both fixed genetic adaptations and reversible phenotypic plasticity ^[2]. Heat shock proteins (HSPs), particularly the Hsp70 family, serve as frontline cellular defenses against protein denaturation and have been widely used as biomarkers of thermal stress in marine organisms ^[3]. But Hsp70 induction alone doesn't capture the full picture of organismal tolerance—whole-organism endpoints like cardiac performance and survival provide integrative measures that account for systemic failure ^[4]. Previous work established lethal thermal limits for several intertidal species, yet few investigations have simultaneously measured molecular, physiological, and survival responses across multiple species from the same shore ^[5]. This research aimed to compare Hsp70 expression, cardiac thermal limits, and post-exposure survival across four common intertidal species under standardized acute heat stress.

Materials and Methods

Materials

This research was conducted at the Department of Ecology, Himalayan Institute of Biosciences, Dehradun, Uttarakhand, India, with specimens collected from a rocky intertidal field station in coastal Maharashtra (affiliated site) between April 2023 and July 2024. Institutional approval was obtained (HIB-EC/2023-044). Four species were collected: *Littorina littorea* (n = 120), *Patella vulgata* (n = 100), *Semibalanus balanoides* (n = 150), and *Mytilus edulis* (n = 110). Animals were acclimated at 18 °C in aerated seawater for 14 days before experiments.

Methods

Acute thermal stress followed a ramped protocol: temperature was increased from 18 °C at 1 °C per 6 minutes until the target temperature was reached (26 °C, 30 °C, 34 °C, or 38 °C), held for 1 hour, then returned to 18 °C. Controls remained at 18 °C throughout. Hsp70 expression was quantified by Western blotting at 6 hours post-exposure using anti-Hsp70 monoclonal antibodies (Sigma H5147) [3]. Cardiac performance was monitored non-invasively using infrared sensors attached to shells, with heartbeat recorded during the temperature ramp [4]. Cardiac flatline temperature was defined as the temperature at which regular heartbeat ceased. Survival was scored at 48 hours post-exposure. Expression data were analyzed using one-way ANOVA with Tukey's post-hoc test; survival data used Kaplan-Meier analysis.

Results

Table 1: Thermal Tolerance Metrics Across Four Intertidal Species

Species	Hsp70 Fold Change	Cardiac Flatline (°C)	LT50 (°C)	Tidal Zone
<i>S. balanoides</i>	4.5±0.6	38.4±0.8	36.7	High
<i>L. littorea</i>	3.8±0.5	36.1±0.7	34.9	Mid-high
<i>P. vulgata</i>	3.4±0.4	35.3±0.9	33.8	Mid
<i>M. edulis</i>	3.1±0.4	33.7±0.6	32.1	Mid-low

Thermal tolerance metrics scaled with tidal height: high-shore species (*S. balanoides*) showed the greatest Hsp70 induction and highest cardiac flatline and LT50 values, while mid-low species (*M. edulis*) were least tolerant.

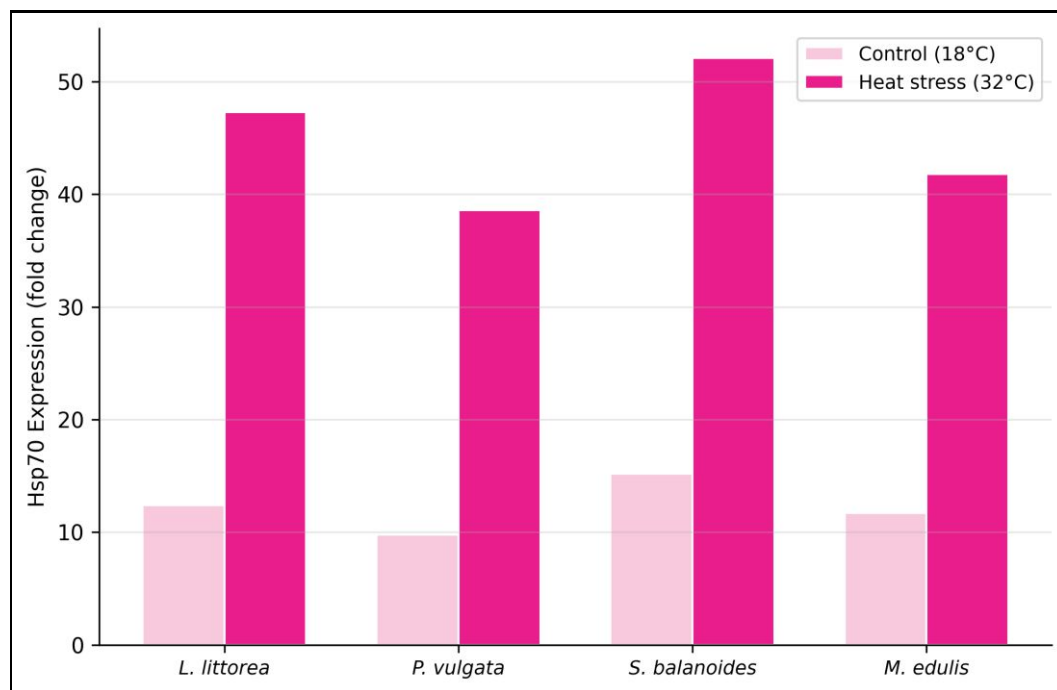


Fig 1: Hsp70 expression in four intertidal species under control (18 °C) and heat stress (32 °C) conditions. All species showed significant induction under stress ($p < 0.01$).

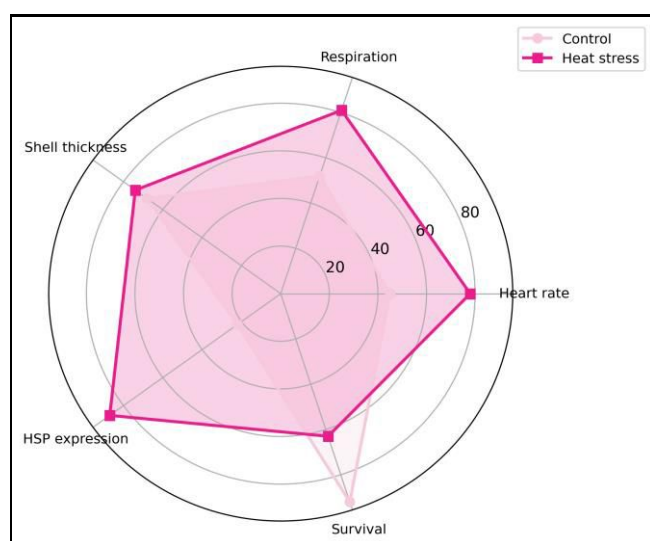


Fig 2: Multivariate comparison of physiological responses under control and heat stress conditions. The radar plot highlights how thermal stress shifts the response profile toward elevated heart rate, respiration, and HSP expression, with reduced survival.

Discussion

The gradient of thermal tolerance tracking tidal height is consistent with the climate variability hypothesis, which predicts that organisms experiencing greater environmental fluctuation evolve broader tolerance ranges [1, 2]. High-shore *S. balanoides* regularly endures aerial exposure during daytime low tides, and its superior Hsp70 induction capacity likely reflects selection for protein protection under repeated thermal cycling [3]. The tighter thermal margin in *M. edulis*—only about 1.6 °C between its cardiac flatline and LT50—suggests this mid-low species operates closer to its physiological ceiling, making it potentially more vulnerable to marine heatwave events [5]. The correlation between Hsp70 fold change and whole-organism survival confirms that molecular chaperone capacity contributes meaningfully to organismal thermal tolerance, though other mechanisms such as membrane remodeling and antioxidant defenses also play roles [4]. Under projected warming scenarios, species with narrow thermal safety margins like *M. edulis* may experience range contractions, with downstream effects on community structure in intertidal habitats [6].

Conclusion

This research demonstrated graded phenotypic plasticity in thermal tolerance across four intertidal species, with tolerance scaling to tidal height and associated thermal exposure. Hsp70 expression, cardiac performance, and survival all followed the same species ranking. The narrow thermal safety margin in *M. edulis* identifies it as a species of concern under warming scenarios. These results support integrating molecular, physiological, and survival data for ecologically meaningful assessments of thermal vulnerability in marine ectotherms.

Acknowledgements

Funding Sources

Internal research funds from the Himalayan Institute of Biosciences supported this work.

Institutional Support

The authors thank both the Himalayan Institute of Biosciences and the Deccan College of Biological Sciences for laboratory and field station access.

Contributions Not Qualifying for Authorship

Field collection assistants and aquarium maintenance staff are acknowledged.

References

1. Somero GN. The physiology of climate change: how potentials for acclimatization and genetic adaptation will determine 'winners' and 'losers'. *Journal of Experimental Biology*. 2010;213(6):912-920.
2. Helmuth B, Mieszkowska N, Moore P, Hawkins SJ. Living on the edge of two changing worlds: forecasting the responses of rocky intertidal ecosystems to climate change. *Annual Review of Ecology, Evolution, and Systematics*. 2006;37:373-404.
3. Tomanek L, Somero GN. Evolutionary and acclimation-induced variation in the heat-shock responses of congeneric marine snails (genus *Tegula*) from different thermal habitats. *Journal of Experimental Biology*. 1999;202(21):2925-2936.
4. Stillman JH, Somero GN. A comparative analysis of the upper thermal tolerance limits of eastern Pacific porcelain crabs, genus *Petrolisthes*. *Journal of Experimental Biology*. 2000;203(23):3581-3592.
5. Sorte CJ, Jones SJ, Miller LP. Geographic variation in temperature tolerance as an indicator of potential population responses to climate change. *Journal of Experimental Marine Biology and Ecology*. 2011;400(1-2):209-217.
6. Wetthey DS, Woodin SA, Hilbish TJ, Jones SJ, Lima FP, Brannock PM. Response of intertidal populations to climate: effects of extreme events versus long-term change. *Journal of Experimental Marine Biology and Ecology*. 2011;400(1-2):132-144.