comparative work on northern and southern *Haliotis discus hannai* populations shows that long-term exposure and selection in warmer waters produces domesticated stocks with enhanced thermal tolerance and superior regulation of carbohydrate and amino-acid metabolism, demonstrating that breeding and translocation programs can deliberately cultivate heat-tolerant lines for deployment in warming regions. Genomic tools are emerging as powerful levers to accelerate thermal adaptation. Quantitative genetic and genomic selection work on *Pacific abalone* reports moderate heritability (0.35-0.42) for heat-tolerance traits and demonstrates that genomic selection models can predict heat tolerance with high accuracy, identifying specific SNP markers and candidate genes that can be used in marker-assisted breeding programs to improve resilience to marine heatwaves. Ecosystem-based designs like abalone-seaweed co-culture further enhance climate resilience by biologically modifying water conditions: in juvenile red abalone, IMTA with the red seaweed dulse elevated pH under simulated ocean acidification, producing faster growth, better condition and stronger shells, and thereby "shepherding" juveniles through their most vulnerable life stage despite deteriorating external seawater quality.

References

Atalah J., Ibáñez S., Aixalà L., Barber X., and Sánchez-Jerez P., 2024, Marine heatwaves in the western Mediterranean: considerations for coastal aquaculture adaptation, Aquaculture, 588: 740917.
https://doi.org/10.1016/j.aquaculture.2024.740917

Bansemer M., Salini M.J., Qin J.G., Harris J.O., Howarth G.S., and Stone D.A.J., 2023, Digestive enzymes of postweaned greenlip abalone (*Haliotis laevigata*) are influenced by water temperatures and dietary protein levels, Aquaculture, Fish and Fisheries, 4(1): e146.
https://doi.org/10.1002/aff2.146

Barkan R., Cooke I.R., Watson S.-A., and Strugnell J.M., 2025, Synthesis of transcriptomic studies reveals a core response to heat stress in abalone (genus *Haliotis*), BMC Genomics, 26(1): 474.
https://doi.org/10.1186/s12864-025-11680-0

Chapperon C., Clavier J., Dugué C., Amice E., Goff L.M., and Roussel S., 2018, Seasonal and diurnal variability in carbon respiration, calcification and excretion rates of the abalone *Haliotis tuberculata* L., Journal of the Marine Biological Association of the United Kingdom, 99(2): 393-402.
https://doi.org/10.1017/S0025315418000097

Chen N., Luo X., Gu Y., Han G., Dong Y., You W., and Ke C., 2016, Assessment of the thermal tolerance of abalone based on cardiac performance in *Haliotis discus hannai*, *H. gigantea* and their interspecific hybrid, Aquaculture, 465: 258-264.
https://doi.org/10.1016/j.aquaculture.2016.09.004

Duncan M.I., Micheli F., Boag T.H., Marquez J., Deres H., Deutsch C., and Sperling E., 2023, Oxygen availability and body mass modulate ectotherm responses to ocean warming, Nature Communications, 14(1): 3811.
https://doi.org/10.1038/s41467-023-39438-w

Fang J., Zhang P., Fang J., Jiang Z., Gao Y., and Du M., 2018, The growth and carbon allocation of abalone (*Haliotis discus hannai*) of different sizes at different temperatures based on the abalone-kelp integrated multitrophic aquaculture model, Aquaculture Research, 49(8): 2676-2683.
https://doi.org/10.1111/are.13769

Frederick A.R., Lee A.M., Wehrle B.A., Catabay C., Rankins D.R., Clements K., and German D., 2022, Abalone under moderate heat stress have elevated metabolic rates and changes to digestive enzyme activities, Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 270: 111230.
https://doi.org/10.1016/j.cbpa.2022.111230

Gao F.-L., Zheng R., Zhang K., Liu K., Huang D., Fang C., Lin H., and Bo J., 2024, Effects of thermal stress from nuclear power plants on the survival rate, behavioral changes, and biochemical and molecular responses of abalone, Aquaculture Reports, 37: 102239.
https://doi.org/10.1016/j.aqrep.2024.102239

Hassan A.L.I., Mock T., Searle K., Rocker M.M., Turchini G., and Francis D.S., 2023, Growth performance and feed utilisation of Australian hybrid abalone (Haliotis rubra × Haliotis laevigata) fed increasing dietary protein levels at three water temperatures, The British Journal of Nutrition, 131(6): 944-955.
https://doi.org/10.1017/s0007114523002519

Hobday A.J., Alexander L.V., Perkins S.E., Smale D.A., Straub S.C., Oliver E.C.J., Benthuysen J.A., Burrows M.T., Donat M.G., Feng M., Holbrook N.J., Moore P.J., Scannell H.A., Gupta A.S., and Wernberg T., 2016, A hierarchical approach to defining marine heatwaves, Progress in Oceanography, 141: 227-238.
https://doi.org/10.1016/j.pocean.2015.12.014

Holland O.J., Smythe C., Clark T.D., Ragg N.L.C., Mondon J.A., Corbett P., and Miller A.D., 2023, Size-dependent thermal limits in Australian hybrid abalone: implications for productivity shifts with ocean warming, Reviews in Fish Biology and Fisheries, 34(1): 271-291.
https://doi.org/10.1007/s11160-023-09812-4

Kang H., Lee Y.-J., Song W., Kim T.-I., Lee W., Kim T.Y., and Kang C., 2019, Physiological responses of the abalone Haliotis discus hannai to daily and seasonal temperature variations, Scientific Reports, 9(1): 8019.
https://doi.org/10.1038/s41598-019-44526-3