

Environmental physiology of the jumbo squid, *Dosidicus gigas* (d'Orbigny, 1835) (Cephalopoda: Ommastrephidae): implications for changing climate

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Dosidicus gigas (d'Orbigny, 1835) is a large, active squid that undergoes a diel vertical migration in the Eastern Tropical and Temperate Pacific. It is a voracious predator on zooplankton and micronekton and supports a large fishery. It is further preyed upon by large vertebrate predators, including whales. Its horizontal distribution is closely tied to productive upwelling regions that are characterized by strong oxygen minimum zones (OMZs). The apparent association with extreme hypoxia is surprising given its large size and high oxygen demand. As part of its daily vertical migration, *D. gigas* experiences daily temperature changes of 15–20°C, oxygen partial pressures ranging from near anoxia (< 0.8 kPa) to air-saturation (21 kPa) and pH changes from ~8.1 to < 7.6 at depth. Oxygen minimum zones are believed to be expanding due to climate change, with minimum oxygen levels in the core of the OMZ declining and the low oxygen horizon shoaling. Simultaneously, surface waters are becoming more acidic and temperatures are rising. Here I review the extensive studies of this species that have been conducted over the past decade. *D. gigas* has a high affinity respiratory protein in the blood that supports a low critical oxygen partial pressure (3.8 kPa

at 20 °C) and aerobic survival at night in the upper 200 meters of the water column. A pronounced pH- and temperature sensitivity of oxygen binding promotes oxygen transport across a depth range and in support of high rates of oxygen utilization but may impose constraints on high-temperature and CO₂ tolerance. At its deeper, colder daytime habitat depth, *D. gigas* undergoes a pronounced metabolic suppression. Reduced activity levels and an apparent suspension of transcription and translation contribute to a ~80% reduction in oxygen demand under 1% oxygen (0.8 kPa at 10 °C). Anaerobic metabolic pathways contribute some energy under these conditions. This metabolic suppression likely limits feeding at depth. Sub-critical oxygen levels, rather than temperature, predator avoidance or prey availability, appear to set the daytime depth distribution. Thus, expanding oxygen minimum zones will alter the daytime depth of peak abundance for these squids while ocean acidification and warming may impose a shallow ceiling above which squid performance is limited. The role of climate change in setting the vertical and horizontal distribution of the species is discussed.

Seibel B. A., 2015. Environmental physiology of the jumbo squid, *Dosidicus gigas* (d'Orbigny, 1835) (Cephalopoda: Ommastrephidae): implications for changing climate. *American Malacological Bulletin* 33(1):161-173. [Article](#)(subscription required).

Changes in pteropod distributions and shell

dissolution across a frontal system in the California Current System

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We tested the sensitivity of the vertical distributions and shell dissolution patterns of thecosome pteropods to spatial gradients associated with an eddy-associated front in the southern California Current System. The aragonite saturation horizon ($\Omega_{\text{arag}} = 1.0$) shoaled from >200 to <75 m depth across the front. The vertical distribution of thecosome pteropods tracked these changes, with all 5 species showing reduced occurrence at depths below 100 m where waters were less saturated with respect to aragonite. Shell dissolution patterns of the numerically dominant thecosome *Limacina helicina* corresponded to the cross-frontal changes in Ω_{arag} saturation state. Severe shell dissolution (categorized here as Type II and Type III) was low in near-surface waters where $\Omega_{\text{arag}} > 1.4$, while peak dissolution occurred in depths where $\Omega_{\text{arag}} = 1.0$ to 1.4. Vertical habitat compression and increased shell dissolution may be expected to accompany future shoaling of waters that are undersaturated with respect to aragonite.

Bednaršek N. & Ohman M. D., 2015. Changes in pteropod distributions and shell dissolution across a frontal system in the California Current System. Marine Ecology Progress Series 523:93-103. [Article](#) (subscription required).

Effects of elevated CO₂ levels on eggs and larvae of a North Pacific flatfish

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The Bering Sea and Gulf of Alaska support a number of commercially important flatfish fisheries. These high latitude ecosystems are predicted to be most immediately impacted by ongoing ocean acidification, but the range of responses by commercial fishery species has yet to be fully explored. In this study, we examined the growth responses of northern rock sole (*Lepidopsetta polyxystra*) eggs and larvae across a range of CO₂ levels (ambient to 1500 μ atm) to evaluate the potential sensitivity to ocean acidification. Laboratory-spawned eggs and larvae were reared at 8°C in a flow-through culture system in which CO₂ levels were maintained via computer-controlled injection of CO₂ into a seawater conditioning tank. Overall, we observed only minor effects of elevated CO₂ level on sizes of northern rock sole larvae. Size at hatch differed among offspring from four different females, but there was no significant effect of CO₂ level on egg survival or size at hatch. In three separate larval growth trials, there was little effect of CO₂ level on growth rates through the first 28 d post-hatch (DPH). However, in the one trial extended to 60 DPH, fish reared at the highest CO₂ level had lower condition factors after 28 DPH, suggesting that larvae undergoing metamorphosis may be more sensitive to environmental hypercapnia than earlier pre-flexion stages. These results suggest that while early life stages of northern

rock sole are less sensitive to ocean acidification than previously examined flatfish, they may be more sensitive to elevated CO₂ levels than a previously studied gadid with a similar geographic range.

Hurst T. P., Laurel B. J., Mathis J. T. & Tobosa L. R., in press. Effects of elevated CO₂ levels on eggs and larvae of a North Pacific flatfish. ICES Journal of Marine Science. [Article](#) (subscription required).

Experimental ocean acidification alters the allocation of metabolic energy

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Energy is required to maintain physiological homeostasis in response to environmental change. Although responses to environmental stressors frequently are assumed to involve high metabolic costs, the biochemical bases of actual energy demands are rarely quantified. We studied the impact of a near-future scenario of ocean acidification [800 μ atm partial pressure of CO₂ (pCO₂)] during the development and growth of an important model organism in developmental and environmental

biology, the sea urchin *Strongylocentrotus purpuratus*. Size, metabolic rate, biochemical content, and gene expression were not different in larvae growing under control and seawater acidification treatments. Measurements limited to those levels of biological analysis did not reveal the biochemical mechanisms of response to ocean acidification that occurred at the cellular level. In vivo rates of protein synthesis and ion transport increased ~50% under acidification. Importantly, the in vivo physiological increases in ion transport were not predicted from total enzyme activity or gene expression. Under acidification, the increased rates of protein synthesis and ion transport that were sustained in growing larvae collectively accounted for the majority of available ATP (84%). In contrast, embryos and pre feeding and unfed larvae in control treatments allocated on average only 40% of ATP to these same two processes. Understanding the biochemical strategies for accommodating increases in metabolic energy demand and their biological limitations can serve as a quantitative basis for assessing sublethal effects of global change. Variation in the ability to allocate ATP differentially among essential functions may be a key basis of resilience to ocean acidification and other compounding environmental stressors.

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Detecting changes in marine

responses to ENSO from 850 to 2100 C.E.: Insights from the ocean carbon cycle

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It is open whether El Niño–Southern Oscillation (ENSO) varies under climate change and how potential changes in the marine system are detectable. Here differences in the influence of ENSO on biogeochemical tracers, pH, productivity, and ocean temperature are analyzed in a continuous 850–2100 Common Era (C.E.) simulation with the Community Earth System Model. The modeled variance in ENSO amplitude is significantly higher during the Maunder Minimum cold than during the 21st century warm period. ENSO-driven anomalies in global air-sea CO₂ flux and marine productivity are two to three times lower, and ocean tracer anomalies are generally weaker in the 21st century. Significant changes are detectable in both surface and subsurface waters and are earlier verifiable and more widespread for carbon cycle tracers than for temperature. This suggests that multitracers observations of both physical and biogeochemical variables would enable an earlier detection of potential changes in marine ENSO responses than temperature-only data.

Keller K. M., Joos F., Lehner F. & Raible C. C., 2015. Detecting changes in marine responses to ENSO from 850 to 2100 C.E.: Insights from the ocean carbon cycle. *Geophysical Research Letters*

42(2):518–525. [Article](#) (subscription required).