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[REVIEW]

Dive Deep: Bioenergetic Adaptation of Deep-Sea Animals

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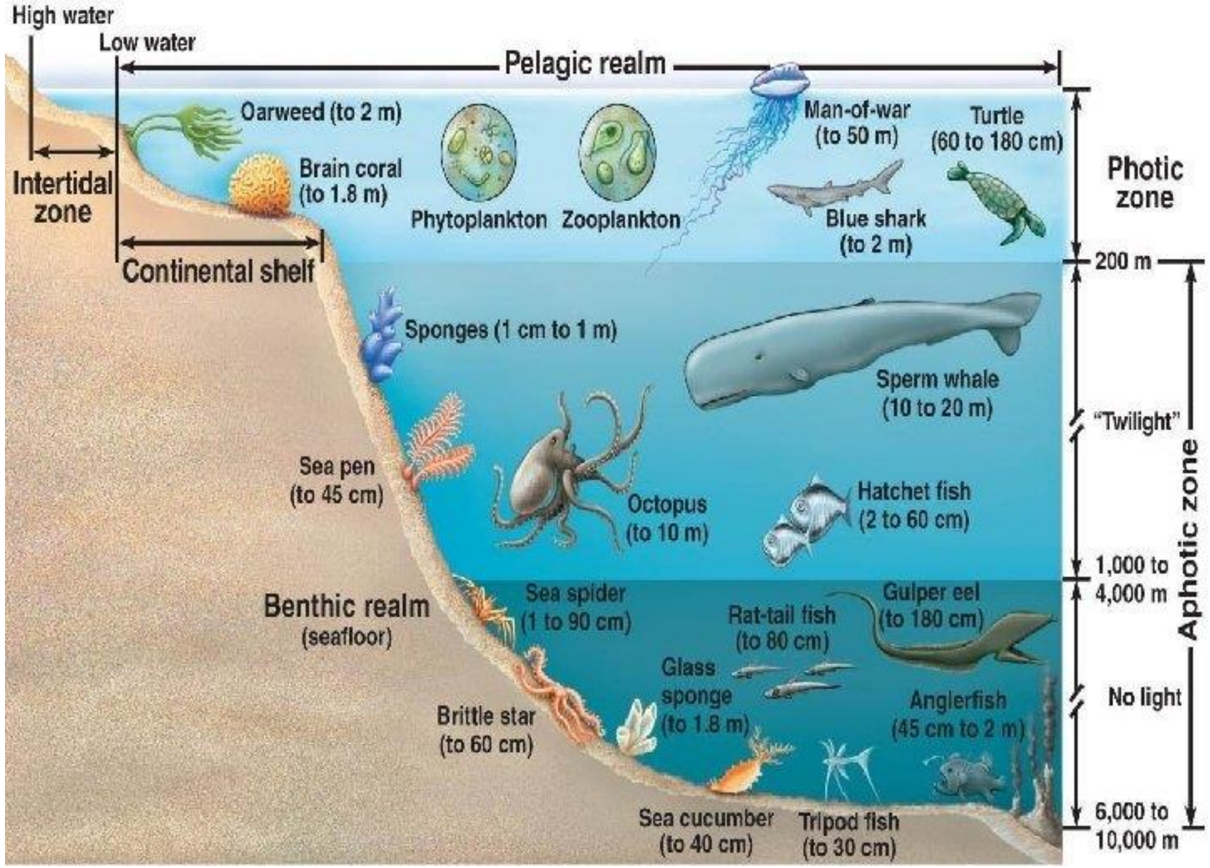
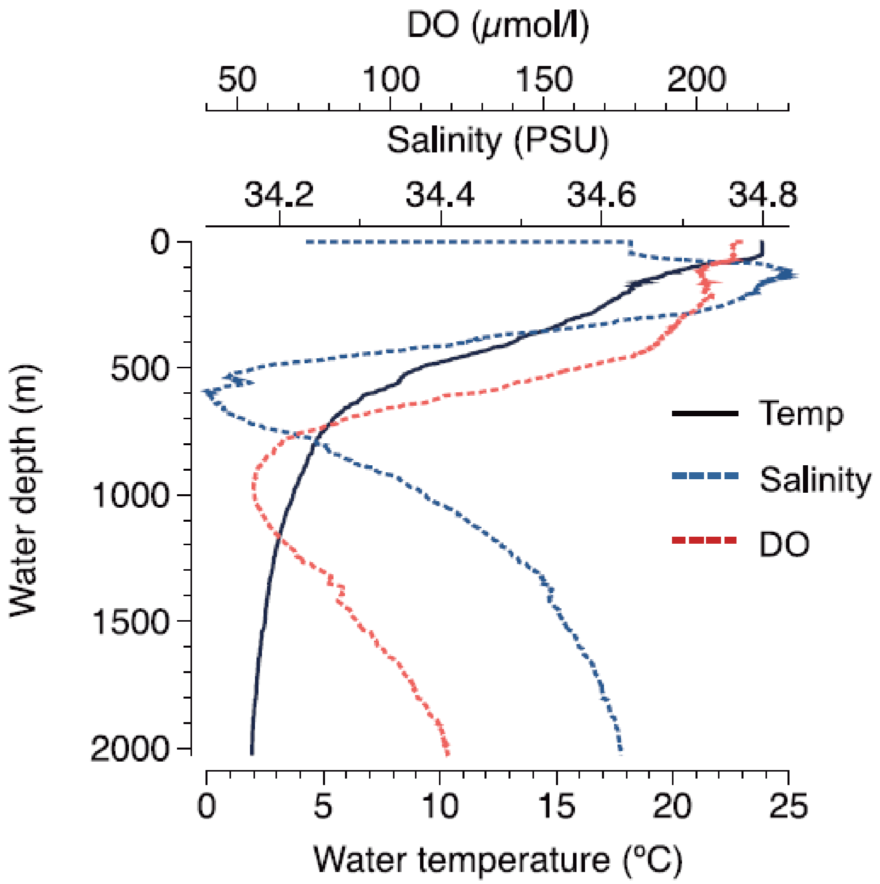
Introduction



- Approximately 99.5% of the Earth's habitable volume is located in the oceans
- The greatest marine biodiversity is found below 1000m in depth

Narcetes shonanmaruae

Introduction: The Physical Environment of the Deep Sea



Vertical profiles of water temperature (Temp), salinity, and dissolved oxygen (DO) in the Pacific Ocean (22°59.4′N, 137°00.6′E) during winter 2021. Data from the Japan Meteorological Agency (JMA).

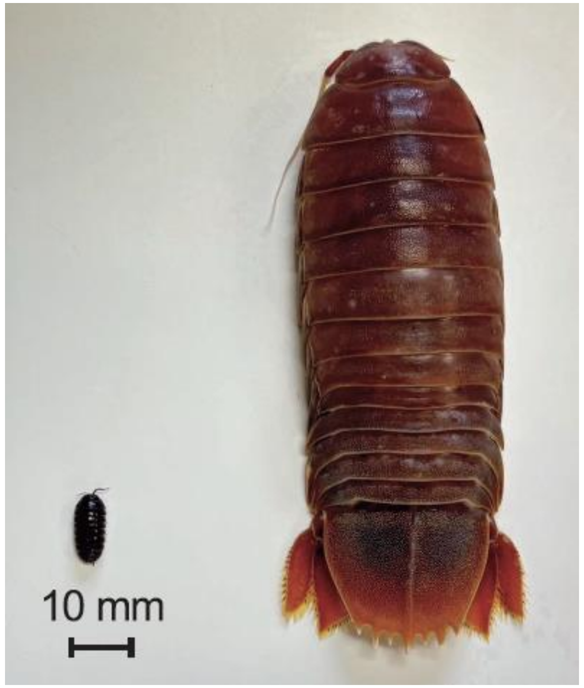
Environmental conditions in the deep sea differ greatly from those found at the ocean surface:

- **TEMPERATURE**: below the thermocline (500m) are relatively stable, typically averaging less than 4°C
- **SALINITY**: It ranges between 34.6 and 34.9 PSU
- **DISSOLVED OXYGEN**:
  - Around 500m, a hypoxic layer is present (50 μmol/L) ⟶ OMZ
  - > 1000 m in depth, dissolved oxygen levels increase to 130–220 μmol/L
- **LIGHT INTENSITY**: It is located below the epipelagic zone

Many species have adapted to live in these extreme conditions

Introduction: Particular Phenomena in the Deep Sea

GIGANTISM



Comparison of body size between the deep-sea isopod Bathynomus doederleinii (right) and the wood louse Armadillidium vulgare (left).
Both are isopods, but differ in body weight by a factor of 340 (deep-sea isopod, 34.4 g; wood louse, 0.1 g). The deep-sea isopod is found at depths of around 400 m in temperate zones, whereas the wood louse is terrestrial.

The Japanese giant crab, Macrocheira kaempferi, is the world's largest arthropod.

LONGEVITY

The Greenland shark, Somniosus microcephalus (81–502 cm in length), which is widespread in the deep waters of the North Atlantic, lives from 272 to 392 years.

Experimental Question

- ❖ How does deep-sea organisms manage energy?
- ❖ How does energy metabolism of deep-sea organisms differ from that of shallow-sea organisms?

Energy input

Abyssal organisms have a lower probability of encountering prey

EFFICIENT USE OF ENERGY RESOURCES

Ambush strategies

Deep-sea anglerfish

Feeding on dead animals

Eurypharynx pelecanoides (pesce pellicano)

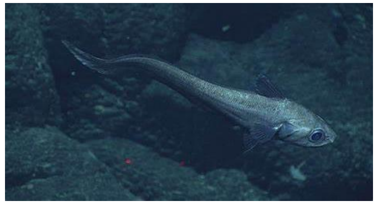
Digestion, assimilation, and specific dynamic action

Organisms that live in the deep sea have developed unique metabolic strategies to cope with extreme conditions, such as low temperatures and high pressure.

DIGESTION

- Deep-sea organisms have evolved cold-adapted enzymes.
- Some enzymes are even activated by pressure
- Certain deep-sea species can digest plant materials like wood and seeds, thanks to specific enzymes
- Wax esters, which are difficult to digest for many terrestrial animals, are instead a crucial energy source for deep-sea marine organisms

Enzymatic Adaptations



Coryphaenoides sp., a benthic deep-sea fish

Hirondella gigas

Digestion, assimilation, and specific dynamic action

ASSIMILATION

- Deep-sea organisms show higher assimilation efficiency compared to related surface-dwelling species
- Animals that feed intermittently, such as ambush predators, also tend to be more energy-efficient than active swimmers

Poromitra crassiceps has a very long intestinal tract, which helps extract energy even from gelatinous and nutrient-poor prey.

SPECIFIC DYNAMIC ACTION (SDA) → = the metabolic increase that follows food intake

- In deep-sea SDA can last up to 16 days after a large meal
- Cost: during the digestive phase, animals tend to remain motionless and less active

⇒ Leading to energy management strategies known as **POWER BUDGETING**

Energy expenditure

- Aerobic animals produce energy through the oxidation of food in the Krebs cycle, consuming oxygen and producing carbon dioxide.

- Metabolic rate is measured through:
  - Heat production
  - Oxygen consumption → 1L O2 consumed = 4,8 kcal produced

- Fats have the highest energy content per gram

- Different levels of metabolism are distinguished based on the activity of the animal:

  - BASAL: at rest and fasting
  - ACTIVE: during intense and brief movements
  - RESTING-NORMAL: minimal movement, but not fasting

Energy expenditure

- The **low metabolism** of deep-sea organisms depends on several factors:

  1. BODY MASS
     - The larger an animal is, the more slowly it consumes energy per gram of body mass

  2. LOW TEMPERATURE
     - Low temperatures reduce enzyme activity and slow biochemical reactions
     - This leads to a natural decrease in oxygen consumption and energy demand
     - However, temperature alone cannot fully explain the extremely low metabolic rates observed

  3. HIGH PRESSURE
     - At great depths, adaptations lead to lower metabolism

  4. LIMITED FOOD SUPPLY
     - Organisms evolve to minimize energy usage and survive long periods without food
     - Yet, studies show that food scarcity mainly affects biomass, not necessarily individual metabolic rates

Energy expenditure

5. <u>REDUCED MUSCLE MASS</u>
   - With less need for rapid movement, many deep-sea animals have less skeletal muscle
   - This results in lower protein and nitrogen content, decreased swimming ability, reduced metabolic enzyme concentrations

6. <u>LOW ACTIVITY AND PREDATION PRESSURE</u>
   - Fewer predators
   - Many species moving slowly to conserve energy
   - Two main evolutionary hypotheses explain this → Visual Interaction Hypothesis; Predation-Mediated Selection Hypothesis

7. <u>EVOLUTIONARY ADAPTATIONS</u>
   - Specialized body compositions (e.g., higher water content)
   - Enzyme systems optimized for low activity
   - Efficient use of occasional food input

Conclusions

- The article by Yagi et al. provides a comprehensive overview of the remarkable adaptive capabilities of deep-sea animals

- Future research:

  - Focus on an ontogenetic analysis from a life history perspective

  - It will be important to develop methods to analyze the impact of global climate change on metabolism at a planetary scale

THANK YOU FOR YOUR ATTENTION!