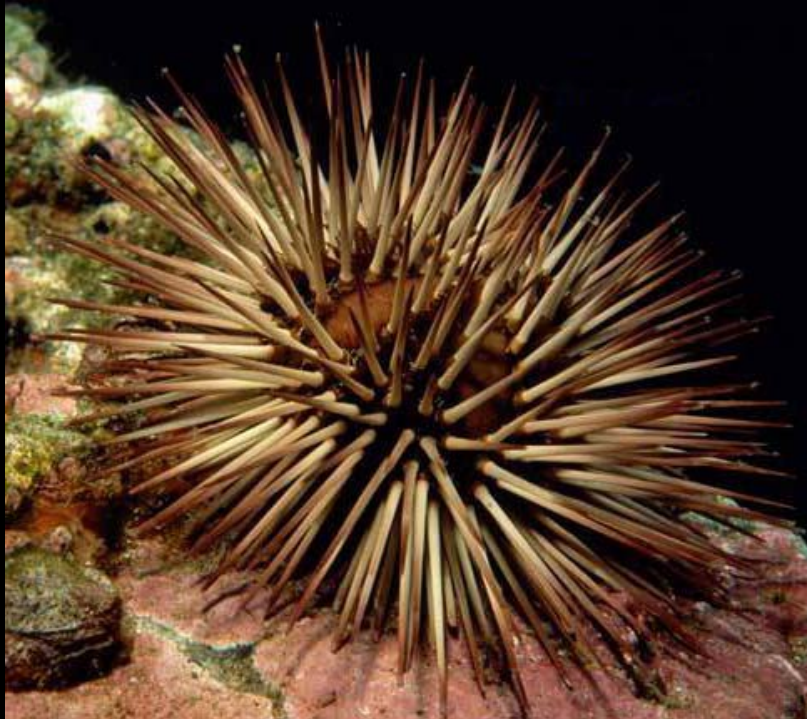
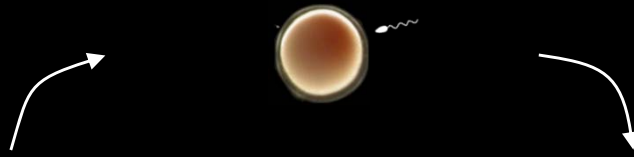
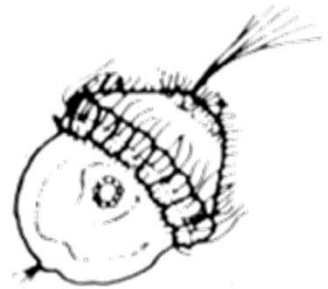


Physical biology: life at small and large scales

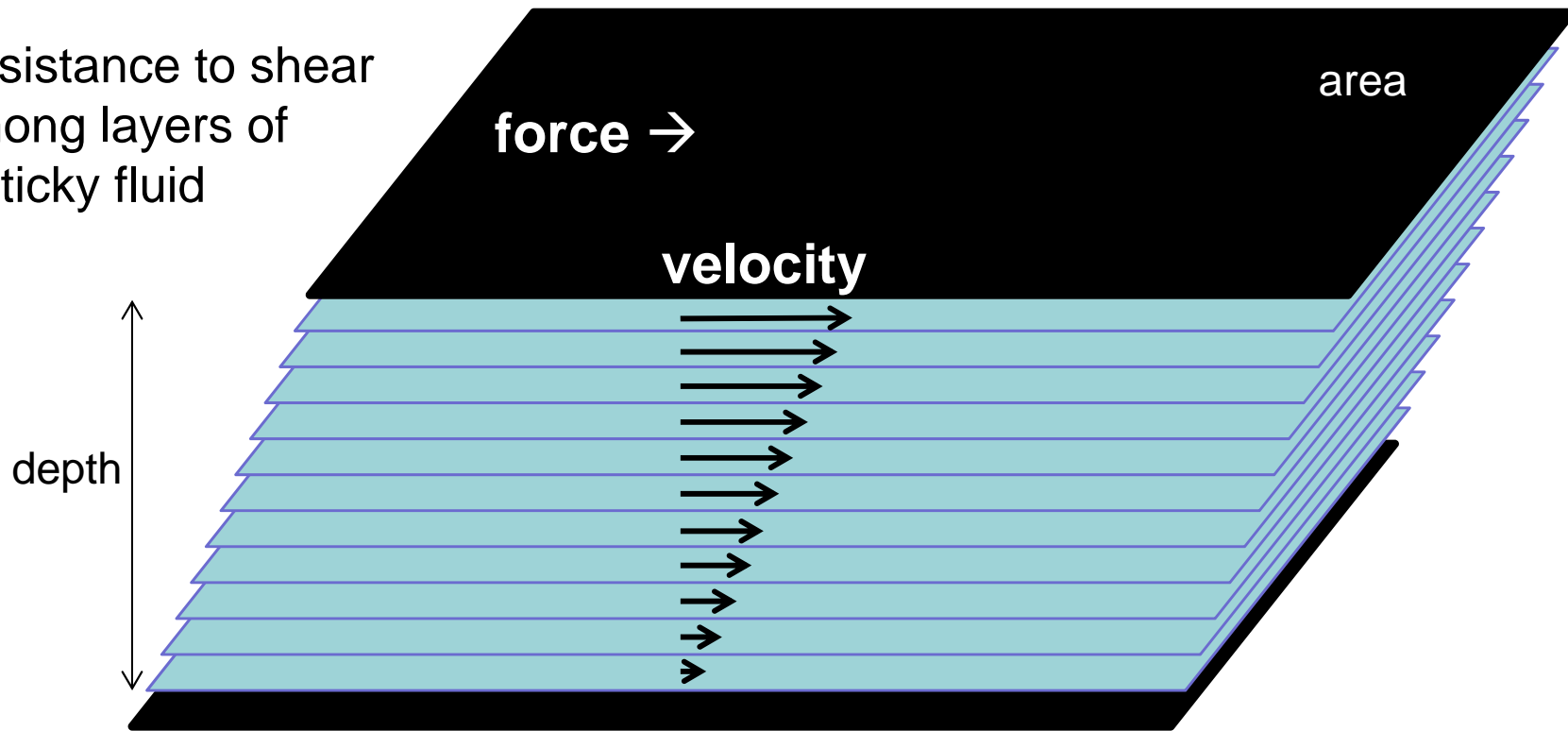


larvae are small and slow



What is viscosity?

Resistance to shear
among layers of
a sticky fluid



$$\text{viscosity} = \frac{\text{force} / \text{area}}{\text{velocity} / \text{depth}}$$

A RANGE OF REYNOLDS NUMBERS

Two forces influence motion of an object through a fluid:

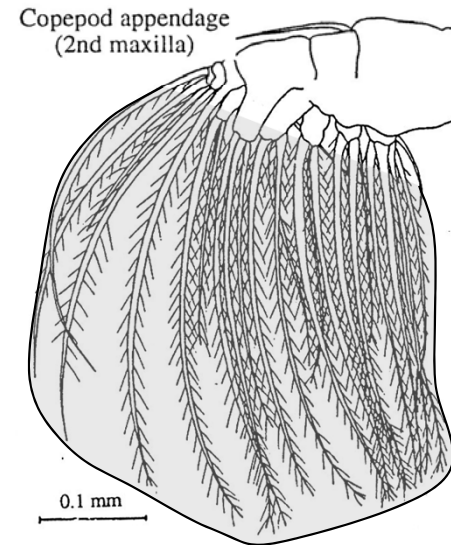
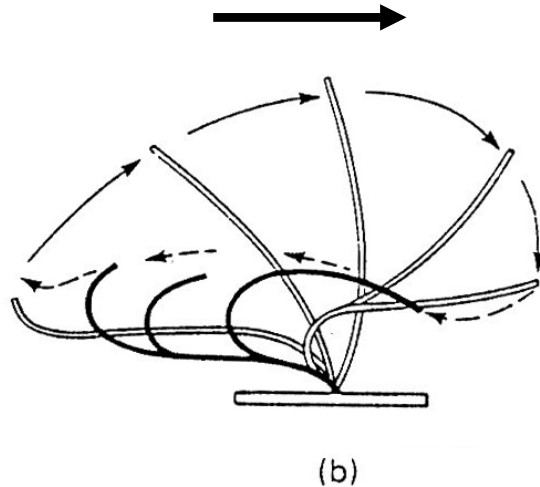
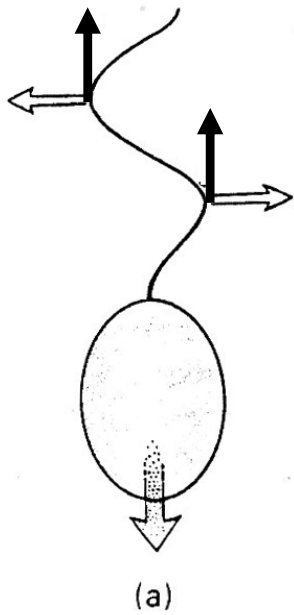
- inertia of the object
- viscosity of the fluid

$$\frac{\text{size} * \text{speed}}{\text{viscosity}} = \text{Reynolds number}$$

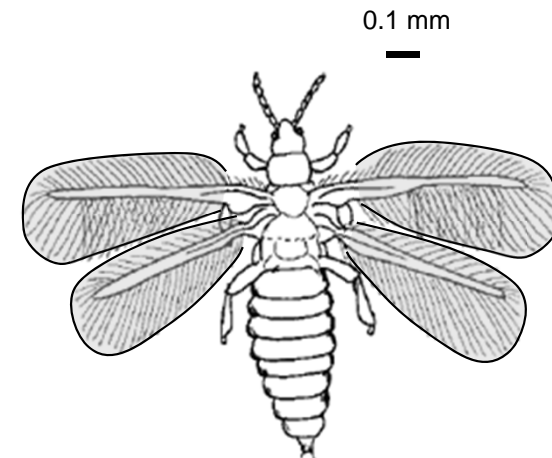
$$Re = \frac{\text{inertial}}{\text{viscous}}$$

Whale swimming at 10 m/s	100,000,000
Fish swimming at 10 m/s	10,000,000
Duck flying at 20 m/s	100,000
Copepod burst swimming at 0.2m/s	100
Larva swimming at 1 mm/s	0.1
Sperm swimming at 0.2 mm/s	0.01
Bacterium swimming at 0.01 mm/s	0.00001

from Vogel (1994)



Copepod
(2nd maxilla)

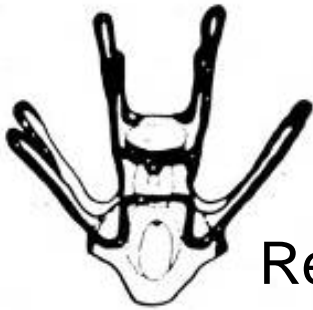


Thrips

Fig. 10.5 Comparison of the direction of force generated by (a) flagella and (b) cilia.

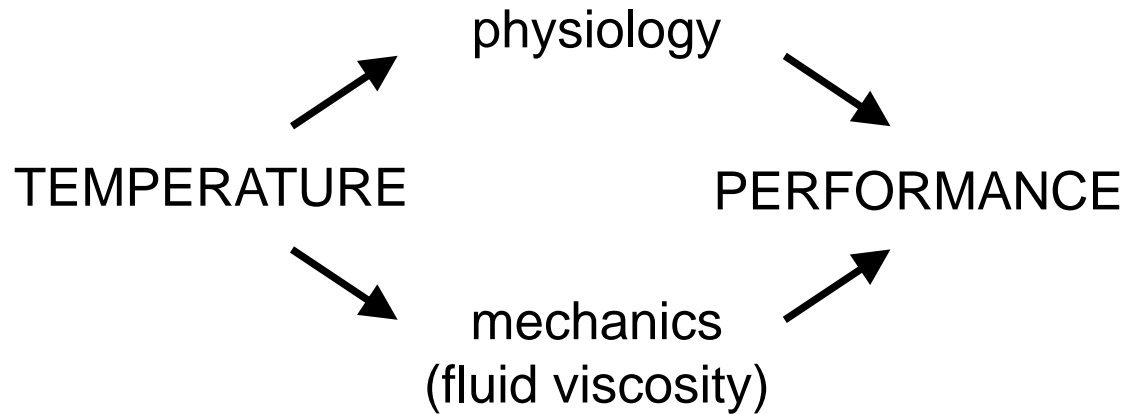
1. How are early life cycle stages influenced by environmental temperature?

(Podolsky and Emlet 1993)

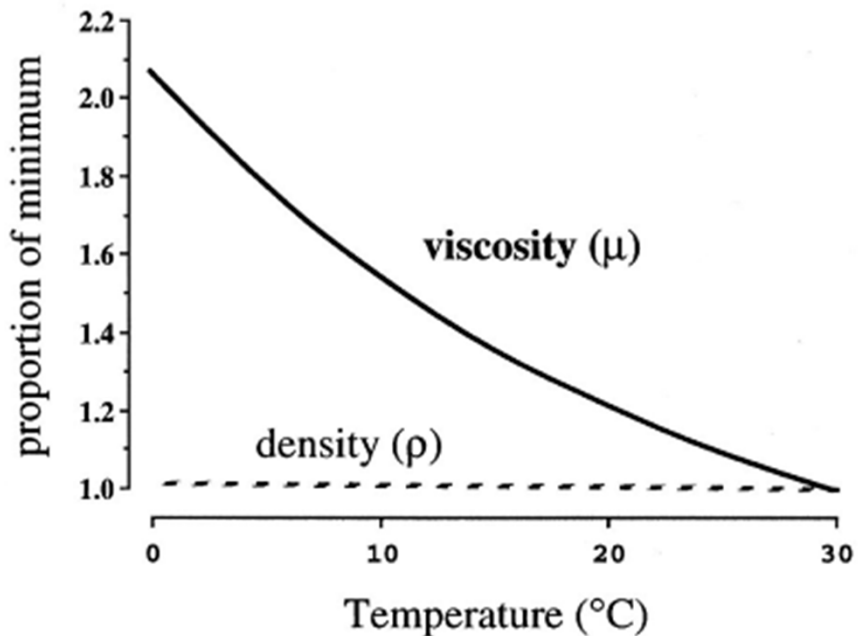


$$Re_{\text{body}} \approx 0.1$$

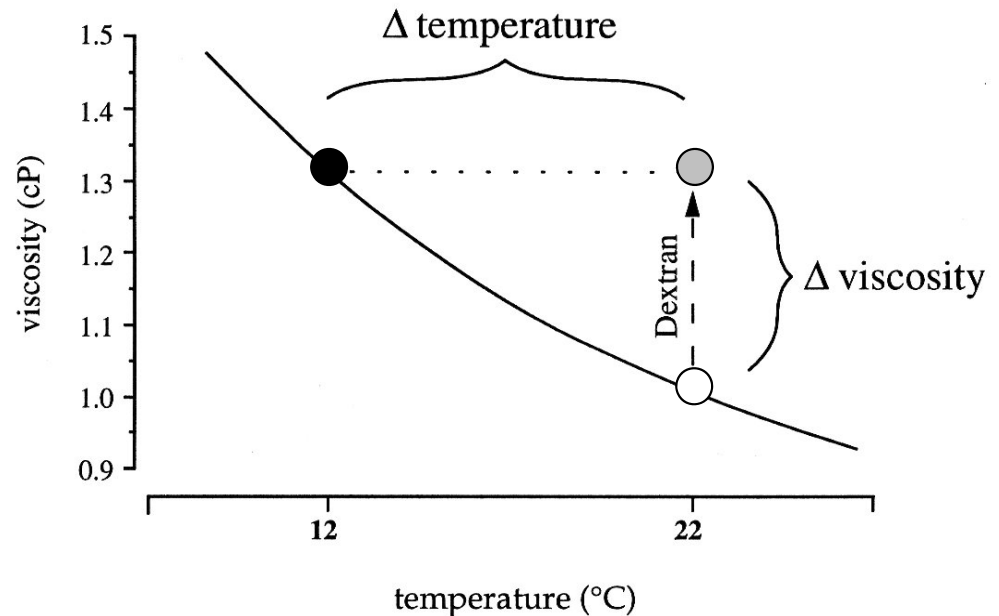
$$Re_{\text{cilium}} \approx 0.01$$



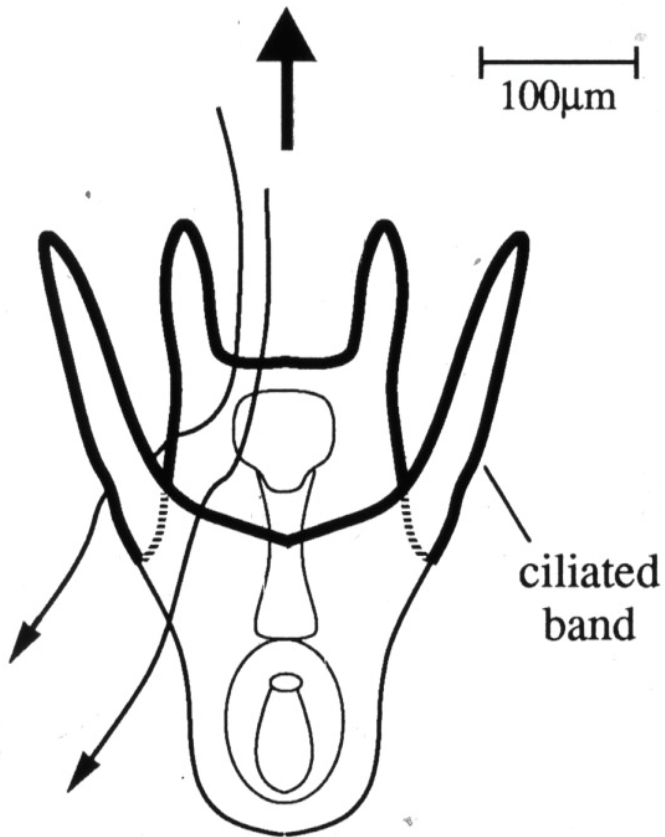
PHYSICAL PROPERTIES OF SEAWATER AS A FUNCTION OF TEMPERATURE



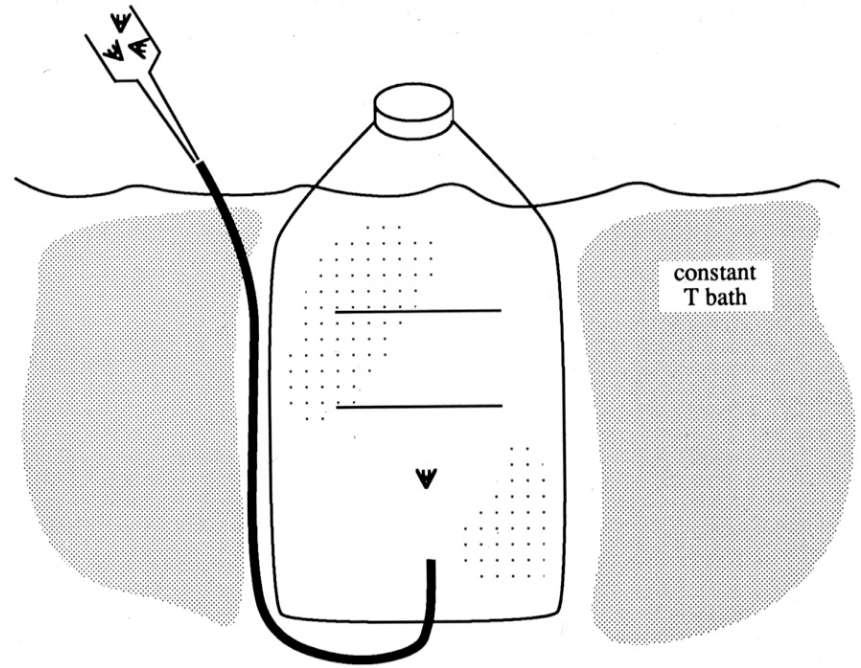
MANIPULATION OF VISCOSITY INDEPENDENT OF TEMPERATURE



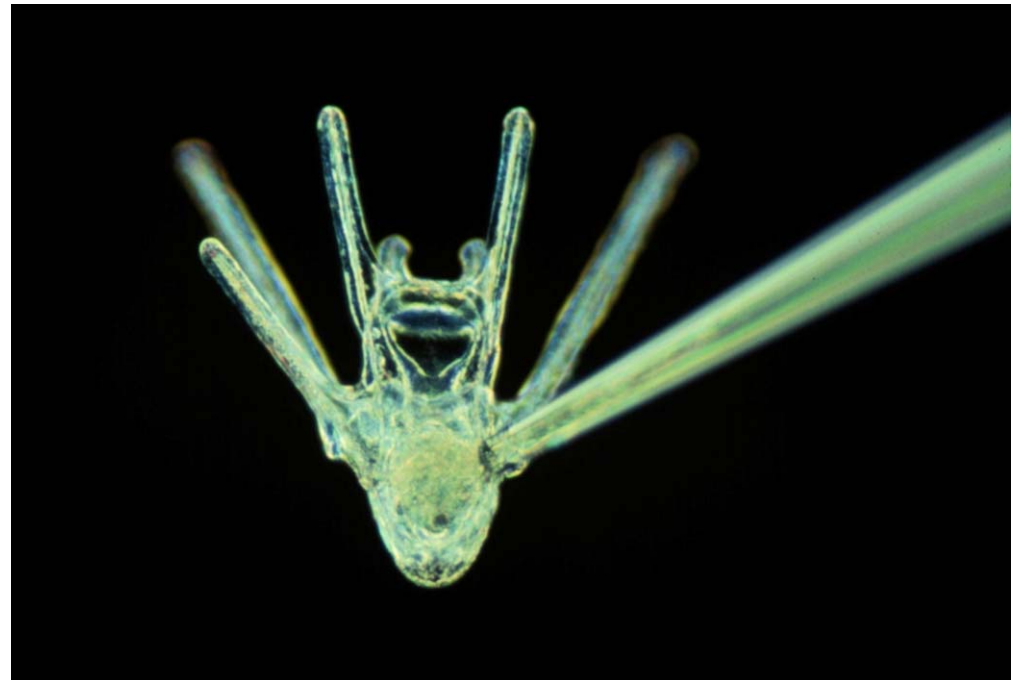
a) Larval swimming & water movement



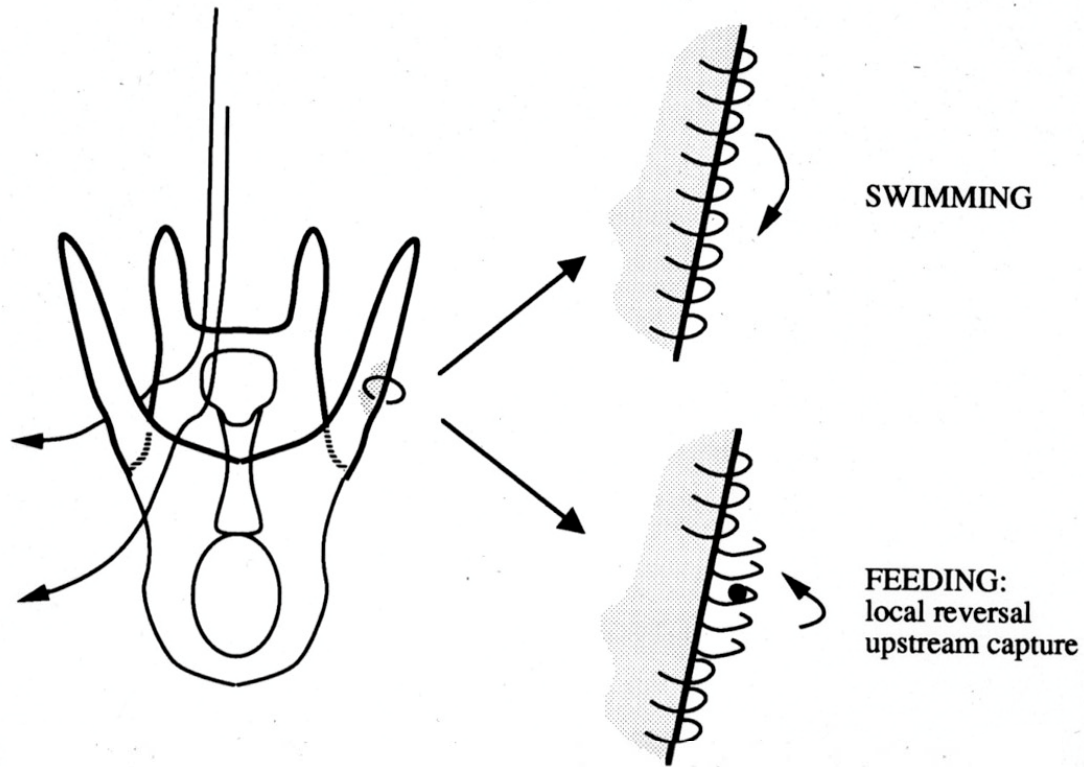
Dendraster excentricus



Measurement of swimming speeds



b) Larval feeding

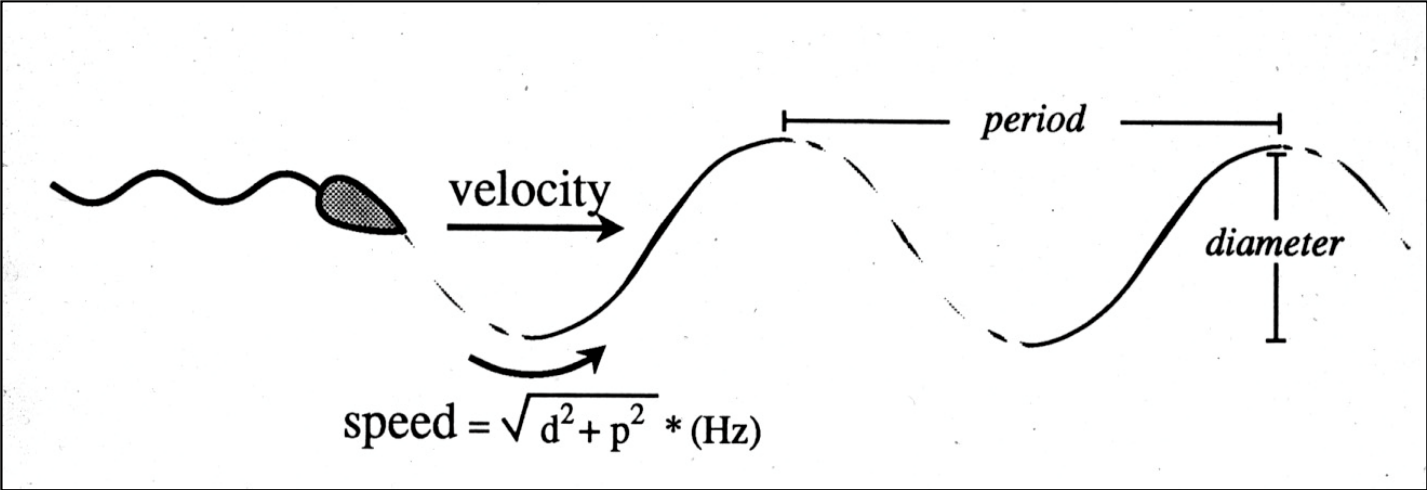
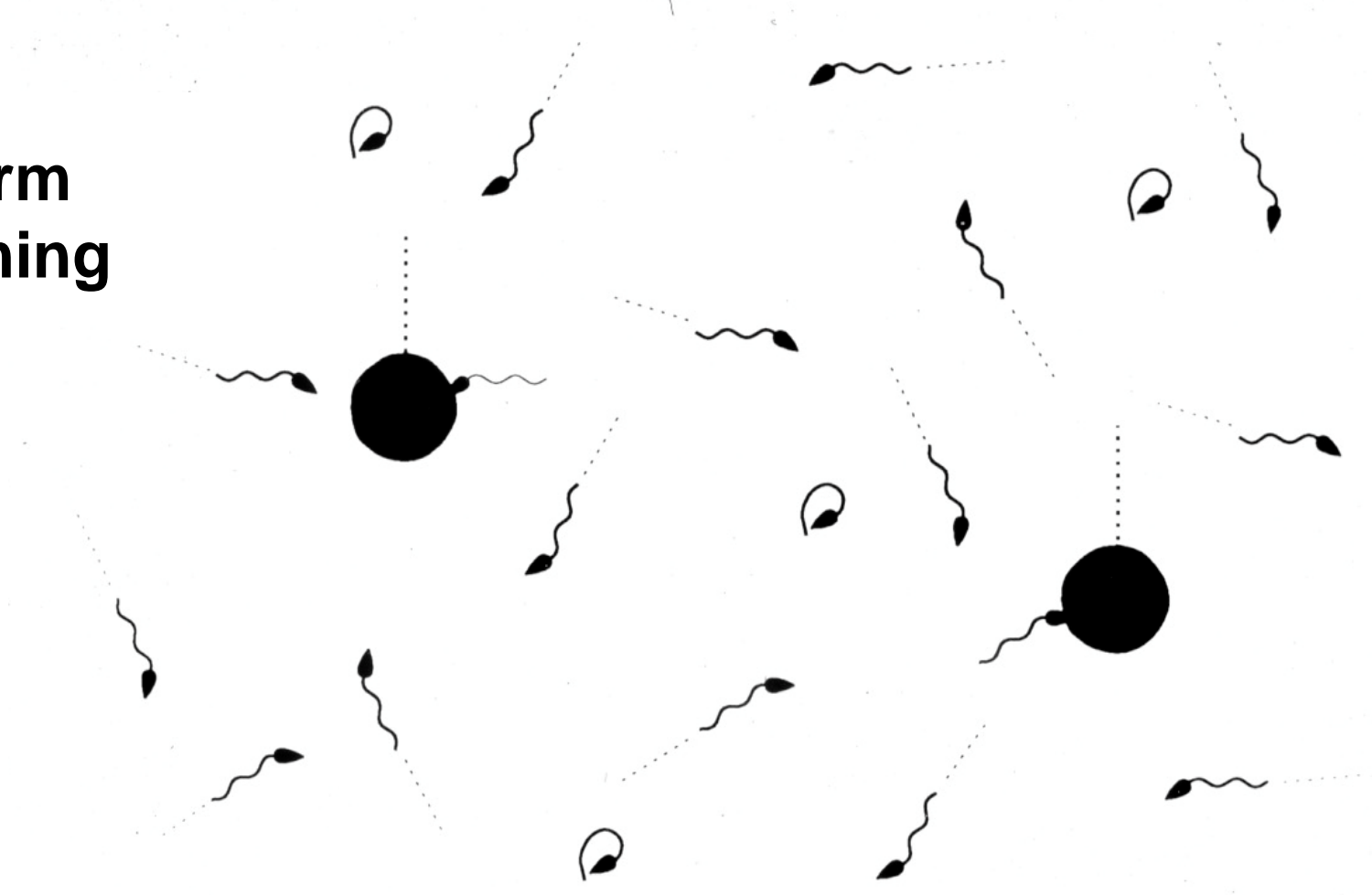


FEEDING EXPERIMENTS

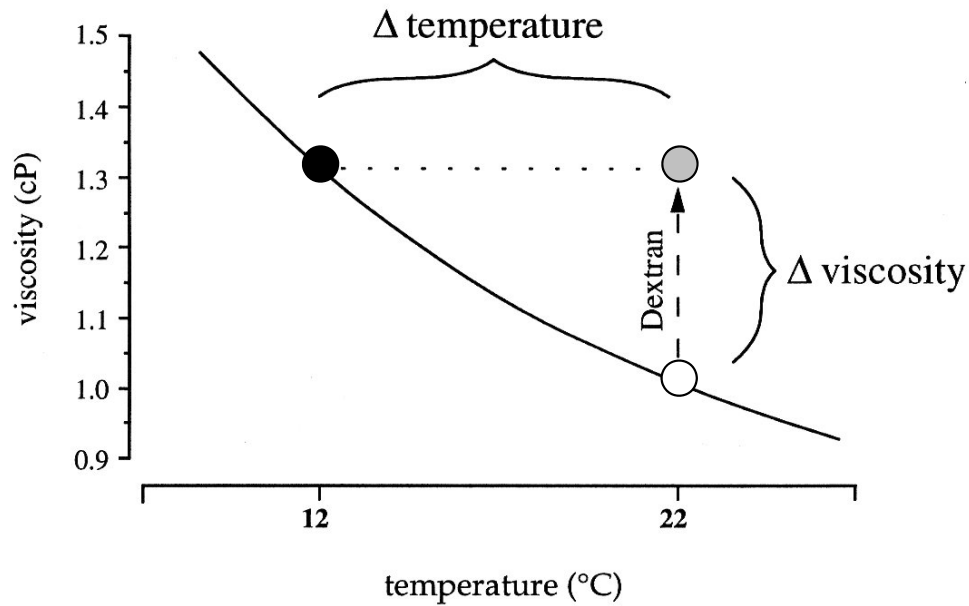
bead sizes (2, 5, 10 μm)
10 min trials



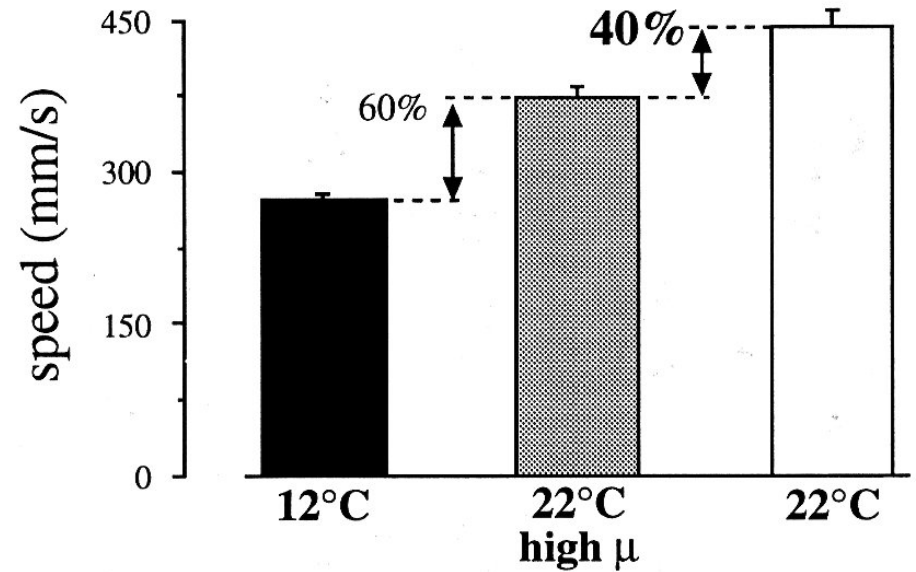
c) Sperm swimming



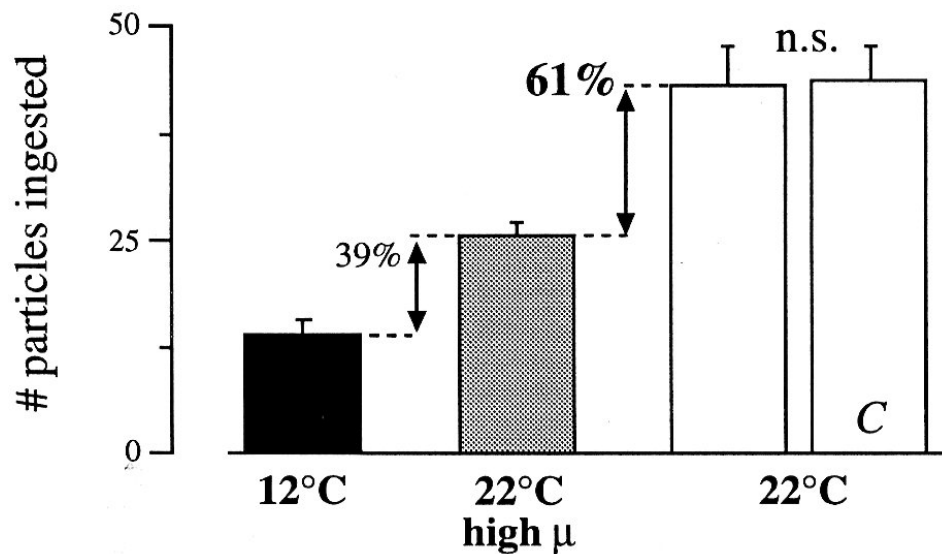
MANIPULATION OF VISCOSITY INDEPENDENT OF TEMPERATURE



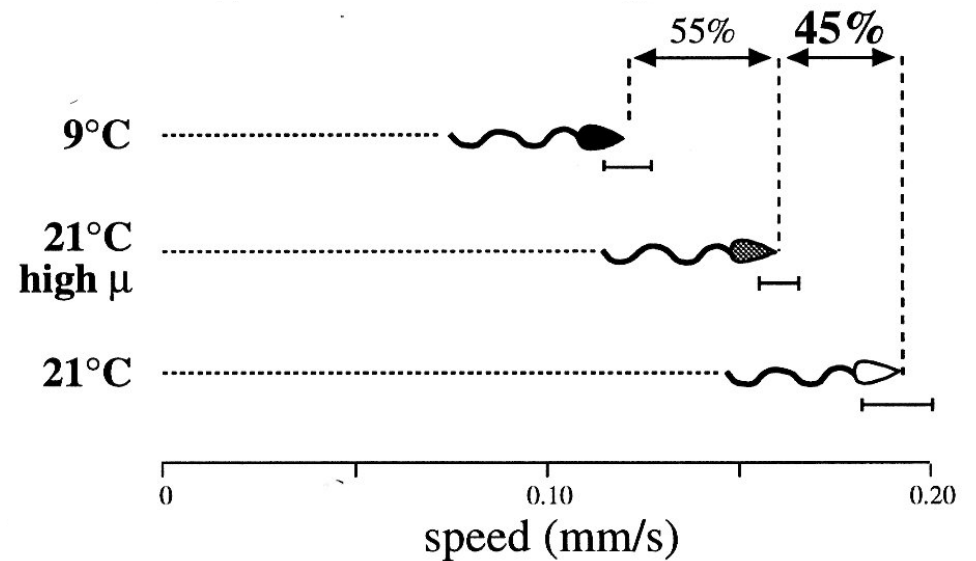
1) larval swimming



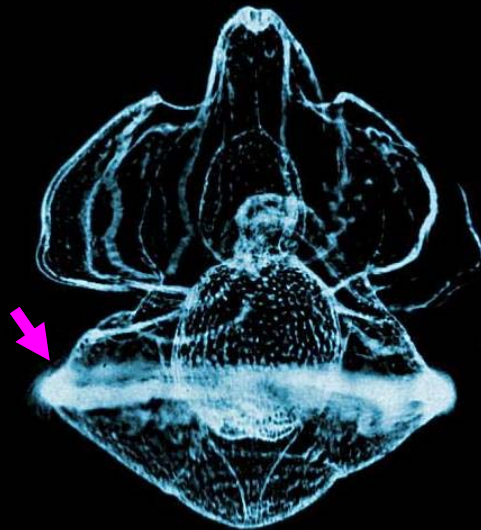
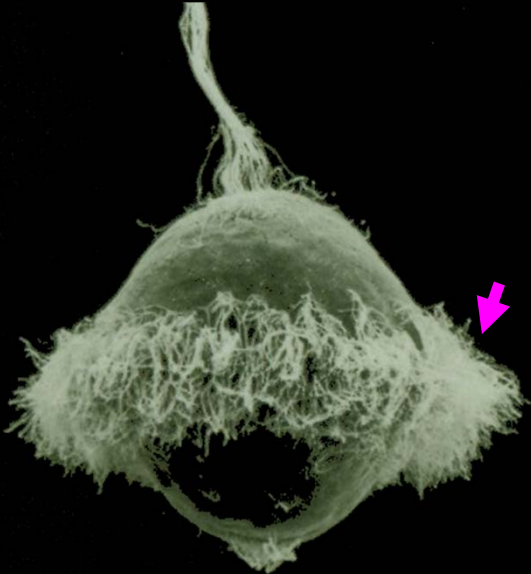
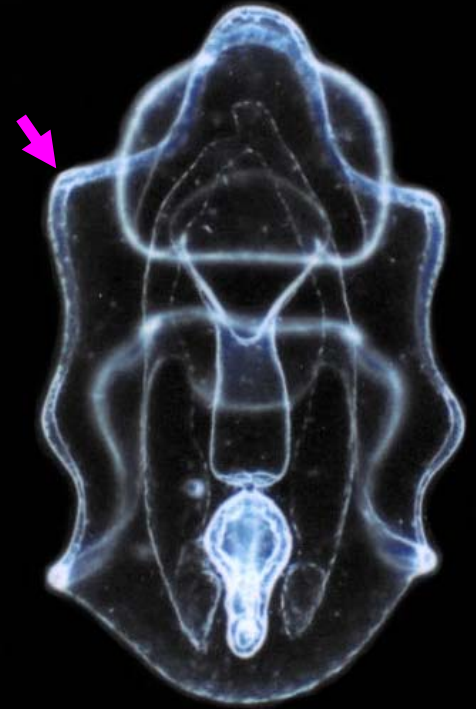
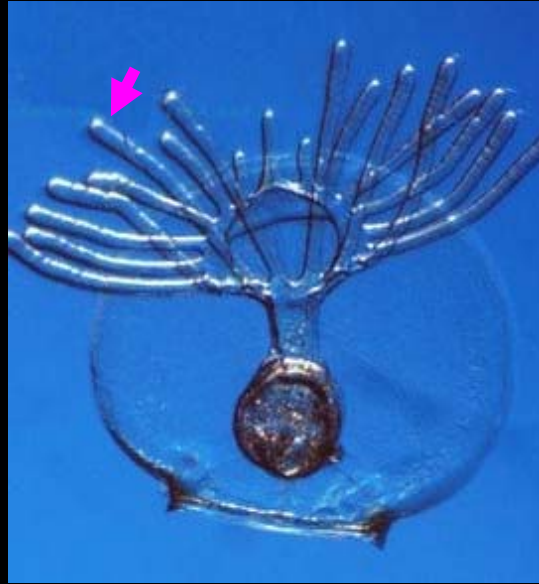
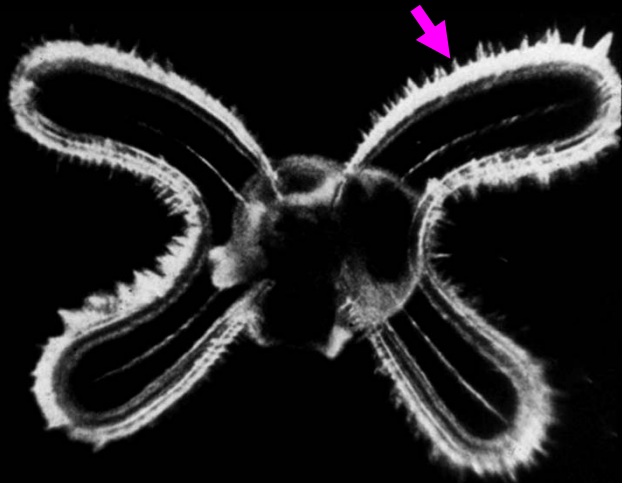
2) larval feeding



3) sperm swimming



larvae are small and slow



→ ciliated band
(swimming & feeding)

→ muscular appendages

most organisms are small and slow

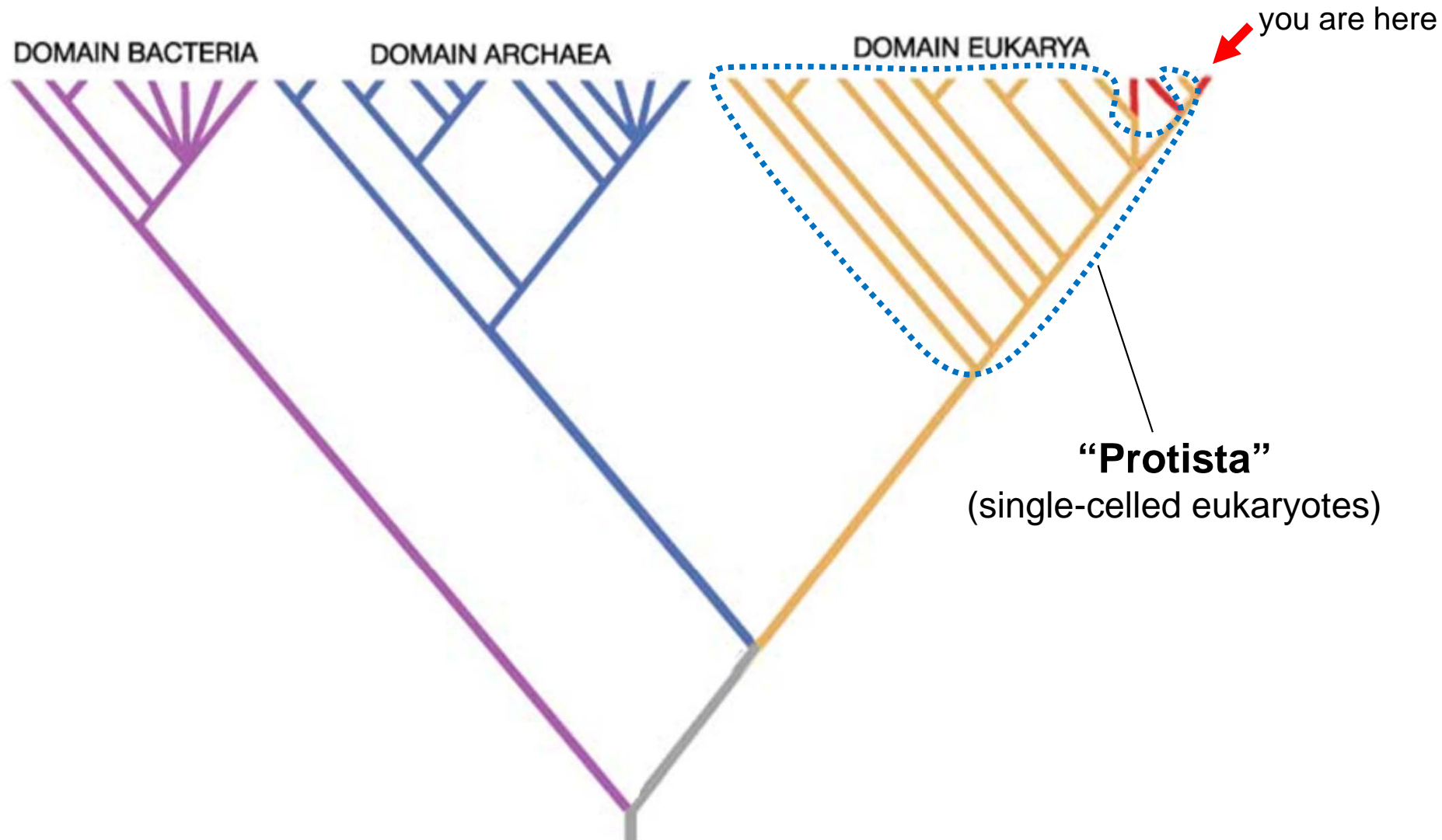
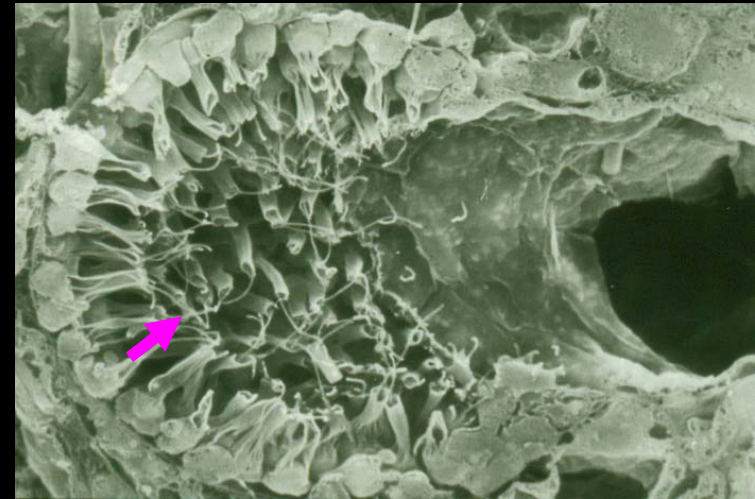
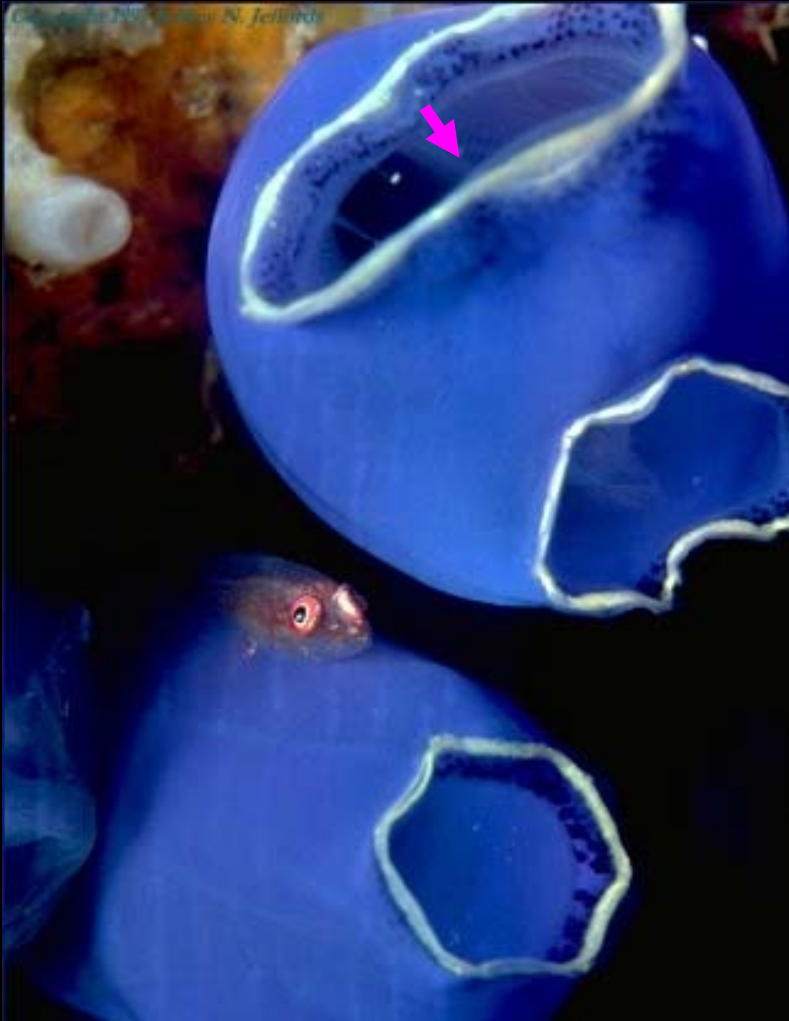
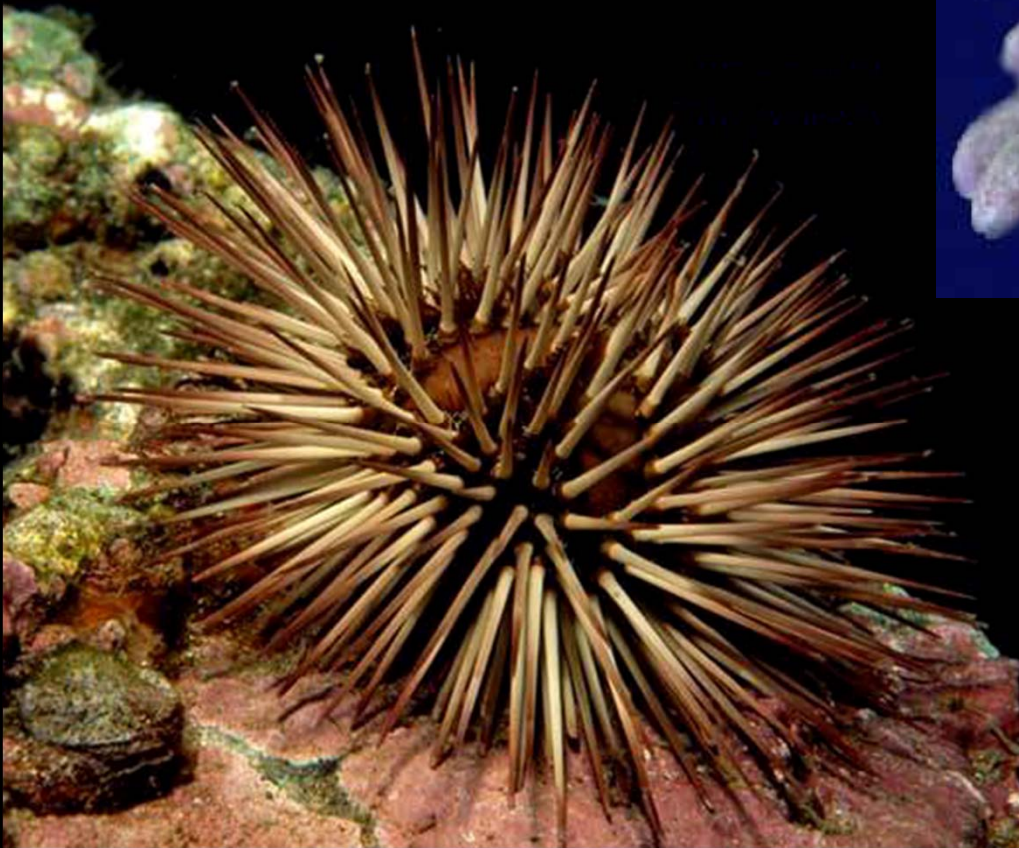


Figure 11.5 An estimate of the phylogeny of all living organisms This tree is based on the analysis of nucleotide sequences of small subunit rRNAs. From Woese (1996).

larger animals are made of
smaller ciliated parts



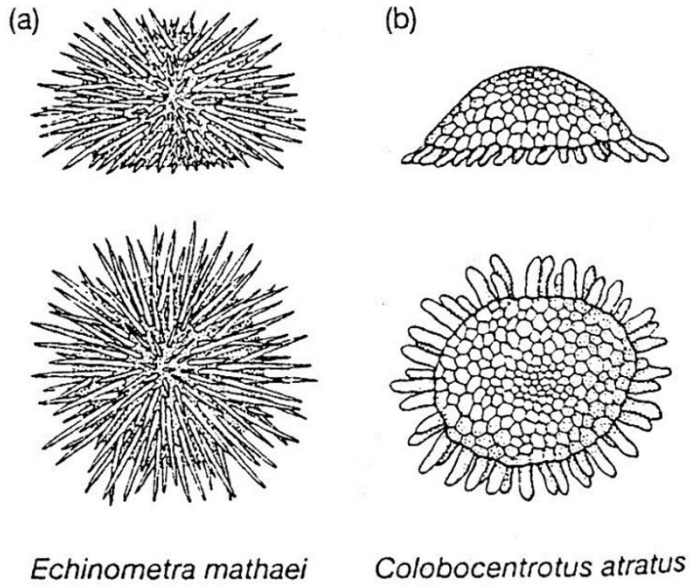
2. How have hydrodynamic forces selected for variation in the morphology of intertidal sea urchins? (Denny and Gaylord 1996)



Echinometra
protected intertidal areas



Colobocentrotus
wave-swept intertidal areas



Denny and Gaylord (1996)

Q: What forces do sea urchins experience?

Figure 8.11 Two species of intertidal sea urchin Redrawn from Denny and Gaylord (1996).

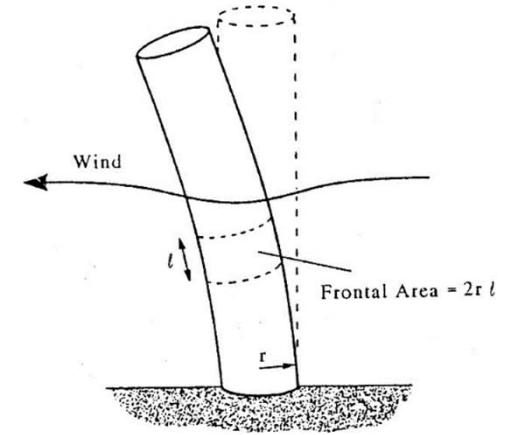


Fig. 4.23 An upright cylinder in flow experiences a drag.

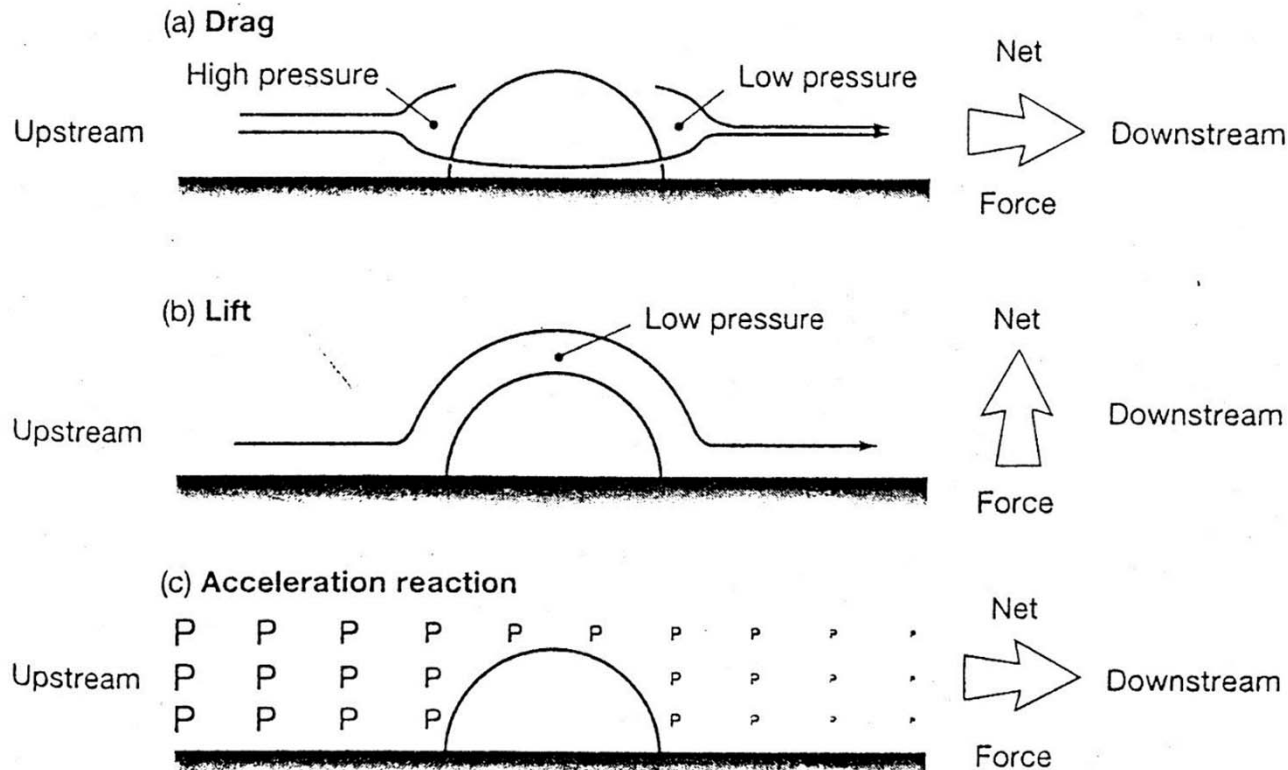


Figure 8.12 Three forces experienced by an urchin clinging to a rock in the intertidal zone

(a) Drag. The fine arrows represent the flow of water around the urchin. The large arrow indicates the direction of the net force due to drag.

(b) Lift. The fine arrow represents the flow of water over the top of the urchin. The large arrow indicates the direction of the net force due to lift.

(c) The acceleration reaction. The P's represent the pressure in water that is accelerating over the urchin from upstream to downstream. Bigger P's indicate higher pressure. The large arrow indicates the direction of the net force due to the acceleration reaction. See text for details.

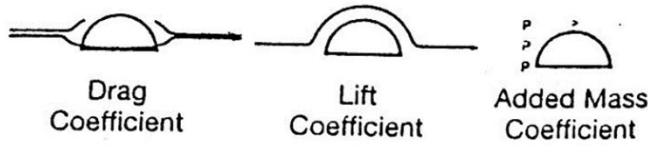
Figure 8.13 Estimates of the forces experienced by sea urchins of different shapes. The drag and lift coefficients reported here characterize the drag and lift experienced by urchins at a water velocity typical of the intertidal (Reynolds

number = 10^5 ; see Denny and Gaylord 1996). The added mass coefficients characterize the acceleration reaction experienced by urchins. Based on the data and equations in Denny and Gaylord (1996).

Denny and Gaylord (1996)

Q: What is the probability of dislodgment?

Fig. 4.24 When the size of an object is increased isometrically, the ratio of frontal to attachment area is constant. As a result, the ratio of drag to strength is constant. In contrast, volume increases faster than attachment area, and the ratio of accelerational force to strength increases.



Flow from left to right

Urchin Shape	Species	Drag Coefficient	Lift Coefficient	Added Mass Coefficient
	<i>C. atratus</i>	0.71	0.18	0.93
	<i>E. mathaei</i>	0.66	0.07	2.90

