

tion at night. During the night there is little general slowing of either reticulo-ruminal activity or respiration-rate while the animal is lying resting, lying ruminating or standing ruminating.

Deep regular breathing at a slow rate is frequently, but not invariably, found in sleeping animals. The kymograph records were accordingly searched for such breathing and a small number of periods were found. These could be detected in spite of the dependence of normal respiration-rate on temperature; on days when the temperature averaged about 50° F. the mean respiration-rate was 19–25/min., whereas at 65° F. it was 45–49/min. in the same two cows. The periods of slow breathing (Fig. 1) were most easily observed at the higher temperatures. Their duration varied from 1 to 10 min., with an average length of less than five minutes, and they frequently ended suddenly. This slow deep breathing was seen only while the cows were lying at night and resting, and the longest total observed in any one night was 36 min. During these periods there was usually a marked slowing of the rate of contraction of the reticulum (Fig. 1). Subsequent recording at the lower temperature disclosed a few periods of slow breathing, also while the animal was lying resting. Because of the slower general rate of respiration, these were less distinct than the periods observed earlier, but were again accompanied by a lowered rate of contraction of the reticulum. Observation of the cows during several periods of slow deep breathing disclosed no loss of consciousness; the periods do, however, appear to represent the maximum relaxation achieved by cattle and the closest approximation to sleep, and it is probably then that the eyes are sometimes closed. The periods were found only when the animal was lying resting and never during rumination.

Rumination occupies a series of periods, usually of less than an hour in length, throughout the twenty-four hours (Fig. 2). The amount of time spent ruminating varies with such factors as the fibrous properties of the diet and the availability of grazing; it frequently totals nine hours out of the twenty-four and, especially in grazing animals, is somewhat concentrated into the hours of darkness. There seems to be no possibility that sleep occurs during rumination, because, in addition to the disturbing effect of the constant chewing and regurgitation, the maintenance of the head in the unsupported position invariably found during rumination would appear to demand a considerable degree of consciousness, to preclude the "immobility of the body" and to demand the function of that "sum total of tonic reflexes of proprioceptive, labyrinthine and visual origin that are responsible for righting the body and maintaining the normal position" and which is usually inoperative during sleep<sup>6</sup>. This may even be necessary, to a lesser extent, for the maintenance of the characteristic lying position of ruminants, especially when the head is not resting on the legs or on the ground.

Since during the night the periods of lying resting are interspersed with periods of standing and of rumination (Fig. 2), it follows that if sleep occurs at all in cattle it must be of the polyphasic type.

It is concluded, therefore, that under normal conditions of management healthy adult cattle and sheep, and probably ruminants in general, sleep little, if at all. If sleep does occur, it can only be of a very light and transient nature. This peculiarity of ruminants may be related to the need for maintaining the thorax in an upright position for proper functioning of the reticulo-rumen, and to the requirement of

time and consciousness for rumination. The implications of this observation are being investigated.

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### Responses of Some Marine Plankton Animals to Changes in Hydrostatic Pressure

It has generally been thought that aquatic animals, which lack gas-filled spaces in their bodies, would not perceive variations in hydrostatic pressure due to small changes in depth, since their bodies are permeated with fluid of very slight compressibility<sup>1</sup>. Only animals possessing gas-filled spaces, such as fishes, with their swim bladders<sup>2</sup>, and certain aquatic insects, with special pressure gauges connected to the tracheal system<sup>3</sup>, had been shown to respond to pressure changes, until recently. Then the discovery that decapod larvae swim upwards, in response to pressure increases<sup>4</sup>, suggested that tests for pressure sensitivity should be carried out on animals not known to possess gas organs.

The animals listed in Table 1 proved to be clearly sensitive. When the pressure was increased, they generally became more active and swam upwards; when it was decreased, they became less active, or completely inactive, and allowed themselves to sink. This behaviour can be termed high 'barokinesis', usually combined with negative geotaxis. The only animals observed to give an active response to a decrease in pressure (low barokinesis, combined with positive geotaxis) were the fishes and the ctenophores. Their behaviour was doubtless correlated with the fact that these animals alone were buoyant, for *Blennius* larvae have a swim bladder<sup>5</sup>, and healthy *Pleurobrachia* reduce their specific gravity in some other way, possibly eliminating heavy ions, as in *Halicystis*<sup>6</sup>. The final column of Table 1 shows the minimum change in pressure which produced a significant response in a proportion of individuals of each species. A millibar is equivalent to 1 cm. of sea water. Bracketing of a figure indicates that no smaller changes were given to the species concerned, which may therefore be much more sensitive than the bracketed figure suggests. Evidently the degree of sensitivity shown is sufficient to help these animals to control their depth.

Other workers have proved that control of depth, in copepods and cladocerans, is largely due to positive phototaxis at reduced illumination<sup>1</sup>. The relative importance of the light response and the pressure response was investigated by confining similar batches of animals in two vertical glass tubes, which were raised and lowered together in the sea. One was

Table 1

Class or Order	Species	Minimum change (in mb.) producing a significant response
Teleostei Decapoda	Larvæ of <i>Blennius pholis</i>	5
	Megalopa larvæ of <i>Carcinides moenas</i>	10
	Corresponding stage of <i>Galathea</i> sp.	10
Isopoda	<i>Eurydice pulchra</i> (pelagic during high water only)	50
Copepoda	<i>Caligus rapax</i>	(800)
Polychaeta	Larvæ of <i>Poecilochaetus serpens</i>	(800)
	Pelagic adults of <i>Autolytus aurantiacus</i>	(800)
	<i>Pleurobrachia pileus</i>	50
Ctenophora	<i>Phialidium hemisphericum</i>	(800)
Hydromedusae	<i>Gossea corynetes</i>	(800)
	<i>Eutima gracilis</i>	(800)

open to pressure changes and the other was sealed at atmospheric pressure. The vertical distribution of the animals inside each tube was recorded with the help of an 'aqualung'. So far, we have used this apparatus only with batches of *Eurydice*, which usually remained near the bottom of the tubes. They swam up only in the tube which was open to the increased pressure at greater depths (2–10 m.). The considerable reduction in light intensity, which at 10 m. was about 1 per cent of the illumination near the surface (vertical extinction coefficient 0.45), appeared to have no effect upon them.

We failed to obtain any clear responses to pressure changes in *Calanus*, *Tomopteris*, *Sagitta*, *Alloteuthis* larvæ and various small plankton animals.

There are special reasons for the pressure response being particularly useful, as a depth-regulating mechanism, to the animals listed in Table 1. The majority of these are large polychaetes and Crustacea of high specific gravity, which have to spend much of their time swimming fairly hard in order to maintain their depth. They sink rapidly during their periodic rests, so they must control the duration of each resting period, if they are to remain suspended. *Calanus*, *Tomopteris* and *Sagitta* do not sink rapidly while resting. Planktonic coelenterates are of specific gravity rather similar to that of sea water; but, if they lacked pressure responses, they would be liable to change level quite widely while resting, because they spend most of their time inactive, with their extended tentacles slowly trailing through the water. This is, of course, the way in which the majority catch their prey.

Fish have to guard against their unstable buoyancy mechanism moving them upwards or downwards, so they might be expected to be particularly sensitive to pressure changes. Nevertheless, the minimum changes to which *Blennius* larvæ responded were not much smaller than those which induced responses in decapod larvæ, and the delay between stimulus and response was generally greater in *Blennius* than in *Carcinides* and *Eurydice*. It is therefore doubtful whether possession of a swim bladder confers a particularly high degree of sensitivity to small pressure changes. No gas organs are known in any of the other animals dealt with here, and it is very unlikely that medusæ or ctenophores possess even the smallest of gas vesicles, for these would easily be visible under the microscope in such transparent animals. Some other mechanism of pressure perception must be sought. So far the only effects of hydrostatic pressure which have been observed in living tissues have been effects due to very high pressures<sup>7</sup>; but these were profound and eventually lethal.

Evidently the very existence of life at the greatest ocean depths depends on special physiological adaptation to high pressure<sup>8</sup>. Considering this, it is less surprising to find evidence that changes of less than a decibar may produce effects on living tissues which are sufficiently important to be appreciated by the animals concerned; but the mechanism of perception is quite uncertain.

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### Astaxanthin in the American Flamingo

THE flamingo, *Phoenicopterus ruber*, derives from its dietary carotenoids the conspicuous rich pink to red colours of its feathers, tarsal and pedal skin and lower bill-mandible. Captive flamingos gradually lose their rich pigmentation unless appropriate dietary measures are taken. The presumptive role of crustacean carotenoids in supplying pigmentation to the birds in Nature is given some support by observations in zoos<sup>1</sup> and by Manunta's<sup>2</sup> reported recovery of an astaxene-like carotenoid from the fat of a flamingo.

In the San Diego Zoo, a flock of two dozen flamingos has received, since March 1954, finely ground carapace (plus some hypoderm) of the California 'spiny lobster', *Panulirus interruptus*, added as a regular supplement to the usual diet of beef- or horse-liver, grass-pellets, millet, wheat, rice, dried flies and ground shrimp. As a result, the American species, *Phoenicopterus ruber*, soon developed striking pink and vermilion colours in the skin (not in the transparent scales) of the tarsals, heel and webbed toes, the lower mandible and the new plumes. Three members of a smaller species, the Chilean flamingo (*P. chilensis*), exhibit bright pink skin over their heels and webbed feet, but not elsewhere; their feathers remain mostly white as in Nature, but now with a few pink ones. The rest of the general body-skin is of normal, pale appearance (like that of domestic fowls) in both species.

Although the birds receive mixed carotenoids in their diet (notably since they pluck grass as well), the various tissues yield chiefly hypophasic carotenoids, and the majority of these seem to be partially oxidized xanthophylls, their chromatographic fractions giving atypical spectral absorption curves. The minor amounts of epiphasic carotenoids include no typical carotenes, but apparently oxidation products of carotenes.

No traces of astaxanthin, or of any acidogenic carotenoid, were detected among the carotenoids of the yellow-orange sub-dermal or visceral fat, the orange adrenals, the liver, pancreas, spleen, lung, muscle, immature ovary or testes of recently expired birds which had received the regular diet. Nor did the carotenoid-rich plasma of blood yield astaxanthin.