The Potability of Sea Water

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On the 2nd of July, 1816, the French frigate, *La Méduse,* two weeks out of the Isle d'Aix, ran on a reef not far from her destination, the port of St. Louis on the west coast of Africa. Unable to heave the vessel off, the chief officers and some of the crew took to six boats. About 150 passengers, officers, soldiers, and crew were placed on a large raft (Fig. 1), the intention being that the boats should tow it to shore. But of discipline there was none. After a short distance, those in the boats yielded to selfish terror, abandoned the raft, and made their way safely to shore.

The raft, provisioned only with six casks of wine, two casks of water, and some biscuit, floated helplessly. On the second night the soldiers broached a wine cask, becoming wild with delirium and furiously attacking the officers. Many were killed or thrown into the sea. The water, along with most of the wine, was lost. On the third day, only 60 persons remained, and they began to devour the dead left on the raft. On the fourth day, all the carcasses were cast into the sea but one, which was kept to feed those who "the day before had clasped his trembling hands, vowing him eternal friendship." The fifth day saw 30 persons left alive, half of whom were covered with wounds and almost irrational. The 15 who retained some strength and reason, to save their lives and the bit of wine remaining, threw the others overboard.

A raging thirst, redoubled in the day by the beams of a burning sun, consumed them so that they eagerly moistened their parched lips with urine cooled in little tin cups, which were often stolen for their contents .They tried to quench their thirst by drinking sea water, but all these means failed or diminished thirst only to render it more severe a moment later. Their anguish was inexpressible. On the 13th day, they were rescued by a ship sent from St. Louis to search for them—15 long-bearded men, almost naked, bodies and faces disfigured by the scorching sun, limbs excoriated, eyes hollow and almost wild.

Thus was the shipwreck of the Medusa, famous in the annals of the castaway at sea (Savigny and Corréard, 1817; Wolf, 1958). There are few such accounts of events in northern or southern latitudes, because few live to give them. Cold is the greatest hazard facing men adrift once they are in a lifeboat (Critchley, 1943; McCance et al., 1956). But in warm regions, on enforced voyages in open boats, lack of fresh water becomes increasingly urgent and an important cause of death. So it was in bygone days before the advent of efficiencies in search and communication. An ancient tradition enjoins men not to drink from the ocean, but, sooner or later, many yield in the exigencies of distress and seem to be led ineluctably to earlier disaster.

Thirsty men adrift or lost on desert shores frequently experiment with drinking sea water—especially after the third day—without harm if only small quantities are taken. But such experimentation is difficult to control, and, when in a group, individuals often drink furtively at night. The fleeting relief it affords gives way to an ever more ardent thirst and more copious drinking. This may be succeeded by silence and apathy. The eyes take on a fixed and glassy expression; the breath, an offensive odor. Then delirium begins—first quiet, later violent—and consciousness is gradually lost. At some time froth appears at the corners of bright, cherry-red lips, and even in nondrinkers the tongue may be covered with an annoying white slime. The victim frequently goes overboard in noisy delirium, on occasion by half-reasoned design or desire; or death comes quietly (Wolf, 1958; Critchley, 1943; Ladell, 1943).

In the face of these facts, we shall consider an outwardly absurd idea, namely, the potability of sea water in mammals.

Sea water drinking, called mariposia, is normal for the bony marine fishes. Their gills serve as excretory organs for salt and help to regulate the salinity of their body fluids. Sea birds, some of which remain away from land for years and are known to drink sea water, may be enabled to do so by means of a special nasal gland. At least it is found that, when an excess of salt is present in the body, this gland secretes a fluid even more salty than sea water. It collects at the tip of the beak and is shaken off by a jerk of the head.

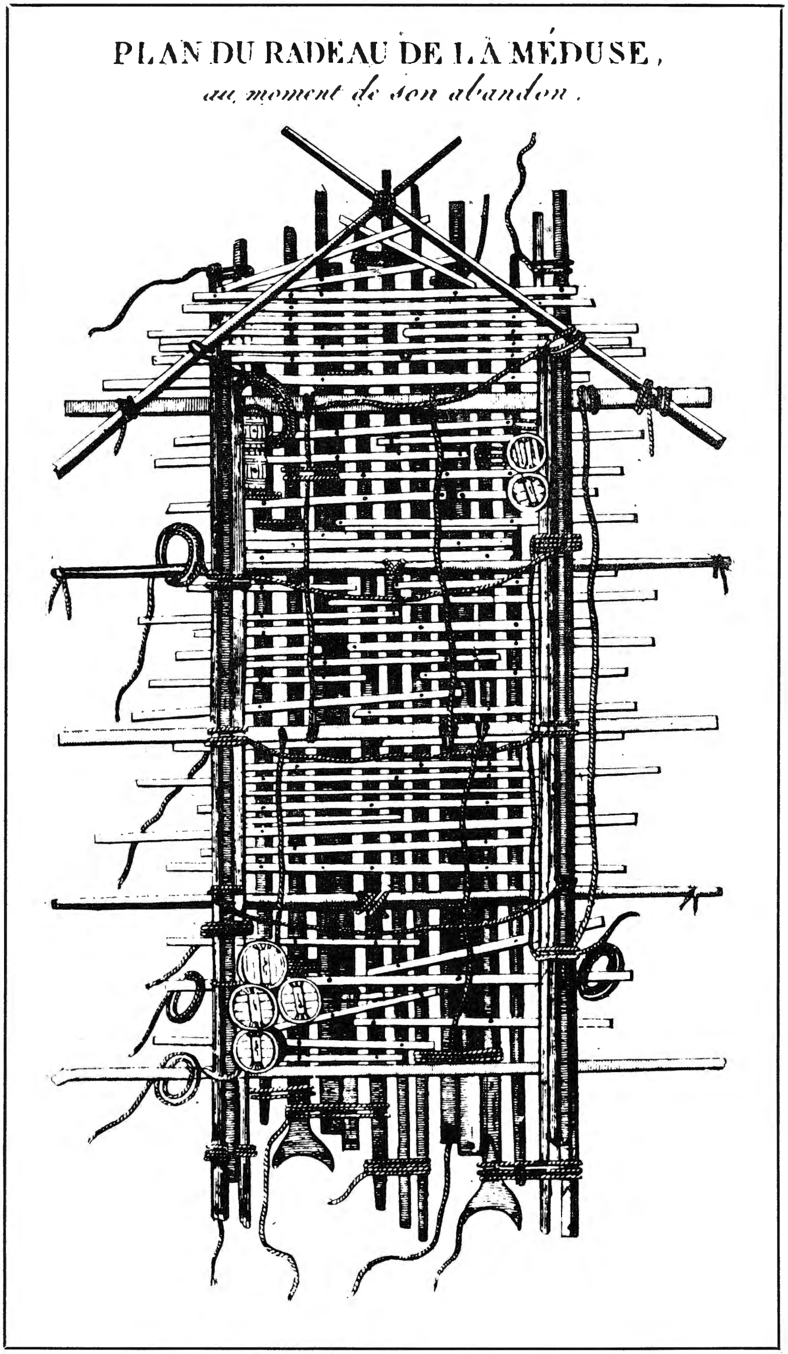

Fig. 1—Plan of the raft of the Medusa, French frigate shipwrecked in 1816. Built of masts, booms, and beams, it was 65 feet long and 23 feet wide. Along with a few casks of wine and water, 150 Frenchmen were huddled aboard, packed so closely as to be unable to move a single step. Their great load caused the raft to ride low in the water with the castaways standing in water up to their middles. Only 15 were saved after 13 days of internecine murder, cannibalism, and tribulations of thirst which drove many to drink urine and sea water. From Frontispiece of *Naufrage de la Frégate Méduse* by J. B. H. Savigny and A. Corréard Paris: Hocquet, 1817.

It is with certain mammals, marine and other, that serious doubts about mariposia arise. To be sure, some wild goats and cattle drink from the ocean, although whether to replenish salt or water, or both, is not certain. There is little doubt that seals and whales and their kind swallow some sea water, if only inadvertently, when taking their food. The leopard seal of the Antarctic has been observed to drink large quantities of sea water, but under unusual conditions (Brown, 1952). Yet it is difficult to come by unequivocal reports of "normal" elective drinking of sea water by marine mammals. The largest body of evidence consists of negative or moot observations, e.g., that they have not been seen to drink sea water (although the thirsty seal greedily drinks fresh water), or that the stomach contents of a whale feeding on plankton ("krill") appear "dry," or that only traces of magnesium and sulfate, which are appreciably concentrated in sea water (Table 1), are found in rectal washings of seals.

It has been estimated from the chemical composition of herring, one food of seals, that there is enough water available—both preformed in the fish and obtainable as a metabolic product of combustion of its protein and fat—to satisfy all the water requirements of these animals (Irving, Fisher and McIntosh, 1935). Even if this were the case for all of their foods (and this has not been established), and they had no need to drink any fluid, it does not follow that seals and other marine mammals do not drink sea water. Yet many biologists have assumed that they do not. Supposedly buttressing this shaky assumption is an old argument of the physiologists, originally invented in connection with the human organism.

A man, they showed, is unable to produce urine much more concentrated in salts than its equivalent of 2% NaCl. Sea water contains about 3.5% of total salts, equivalent osmotically to 3.2% NaCl (Table 1). If 100 gm of sea water were drunk, providing an excess of 3.2 gm of "salt" in the body, then, to eliminate that excess in the urine, it would appear that 160 gm of urine must be excreted, making for an undesirable loss of 60 gm of water from the body. Therefore, the reasoning is that sea water drinking should be proscribed for man. Since a seal is not known to produce urine sufficiently saltier than man's to nullify this, a similar physiologic interdiction was seen for it. The desert rat is one of few mammals that can produce a urine more concentrated in salt than sea water. Here, it seemed, was a creature possibly able to drink sea water profitably. And so it was found.

Fortified with a not obviously assailable theory and secure in the empirical certitudes of tradition and vast human experience, many physiologists denounced claims that sea water is a potable fluid for mammals with unexceptional kidneys.

During World War II, a renewed concern over U-boat victims and others set adrift caused physiologists to reexamine their stock of doctrines on mariposia. W. S. S. Ladell, in England, for instance, took hold of a curious and subtle idea, which can be understood by an illustration.

When a man is deprived of water, his urine output becomes reduced, and its concentration of total solute approaches a "maximum." Most of this is nitrogenous waste such as urea. Relatively little is salt; for simplicity, let us call its concentration zero. For our purposes solute excretion is best described in terms of osmotic units. Let us take the maximum total solute concentration of a man to be 1.2 osm/liter. If salt had been present and maximally concentrated at ca. 2%, its osmotic concentration would have been about half of the total, i.e., approximately 0.60 osm/liter. Salts of sea water (3.5%) have a concentration of approximately 1.0 osm/liter, a value greater than can be attained by salts in human urine.

The key to Ladell's concept is that, even when a man is deprived of water, his kidneys continue to excrete. If he produces 0.40 liter of maximally concentrated urine per day, his total solute excretion is 0.40 × 1.2 or 0.48 osm/day. If he takes in and excretes an extra 0.48 osm/day in the form of salt, his total solute excretion becomes 0.96 osm/day. Keeping to its maximum concentration, his urine volume would increase to 0.80 liter per day to accommodate the extra salt. This constitutes an undesirable loss of an extra 0.40 liter per day of urinary fluid. However, if this extra salt had been taken as sea water, it would have meant taking 0.48 liter per day of sea water. This fluid intake exceeds the 0.40 liter per day loss of urine conditioned by the salt by 0.08 liter per day. It therefore provides, relatively, a small net gain of fluid to the body. All extra salt would be eliminated, and the urinary salt concentration would be .48/.80 or 0.60 osm/liter, a value not exceeding the concentrating power of the kidney for salt.

This in essence is the theory of "osmotic space" (Fig. 2 and 3). A relatively salt-free, nitrogen-obligated volume of urine accommodates salt which is to be excreted; and a virtually nitrogen-free, salt-obligated increment of urinary volume accommodates nitrogen. Both types of solute are excreted in accord with restrictions imposed by the limited capacities of the kidney to concentrate salt and total solute (Wolf, 1958).

Unfortunately Ladell's experiments to test the theory in men did not come up to expectations, and his idea was subsequently misinterpreted or ignored. The theory seems essentially valid, however, and its "failure" in man was probably no failure at all. Man is a relatively poor urinary concen-

TABLE 1
Surface Composition of "Open Ocean" Water.

Individually, bodies of water vary in total dissolved solids not only among themselves, but at different places, depending on relative evaporation rates, proximity to river mouths, etc. Thus, the Mediterranean near Gibraltar is 3.6%; off Syria, 3.9%. The Gulf of Suez is 4.1%; the Black Sea, generally, 1.8%; the Baltic, 0.7%. For 60 to 120 miles off the mouth of the Amazon River the sea surface concentration may be only 1.0% to 1.4%, but it rises rapidly beyond these distances and is "normal" at 200 miles.

Major Constituents of Sea Water*
(grams per 100 grams of water)

Positive Ions	Per Cent	Negative Ions	Per Cent
Sodium	1.0559	Chloride	1.8980
Magnesium	0.1272	Sulfate	0.2649
Calcium	0.0398	Bicarbonate	0.0139
Potassium	0.0380	Bromide	0.0064
Strontium	0.0013	Fluoride	0.0001
Sub-total	1.2622	Sub-total	2.1833

Total 3.4455

* Sea water of this composition has a density of 1.024, a freezing point of −1.87°C, an osmolality of 1.01 osm/liter and an osmosity of .550 mM/liter, making it the osmotic equivalent of 3.2% NaCl (Wolf, 1958, 1966).

trator, and more inclusive calculations than given above suggest indeed that, without fresh water, sea water should not be potable in his species, at least in steady state. When we apply this theory to the cat (Fig. 4), a land relative of the seal and also a carnivore, fish lover, and one of the best urinary concentrators in the animal kingdom, quite different predictions are forthcoming (Wolf et al., 1959).

First, a cat (much as a seal, but not a man) ought to be able to obtain all the water it requires from a diet of various fish, without drinking. Such water, derived both from that already preformed in the fish (let us say, 68%) and from the oxidation of fish protein and fat, is sufficient to cover all losses of water from the urine, lungs, feces, and skin. Second, a cat ought not be able to obtain its full water requirement from this same fish from which a third of the water has previously been removed by drying. These two "predictions" have actually been empirical facts for many years. Third, a cat should be able to obtain its full water requirement from this partly desiccated fish plus specified amounts of sea water, and, if this sea water be disallowed, the cat should die. In another way, it should be able to depend for its survival on an admixture of sea water and water-poor fish, neither of which alone will support it. Fourth, the urinary salt concentration of a cat maintaining itself on sea water need not be as high as the salt concentration of sea water, because the urinary fluid, derived from both food and sea water, exceeds in volume the sea water ingested (Fig. 2 and 3). All of these predictions have been verified experimentally (Wolf et al., 1959).

What does this mean? For one thing, it strongly suggests that we take another look at the question of sea water drinking in marine mammals, untrammeled by the belief that mariposia can profit the water and salt economy of a mam-

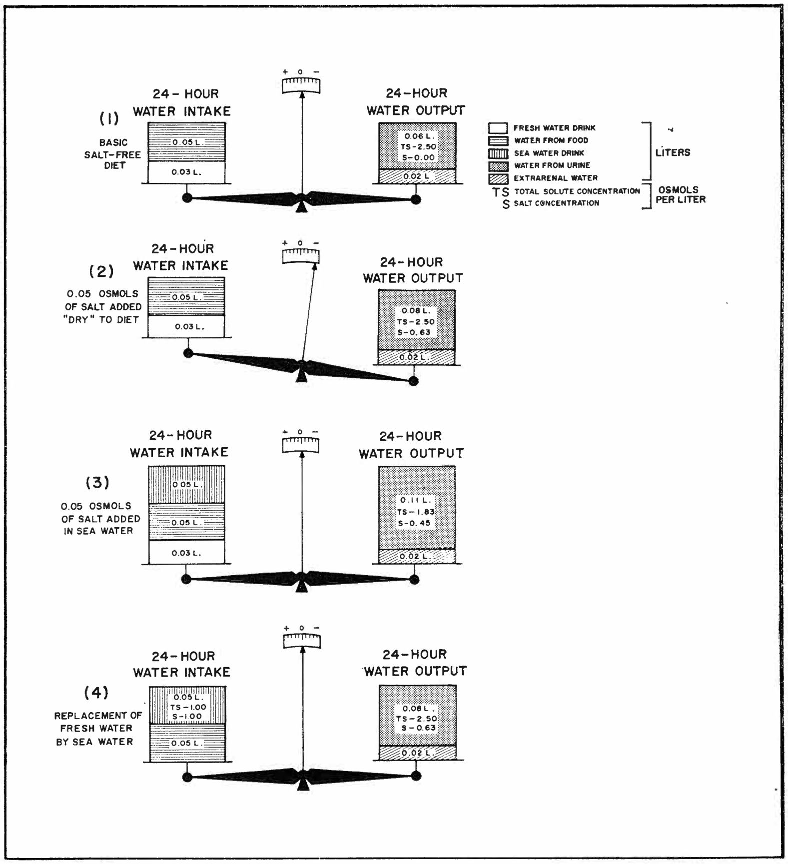

Fig. 2.—Mechanism for utilization of sea water by a cat or similar carnivore. Osmotic concentration of salts in sea water is taken as 1.00 osm/liter; maximum urinary salt concentration is assumed to be 0.90 osm/liter.

(1) Water balance (equality of water intake and output) is indicated by scale pointer on 0. Water from food and drink just matches the aqueous requirement for the salt-free diet. End products of metabolism (urea waste, etc.) are in urine, maximally concentrated to 2.50 osm/liter. Extrarenal water represents all fluid loss other than urinary, i.e., from lungs, skin, etc.

(2) Negative water balance (output exceeds intake), as indicated by scale pointer, and body dehydration are caused by adding 0.05 osm of "dry" salt to the daily diet of (1). In order to excrete this salt load, an extra 0.02 liter of urine must form (total volume, 0.08 liter per day), still maximally concentrated in total solute. Nevertheless, the resulting salt concentration of 0.63 is considerably less than the assumed maximum of 0.90 osm/liter for the animal.

(3) Instead of adding 0.05 osm of salt "dry," as in (2), it could have been added as 0.05 liter of sea water, since the concentration of that fluid is 1.00 osm/liter. In this case, both the extra salt and the extra water enter into the urine. By virtue of the latter addition, both salt and total solute are diluted to submaximal concentrations. Being relatively dilute, the urine now contains, in effect, 0.03 liter of "free" water which could be eliminated by despensing with the 0.03 liter of fresh drinking water.

(4) Thus, without fresh drink, the animal still maintains water and salt balance, but the urine is maximally concentrated, as in (2). In this way three volumes of fresh water requirement would be met by five volumes of sea water, and any part of the fresh water ration could have been replaced (i.e., saved by admixing) by sea water in the same ratio. To the extent that salt is initially present in the food, the available osmotic space for salt in the urine and the permissible intake of sea water are reduced.

mal only if its urinary salt concentration can exceed that of sea water. For many of these animals it now appears that sea water may be a potable fluid. They may or may not drink it, but it is no longer incumbent upon physiologists to conjure up precious schemes by which, it is imagined, marine mammals must avoid swallowing sea water.

Theory or no, we cannot refrain from considering the claims that the human castaway not only can but should drink sea water when fresh water supplies are exiguous. Some of these claims were made seriously from 1952-1960 and were of an evidential nature (Bombard, 1954; Aury, 1954). Many non-physiologists, unperplexed by theory or doctrine, found them plausible or convincing. In some instances survival policy—the do's and don'ts for those who might be set adrift—and the behavior of castaways were affected by them.

Ignoring special cases where sea water drinking is at least less hazardous, as in the Black Sea with its relatively low salinity (Table 1), we may contemplate three claims.

1. In hot climates much salt is lost through sweating; it should be replaced by drinking sea water. This is a more complicated proposition than meets the eye. The simplest argument against it is that sweat is a rather dilute salt solution, say, 0.2%. Its removal from the body, whose fluids contain about 0.9%, therefore tends to concentrate salt in the residual body fluid and engender or exacerbate thirst. Addition of 3.5% salt in the form of sea water should hardly constitute logical therapy. Nevertheless, it is well known that even excessive drinking of plain water in a hot environment may not assuage thirst, whereas the addition of some salt to it—20% to 40% of sea water, as Thor Heyerdahl reported on the *Kon-Tiki* voyage—not only relieves thirst, but actually reduces inroads on the fresh water supply. One neutralizes the force of this point in recognizing that it is only apparently and not actually germane. It is relevant only where fresh water supplies are luxurious, and, thus, does not concern our problem.

2. Ladell, with a large experience in human salt and water metabolism, has soberly presented the view that, if chances of being picked up at all depended on keeping fit and alert for the first week, it might be well to drink some sea water, no more than 250 cc/day, whose effect might be to stave off disabling circulatory failure. If chances of rescue depended on remaining alive for the maximum length of time, he would avoid sea water. Admittedly this is an "iffy" matter, special and unsettled.

3. It has been contended categorically that one can live upon

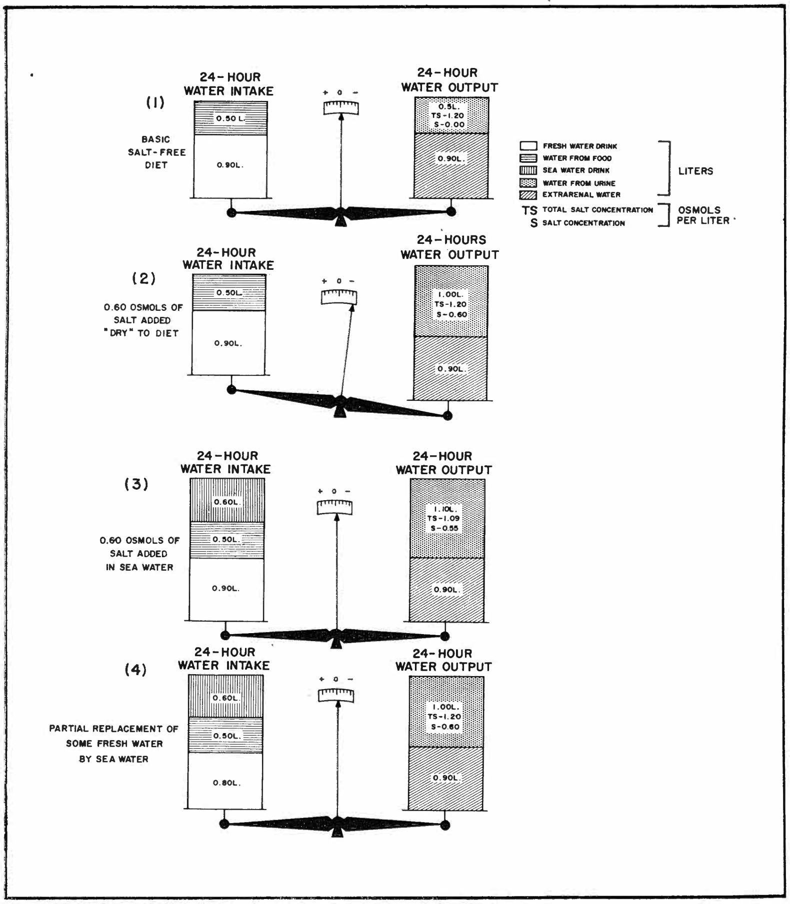

Fig. 3—Theoretic utilization of sea water by man. These diagrams parallel those of Figure 2. Major differences are that maximal urinary concentration of total solute in man is only 1.2 osm/liter; of salt, 0.60 osm/liter. Because of his relatively low urinary concentrating ability, man is unable to employ his urinary osmotic space as effectively as the carnivore. Of his fresh water requirement, indicated as 0.90 liter in (1), no more than 0.10 liter could theoretically be replaced by 0.60 liter of sea water, as in (4), with maintenance of water and salt balances. Even this modest possibility has not yet been proved practicable.

No dehydrated animal can improve its water balance by drinking its own urine. Since newly forming urine is always maximally concentrated in total solute, there is no available osmotic space left which could accommodate more of the *same* solute, and no "free" water can be obtained.

the provision of the oceanic environment. On May 25, 1952, the French physician, Alain Bombard, to test this conviction, set out with a companion from Monte Carlo, in a small dinghy appropriately called *l'Hérétique*. During an 18-day journey which took them to Minorca, they drank sea water, fish juice (pressed from the flesh of sea perch in a fruit press), and also the pint or so of fresh water condensed on the bottom of the boat at night. The raft was shipped to Tangier, from whence Bombard continued his adventure alone, drifting to Casablanca and the Canary Islands. On October 19 he left Las Palmas and for 65 days floated across the Atlantic to Barbados. He subsisted on fish, fish juice, rain water, and some sea water. ". . . I got there," he wrote, to the consternation of orthodox physiologists (Bombard, 1954). "I had conquered the menace of thirst at sea."

Scientifically, Bombard's achievement is dimmed by the fact that it is impossible to ascertain from his account exactly what and how much he consumed, so that his views remain generally unproved. Neither have they been disproved experimentally, but that is hardly remarkable. On a major point, no real contact has ever been made between those professional physiologists who assert that sea water can never benefit a dehydrated man, and a once pro-Bombard faction which recommended that sea water be taken early, before dehydration sets in, if it is not to be dangerous. This is a complicated issue which cannot be treated further here.

So far as is known, man is among the least adapted of the mammals for physiologic mariposia. Whatever else may be said, and it should be said so that there will be no misapprehension on this important question, it must be stated that no professional physiologist can yet advise the castaway who is at sea or on desert shore, and short of fresh water to drink sea water in order to subsist.* Is there no more? Must we assent to the poet's "Water, water everywhere, nor any drop to drink" and shut the gates of hope?

There remains one curious question—almost a riddle—connected with sea water drinking: if a castaway at sea has a limited supply of fresh water, is he better off to use it alone or to admix it with some volume of sea water, thereby diluting the sea water and augmenting his total supply of potable fluid? Experimentally this is most difficult to resolve, and various answers have been given on conceptual grounds. The theory of osmotic space suggests that it should be possible to reduce (but not supplant) the fresh water requirement —even of a man—by admixing, but much less effectively in man than in a carnivore (Fig. 2 and 3). However, the actual mixing ratios to use, the permissible intakes of sea water, the degrees of preexisting dehydration and starvation, the mean air temperature (as this affects sweating), and the kind of food (e.g., fish and/or fish juice) available, are considerations which, by their complexity, conspire to preclude solution by theory alone.

But the theory of osmotic space enlarges our perspective and should lead to the design of further experimental tests with some promise of new insights. After all, the prac-

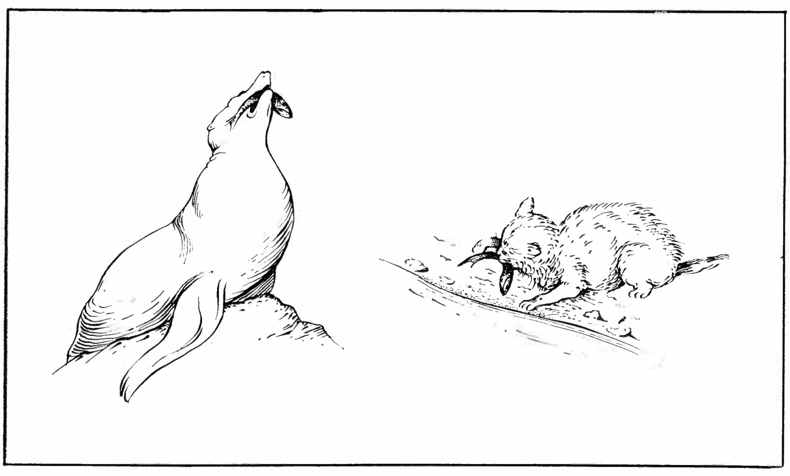

Fig. 4—A terrestial and an aquatic carnivore, both fish lovers. The cat can profitably drink sea water. Does the seal?

* In the report prepared on this subject for the World Health Organization (1962), F. W. Baskerville, J. Fabre, H. Laborit, R. A. McCance and A. V. Wolf listed six points of advice to those who may have to abandon ship:

(1) Unless you are in charge of a party, do as you are told. Try to remain cheerful. Discipline and morale count for more than anything else.

(2) If you have a remedy for seasickness, take it.

(3) If the temperature is low, your immediate and most dangerous enemy will be cold, so put on as many woollen clothes as you can. They will help keep you warm in the water or on a covered raft, and even if you are fully clothed your life-jacket will always keep you afloat.

(4) If the temperature is high, avoid sunburn, keep yourself as much as possible in the shade, and keep your clothes moist to reduce sweating and so conserve body water.

(5) Drink no water for the first 24 hours you are adrift. Then take 500 ml (a pint) of fresh water daily until supplies run low, thereafter 100 ml until the water is finished.

(6) *Never drink sea water.* Never mix sea with fresh water if fresh water is in short supply. Sea water has been used to moisten the mouth, but the temptation to swallow it may be irresistible and it is better not to use it for this purpose. Never drink urine.

tical issue for man is not whether a castaway, like a cat, can maintain himself indefinitely on sea water, but whether he can use it to prolong his survival.

To thereby gain an extra day would be to win an extra day toward rescue; an extra day in which rain might fall; or just an extra day.

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