Nature's Christmas issue a year ago carried an article entitled 'Naming the Loch Ness monster'. This year, **Carl Sagan** writes on 'Detection times and number densities of rare mobile organisms: application to Loch Ness'.

If there are any, could there be many?

IN simple collision physics, when one moving object may collide with a number of stationary and dissimilar targets, the mean free time for collision is $t = (n\sigma v)^{-1}$, where n is the number density of stationary targets, σ is the mean collision cross-section and v is the relative velocity (assumed constant). If targets are also moving, a factor of order unity multiplies the denominator of this equation; for example, if all objects have Maxwell-Boltzmann velocity distributions, the multiplier is $2^{1/2}$.

This same equation, slightly modified, can be used to deduce the number density in three dimensions of a distributed rare mobile organism from the mean free time between sightings of this organism by a stationary or moving observer. In this case the collision cross-section $\sigma = \pi r^2$ where r is the target visibility range—the linear distance over which the target is within the resolving power of the observer; or the distance to optical depth unity in the enveloping medium; or the distance to the horizon, whichever is least. When t is measured by a stationary observer, the mean distance between organisms will then be

$$S = 2(3t\, r^2\, v/4)^{1/3} \qquad (1)$$

If the total volume in which the organisms are contained is V, the total population of organisms in this volume is

$$N = V/(\pi r^2 vt) \qquad (2)$$

These relations assume that the organisms being observed are neither attracted to nor repelled by the observer, and that the observer has chosen a typical locale in the organism's habitat—for example, not in the vicinity of concentrations of predators or prey. Under these circumstances equations (1) and (2) provide expectation values for the mean separations and total numbers of organisms. In the common case that the geometry is two- rather than three-dimensional (as, for example, for land animals and to a significant extent even for birds), n is replaced by $\mathcal{N}$, the column density of organisms, σ is replaced by r, $S = 2(rvt/\pi)^{1/2}$ and $N = A/rvt$, where A is the area of the total habitat.

As a practical application, consider the interesting and controversial set of observations suggesting the presence of large organisms in Loch Ness[1]. Sonar and underwater stroboscopic photography in 1975 imply $t \simeq 10^4$ to 10^5 s for some unidentified large animal of characteristic dimensions 10 m. We adopt $t \simeq 3 \times 10^4$ s, but bear in mind the impression of the observers that in 1975 the organisms may have been attracted by the observational equipment and therefore that the appropriate t is significantly longer. Because of the turbidity of the loch, $r \simeq 10$ m; and a rough estimate of the swimming velocity of the unknown animals is $v \simeq 3\,\mathrm{m\,s^{-1}}$.

Equation (1) then immediately gives $S \simeq 0.4$ km, a very large mean separation distance. The total volume of Loch Ness is approximately $10^{16}\,\mathrm{cm^3}$, whereupon, from equation (2), $N \simeq 300$. Because of the cube root in equation (1), our estimate of S is reasonably independent of the uncertainty in t. But our uncertainty in estimating the total population is proportional to the uncertainty in our estimate of t. If the targets were indeed attracted to the observing apparatus, then N is less, and a conservative estimate places N between several tens and several hundreds. Curiously, this is just the estimate derived independently from biomass calculations, assuming that the diet of the unknown organisms is exclusively migratory salmon[2] or exclusively non-migratory prey[3]. While the agreement of these two quite different sets of calculations—from the waiting time for observation in 1975 and from the biomass of the loch—should not be overstressed, the agreement does tend to support the contention that there is a real population $\simeq 10^{2\pm1}$ of large organisms inhabiting Loch Ness.

The negative photographic results for 1976 have been attributed[4] to the sharply diminished fish population and significant increase in temperature in the loch, connected with the 1976 drought. If the 1976 results were not anomalous, we might deduce $t \geqslant 10^7$ s, and $N \leqslant 1$. However, sonar encounters at larger r were recorded in 1976.

The nature of these organisms seems still more uncertain than their existence, but it appears more likely that they are a minor variant of a fairly abundant contemporary taxon than, for example, the only surviving group of aquatic Mesozoic reptiles. The large calculated separation distances in a medium as turbid as Loch Ness suggests that the organisms might be equipped with echo locator organ systems and may communicate at audio frequencies. Hydrophones should be an important adjunct to any continuing study.

Similar calculations of organism spacing and loading density could be made on other planets, were macro-organisms to be discovered there—as, for example, on Mars with the Viking lander imaging system. □

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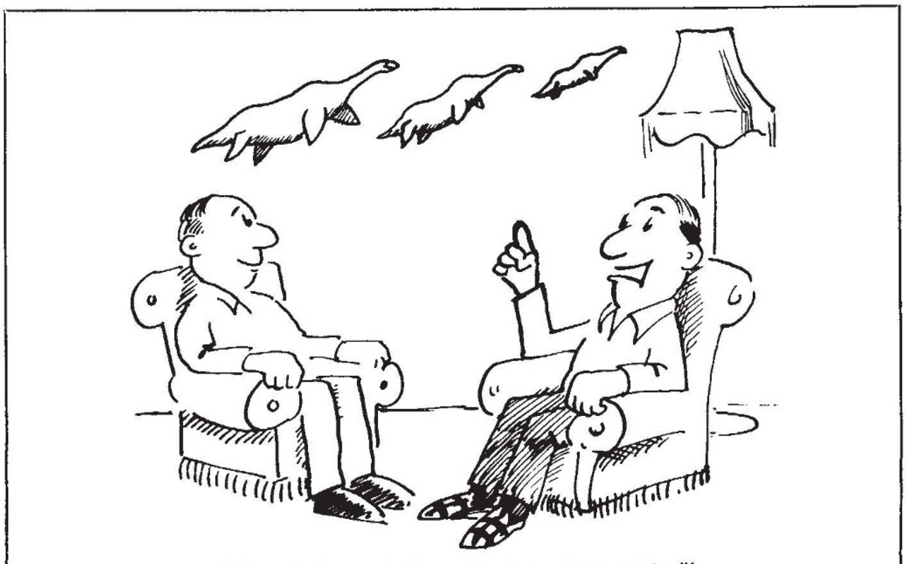
Carl Sagan is Director of the Laboratory for Planetary Studies, Center for Radiophysics and Space Research, Cornell University, Ithaca, New York.

Ray Hyden



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