of vision of fish is believed to be small, their threshold of visibility will scarcely be affected by atmospheric scattering and cannot depend only upon intensity discrimination as such. However, as Dr. Craik pointed out in discussion, when atmospheric scattering is negligible, the range of visibility of a white object will still be smaller than that of a black one. An object will become invisible when it is so far away that its image on the retina reaches a certain minimum size for any given brightness. If the threshold of visibility is a function of the product area by contrast only, then since area decreases as the reciprocal of the square of the distance, the difference in range should now be about half as great as it was for intensity discrimination alone. But the contrast to be taken into consideration here is the average contrast (say 0·8) of the object, rather than the contrast of the darker parts. The difference between the critical ranges of visibility of black and white objects will thus be again of the order of 10 per cent. It may be pointed out, however, that a black bird 10 per cent smaller in linear dimensions than a white bird would become invisible at the same range as the latter.

When the sky is clear, the situation is different. If direct sunlight strikes the white plumage of a bird, the latter will acquire a brightness of the order of 25,000 candles/m.^{2} (the sun giving an illumination of 100,000 lux)[2]. This brightness is much above that of blue sky, which is stated to be[3] 4,000 candles/m.^{2}. This agrees with what we observed in our experiment. In sunshine, white birds may therefore be very conspicuous to fish, and if anything more so than black.

It is therefore not clear that white birds are on the whole less easily seen than others, and in this way stand at an advantage. A closer analysis of the problem from the fish's point of view shows how complex it really is. For example, as the surface of the sea is generally agitated, it is not certain what a marine fish does see of objects in the air. Ward's[4] observations suggest that they would see very little. There are at the edges of the 'window' in the area of total reflexion dark ripples which may well be confused with birds. This casts doubt upon the implicit assumption on which the above calculations are based, namely, that the fish take action as soon as the bird becomes visible. Definite information is needed about the actual stimuli which make fish dive.

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[1] Craik, K. J. W., NATURE, 153, 288 (1944).

[2] Fabry, Ch., "Les Principes de la Photométrie en Astronomie et en Physique", Mémorial des Sciences Physiques, Fasc. XXIV (Paris, 1934).

[3] Walsh, J. W. T., "Photometry" (London, 1926).

[4] Ward, F., "Animal Life Under Water" (Cassell, London, 1919).

As Pirenne and Crombie have pointed out above, scattered light can, in the long ranges at which aircraft are spotted, have an effect on contrast which is not present at short ranges, but calculations for short ranges show that one might expect a considerable difference in spotting range for black and white birds. A considerable part of the brightness of a roughly hemispherical object such as a bird, seen from below with overcast sky, is contributed by skylight and not by light reflected from the sea. Estimating the reflexion factor of the bird's plumage at 0·9, this would make the mean brightness of the underside about 0·15 of that of the cloud background. This should have a definite effect on maximum spotting range, for at the human threshold, in clear air, the visibility of an object of high contrast is determined mainly by the total reduction in incident light or 'subtractive energy', that is, the contrast multiplied by the angular area. Thus an object of half the background brightness will require to have about twice the area, or to be brought to about $1/\sqrt{2}$ of the distance, to be visible. The same is likely to apply to fish (though their absolute visual acuity is poorer); and for objects blurred, as Pirenne and Crombie point out the image of the bird will be, by surface ripples. On this basis, a contrast of 0·85 should produce a 7 per cent reduction in spotting range, which is of the same order as that to be expected with aircraft. Further, the conditions of cloudless blue sky, under which the bird will be brighter than the sky, are rather rare in temperate climates and there will be other conditions, such as sun shining through breaks in cloud, in which the brightness of the bird may exactly equal that of the background.

Rough experiments with paper disks on white backgrounds confirm this, particularly for peripheral vision, in which human acuity is poorer and perhaps approximates more closely to that of fish. To exaggerate the contrast very slightly, and thus obtain definite results with relatively few readings, punched paper disks of dead black and grey paper 5 mm. in diameter were mounted on white card, giving measured contrasts of virtually 1·0 and of 0·75. They were viewed at 15° from the visual axis, at the following distances. A blank card was sometimes presented, and the number of times when the observer failed to report the presence of a spot was recorded; he took about 5 sec. to judge.

	Grey spot	Black spot	No spot
Observer A			
Errors at 4·2 m.	17/20	1/20	0/20
Errors at 3·75 m. (— 10%)	11/20	0/20	0/20
Errors at 3·4 m. (— 20%)	1/20	—	0/20
Observer B			
Errors at 3·8 m.	15/20	2/20	2/20
Errors at 3·4 m. (— 10%)	5/20	—	0/20
Errors at 3·0 m. (— 20%)	1/20	—	0/20

Thus the errors at the longer distance are markedly greater with the grey than with the black spot, and when the distance is reduced the errors on the grey disk decrease, equalling at somewhere between 10 and 20 per cent shorter range those obtained with the black disk at full range. This is in good agreement with the above theory, on which the reduction for this contrast should be $1-\sqrt{0{\cdot}75}$ or 13 per cent. Thus there should be some advantage in white plumage if fish dive as soon as the bird reaches threshold visibility, but I agree that whether in fact they do so should, if possible, be directly investigated.

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DR. K. J. W. CRAIK's suggestion[1] that the white coloration of sea-birds is adaptive in the sense of rendering them less conspicuous to their prospective victims cannot be considered convincing in view of the following difficulties.

A by no means negligible number of predomin-