XLVIII. THE ORIGIN OF THE VITAMIN *A* IN FISH OILS AND FISH LIVER OILS.

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DURING the last two years the authors have been collaborating in an exhaustive investigation of the nutritive value of the edible oils and fats with particular reference to the dietary unit referred to as vitamin *A*. Of the time spent in this work a very large proportion has been devoted to the study of the oils of marine origin and in particular the fish liver oils, chiefly because it has been shown by Zilva and Miura [1921] that these oils represent by far the most valuable sources of the vitamin of all the groups into which the edible oils and fats are divided. Our study of the liver oils has been naturally divided into several phases each concerned with a distinct aspect of the subject and the present communication deals with the question of the origin of the relatively enormous stores of vitamin *A* which are found in the livers of many species of fish. The results set out in this paper supplement some recorded by Hjort who at our suggestion has studied a number of marine organisms in connection with this enquiry [1922].

It is now generally agreed that the higher land animals derive their supplies of vitamin *A* either directly or indirectly from green plants and the probability of a similar relationship existing in the sea has been suggested by Jameson, Drummond and Coward [1922]. The fundamental dependence of all marine animal life on the marine flora, particularly the microscopic flora, has been recognised for many years past, and the studies of Jameson, Drummond and Coward have shown that a typical marine diatom grown in pure culture can synthesise relatively large quantities of vitamin *A*, whilst Coward and Drummond [1921] showed earlier that higher forms of marine algae, whilst far less potent sources of this factor than diatoms, may contain a concentration approximately as high as that of typical land plants such as cabbage.

There appear to be no adequate grounds for doubting that the ultimate origin of the vitamin *A* in marine oils and liver oils is represented by the

marine plants possessing photocatalytic pigments, particularly those which are included in the term plankton. Our studies of fish eggs show us that the young fish normally begins its life with a considerable store of vitamin A derived from the yolk-sac. We have reasons for believing that there may be a transference of vitamin from the liver or tissues of the spawning fish to the eggs although as yet our experiments on this subject are incomplete.

Apart from our experimental work the existence of such a transference would appear probable from our knowledge concerning the transport of vitamin from tissues to the eggs or milk of certain terrestrial species.

Probably the vitamin-A content of the yolk-sacs is sufficient for the requirements of the developing larvae for some time, but it is well known that the period between the stage at which the contents of the yolk-sac are nearly absorbed and that at which the young fish are entirely dependent on external food is a very critical one.

The careful studies of Lebour [1918, 1919, 1, 2; 1920, 1921] and others have shown us that post larval fish feed very largely on copepods. Her work may for our purpose be summarised by quoting two paragraphs from one of her most valuable papers [1920].

"One finds that certain copepods and other entomostraca constitute by far the larger part of the food of nearly all the very young fish, and that usually each species of fish selects its own favourite food to which it keeps, indiscriminate feeding seldom or never taking place, and one can usually assign to each fish its own particular food." "Few fish are vegetarians, and it is unusual for any but the youngest fish to eat diatoms." "Very young herring or sprat and a few others often contain green remains which probably belong to some algae, and occasionally diatoms can be recognised in this but even before the yolk sac is absorbed the gut may contain larval molluscs and small crustaceans."

But whilst there is little or no direct feeding of fish on diatoms these and other microscopic organisms form the diet of the copepods and larval molluscs which play so important a rôle in the nutrition of young fish. The relationship between these two groups of organisms has been traced by a number of investigators with some care, but it is only necessary here to call attention to the very rapid multiplication of the plant life of the sea which takes place in the spring and which is intimately connected, as Moore has shown [1921], with the increase in light intensity during that period. Some short time after the rapid rise in diatoms and other plant organisms there is an associated rise in the numbers of microscopic animals, particularly copepods, and the occurrence of these two related phenomena has a very important bearing on the survival and development of the young fish hatched out at that season [Hjort, 1914].

By the kindness of Dr O. Borley of the Fisheries Laboratory, Lowestoft, we were enabled to study the vitamin-A content of a number of plankton samples collected during the spring of 1922.

The samples after being dredged, sifted through muslin and pressed, were preserved in an equal bulk of absolute alcohol and sent directly to us in London. On arrival they were evaporated to dryness *in vacuo* at 40° and ground well to mix the organisms thoroughly with the material extracted by the alcohol. The dry material was administered to rats in the usual manner for testing for vitamin *A*, and all four samples were found to be highly potent as sources of that factor when administered in daily supplements of 0.1 g. to the rats.

The four samples studied were representative of the staple food of a large majority of the small fish. The analysis of the samples for which we are indebted to Dr Borley is given below.

Table I. *Plankton samples.*

Locality	1 52.2 N. × 3.8 E.	2 Sandetti Lightship 51.15 N. × 1.52 E.	3 Pas de Calais 50.58 N. × 1.30 E.	4 Pas de Calais 50.58 N. × 1.30 E.
Principal contents				
(1) Copepods	<i>Temora longicornis</i> * <i>Pseudocalanus elongatus</i> <i>Calanus finmarchicus</i> <i>Acartia longiremus</i>	<i>Temora Pseudocalanus</i> <i>Calanus</i> <i>Acartia</i> <i>Centrophages typicus</i>	<i>Temora Pseudocalanus</i> <i>Calanus</i>	
(2) Mysids	<i>Schistomysis spiritus</i> <i>Gastrosaccus spinifer</i>		<i>Macropsis</i> <i>Gastrosaccus</i>	
(3) Amphipods	<i>Paratylus swammerdami</i>			
(4) Larvae	Decapod	Decapod	Decapod	Decapod
(5) Miscellaneous	<i>Sagitta hexaptera</i> <i>Pleurobrachia</i>	<i>Oikopleura</i> Polynoid polychaetes	<i>Sagitta</i>	
(6) Post-larval fish	Herring			

* The species in italics were the most numerous in each sample.

Samples 1 and 2 were particularly interesting in that they consisted almost entirely of the very widespread genera of copepods *Temora*, *Pseudocalanus* and *Calanus*. These organisms directly or indirectly represent a very important stage in the food supply of the cod and thrive on diatoms such as *Nitzschia closterium* [Allen and Nelson, 1910], which has been shown to be a very rich source of vitamin *A* [cf. Jameson, Drummond and Coward, 1922].

Small fish. Having shown that the food of the majority of the small fish and certain other marine organisms is relatively rich in vitamin *A*, the next step was to study whether this factor is transferred to the tissues of the species which feed upon them. For this purpose we have taken one or two representative species from different groups without attempting to study the matter exhaustively, and have where possible selected those which most

frequently form the food of the cod and the related species which yield large quantities of marketable medicinal oils.

The food of the cod is not at all times the same. In Norway the early spring rise in diatoms leads to the vast multiplication of copepods, which form the food of enormous shoals of small fish which come in to the northern coast (Finmarken) to spawn. These shoals are chiefly composed of the caplin or capelan (*Mallotus vilosus*) and they are followed by great numbers of cod, coal-fish, haddock and other species which devour them in enormous quantities [Hjort, 1914]. Other species of young fish are frequently consumed by these larger species, but their diet also includes certain shell fish, larger crustacea, salps, and especially in the case of cod on the Newfoundland banks, squid.

The results of our few tests are given in Table II, but they only represent the testing of a few miscellaneous products we had on hand. No attempt has been made to examine these and similar products exhaustively.

Table II.

Species	Approximate daily dose to rats	Results
Caplin, <i>Mallotus vilosus</i>	0.1 g.	Rapid growth
Sprat, <i>Clupea sprattus</i>	1.0 g.	" "
Young herring, <i>Clupea harengus</i>	0.4 g.	" "
Mussel, <i>Mytilus edulis</i>	4.0 g.	Good "
Periwinkle, <i>Littorina littorea</i>	1.0 g.	" "
Shrimp, <i>Crangon allmanni</i>	0.01 g.*	" "

* Of unsaponifiable matter.

Of these species the periwinkle is interesting as being an example of a direct transference of the vitamin from the algae on which it feeds (*Enteromorpha*, etc.). The fat extracted from these animals after feeding is deeply coloured with chlorophyll and other pigments derived from these green weeds.

It would be an almost insuperable task to demonstrate an actual transference of vitamin A right through from a diatom such as *Nitzschia* to its final location in the liver of the cod, but it would appear that we are justified in assuming that such transference does indeed take place by relying on the fact that as yet synthesis of this dietary factor by an animal organism has not been demonstrated, whereas such synthesis is readily carried out by certain plants both marine and terrestrial. The dependence of marine animals on certain products of the synthetic powers of marine plants may indeed be as fundamental as that which exists between these two great groups of organisms on land, for many examples may be recalled such as that given by Fabre-Domergue and Bietrix [1900] who showed that a supply of microscopic plant life would save the lives of larval fish (soles) which were failing from malnutrition in spite of the fact that their yolk was not completely absorbed.

We have included in this paper a few of the unpublished results obtained with molluscs by the late Dr H. Lyster Jameson as well as the examination of certain material he had collected for other purposes since they have a certain bearing on the main subject.

SUMMARY.

1. The ultimate origin of the vitamin *A* found in the oils derived from fish, and particularly the fish liver oils, would appear to be chiefly the unicellular marine plants. Except very occasionally these organisms are not consumed directly by the fish.

2. The extraordinary rise in the number of marine plants which begins as soon as the intensity and duration of sunlight increase early in the year is followed by a rapid rise in the organisms, largely copepods, and larval decapods and molluscs, whose growth and development are dependent on their food supply which consists of minute plants. These minute animals, which form a large proportion of plankton, contain relatively large quantities of vitamin *A* presumably derived from the diatoms on which they have thriven.

3. The plankton forms the staple food of innumerable species of marine animals from small fish to some whales. This no doubt accounts for the presence of vitamin *A* in the tissues or fat depots of these animals.

4. The fish which yield the large bulk of the liver oils, cod, haddock, coal-fish, etc., feed on many species. At one season in northern Norway and Newfoundland they feed extensively on a small fish, the capelan or caplin, which has been found to be very rich in vitamin *A*, doubtless derived from its food.

5. The origin of the vitamin *A* in fish oils and fish liver oils has therefore been traced back to the synthetic powers of the marine algae which form the fundamental food supply of all marine animals.

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