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Vitamin A and Australian Fish Liver Oils

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Research by an organic chemist at the University of Melbourne and support from Australia's Council for Scientific and Industrial Research provided the basis for a wartime industry when Australia was unable to maintain access to traditional supplies of cod liver oil from Britain and Norway in the 1940s. Two major pharmaceutical companies gathered oil from the livers of sharks in southern Australia that was rich in vitamin A, and so met domestic and military needs for this nutritional supplement. Other companies joined in and by the end of the war Australia had a flourishing industry that derived synergy from the marketing of shark flesh for human consumption. South Africa was a leader among countries that expanded fish-oil production in the late 1940s, as a result of which Australian producers suffered from import competition. A Tariff Board hearing found that the Australian industry was unable to meet local needs and so did not recommend increased tariffs. The industry struggled for years until the perceived nutritional benefits of other components of the fish oils helped to revive markets.

Introduction: Cod Liver Oil

Vitamin A is an essential nutritional factor that can be derived from foods containing either the vitamin itself or chemical precursors (carotenoids) that are readily converted to it. The advice distributed by the Australian Government in 1939 was typical of its day and identified carrots, fresh fruit (especially apricots), green vegetables such as spinach, and fish liver oils as the richest sources and recommended appropriate daily servings.[1] Cod liver oil was invariably chosen by parents concerned for development of their children and for well over a century it enjoyed iconic status in western societies.

The major producers of cod liver oil were in the Northern Hemisphere, where consumption of cod liver oil for its nutrient value by children and as an anti-inflammatory by older adults was widespread, especially in north-eastern Europe.[2] The general nutritional benefit of vitamin A probably relates to digestion of fats, but there is also a strong correlation between vitamin A intake and dark-vision adaptation. Home medication of this kind persists to this day, and the oil is also used as a nutritional supplement for animals. Cod liver oil was also recognized as a prophylactic for the development of the bone malformation known as rickets. Early in the twentieth century this folklore received medical approbation as the nature of rickets came to better understood and the role of nutrition and also of exposure to ultraviolet light (in sunshine) was clarified. By 1913[3] vitamin A had been identified as a component of cod liver oil at about the 1% level, partly accounting for its value as a nutritional supplement; it was only later that a substance present in even lower concentration, vitamin D, was identified as the anti-rachitic factor.[4] Today the oil is valued as much for its content of omega-3 fatty acids and other constituents as it is for its vitamin content.[5]

Britain, Norway, Greenland, Iceland and Canada, all major fishing nations, were well placed to be major producers of cod liver oil. According to the history of the major Norwegian producer, Möller's, the health value of cod liver oil began to be appreciated in the late eighteenth century. In the early 1850s Peter Möller (1793–1869) developed a new method of releasing oil from livers by steaming, and in 1854 at Lofoten on Norway's Arctic coast he founded the family company to market this superior product with its lower 'fishy' taste. Möller's steaming method was widely adopted.

The 1933 Newfoundland Royal Commission (the Amulree Commission)[6] reported that production of cod liver oil, having averaged 1.2 million gallons over many years and peaked

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at 2 million gallons in 1918, then began to decline and by the early 1930s had fallen to 250,000 gallons. The main markets for the Canadian product were in the USA where, as in Canada, home medication of this nutritional supplement was widely practised. Changes taking place in the industry also affected British producers, who formed a co-operative venture, British Cod Liver Oil Producers, based in Hull, in 1934.[7]

The dominance of cod as the source of potent liver oil was unchallenged for many years, but in the early 1930s the harvesting of dogfish (a shark species) off the north-east coast of Canada began to provide another source. At this time, also, the British chemist I. M. Heilbron (1886–1959)[8] initiated work on vitamin A; of particular relevance is the examination of the liver oils of halibut and sturgeon, as well as cod.[9]

First Investigation of Australian Fish Oils

In Australia, in 1919 the Royal Commission on Victorian Fisheries and Fisheries Industries found that the fishing industry was fragmented and lacked a research base that might have assisted its development and provided the basis for marketing of new products.[10] In Victoria, the focus of the Commission's inquiry, the industry 'was carried on in a wasteful and unsystematic manner'. Referring to fish oil, the Royal Commission stated that 'the world's annual output of the medicinal oil obtained from the liver of the cod fish amounts to many millions of gallons. The livers of some species of sharks are so large, and contain such an abundance of oil, that special fisheries for sharks exist in certain parts of the globe. Sharks that are captured incidentally, when deep sea nets are hauled, are in many countries taken ashore to be converted into oil and fertilizer.' The Royal Commission recommended the establishment of plants to recover oil and fish meal from fish-cleaning operations and observed that 'sharks and other vermin could then be put to useful account'.

It was some years before there was further high-level consideration of fisheries in Australia, but in September 1927 the Commonwealth Development and Migration Commission, charged with 'applying scientific methods to economic and political problems in the interest of national development and efficiency' under its chairman, H. W. Gepp,[11] convened an industry conference in Melbourne.[12] Although discussion chiefly concerned the supply of table fish, the utilization of byproducts such as oil and fish meal were considered and sub-committees were established to provide more information.

This signal of possible Australian industrial interest together with the British scientific work on vitamins might have caught the eye of a young English chemist who had taken up an appointment at the University of Melbourne in 1924. He was William Davies (1895–1966), a graduate of the University of Manchester who had studied for his DPhil degree at Oxford with Robert Robinson before his appointment at the University of Melbourne.[13] Davies was appointed as a Senior Lecturer, promoted to Associate Professor in 1936 and Professor of Organic Chemistry in 1953.[14]

In early 1934, as Davies planned a period of sabbatical leave in Britain, he secured a research grant of £10 from the Chemical Society of London, of which he was a Fellow, to investigate the 'Vitamin-A content of some Australian fish oils'. He left Australia in late 1934 and returned in mid-1935. His leave was spent in the then-customary fashion for chemists visiting 'the old country', which is to say that he visited a number of chemistry departments (the University of Manchester's almost certainly among them), attended meetings of the Chemical Society, and stayed with relatives. Davies evidently spent some time working with Jack Cecil Drummond, professor of biochemistry at University College, London, a nutritionist who had published extensively on fat-soluble vitamins.[15] In his first publication on fish liver oils,[16] Davies noted that their results were obtained 'by utilizing the practical experience gained by one of us in the non-biological methods used in Prof. Drummond's laboratory in London'. Since Field was a graduate student and Davies had only recently been in England, it is clear that he had worked in Drummond's laboratory, taking the opportunity there to prepare himself for the project he was to undertake once he returned to Australia.

Two quantitative analytical methods were used by Davies and Field, one based on the depth of the blue colour of an antimony complex of vitamin A (colorimetry) and the other on ultraviolet light absorption by the vitamin itself. Before the vitamin content could be estimated, the oil

needed to be separated from the tissue and then treated so as to remove extraneous organic material. Two methods of extraction were used. In the dry method the liver was minced, mixed with 2–3 times its weight of anhydrous sodium sulfate, and left in a desiccator overnight. Extraction with low-boiling petroleum ether and subsequent removal of the solvent by distillation yielded the oil. An alternative method was used for the most oily livers, those of gummy and snapper sharks (*Mustelus antarcticus* and *Galeorhinus galeus* respectively), which were steamed to release the oil, about 60% of which was recovered in this way. The remaining oil was recovered by solvent extraction as above. Similar proportions were reported by Shorland for extraction from livers of New Zealand ling (*Genypterus blacodesi*).[17] As others had observed, the oil recovered in the steaming method was lighter in colour than that recovered by the dry method.

For determination of the vitamin A content, a weighed sample of oil was saponified by alcoholic potassium hydroxide and the resulting alcohols (mainly glycerol) and fatty acids were removed. An aliquot of the unsaponifiable residue was then dissolved in chloroform, and after suitable dilution the vitamin A was estimated by the Carr-Price method, comparing the intensity of the blue colour with a stepped series of standards in a Lovibond Tintometer (Fig. 1).[18] It had been known for some time that vitamin A, when treated with acidic substances, produced coloured complexes, and the use of one of these, the Lewis acid antimony trichloride, was developed in 1926 as an analytical method by scientists of British Drug Houses Ltd[19] and was adopted world-wide as the standard method.[20] Many years later the blue colour was shown to be caused by the formation of a cationic species in which the charge was distributed across the conjugated double bond system of the vitamin A molecule.[21] For the ultraviolet assay an aliquot was dissolved in cyclohexane and the vitamin A content estimated by measuring the absorption at 328 mμ by means of a spectrophotometer. Colorimetric analyses such as those using the tintometer were common, but the ultraviolet spectrophotometer represented new scientific technology.[22] No bioassays were undertaken.

When processing the bulk samples, further purification of the unsaponifiable residue was effected by removing sterols by means of crystallization from methanol. Some vitamin A was lost through oxidation during the repeated handling, and so more reliable results were obtained from the micro samples, for which this step was omitted. The authors noted that the internationally standardized method did not require the removal of sterols. Their results were expressed as percentages of vitamin A, according to the method of Carr and Jewell.[23]

Figure 1. The Lovibond Tintometer (partly dismantled) used by Davies in his fish liver oil work (photo: Nola Orr, University of Melbourne Cultural Collections).

When several batches of liver were processed, Davies and Field found great variation in all three of liver weight, oil content and vitamin A concentration in the oil. In addition, the data for salmon and snapper showed the seasonal variation of the yield of vitamin A (Table 1) that had been observed for the northern-hemisphere halibut.[24] The liver oils of several of the species examined by Davies and Field had vitamin A content comparable to that of cod liver oil. Only the school or snapper shark seemed to offer an economic prospect, especially in summer when the value may exceed those observed for fish caught in August. The shark liver oil contained about 1% of vitamin A; though this is lower than the concentration in most halibut oils, the greater weight of the shark livers makes it a rich source of the vitamin. The sharks are abundant in southern Australian waters and popular with commercial fisheries because their flesh is 'widely sold and eaten, though not under its proper name'.[25]

Involvement of CSIR

Australia's Council for Scientific and Industrial Research (CSIR), forerunner of the

Table 1. Typical results from Davies-Field investigations (1937)

Fish species	Month of catch	Average liver weight (g)	Oil content (%)	Vitamin A – Carr-Price colorimetric	Vitamin A – UV absorption
Salmon	July	11.2	7.3	0.063	0.077
Salmon	November	16	6.8	0.27	NA
Snapper	July	80	5.8	0.038	0.034
Snapper	November	83	4.9	0.33	0.31
Murray cod	August	33	6.2	0.07	0.066
School shark	August	575	49.9	0.91	0.85
Yellow tail	October	236	10.9	0.46	0.44
Blue-fin tuna	October	148	2.0	0.18	0.20
Bream	November	30	5.2	0.61	NA
Barracouta	December	11.1	1.8	2.3	2.4

present Commonwealth Scientific and Industrial Research Organisation (CSIRO), established a Fisheries Investigation Section in 1937[26] and engaged Dr Harold Thompson to be its head. Thompson had served a decade as Scientific Adviser to the Fishery Board of Scotland and then, at the joint invitation of the Empire Marketing Board and the Government of Newfoundland, as Director of Fishery Research in Newfoundland. Thompson was born in Aberdeen in 1890, and there studied for his MA (1912) and MSc (1920, following war service) degrees. He was awarded the DSc (1927) for his work on the natural fluctuations of haddock populations.

Announcing Thompson's five-year appointment in September 1936, the Australian Government emphasised the importance of deep-sea fishing, for which a vessel was currently under construction, and the need for development of fish preservation methods and 'manufacture of by-products such as fish meal, and oil'.[27] Six weeks after he arrived in Melbourne, Thompson was interviewed by Phillip Crosbie Morrison.[28] The topics covered were fish populations and likely catches, the canning and curing of fish, and the use of fish meal as cattle food. Fish liver oils, which were to become an important product of the Australian fisheries over the next two decades, were not mentioned. Thompson had begun his work by visiting a number of coastal regions in Australia, noting that little had been done by fisheries departments in the states and that there were great opportunities for increasing the size of the industry.

Thompson's experience in Britain and especially in Newfoundland would have made him aware that, in addition to fish stocks and the uses of fish flesh, there was a valuable by-product to be recovered from fish livers, namely the oil rich in vitamin A. Indeed, Thompson's wife Johan, who held a BSc degree from Aberdeen and had worked for nine years as a dietician in the School of Domestic Science there, had been one of twenty staff in the Newfoundland laboratory where her work had involved analysis of the oils for their vitamin A and vitamin D content.[29] She was never employed in this capacity in Australia, however, and was probably involved in home duties and raising their son, Harold Lindsay Thompson.

The broader Australian scientific community was also showing interest in vitamin A. At a conjoint meeting of the Chemical Societies of Sydney held at Sydney Technical College on 23 June 1937, Dr Fritz Reuter[30] spoke about the polyunsaturation of the vitamin A molecule that was responsible for its ready auto-oxidation in air and also the colour formed by complexing with antimony trichloride. He also drew attention to provitamins such as β-carotene, a vegetable pigment that is converted *in vivo* to vitamin A, but did not mention fish oils or the potential for Australian production. The text of his talk was printed by the Australian Chemical Institute.[31] Later that year the Institute published an article by W. D. Leech, Director of the Australasian Food Laboratories, on analytical methods for determination of vitamin concentrations.[32] Both the colorimetric and the UV absorption methods were covered, with the latter being judged the more reliable. This view concurred with that of the British Pharmacopoeia, which had advised

in 1936[33] that the UV spectroscopic method was to be preferred to the colorimetric method, and while 'it is natural for those engaged in industry to press for adoption of chemical or physical methods of assay because of the greater degree of precision with which they can be carried out', the view of the Pharmacopoeia Commission was that 'as the vitamin activity of cod-liver oil is a biological property, the biological method of assay should be the decisive one'.

The CSIR Fisheries Investigation Section, recently established at Cronulla, New South Wales, did not possess chemical laboratories of its own, nor scientists trained in applied chemistry, and so Thompson encouraged Davies to undertake further work on fish oils and their vitamin content. Speaking to an audience of professional and sporting fishermen, Thompson outlined his general plans for the development of Australian fisheries and, alluding to the work at the university, said that 'Australia may become an important producer of high-grade medicinal vitamin oils if the hopes of the fisheries branch … are realized … (and) also an important exporter of them'.[34] An officer of the CSIR, W. G. Jowett[35] was seconded to Davies' laboratory to assist with the work. Support also came from funds provided to the University of Melbourne by the Australian Government.[36] As well as referring to the work of Davies and Field, Jowett and Davies alluded to a short investigation of barracouta (*Thyrsites atun*) that had been carried out several years earlier by N. F. B. Hall of the University of Sydney. The account of this work was not published, but was retained by the Fisheries Section. While the potential for production of fish meal was also considered by the researchers, the main emphasis was on vitamin A, of which the Australian fish liver oils were shown to have high values when compared with those from most common northern-hemisphere fish. The authors speculated that this had something to do with 'the bright sunlight in these latitudes' that was also held to be responsible for 'high and uniform vitamin potency of Australian and New Zealand butters'.[37]

As in the earlier work, Jowett and Davies found considerable variations. Vitamin A content of liver oil from sea mullet ranged from zero to 1.43%; for barracouta, 0.34–4.1%; salmon, 0.034–1.2%; snapper, 0.14–0.28%; tuna, 0.005–1.46%; snapper shark, 0.12–1.10%; and gummy shark, 0.006–0.62%. However, the sharks had much heavier livers and so yielded much more oil per fish than the smaller species. It was speculated that smaller fish of a given variety use the vitamin A whereas their larger brethren accumulate it, in accord with data for cod[38] and halibut.[39] The seasonal variation observed in both the Australian studies and northern-hemisphere studies of halibut liver oil was ascribed to spawning and feeding behaviour. The mean liver-oil content of barracouta was 6.4% (3.5–10.4%) in April, and 5.05 (2.4–10.2%) in November, and 1.8% in December. The mean oil contents were 1.1% (0.34–1.55%); 2.0% (0.5–4.1%); and 2.3%, respectively. Because the April and November figures were based on determinations of four bulk samples and the December result on a single bulk sample, and the December fish were caught off the Victorian coast whereas the April and November fish came from the south-east corner of Tasmania, the authors acknowledged that the seasonality deduction 'must remain a tentative one' because of small and inconsistent data sets, even though it accorded with the northern-hemisphere result. Oil derived from fish bodies and especially from other viscera were also found to contain vitamin A, as had been observed for northern-hemisphere fish, but the livers were the main repository of the vitamin.

Davies did not continue with the fish-oil work but it was continued in other hands in Australia and New Zealand.[40] The University of Melbourne included information about Davies' vitamin A work in its stand at the exhibition organized by the Australian Chemical Institute in Melbourne in March 1938, showing the oils and the methods of estimation. A newspaper report began with 'if you want to know how much food value there is in fishes or how much vitamin there is in their oil go to the chemical exhibition at the Glaciarium'.[41] Jowett and Davies were jointly awarded the University of Melbourne's Grimwade Prize in 1938 for their work on the fish liver oils.[42]

Davies did extend his investigations to the oil of the mutton bird, *Puffinus tenuirostris* (also known as the short-tailed shearwater and sometimes described as 'the local petrel') that was at the time being sold in Victoria for the same purpose as cod liver oil.[43] He found that the oil was practically devoid of vitamins A and D and

Table 2. Imports to Australia of bulk cod-liver oil (gallons)

Country of origin	1937–8	1938–9	1947–8	1948–9	1949–50	1950–1
United Kingdom	66,213	65,186	90,213	53,607	77,696	96,281
Norway	13,058	11,385	23,525	7,594	1,867	13,488
Other foreign countries	264	275	1,500	1,526	3,517	2
New Zealand			609	555	–	2,545
Other British countries			–	4	2,081	518
TOTAL	**79,535**	**76,846**	**115,847**	**65,284**	**85,461**	**112,834**

moreover had low nutritional value, so it was unlikely to be developed for commercial purposes. The mutton bird 'oil' was, in fact, mostly a wax,[44] the non-saponifiable portion of which consisted of cetyl alcohol (65%), oleyl alcohol (28%), and cholesterol (7%). Such waxes are of no nutritional value since they pass through the animal undigested.

Creation of an Australian Industry

Following the outbreak of war in September 1939, Australians were soon deprived of supplies of cod liver oil (approximately 80,000 gallons/year, see Table 2) and Australian companies moved quickly to arrange local production of oils rich in vitamin A. Two plants were established in Melbourne and one in Adelaide, accounting for the bulk of wartime production, and smaller plants were opened in South Australia, Tasmania, New South Wales and Western Australia.[45]

At a Fisheries Conference convened by CSIR in November 1940, Thompson mentioned by-products but it was clear that his main focus was edible fish.[46] Exploration of fish oils and assay methods continued, however, largely duplicating the work of Davies. The staff of the Fisheries Section collaborated with a young officer from the CSIR Division of Food Preservation and Transport, Clem Kuchel. Liver oil from Yellowtail Kingfish (*Seriola dorsalis*) was shown to have vitamin A content of 42,000 International Units[47] per gram and 9,000 International Units per gram of vitamin D, this latter result being provided by the Commonwealth Serum Laboratories. These figures are, respectively, 36 and 110 times the cod liver oil values and the authors noted the need for the liver oil to be diluted with peanut or other oils for use in products such as medicinal emulsions.[48] In a companion piece, Ferguson Wood provided more information on extraction and assay and pointed to the expansion of the fishing industry required to provide vitamin-rich oils for stock feeding.[49]

The Australian Government, through its Medical Equipment Control Committee (MECC, Department of Defence), headed by Sir Alan Newton, encouraged the establishment of the local industry, in which the Nicholas company took the lead.[50] 'For a while there was an exportable surplus', Mellor observed, 'but increasing local demand and the call up of fishermen for the Services soon reduced this to zero'. Over 8,000 tons of vitamin oil concentrate were provided to the army for use in 'fortified margarine, enriched chocolate, and other foodstuffs' and a surplus over civilian and military requirements 'permitted the export of large quantities to India for the use of the armies in Burma'. A retrospective newspaper account, possibly sourced from the company,[51] placed stress on the request from the Commonwealth Government for the company 'to find a substitute for cod liver oil' that caused their research chemists to collect shark livers and eventually to produce the oil in commercial quantities; however, the account did not mention Davies' investigations nor the work of Thompson (who was appointed Controller of Fisheries during the war) and CSIR.

During the war CSIR continued to work on fish liver oils, although the experiments were hampered by lack of equipment.[52] In addition, the Melbourne-based firms Australian Fish Derivatives and Australian Packers received assistance with and advice on analytical techniques from the Commonwealth Serum Laboratories under their Director Dr Frederic Morgan. Thompson continued to present the Medical Equipment Control Committee with plans for a national industry, but the industry was already developing. Fauldings in Adelaide produced 1,039 gallons of oil in the year to November

1942, while the combined output of Australian Fish Derivatives and Australian Packers had reached 100,000 gallons of commercial product fortified by vitamin D_2 by May 1942, and the Australian totals for 1943 and 1944 were, respectively, 3,582,200 and 4,077,100 pounds.[53]

Nicholas and Australian Fish Derivatives

Nicholas Pty Ltd, the company founded in 1916 to develop the production of aspirin in Australia, commenced vitamin A work in February 1940 and by the end of the year had established production of 'Scomol', which consisted of purified liver oil obtained from the school shark (*Galeorhinus australis*) diluted with peanut oil so that it matched the specification of the British Pharmacopoeia for *Oleum Vitaminatum B.P.* This standardized the concentration of vitamin A at 1,000 International Units and of vitamin D at 100 International Units per gram.[54] Because the shark liver oils contained little or no vitamin D, the synthetic vitamin was added to the oil to achieve the standard. The company's work was the subject of a number of retrospective pieces. In 1941 Kuchel moved from CSIR to the Nicholas subsidiary Australian Fish Derivates in Melbourne, where he described the company's vitamin A work in an address to the Biochemical Group of the Victorian Branch of the Australian Chemical Institute on 28 June 1943.[55] The authors dated the beginning of the Australian industry to late 1939, following the results published by Davies and his students, and mentioned the wartime request from the MECC for 'a substitute for the 80,000 gallons or so of cod liver oil imported annually'. Details were given of vitamin A concentrations in liver oils of several shark species, the richest of which were the snapper and gummy sharks, and Kuchel's talk covered extraction methods and analyses.

Much later, the Royal Australian Chemical Institute,[56] as part of a series about Australian industry, mentioned the company's decision in 1939 to diversify production, their establishment of research laboratories in Melbourne and their engaging of experienced chemists.[57] The first Nicholas plant was described as 'an empty kerosene drum, an empty oil drum, ten yards of glass piping and half a dozen drain pipes'. The start-up was also described in the company history,[58] which placed the initiative with engineer Arthur Lightfoot, who while traveling in America, 'heard that a species of shark … had livers rich in vitamin A' and suggested that the company should take up such work'. Chief Chemist R. G. Smith, one of the authors, recalled the Melbourne/CSIR work and that the company recruited a team of young chemists, established a subsidiary company, Australian Fish Derivatives Pty Limited, negotiated with fishermen, and worked to set up an extraction plant with pressure cookers, an innovation copied from American practice. Nonetheless, 'the smell was appalling and everyone who could kept well away'. The Australian oils were 15–50% more potent than cod liver oil but did not contain vitamin D, so the product was augmented with synthetic supplies imported by air. In cold conditions the oil could go cloudy or even solidify, a problem that was overcome by 'winterizing'—chilling to remove the higher melting fraction (termed 'stearine') which, because it contained vitamin A, was included in an healing ointment marketed as 'Ungvita'.

A Chemical Exhibition was organized in Melbourne in 1947 by the Australian Chemical Institute, repeating a success they had had with an exhibition nine years earlier. A quantity of shark liver was exhibited by the Nicholas Company, with the product dramatized by showing 'an unborn baby schnapper (sic) shark about 12 in long and still attached to the egg sac'.[59]

Australian Fish Derivatives advertised their product, 'Scomol', in the Australian Women's Weekly (Fig. 2). The advertisements explained the suspension of supplies of cod liver oil from overseas and the development of the local product, which was said to be 'bland, without the penetrating taste of previously imported fish liver oils', and showed a sketch of fish, presumably cod, being unloaded from a fishing net. Fishing activities featured in two of the advertisements. One showed a serviceman in uniform greeting a child whose health is attributed to Scomol, which had 'completely superseded cod liver oil', and another included advice from a pharmacist.[60]

Australian Packers Corporation

Less information is available about the other Melbourne-based company, the Australian Packers Corporation, an American company that was

Figure 2. Advertisements placed in the *Australian Women's Weekly* for the Australian Fish Derivates products, Scomol. (a) Saturday 16 May 1942, p. 28 (b) Saturday 27 May 1944, p. 24.

registered in Australia in 1944. The company chartered the ketch *Ruby* to fish for shark in Bass Strait, and the boat returned to Melbourne in September with ten tons of snapper shark. The oil obtained from the shark livers was to be processed for manufacture of margarine.[61] Vitamin A was added to margarine to raise its nutritional value to that of butter.

A presentation to the congress of the Australian and New Zealand Association for the Advancement of Science held in Hobart in January 1949, presented by R. G. Smith on behalf of the authors, was the source of a further article in the Institute's journal.[62] The authors, both Associates of the Institute who were employed by Nicholas Pty Ltd, dealt extensively with the colorimetric and UV absorption methods, but also covered the biological assay which they described as 'inherently difficult'. It consisted of vitamin A dosing of vitamin-deprived rats and assessment of their growth over a 3–5 week period. Cod liver oil and carotene standards were employed.

F. H. Faulding & Co. Ltd

Accompanying neat cod liver oil on the pharmacy shelves were a number of aqueous emulsions containing cod-liver oil and 'hypophosphites' of calcium and sodium. These products were typically advertised as restoring 'vigour, fresh impulse and mental alertness' after illness. One prominent product of this type in mid-century Australia was Hypol, manufactured in Britain (following its invention in late nineteenth century) and distributed by the Bickford Company of Adelaide.[63] The hypophosphites, salts of phosphinic acid, H_3PO_2, supplemented dietary intake of the essential nutrient, phosphorus, and were valued as a 'nerve tonic'. These international products had their local imitators, one being 'Milk Emulsion' marketed by Faulding for the warding off of winter ailments.[64]

Faulding claimed to be the first to begin production of vitamin A from liver oils of the snapper or school shark—'not a man-eater'—but it was only in 1942 that newspaper coverage described their network of fisherman-collectors

and that 'in the factories the oil is spectrophotometrically standardised'.[65] Later advertisements made good use of technical detail, which had a scientist affixing a photographic plate to a spectrometer[66] with accompanying text that specified the presence of 8,000 International Units of vitamin A and 800 International Units of vitamin D in every tablespoonful (Fig. 3). Despite the possibility that importing of northern-hemisphere cod liver oil would resume when hostilities ended, Faulding continued production from locally obtained livers that were snap-frozen by fishermen and transported to their expanded works in Adelaide.[67]

The experience of this company with shark liver oils was described at a pharmaceutical conference in September 1947 by research chemist E. H. Phillips.[68] Although all methods suffered from limitations, the absorption of UV light at 328 nm was preferred, and Phillips included some discussion of the factor used to convert a UV value to the biologically based International Unit. Like earlier investigators, those at Faulding found great variation in oil yield from the livers and in the vitamin A content of the oil, and although a range of factors such as time of year, gender and sub-species (as evidenced by skin colouring) were examined, no firm correlations could be established.

The Faulding company history celebrating 150 years of operation[69] discusses the shark liver oil work in a section headed 'Opportunities of War'.

Just as World War I had provided Faulding with the opportunity to consolidate and extend its operations, so too did the period of World War II. The Federal Government remained particularly concerned about the potential threat to supplies of drugs and, in August 1940, established the Medical Equipment Control Committee to encourage the local development of those drugs and chemicals previously imported. To this end, several companies, Faulding among them, were given financial assistance to produce particular drugs and chemicals.

Among other products, the account continued, the company explored the production of a substitute for cod liver oil, the source of vitamin A, which had been imported from Scandinavia. This was in competition with Nicholas, in Victoria, who sought similar supplies. This involved Faulding in work with the fishing industry, and

Figure 3. This advertisement, which appeared in the Adelaide *Advertiser* in April 1948, emphasized the control of vitamin content by use of modern scientific instrumentation.

'in early 1945 it was advanced a loan of £2,000 to enable the infant cooperative to purchase and install a freezing plant at Beachport in the south east of the state'. In October 1940 the company was advised by Sir Cedric Stanton Hicks, professor of physiology and pharmacology at the University of Adelaide, to research the liver oil of the tuna that were common in local waters. This source was unsuitable but the company soon turned to liver oil from the schnapper shark (*sic*) and early in 1941 they entered into an agreement with fishermen for supplies of shark liver at 8 pence/lb, double the price of the shark flesh. As had their Victorian rivals, the company

also partly financed the construction of fishing boats. While many of the livers were processed at the company's Torrenside plant, some fishermen preferred to undertake the extraction ('boiling down') themselves and sell the oil to Faulding at £1 per gallon. The company supported the fish liver oil work of R. F. Condon, one of Hicks' students, who continued with the project after his graduation.

After the War

The three major producers—Australian Packers Corporation, F. H. Faulding & Co Ltd, and Australian Fish Derivatives Pty Ltd—continued production after the war and even envisaged the generation of export income from their products.[70] Vitamin A, it was reported, was 'sought by drug companies, food processors to fortify margarine and other foodstuffs, and by manufacturers of chicken food'. Australian production at that time[71] was about 1½ trillion units of the vitamin, valued at approximately £70,000, but New Zealand production was double that, and worth approximately £200,000. Australian fish stocks were abundant, and could yield 7–8 trillion tons a year, worth about £600,000. However, Australian fishermen were unwilling or unable to capitalize any new venture, with boat and equipment likely to cost between £5,000 and £10,000. Funding an expansion of the industry must have been possible, however, since a fourth company specializing in the extraction of fish liver oil, AA Emulsion Co. Pty Ltd, was incorporated before the end of the same month,[72] with plans to market its products through the oil company, H. C. Sleigh.

Production in the northern hemisphere had resumed on a substantial scale. Wartime rationing had placed British children in danger of vitamin deficiency and the development of ricketts, causing the government to supply free cod-liver oil to children under ten years of age.[73] The programme continued after the war and proponents claimed the following benefits: prevention of the common cold, curing arthritis, anaemia and vitamin A and D deficiencies, prenatal dietary supplement and supplementary treatment for tuberculosis.[74] As a result, one English company was processing the livers of 82 million cod a year (the flesh being marketed for food) and producing 13,000–16,000 tons of cod liver oil, which was marketed internationally. This led to suggestions that Australia's vitaminized oil was no longer needed. Rebutting these suggestions, A. F. Scammell, Managing Director of F. H. Faulding & Co Ltd[75] said 'we can understand the British attitude, because they are large producers of Cod Liver Oil, but the Australian authorities should carefully investigate this matter and take steps to see that propaganda of this sort does not adversely affect the production of *Oleum Vitaminatum* in Australia'.

Two other factors mitigated against continued, or at least expanded, production in Australia. Speaking at the Jubilee Conference of the Pharmaceutical Society of Australia, the Nicholas company's C. C. Kuchel described the syntheses of vitamin A and certain of its derivatives (esters with fatty acids such as palmitic) that had made the synthetic products available over the previous two years.[76] The laboratory synthesis of vitamin A in 1950[77] was soon followed by commercial production, which enabled the formulation of accurately known doses. The approach of the Pfizer company was to incorporate vitamin A, in the form of its palmitate ester, into micro-beads of gelatin (approximately 70,000 per gram) and such products were widely used in animal feed.[78] The synthetic products were also available as semi-purified products dissolved in cotton seed oil or corn oil at extremely high potencies. In addition to the high vitamin concentrations, 'the great advantage of the synthetic products is their freedom from fishy odour and taste', Kuchel said, and they could also be marketed as aqueous emulsions along with water-soluble vitamins. Referring to the consequent reduction in cost of vitamin A preparations, Kuchel opined 'that the synthetic products will entirely supplant natural oils in all their uses in the next few years. The fish liver oil industry has certainly received a rude shock, but, for example, emulsions for both medicinal and veterinary purposes will be used for some time to come'. This message was reinforced a decade later in the chemical industry survey[79] that noted the continued use of fish-oil vitamins in agricultural and veterinary products. For example, in 1954 Nicholas began production of a stabilized, dry vitamin A product, using a process originally developed by America's Nopco Chemical Company. Nopco's patent[80] describes the product as a mixture of

fish liver oil, wax or mineral earth, wheat flour and an antioxidant.

There was also contrary evidence about the value of nutritional supplements, since CSIRO investigations had shown that sheep could derive necessary vitamin A from carotene (pro-vitamin A) in green-feed crops such as lucerne and grains, so 'graziers may be wasting time and money on vitamin A treatment of their sheep in circumstances where it can be of no value'.[81] The supplements continued to be popular, however, in the poultry industry.

Import figures provided by the Commonwealth Statistician to the Tariff Board (see Table 2) showed that by the late 1940s cod liver oil was imported in quantities comparable to those imported before the war.

The Threat from Imports

By 1949, shark fishing was thriving, with sixty boats operating off the Victorian coast, marketing the shark flesh as 'flake' for consumption in Victoria and providing liver for oil production. However, an economic threat appeared on the horizon in the form of shark liver oil from South Africa that was produced with 'cheap coloured labor' according to a newspaper account.[82] It was explained that the American market, to which South African oil sales had previously been directed, had been taken over by even cheaper vitamin-A-rich oil from a resurgent Japan, causing the South Africans to seek new markets and finding them in Australia. Calls for an increase in duty on imported oil naturally followed.

The South African company, Marine Oil Refiners of Africa Ltd, based in Simonstown, near Cape Town, used the Solexol Process that had been developed by Kellogg in the United States for refining of vegetable oils with propane, and later extended to fish oils including cod liver oil.[83] Fish liver oils in South Africa had typical vitamin A potencies of 10,000–20,000 I.U.A./g, with some reaching 50,000, and after hydrolosis vitamin A could be extracted from the unsaponified portion by liquid propane under pressure.[84]

Responding to the calls for tariff protection, the Minister of State for Trade and Customs, Neil O'Sullivan, referred to the Tariff Board on 4 December 1950 the question of 'what rates of duty should be imposed on fish oils at present charged with duty under existing Tariff Items'. Whale and seal oils were excluded from consideration.[85] Submissions in favour of increased duties were received from Australian Packers Corporation and several of the minor players,[86] while Faulding and Australian Fish Derivatives (the largest of nine producers) opposed increases.[87] Among the points made to the Tariff Board were:

- Australian Vitamin Oils had been in production for two years, fishing in SA and Tasmania.
- Australian Packers enjoyed 'protected industry' status during the war years for local productiion, but also exported.
- Competition from Japanese producers, who had flooded the post-war US market, and South African producers was a problem.
- Conrad Topper, J&T Trading, said they could produce 20,000 gallons/year but had stockpiled material because they could not compete with imports.
- H. J. Miller, Faulding, said they started production in 1938. The company submitted production data in confidence.
- McCready, for the Nicholas subsidiary Australian Fish Derivatives, said they had commenced production at the request of MCEC and had capacity to produce 25,000 gallons/year but never reached this figure due to shortage of raw material. In 1946 Nicholas purchased K. Greenwell Pty Ltd, New Zealand, and received regular shipments from them. The export market collapsed in 1950 when prices fell, and Nicholas were now importing from South Africa. The main outlet was in veterinary uses (their main products) for which high potency was not required.

Not all producers submitted data but from those who did respond the data are shown in Table 3.

Production in the order of 30,000 gallons was overshadowed by imports (see Table 2) approaching 100,000 gallons. The Board reported on 24 December 1951, recommending (p. 52) no change because there were not enough sharks and not enough fishermen to catch them, so the industry would not benefit from an increase in the tariff. The decision was not unanimous, since one member, P. B. Newcomen, dissented, but chair Cumming and members Higgins and Morris were in favour.[88]

Table 3. Data for liver oils (gallons) of various potencies

Year	Total production	Faulding production	Nicholas production
1947–8	34,876	1141	
1948–9	33,384	198	
1949–50	22,578	2157	29,264[A]
1950–1			8,195[B]

[A]The data provided to the Tariff Board are inconsistent since the Nicholas figure exceeds the total and may have been a sum over several years.
[B]Total for nine months to 31 March 1951.

The decline in local processing of fish oils continued until there was a revival of interest in the nutrient properties of oils. While there was some interest in omega-3 fatty acids, attention has now shifted to other components of the oils such as the polyunsaturated hydrocarbon squalene and diacyl glyceryl ethers (DAGE). CSIRO have continued research in this area and health authorities have publicized the perceived benefits.[89] Among Australian companies that have relied on CSIRO research to guide their commercial operations are Deep Sea Oils Pty Ltd,[90] which exports cold-pressed shark liver oils for use in nutriceutical markets in USA, Europe and Japan, and Ocean Oils Ltd which produces oils rich in valuable components.[91]

Concluding Remarks

Although the case has been made[92] that important sectors of Australian manufacturing industry began in the 1930s to prepare the country for production in time of war, it would be stretching credulity too far, I believe, to claim that William Davies at the University of Melbourne foresaw in 1934 that such a time would come soon. Nonetheless, when Australia was completely isolated from supplies of vitamin A rich cod liver oil, it was Davies' work that led to the development of an import-replacement industry. Even when the government research organization, CSIR, became involved under the leadership of Harold Thompson, their emphasis was on self-sufficiency in general rather than wartime exigency. As war began however, the Australian Government urged the development of a local industry, based on the liver oil of snapper or school sharks, and two major pharmaceutical companies—Nicholas in Melbourne and Faulding in Adelaide—seized the opportunity and quickly developed a new industry. A key person was C. C. Kuchel who had worked on fish oils with CSIR but soon moved to the Nicholas subsidiary, Australian Fish Derivatives, where he led the work for some years. CSIR continued to provide assistance to other companies wishing to develop fish liver oil businesses but Davies' contribution was soon forgotten and when Thompson retired in late 1954 at age 64 the press notices, most notably in provincial dailies[93] concentrated on his achievements in what we would now call sustainable fishing but did not mention the shark liver oil work. Thompson returned to Edinburgh where he died in May 1957.[94]

The Australian fish oil industry, although it met domestic and military requirements in the war years, was never really at world scale, and when imports resumed in the late 1940s it suffered severe competition. Indeed, the Nicholas company abandoned local production and met its needs by imports from South Africa, which had emerged after the war as a major producer. Considering the case for protection, the Tariff Board found that the industry was unable to expand to meet local needs, and so importation was necessary and should not be hindered by increased tariffs. CSIRO, successor to CSIR, has continued research in the area and the industry survives, in modern form, as a supplier of oils rich in squalene and diacyl glyceryl ethers (DAGE) for which various health benefits are claimed by the producers and by nutritional advocates. Other nutritional supplements such as vitamins are imported and formulated for sale in Australia.

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87. Submissions from Henry Joseph Mealor, F. H. Faulding & Co.; Frank Alexander McCready, Australian Fish Derivatives (Nicholas); Brent Hevilaid Evans for importers; various others including poultrymen, Drug Houses of Australia (DHA), Burroughs Wellcome, Elliotts & Australian Drug.
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