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A Pilot Investigation of Northern Australian Shark Liver Oils: Characterization and Value-adding

Peter Nichols, Mark Rayner and John Stevens

FRDC Project 99/369

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1. NON-TECHNICAL SUMMARY

99/369 A pilot investigation of northern Australian shark liver oils: characterization and value-adding

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OBJECTIVES

- Characterize liver oils from northern sharks (NT, WA, Qld), including examining possible changes with location, season and other factors. The key components to be examined will be the omega-3 PUFA and vitamins.
- Provide initial comment on the potential commercial usefulness of the liver oils from northern sharks.

OUTCOMES ACHIEVED

Liver oil profiles were obtained for northern Australian sharks during this pilot study. The profiles indicate new sources are available for omega-3 and diacylglyceryl ether containing oils. These two types of oils have been manufactured over the last 5 years in Australia from by-catch and by-products of other fisheries. The by-products from the northern shark fishery offer a potential new source for these valuable oils.

The content and composition of liver oil from around twenty species of northern Australian sharks were examined. Oil content in the livers obtained from northern sharks ranged from about 10-70% (percent of liver, wet weight basis). For livers with an oil content greater than 40%, it was possible to obtain the oils by a process involving the following: breaking the liver up, heating, and separation. Species containing liver oil levels greater than 40% included school, gummy, handle bar, spot-tail, milk shark, thick skin, silky, whiskery, tiger, whaler, blacktip (about half the specimens), blacktip/school and blue sharks. Species with less than 40% liver oil content were: blacktip (about half the specimens), hammerhead, white cheek, and pick handle sharks. Based on oil class composition, three groups of oils were apparent:

1. oils containing triacylglycerol (TAG) as the dominant class (>90% of total oil);
2. oils containing intermediate levels of TAG (20-75% of total oil);
3. oils containing diacylglyceryl ethers (DAGE) as the major class (>50% of total oil).

Most species were in group 1; this group generally contained high oil levels (>40% of liver). Group 2 comprised selected specimens of blacktip, hammerhead, and pick handle shark; this

group generally corresponded to the low oil (<40% of liver) group. Group 3 was comprised of one species, tiger shark. At this time, DAGE derived from liver oils from Australian deep-sea sharks are being marketed both nationally and internationally. The discovery of the occurrence of high levels of DAGE in tiger shark liver oil provides a potential new source of this oil for the local marine oils industry.

Previous interest in Australia in shark liver oils, principally derived from deep-sea species, has centered on the hydrocarbon squalene, and to a lesser extent DAGE. The wide range of northern Australian shark species analysed do not contain appreciable levels of squalene.

The major fatty acids in liver oils from most species were: 16:0 (palmitic acid), 18:1ω9c (oleic acid), 22:6ω3 (docosahexaenoic acid, DHA) and 18:0. Lower levels of 16:1ω7c (palmitoleic acid), 20:5ω3 (eicosapentaenoic acid, EPA), 18:1ω7c (vacennic acid), 14:0 (myristic acid), 20:4ω6 (arachidonic acid, AA) and 22:5ω3 (docosapentaenoic acid, DPA) were also observed. Liver oils were separated into two broad groups based on the combined level of the two major omega-3 PUFA, EPA and DHA.

- The first group contained species with appreciable (mean level approximately 20%) levels of EPA and DHA in the liver oil. This included whiskery (collected July 1999 from WA), blacktip, hammerhead, spot tail, blue, whaler, Pacific white, pick handle, milk and handle bar sharks.
- The second group of species contained markedly lower levels of omega-3 PUFA (<5%) and included blacktip/school, selected whiskery, school and gummy, silky, thick skin, pig eye, and tiger sharks.

Regional and seasonal variation in oil composition were apparent, but were not major factors in the between sample variation, and may be expected to have little influence for any future commercial operations targeting specific liver oils from northern Australian sharks. Rather, the key factor resulting in differences in liver oil composition is species make-up.

The discovery of PUFA-containing and DAGE-rich liver oils in northern Australian sharks demonstrates that suitable raw material is available and the potential exists with the research capability and industry expertise in Australia for further products to be developed. With the acknowledged problem that fish oil resources may be limiting in the near future, and that fish oils from northern hemisphere waters may be contaminated by organochlorines and other deleterious materials, the potential for "clean and green" Australian omega-3 products is further enhanced.

KEYWORDS: northern Australian sharks, liver oils, triacylglycerols, diacylglyceryl ethers, omega-3 polyunsaturated fatty acids (PUFA), DHA, EPA

2. ABBREVIATIONS

AA	Arachidonic acid, 20:4ω6, also termed 20:4(n-6)
AAOCS	Australasian Section of the American Oil Chemists' Society
AGAL	Australian Government Analytical Laboratories
CHD	Coronary heart disease
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAGE	Diacylglyceryl ether
DHA	Docosahexaenoic acid, 22:6ω3, also termed 22:6(n-3)
DPA	Docosapentaenoic acid, 22:5ω3, also termed 22:5(n-3)
EPA	Eicosapentaenoic acid, 20:5ω3, also termed 20:5(n-3)
FAME	Fatty acid methyl ester
FID	Flame ionization detector
FFA	Free fatty acid
FRDC	Fisheries Research and Development Corporation
GC	Gas chromatography
GC-MS	Gas chromatography-mass spectrometry
HC	Hydrocarbon
IS	Internal standard
LA	Linoleic acid, 18:2ω6, also termed 18:2(n-6)
LC-PUFA	Long-chain ($\geq C_{20}$) (see also PUFA)
MUFA	Monounsaturated fatty acids containing one carbon-carbon olefinic centre, generally with *cis* configuration. e.g., oleic acid [18:1ω9c, also termed 18:1(n-9)c]
Omega-3	Family of polyunsaturated acids with two or more *cis*-unsaturated centres, separated from each other by one methylene group and having the first unsaturated centre three carbons from the end methyl
Omega-6	Family of polyunsaturated acids with two or more *cis*-unsaturated centres, separated from each other by one methylene group and having the first unsaturated centre six carbons from the end methyl
PL	Polar lipid (also termed phospholipid)
PUFA	Polyunsaturated fatty acids
SAT	Saturated fatty acids without carbon-carbon unsaturation, e.g., myristic (14:0) and palmitic (16:0) acids
ST	Sterol
TAG	Triacylglycerol, also termed triglyceride
TLC-FID	Thin layer chromatography-flame ionization detection
TMS	Trimethyl silyl (ether derivative)
TSE	Total solvent extract
UN	Unidentified
WE	Wax ester

3. BACKGROUND

The FRDC-funded Fish Oil study (94/115) was completed in December 1997 (Nichols *et al.* 1997). Included in project 94/115 was the examination of liver oils from selected temperate, deep-sea and shallow water sharks and other fishes. Marine oil products (e.g., wax ester based degreasers, squalene, DAGE-rich oils, omega-3 rich tuna oils) have now resulted from aspects of the research. Flesh from fishes from the northwest shelf and Qld waters have been examined for their beneficial omega-3 oil content (Belling *et al.*1997, Evans *et al.* 1986, Fogerty *et al.* 1986, Gibson 1983, Sinclair *et al.* 1983) and during a recently completed wider CSIRO study (FRDC 95/122: "Seafood The Good Food", Nichols *et al.* 1998b&c). However, to our knowledge, only very limited research has been performed on liver oils from selected northern (including subtropical) sharks. The preliminary findings obtained as part of FRDC project 94/115, included the presence of triglyceride-containing omega-3 oils, rather than squalene associated with the deep-sea shark species. Increasing interest in omega-3 oils is occurring nationally. For example, the first Australian omega-3 oils derived from tuna waste are now being commercially manufactured, in part as an outcome of the earlier FRDC-funded research.

The Northern Shark Fishery is currently managed as three separate Commonwealth-State/Territory Joint Authorities across the top end of Australia between 123°45'E and 141°20'E. However, fishing for northern shark species extends down both the WA and Qld coasts. The targeted current annual catch of northern shark is about 1600 tonnes live weight, with the Australian blacktip *Carcharhinus tilstoni* and spot-tail shark *C. sorrah* dominating. The current annual value is about $5 million.

With this background, the CSIRO Marine Research proposed to build on the preliminary northern shark oils research conducted during FRDC project 94/115. Interest has been received from companies and fishers in northern States (WA, NT, Qld) on the liver oil composition of northern shark species. To our knowledge, there is presently no published data on the liver oil content and composition of northern Australian sharks.

Our hypothesis was that the northern oils may contain omega-3 PUFA, together with other valuable fatty acids and constituents. Dependent on their profiles, the oils may be suitable for consideration of commercial exploitation. This pilot project aimed to: characterise liver oils from NT, WA and Qld sharks, including changes with location, season and other factors. The latter would be dependent on appropriate samples being available. The key components to be determined would be the omega-3 oils, with vitamins also examined.

Should this pilot research project indicate potential commercial value of northern Australian shark liver oils, further research could be developed to value-add the oils, as undertaken with FRDC project 94/115 for deep-sea shark and tuna oils. Future research beyond this pilot study should be included as part of, or work in association with projects primarily aiming to assess the shark

stocks in these regions. Any accompanying shark liver oil research would aim to transfer resultant know-how and technologies to industry.

4. NEED

To maximise the return to fishers and other areas of the Australian fishing industry, better use of existing resources is needed. Southern fisheries have recently seen development of several marine oil based products. The potential may exist for a similar approach with northern fisheries, in this case specifically northern Australian sharks.

Presently there is to our knowledge little information available on the oil composition of the livers from northern Australian sharks. A prerequisite therefore in the consideration of the development of possible marine oil products is the characterisation of the oil resource. This pilot project aims to address this key need. The research undertaken aims to assist the fishing industry maximise the return on northern and other shark species at whatever catch levels are determined to be sustainable.

5. OBJECTIVES

The project objectives were unchanged from those submitted in the original proposal.

- Characterise liver oils from northern sharks (NT, WA, Qld), including examining possible changes with location, season and other factors. The key components to be examined will be the omega-3 PUFA and vitamins.
- Provide initial comment on the potential commercial usefulness of the liver oils from northern sharks.

6. METHODS

6.1 Samples

Specimens of livers, flesh, and liver oils from shark were obtained from commercial fishers. For most samples analysed, identifications were provided by fishers and suppliers (Table 1). Some species were identified from photographs supplied by fishers. For most species collected, between 1 to 6 individual specimens were available, from which up to three specimens were randomly selected for analysis. In a few cases, only 1 or 2 individuals were analysed as replicate samples were not available. All tissues were stored at -20^{o}C until analysed. A representative image of a northern shark and liver is shown in Figure 1.

6.2 Sample preparation and analysis

Analytical protocols used were developed for marine oils during previous FRDC-funded projects (91/77 and 94/115) performed by CSIRO Marine Research. Details of all procedures are available in the FRDC final reports, the literature (e.g., Bakes and Nichols 1995; Bakes *et al.* 1995; Nichols *et al.* 1994; Volkman and Nichols 1991) and laboratory manuals. A brief description of the methods follows.

Oil was extracted from replicate specimens (up to n=3 for each species per sampling date) of individual species using the Bligh and Dyer (1959) one-phase methanol:chloroform:water extraction (2:1:0.8 v/v/v) procedure. Samples were extracted overnight and the phases were separated the following day by the addition of chloroform and water (final solvent ratio, 1:1:0.9 v/v/v methanol:chloroform:water). The total solvent extract (TSE) was concentrated (solvents removed *in vacuo*) using rotary evaporation at 40°C. All samples were made up to a known volume in chloroform and stored at -20°C. TSE samples were stored for up to three days before oil analyses were commenced.

For many of the oil-rich (>40% oil, wet weight) samples analysed, it was possible to obtain oil from the shark livers without using the solvent extraction procedure described above. Generally it was possible to obtain the oil in the laboratory by a process involving:

- breaking up the liver using a spatula
- warming the mixture (to approximately 80°C)
- separation by centrifugation.

Using this procedure, it was possible to obtain liver oil free of other tissue material.

An aliquot of the TSE or total oil was analyzed using an Iatroscan MK V TH10 TLC-FID analyzer to determine the abundance of individual oil classes (Volkman and Nichols, 1991). Each replicate TSE sample of individual species was analysed in duplicate using silica gel SIII Chromarods (5 µm particle size). Samples were applied using 1 µL disposable micropipettes. Chromarods were developed in a glass tank lined with pre-extracted filter paper. The solvent system used for the oil separation was hexane-diethyl ether-acetic acid (60:17:0.2 v/v/v), a mobile phase resolving non-polar compounds such as wax esters (WE), triglycerides (TAG), free fatty acids (FFA) and sterols (ST) from polar lipid (PL). A second non-polar solvent system of hexane-diethyl ether (96:4 v/v) was also used for selected samples to resolve hydrocarbons (HC), WE and steryl esters (SE), and TAG and diacylglyceryl ethers (DAGE). After development, the chromarods were oven dried and analyzed immediately to minimize adsorption of atmospheric contaminants. The flame ionization detector (FID) was calibrated for each compound class [e.g., phosphatidylcholine, cholesterol, cholesterol oleate, oleic acid, squalene, TAG and DAGE (purified from fish and deep-sea shark liver oil respectively); 0.1-10 µg range for each oil class]. The relative level of each oil class determined by TLC-FID represents the amount of each class divided by the sum of the individual oil classes. Peaks were quantified on a personal computer using DAPA software (Kalamunda, WA). Iatroscan results are generally reproducible to ±10% or better for individual lipid classes (Volkman and Nichols, 1991; Nichols *et al.* unpublished data).

An aliquot of the TSE was treated with methanol-hydrochloric acid-chloroform under nitrogen (10:1:1 v/v/v; 80ºC, 2 hr) to form fatty acid methyl esters (FAME). Following the addition of water, FAME and free sterols were extracted into hexane/chloroform (4:1 v/v, 3 x 1.5 ml), transferred to vials, reduced under a stream of nitrogen and stored in chloroform. Samples were then treated with N,O-Bis(trimethylsilyl)-trifluoroacetamide (BSTFA) to form TMS derivatives (of free sterols) prior to instrumental analysis.

Gas chromatographic (GC) analyses of FAME and sterols were performed with a Hewlett Packard 5890A GC equipped with an HP-5 cross-linked methyl silicone fused silica capillary column (50 m x 0.32 mm i.d.), an FID, a split/splitless injector and an HP 7673A auto sampler. Hydrogen was the carrier gas. Following addition of methyl tricosanoate and/or methyl nonadecanoate internal standard, samples were injected in splitless mode at an oven temperature of 50°C. After 1 minute, the oven temperature was raised to 150°C at 30°C/min, then to 250°C at 2°C/min and finally to 300°C at 5ºC/min. Peaks were quantified with Millennium Scientific Software (Waters, USA). A previously characterized laboratory FAME standard was routinely run with sample batches to both assist with peak identification and assess GC performance, particularly the response for PUFA.

Verification of the identification of individual components was performed using gas chromatographic-mass spectrometric (GC-MS) data and by comparing retention time data with those obtained for authentic and laboratory standards. GC results are subject to an error of ±5% for individual components. GC-MS analyses were performed on a Thermoquest GCQ GC-MS (Finnigan, USA) fitted with an on-column injector. The GC-MS was operated in scan mode, with an ionizing voltage of 70 eV. The GC was fitted with a column similar to that described above.

6.3 Fatty acid nomenclature

Fatty acids are designated by total number of carbons: number of double bonds, followed by the position of the first double bond (unsaturated centre) from the methyl (ω or n-) end of the molecule. For example, the structure of docosahexaenoic acid (22:6ω3) has 22 carbons, with 6 double bonds, the first double bond being 3 carbons from the methyl end of the molecule. The suffixes c and t indicate *cis* and *trans* geometry. The prefixes i and a indicate iso (2-methyl) and anteiso (3-methyl) branching respectively.

The term omega-3 fatty acid denotes PUFA with two or more *cis*-unsaturated centres, separated from each other by one methylene group and having the first unsaturated centre three carbons from the end methyl. Similarly, omega-6 denotes PUFA with two or more *cis*-unsaturated centres, separated from each other by one methylene group and having the first unsaturated centre six carbons from the end methyl. Further definitions and abbreviations are provided in section 2.

6.4 Vitamins

Vitamin analyses were conducted by the Australian Government Analytical Laboratories (AGAL, Melbourne, Australia) using standard procedures.

7. RESULTS AND DISCUSSION

7.1 Selection of species

Communication with key fishers and State agencies, as undertaken in the formulation of the project proposal, was expanded to include formal requesting of samples. A representative letter sent to fishers, together with the sampling protocol, is appended (Appendix 3). A sampling kit, including specimen bags, labels, esky and blue ice, and sampling and transportation protocols, was sent to all industry contacts. Specimens were obtained from southern WA through northern Australia to northern NSW. A listing of industry contacts together with species supplied (and common and scientific names) is shown in Table 1. For some species, where only regional common names were supplied (with no accompanying photograph) it was not possible to determine the scientific species name. A total of around 100 specimens were obtained from 19 species during the project. Several fishers supplied shark livers on more than one occasion in order to examine possible seasonal changes occurring in liver oil composition. The provision of the same shark species from different regions also provided an opportunity to examine regional differences in liver oil composition.

7.2 Format of results on oil and fatty acid content and composition

The presentation of results in the literature on the oil and fatty acid content and composition of Australian seafoods varies considerably. The uptake of dietary oil depends on the oil class distribution; in many studies to date on Australian seafood, oil class composition including cholesterol has not been reported. The measurement and presentation of the wider range of oil parameters for marine oils is now possible due to developments in methodology and instrumental procedures. The inclusion in this study of additional lipid class parameters is also due to the recognition by nutritionists of the importance of such data to better understand the nutritional content and value of food items.

In this study, results presented for individual species are oil content (percent of wet weight of liver), oil composition including cholesterol (percent of total oil), and fatty acid composition (percent of total fatty acids).

7.3 Oil content

Oil content in the livers obtained from northern Australian sharks ranged from around 10% to 70% (wet weight basis, Table 2). We found that for species with a liver oil content of less than 40%, extraction of the liver using organic solvent (or other suitable processing) was often required. For livers with an oil content greater than 40%, it generally, although not always, was possible to easily obtain the oil in the laboratory by the process developed in this study (section

6.2). Using this procedure, it was possible to obtain liver oil free of other tissue material. Fishers who supplied oils used a variety of procedures. The suitability of, yields achieved, and oil quality obtained for the various methods for oil recovery, would be worthy of discussion between fishers.

Species containing liver oil levels greater than 40% included the following: school, gummy, handle bar, spot tail, milk shark, thick skin, silky, whiskery, tiger, whaler, blacktip (around half the specimens), blacktip/shool and blue sharks (Table 2). Species with less than 40% liver oil content were: blacktip (around half the specimens), hammerhead, white cheek, and pick handle sharks (Table 2).

7.4 Oil class composition

The percentage (relative) abundance of oil classes present in the shark liver oils is shown in Tables 2 to 4. Results obtained for liver oils produced and those supplied by industry are presented in Tables 2 to 4. Three groups of oils were apparent:

1. oils containing triacylglycerol (TAG) as the dominant class (generally >90% of total oil
2. oils containing intermediate levels of TAG (20-75% of total oil)
3. oils containing diacylglyceryl ethers (DAGE) as the major class (>50% of total oil).

Most species analysed in this study were placed in group 1; this group also generally corresponded to the high oil (>40% of liver) group noted in Section 7.3. Group 2 comprised selected specimens of blacktip, hammerhead, and the pick handle shark; this group generally corresponded to the low oil (<40% of liver) group noted in Section 7.3. Group 3 was comprised of one species, tiger shark (Table 4).

Based on these findings, most northern Australian shark species represent good sources of TAG-rich oils. The high levels of TAG are noteworthy, with many samples containing >98% TAG, including those supplied by industry (Tables 2 and 3). TAG is the commonly used form of marine oils in nutraceutical products and aquaculture feeds. TAG is also more stable than the other major fatty acid-containing oil classes (FFA and PL). The higher the level of TAG in the starting oil, the less processing is required to produce value-added products. For example, with tuna and salmon waste oils, considerable levels of FFA, ST and PL may be present (in excess of 10%), and multi-step purification is required of these oils for manufacturers to obtain oils with acceptable specifications. Oil with high levels of these or other impurities require more processing, which is both time-consuming and costly.

Previous interest in Australia in shark liver oils, principally derived from deep-sea species, has centered on the isoprenoid hydrocarbon squalene, and to a lesser extent DAGE. None of the wide range of northern shark species analysed in this study contained squalene, as also shown in our earlier research on school and gummy sharks obtained from temperate waters (Bakes *et al*.

1995, Nichols *et al*. 1998a). The occurrence of squalene-rich livers may be restricted to deep-sea species and the plankton-feeding basking shark.

Sterol levels in the liver oils ranged from below detection (0.0%) up to 6.3%; the mean value was 0.7%. In comparison, the level of ST in crude tuna oil used to manufacture value-added products is around 0.5% (Nichols *et al*. unpublished data, may include some diglyceride). The samples containing the highest levels of sterol were generally those with the lowest oil yield, which also corresponded to those oils containing elevated levels of PL. GC analysis of the transmethylated FAME fraction revealed that cholesterol was the predominant sterol present.

Nutraceutical products containing DAGE are now available in Australia and in other countries. The results obtained during this study on tiger shark liver oil represents, to our knowledge, the first such report for this species. Tiger shark liver oil represents a new source of DAGE available for use by industry. Further information on the fatty acid and glyceryl ether diol (GED, derived from DAGE) composition of tiger shark liver oil is presented in Sections 7.5 and 7.8.

7.5 Fatty acid composition

The fatty acid compositions of liver oils from northern Australian sharks are shown in Tables 5-14. The major fatty acids in most species were: 16:0 (palmitic acid), 18:1ω9c (oleic acid), 22:6ω3 (docosahexaenoic, DHA) and 18:0. Lower levels of 16:1ω7c (palmitoleic acid), 20:5ω3 (eicosapentaenoic acid, EPA), 18:1ω7c (vacennic acid), 14:0 (myristic acid), 20:4ω6 (arachidonic acid, AA) and 22:5ω3 (docosapentaenoic acid, DPA) were also observed.

The sharks examined in this study were separated into two broad groups based on the combined relative level of the two major omega-3 PUFA, EPA and DHA. Group 1 species contained appreciable levels of EPA and DHA in the liver oil (mean level approximately 20%; Tables 7-9 and 12-13; Figure 1). This included whiskery (collected July 1999 from WA), blacktip, hammerhead (with the exception of NSL 41), spot-tail (except NSL 68), blue, whaler, Pacific white, pick handle, milk and handle bar sharks.

The group 2 species contained markedly lower levels of omega-3 PUFA (<5%) in the liver oil, and included blacktip/school, whiskery (collected June 2000 from WA), school and gummy (with the exception of NSL 45), silky, thick skin, pig eye, and tiger sharks. Although containing mainly DAGE, compared with TAG found in the other species examined, liver oil from the tiger shark is included in this second low PUFA-containing group.

As noted above, the fatty acid profile of liver oil from tiger shark was generally similar to that of other low PUFA-containing species. The average combined level of EPA, DHA and other omega-3 PUFA in liver oil from tiger shark was 4.5%. This value is in the range observed for liver oils obtained from DAGE-containing deep-sea species (Bakes *et al*. 1995).

Long-chain polyunsaturated fatty acids (LC-PUFA, C_{20} and C_{22}) have received considerable attention in recent years. In particular, the omega-3 (or n-3) PUFA, are increasingly recognized for their role in the protection against coronary and ischemic heart disease, in the treatment of malaria, arthritis, as treatment for the lowering of blood pressure and reducing hypertension and against other disorders (Kinsella 1986, 1987). Studies on the dietary intake of these fatty acids is ongoing in many laboratories. Omega-3 PUFA have also received interest from aquaculture and related industries, particularly in the rearing of larval fishes and crustaceans (Kanazawa 1985).

These findings have generally enhanced the image of fish as a healthy food for consumers. Capsules of fish oils that contain high levels of the essential PUFA, EPA and DHA, are marketed nationally and internationally (e.g., MaxEPA and related products). There is an increasing body of evidence suggesting that DHA plays an important role in infant development and is active against a range of disorders. Animal studies conducted by the CSIRO Health Sciences and Nutrition and elsewhere have demonstrated that, contrary to popular assumption, DHA rather than EPA is likely to be a principal active omega-3 fatty acid for a wide range of cardiovascular effects, which could all contribute to reduced mortality and improved health. CSIRO Health Sciences and Nutrition has proposed that further research needs to be conducted in this area on Australian DHA-rich oils. Oils rich in DHA would better find ready markets when the greater potency of such oils has been more widely demonstrated in well controlled laboratory and clinical trials.

There has been wide-spread interest in Australia in the importation of omega-3 products, but prior to the commencement of the precursor to this study (FRDC project 94/115), there had been limited development towards the production of an Australian-equivalent omega-3 oil or product. During project 94/115, the high level of DHA in tuna oil was demonstrated, with uptake of this research by Australian industry resulting in DHA-rich products being developed (Nichols *et al.* 1997, see also: www.numegalipids.com.au and www.clovercorp.com.au).

With the above background, an objective of the current project was to provide research to assist Australian industry to develop further marine omega-3 based products, and in the long term to reduce the import of similar products from overseas. The findings of this study on the liver oil composition of northern sharks demonstrate that raw material is available and the potential now exists with the research and industry expertise in Australia for further products to be developed. With the acknowledged additional problem that fish oils from northern hemisphere waters may be contaminated by organochlorines and other deleterious materials, the potential for "clean and green" Australian omega-3 products is further enhanced.

There is increasing local interest in direct use of the lower value or unrefined marine oils for manufacture of new Australian products. Based on a predicted increasing market size and demand for omega-3 oils in nutritional products, the potential exists to add-value to the raw oils that could be manufactured locally. The Australian-derived oils available, including oil from northern sharks, do not match the 18:12 ratio (weight percent) for EPA to DHA found in most

encapsulated products (Figure 1). DHA is generally more abundant than EPA in Australian oils. The ratio of EPA to DHA also varies between species (Figure 1). Similarly, the ratio may also vary based on changes in diet, environment and other factors. In recent times it has been recognized that EPA and DHA play different roles in human nutrition. Therefore precise knowledge of the relative levels of these two essential fatty acids will be important both when targeting oils for further development and as a marketing feature of future Australian products.

The present study showed low levels of EPA and DHA in liver oil from school (*Galeorhinus galeus*) and gummy (*Mustelus antarcticus*) sharks (Table 11). In contrast, oil obtained from the same species collected from Tasmanian waters contained elevated levels of these two essential fatty acids, in particular DHA (Nichols *et al.* 1998a). The reason(s) for the difference in PUFA levels in these two species collected from WA (Table 11) and Tasmanian waters (Nichols *et al*. 1998a) is presently unknown, but may be due to incorrect identification of the WA specimens, or to changes in diet, environment and other factors.

High levels of AA have been previously reported for the flesh of tropical Australian fishes (Belling *et al*. 1997, Evans *et al*. 1986, Fogerty *et al.* 1986, Gibson 1983, Sinclair *et al*. 1983, Nichols *et al*. 1998b&c). Sources of both AA and DHA are needed for adding to infant formula. With unsupplemented bottle feeding, a deficiency of DHA content (up to 50%) exists in erythrocyte lipid, phosphatidylcholine and phosphatidylethanolamine compared to breast-fed infants (Putnam *et al*. 1982; Simopoulos 1989). DHA supplemented (fish oil source) formula-fed infants exhibited a more rapid rate of development of visual acuity compared to control formula-fed babies (Uauy 1990, Uauy *et al*. 1990). It is interesting to note that the AA:EPA:DHA ratio in northern hemisphere fish oil (commonly 0.2:2.1:1.0, Singh and Ward 1997) differs markedly from human milk (2:0.2:1). The high levels of EPA in fish oils from northern hemisphere species may act as an antagonist or an inhibitor of the infant's own endogenous AA synthesis. Therefore infant formula may require AA co-supplementation (Singh and Ward 1997).

Levels of DHA in breast milk also may be elevated by consumption of fresh fish. Of the species examined during FRDC project 95/122, 108 contained in excess of 20% DHA, with 66 containing > 30% DHA (Nichols *et al*. 1998b&c). Australian fish are therefore generally considered excellent sources of DHA. Most species containing high levels of AA also contained >20% DHA. Of the fish that showed elevated levels of both AA and DHA, a smaller group contained lower levels of EPA, with EPA:DHA ratios of 0.4 or less. A ratio of AA:EPA:DHA that is closer to that observed in breast milk (2:0.2:1) was observed for tuskfish (blackspot tuskfish, 0.9:0.3:1; Venus tuskfish, 0.3:0.1:1), yellowspot boarfish (1.1:0.3:1), parrot fish (0.8:0.2:1) and red throat emperor (1:0.2:1) (Nichols *et al*. 1998b&c).

With this background on the occurrence of elevated levels of both DHA and AA in selected tropical fishes, we were interested to determine whether the attractive levels of DHA in the liver oils of northern Australian sharks was accompanied by high levels of AA. AA levels ranged from 0% to 8% (Table 5-14). Shark species containing around 5% AA in their liver oil were:

whiskery (Esperance, July 2000), selected hammerhead specimens, milk, whaler and blacktip (Howard Springs and Townsville).

7.6 Effect of season on oil and fatty acid content and composition

The provision of a limited number of samples of the same species from the same location at different times provided an opportunity to examine seasonal changes in liver oil composition.

For the PUFA-rich oils, levels of the essential PUFA, EPA and DHA varied for liver oils collected on different dates (e.g., hammerhead DHA 13.5% July 1999, 23.3% and 12.9% September 1999, Table 8; blacktip DHA 14.3% and 17.9% July 1999, 12% to 16.8% September 1999, Table 7). From these limited results it can be seen that variation between individual specimens of these two species collected on the same date was similar to any seasonal variations occurring. Similarly, the composition of liver oil from the tiger shark (sampled January 2000 and June 2000, Table 14) showed only small variations. However, between specimen variation may account for most of this.

Liver oil from whiskery shark samples from Esperance WA showed marked variation from two collections (July 1999 and June 2000, Table 6). Oils from June 2000 contained lower levels of EPA and DHA (0-2%) compared with the earlier sampling 1-20%, Table 6). Protein fingerprinting of flesh for one of the July 1999 samples revealed that the sample was almost certainly not a whiskery shark.

Although a wide number of seasonal samples have not been analysed, it is believed to be unlikely that seasonal variation is a major factor in the between sample variation, and will have limited influence for possible commercial operations targeting specific liver oils from northern Australian sharks. The key factor resulting in differences in liver oil composition is most probably species make-up, with sex, size and age also of likely importance.

7.7 Effect of sampling location on oil and fatty acid content and composition

The provision of the same species from different regions provided an opportunity to examine regional differences in liver oil composition.

Liver oil from tiger shark collected from NT and northern NSW was dominated by DAGE, and also showed similar fatty acid and GED profiles (Tables 4, 14 and 15). With the exception of one sample (NSL 41), liver oil from hammerhead shark showed similar lipid class and fatty acid, including PUFA, compositions (Tables 2 and 8). Variation between specimens from the same region was similar to variations observed between regions.

For blacktip shark, considerable variation between regions was observed in PUFA levels for selected liver oil samples. For example, samples from Hervey Bay contained very low levels of PUFA, whereas liver oils from sharks from Townsville and NT showed higher levels (generally >30%). A number of different species are included under the common name blacktip; the differences in oil composition noted for this group are deemed more likely to be due to actual species differences.

As noted for variations observed in oil and fatty acid composition with season, at this stage it is believed to be unlikely that regional variation is the major factor in the between sample variation. Regional differences will have little influence for commercial operations targeting specific liver oils from northern sea sharks. Rather, the key factor resulting in differences in liver oil composition is again most likely to be species make-up, and other factors noted above (section 7.6).

7.8 Glyceryl ether diols (GED, derived from DAGE)

The Iatroscan TLC-FID analyser provides a rapid analysis for measuring DAGE without any sample treatment and derivitization. The transmethylation process used in this study to prepare FAME also converts the DAGE present to the corresponding 1-alkyl glyceryl ether diols (GED). The diols are then extracted with the FAME and converted to di-O-trimethylsilyl (TMS) ethers prior to analysis by GC. GC-MS analysis of the samples readily indentified the GED components from their base peak at m/z = 205.

DAGE were either absent or present as minor constituents in liver oils from most species analysed in this study, with the exception of tiger shark where they accounted for between 57% to 63% of the total oil (Table 4). The major GED (as percentage of the total GED) were: octadec-9-enylglyceryl ether [18:1(n-9)c, 42-52 %], hexa-decylglyceryl ether [16:0, 14-21 %], hexadec-7-enylglyceryl ether [16:1(n-7)c, 8-9 %], octadec-7-enylglyceryl ether [18:1(n-7)c, 3-4 %], octadecylglyceryl ether [18:0, 7-9 %] and tetradecylglyceryl ether [14:0, 1-3 %] (Table 15). A number of other GED were also present as minor components. The distribution of alkyl chains in the GED is generally similar to the fatty acid profiles, with the exception of lower levels of PUFA and $C_{22:1}$.

The GED profile of liver oil from the tiger shark is similar to profiles reported for liver oils from deep-sea sharks (Bakes *et al.* 1995, and references therein). Since the 1960s, there has been suggestions that DAGE are important in the treatment of haematopoiesis and radiation sickness and other disorders (e.g., Blomstrand and Ahrens 1959, Brohult 1962, Brohult *et al.* 1977 and 1986). In the past 5 years, renewed interest in this area has resulted in a number of popular-style books written on this subject (Croft 1998, Pugliese and Heinerman 1999, Solomon *et al.* 1997).

At this time, DAGE derived from liver oils from Australia deep-sea sharks are being marketed both nationally and internationally. The discovery, in this study, of the occurrence of high levels of DAGE in tiger shark liver oil with a similar GED profile to oils found in deep-sea shark livers provides a new potential source of this oil for the local marine oils industry.

7.9 Vitamins

Levels of vitamin A (retinol) and E (α-tocopherol) were determined for seven representative shark liver oil samples collected during the study (Table 16). Analyses were performed by AGAL using standard methods. Vitamin A was in the range 4.3 to 61 mg per 100 g of oil for six of the oils examined (hammerhead, spot tail, whaler, blacktip (2 samples), and tiger sharks). In contrast liver oil from blacktip/school shark contained markedly lower levels of vitamin A, at 0.03 mg per 100 g. Similar results were observed for vitamin E, which was measured at 10 to 45 mg per 100 g in all liver oils except that from blacktip/school shark. Vitamin E was also markedly lower in liver oil from this species, at 0.39 mg per 100 g. Liver oil from the blacktip/school shark contains only very low levels of PUFA (1.4-2%, Table 5), consistent with the low levels of vitamins A and E in this species.

Limited literature is available on the vitamin content of Australian marine oils. In a previous study of liver oils from gummy and school sharks collected from Tasmanian waters, Vitamin A was 6.9 and 14 mg per 100 g respectively, with vitamin E 18 and 8.3 mg per 100 g of oil (Nichols *et al*. 1998). The white-spotted spurdog contained vitamin E at 25 mg per 100 g of oil (Sunarya *et al.* 1996). Thus with the exception of the blacktip/school shark sample, vitamin levels in the liver oils of northern Australian sharks is generally in the range reported for other shark species.

Vitamin E levels in fish oil capsules is generally in the range of 5 to 20 mg per 1 g. Such values are an order of magnitude higher than is naturally present in the liver oils of northern Australian sharks based on our results. For any future processing of liver oils from northern sharks, addition of antioxidants, such as vitamin E, may be needed to ensure product stability.

7.10 Taxonomic considerations

A number of species analysed showed considerable intra-species variation in fatty acid composition (section 7.5 - 7.7). For example, the fatty acid composition of liver oils of whiskery shark collected from Esperance WA in July 1999 and June 2000 differed markedly, with PUFA levels markedly lower in the June 2000 samples. Protein fingerprinting of flesh of one of the July 1999 samples revealed that the sample was almost certainly not a whiskery shark.

Similar differences were also noted for liver oils obtained from blacktip shark. Blacktip shark includes at least three species – *Carcharhinus limbatus* (common blacktip shark), *C. tilstoni* (Australian blacktip shark) and *C. melanopterus* (blacktip reef shark). The levels of PUFA varied markedly across the specimens of blacktip liver oils analysed. Liver oil from samples of *C. limbatus* obtained from Hervey Bay contained markedly lower levels of LC-PUFA (Table 5). Based on these findings, we propose that the two very similar blacktip species, *Carcharhinus limbatus* and *C. tilstoni*, may be distinguished based on their liver oil profiles.

Should industry interest exist for exploiting liver oils derived from northern Australian sharks, the need to clearly identify and separate species will need to be factored into preparation of liver material for processing. Similarly, the need to characterize oil and fatty acid profiles will also exist.

8. BENEFITS

The northern Australian shark livers represent potential new sources of omega-3 PUFA-containing and DAGE-rich oils. The principal benefactors will be the individual companies attempting to exploit the marine oil resources associated with the by-products and by-catch of the Australian Fishing Industry. The community at large will benefit through more efficient use of the resource and reduction in fisheries waste, as well as through the possibility of developing local sources of refined marine oil products. Finally, the Australian economy will benefit should the production of value-added products occur. The study was designed to benefit Australian consumers, seafood marketing authorities, scientists examining the beneficial effects of consumption of seafood and fish oils from marine species, health and medical bodies including nutritionists, and ultimately the wide range of catching sectors of the industry by increased seafood sales in this instance of by-product species.

The responses from all States and other relevant organisations were very positive and supportive of the project, and assistance with obtaining samples was provided by several organisations and many fishers. In addition to this final FRDC report, some of the results of the study have been presented in reports provided directly to industry (Appendix 3). Results were also released in other forums including at national and international scientific presentations and conferences (Appendix 3).

A related and recently completed FRDC-funded project (94/115) worked closely with industry on the development of Australian value-added shark liver oils (Nichols *et al*. 1997). The establishment and appropriate archiving of a database on the oil composition of northern Australian shark species will be of wider benefit to the Australian marine oils industry.

9. FURTHER DEVELOPMENT

Discussions and planning have occurred regarding future stock assessment research on northern sharks as noted in Section 3. Should such research progress, it would be important to take advantage of sampling and observer programs to expand on this pilot study on liver oils derived from northern Australian sharks, including pursuing areas for future research noted below. Further assessment of the fisheries resource, including livers, will be needed.

With aquaculture becoming a larger source of seafood to the domestic market, research and development on alternate non-fish based feeds is underway. Care must be taken to ensure that the increasingly recognised health benefits of seafood, in particular the omega-3 PUFA provided via the marine food-chain, are not compromised. It would be useful to examine the use of northern Australian shark liver oils as possible sources of PUFA-rich TAG for use in aquaculture feeds. The use of the PUFA-rich TAG oils from northern sharks may therefore be

an alternate source of these beneficial oils. Similarly the use of DAGE-rich oils, as found in tiger sharks, in aquaculture feeds is worthy of consideration. Research is recommended in these areas.

The effect of season on the oil composition of northern sharks has been examined for a limited number of species. Further studies to determine both spatial and temporal variation in oil composition of commercial sharks are recommended.

Samples of oils obtained from this project, or obtained from industry, should be sent to national nutraceutical companies to assess interest in their suitability for possible development of omega-3 oil products. At the time of report preparation, selected oils have been sent to one company, with initial positive feedback obtained.

Screening of shark liver oils obtained during this study for a range of bioactivities (e.g., anti-inflammatory, anti-cancer, antibacterial, other) would also be a particularly useful avenue to pursue.

10. CONCLUSION

Liver oil profiles have been obtained for 19 species of northern Australian sharks during this pilot study. The profiles indicate new sources are available for omega-3 PUFA and DAGE containing oils. These two types of oils have been manufactured in recent years in Australia from by-catch and potential by-products of other fisheries. The scope may exist to utilize the northern shark fishery as potential new sources for these two valuable and increasingly sought-after oils.

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Figure 1. Representative image of northern Australian shark specimen and liver. Image supplied by Keith Harris.

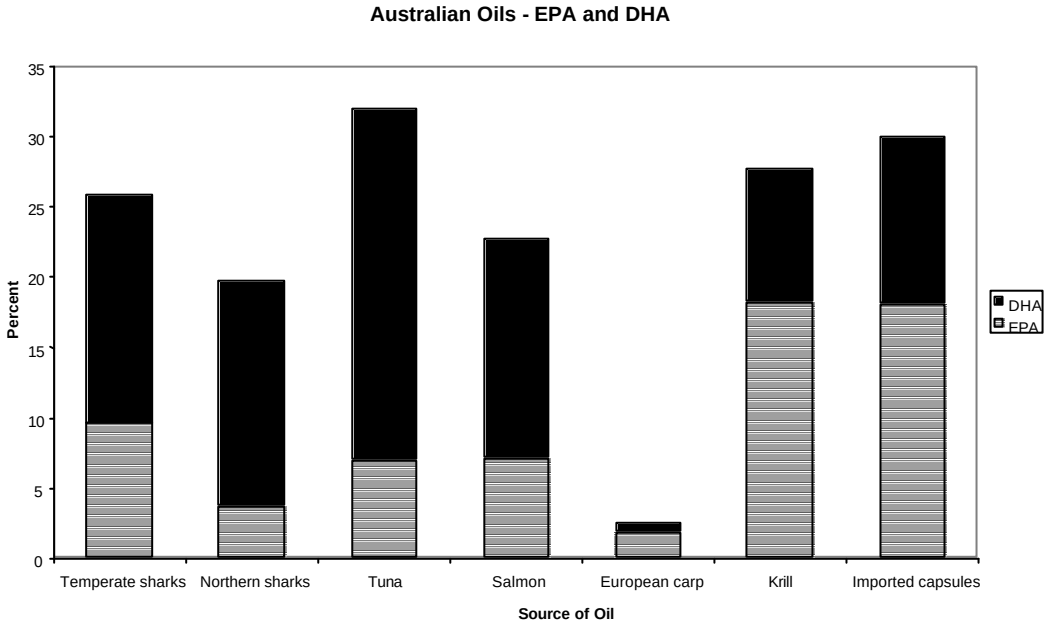

Figure 2. EPA and DHA composition (as % of total fatty acids) of selected oils from Australian species and imported fish oil capsules. Northern Australian shark data represents mean data for 41 specimens shown in Tables 7-9 and 12-13.

Table 1. Sample location details and suppliers for Northern Australian shark livers

Species	Scientific name	Sample	Replicates (n)	Location	Date collected	Supplier
Whiskery	*Furgaleus macki*	NSL 2-6	3	Esperance, WA	1-Jul-99	Lee Warner
School shark	*Galeorhinus galeus*	NSL 42-44	3	"	26-Jun-00	"
Gummy shark	*Mustelus antarcticus*	NSL 45-47	3	"	"	"
Whiskery	*Furgaleus macki*	NSL 48-50	3	"	"	"
White cheek	*Carcharhinus dussumieri*	NSL 7	1	Townsville, Qld	27-Jul-99	John Ling
Spot-tail	*Carcharhinus sorrah*	NSL 9	1	"	"	"
Australian blacktip	*Carcharhinus tilstoni*	NSL 11-12	2	"	"	"
Scalloped hammerhead	*Sphyrna lewini*	NSL 15	1	"	"	"
Spot-tail	*Carcharhinus sorrah*	NSL 22,24	2	"	26-Sep-99	"
Scalloped hammerhead	*Sphyrna lewini*	NSL 25-26	2	"	"	"
Australian blacktip	*Carcharhinus tilstoni*	NSL 27,28,30	3	"	"	"
Blue	*Prionace glauca*	NSL 18	1	Cairns, Qld	25-Aug-99	Kit Phua
Whaler		NSL 19	1	"	"	"
Whaler		NSL 20	1	"	"	"
Pacific white tip		NSL 21	1	"	"	"
Australian blacktip	*Carcharhinus limbatus*	NSL 33	1	Hervey Bay, Qld	30-Oct-99	Keith Harris
Scalloped hammerhead	*Sphyrna lewini*	NSL 34-35	2	"	"	"
Weasel	*Hemigaleus microstoma*	NSL 37	1	"	"	"
Blacktip/school	*C. limbatus/C. tilstoni*	NSL 38-40	3	"	"	"
Scalloped hammerhead	*Sphyrna lewini*	NSL 41	1	"	"	"
Tiger	*Galeocerdo cuvier*	NSL 51	1	South Headland, WA	15-Jul-00	Paul Hayler
Silky	*Carcharhinus falciformis*	NSL 52-54	3	"	"	"
Thick skin	*Carcharhinus plumbeus*	NSL 55-56	3	"	"	"
Unidentified		NSL 58	1	"	"	"
Pig eye	*Carcharhinus amboinensis*	NSL 60-61	2	"	"	"
Milk shark	*Rhizoprionodon acutus*	NSL 62-63	2	Howard Springs, NT	10-Oct-00	Rob Ladlow
Whaler		NSL 64-65	2	"	"	"
Spot-tail	*Carcharhinus sorrah*	NSL 68-69	2	"	"	"
Australian blacktip	*Carcharhinus tilstoni*	NSL 70-71	2	"	"	"
Scalloped hammerhead	*Sphyrna lewini*	NSL 74-75	2	"	"	"
Handle bar		NSL 76-77	2	"	"	"
Scalloped hammerhead	*Sphyrna lewini*	NSO 1	1	Esperance, WA	1-Jul-99	Lee Warner
Scalloped hammerhead	*Sphyrna lewini*	NSO 2	1	Townsville, Qld	27-Jul-99	John Ling
Australian blacktip	*Carcharhinus tilstoni*	NSO 3	1	"	"	"
Blacktip	*Carcharhinus spp.*	NSO 14,15, 17-20	6	"	20-Sep-99	"
Scalloped hammerhead	*Sphyrna lewini*	NSO 16	1	"	"	"

Tiger shark	*Galeocerdo cuvier*	NSO 21,23	2	Ballina, NSW	15-Jan-00	David Woods
Whaler		NSO 22	2	"	22-Mar-00	"

Species identifications were provided by fishers, with some species identified from photographs supplied by fishers (Hervey Bay samples). Where the scientific name is not shown, species identification requires confirmation.

Table 2. Lipid class composition of liver oils from northern Australian sharks

Species	Sample	Location	Date collected	Percentage composition								Oil yield
				HC	WE	DAGE	TAG	FFA	Other	ST	PL	(%,ww)
Blacktip/school	NSL 38	Hervey Bay, QLD	30-Oct-99	0.0	0.0	0.0	99.5	0.0	0.0	0.0	0.5	71
	NSL 39	"	"	0.0	0.0	0.0	99.2	0.0	0.0	0.4	0.5	70
	NSL 40	"	"	0.0	0.4	0.0	91.4	3.6	0.0	1.1	3.6	68
Blacktip	NSL 11#	Townsville, QLD	27-Jul-99	0.0	0.2	0.0	97.9	0.7	0.6	0.3	0.3	18
	NSL 12	"	"	0.0	0.2	0.0	97.7	0.8	0.0	0.9	0.3	56
	NSL 27	"	29-Sep-99	0.0	0.3	0.0	98.3	0.7	0.0	0.4	0.2	63
	NSL 28#	"	"	0.0	0.1	0.0	92.6	0.6	0.0	0.8	6.0	n/a
	NSL 30	"	"	0.0	2.8	0.0	96.1	0.4	0.0	0.6	0.1	34
	NSL 33#	"	30-Oct-99	0.0	2.3	0.0	70.8	6.6	0.0	1.2	19.2	12
	NSL 70#	Howard Springs, NT	10-Oct-00	0.0	0.9	0.0	96.2	0.0	0.0	0.4	2.5	28
	NSL 71#	"	"	0.0	3.8	0.0	77.4	3.3	0.0	2.1	13.4	11
Whiskery	NSL 2	Esperance, WA	1-Jul-99	0.0	0.1	0.0	98.9	0.2	0.2	0.1	0.5	61
	NSL 3	"	"	0.0	0.1	0.0	98.8	0.3	0.3	0.2	0.3	57
	NSL 6	"	"	0.0	0.2	0.0	99.1	0.1	0.0	0.4	0.1	63
	NSL 48	"	26-Jun-00	0.0	0.0	0.0	94.7	3.3	0.2	1.2	0.6	37
	NSL 49	"	"	0.0	0.0	0.0	98.7	0.7	0.3	0.2	0.2	60
	NSL 50	"	"	0.0	0.0	0.0	96.5	1.6	0.6	0.3	0.8	33
Scalloped hammerhead	NSL 15	Townsville, QLD	27-Jul-99	0.0	0.1	0.0	98.5	0.4	0.0	0.4	0.6	43
	NSL 25	"	26-Sep-99	0.0	0.9	0.0	98.4	0.3	0.0	0.3	0.1	30
	NSL 26#	"	"	0.0	1.5	0.0	64.4	2.9	0.0	1.7	29.5	9
	NSL 34#	Harvey Bay, QLD	30-Oct-99	0.0	3.6	0.0	75.1	0.9	0.0	0.7	19.7	14
	NSL 35#	"	"	0.0	6.9	0.0	70.0	2.3	0.0	1.7	19.0	12
	NSL 41#	"	"	0.0	0.0	0.0	98.9	0.5	0.0	0.3	0.3	26
	NSL 74#	Howard Springs, NT	10-Oct-00	3.7	1.9	0.0	65.8	14.8	0.0	3.7	10.0	10
	NSL 75#	"	"	0.0	1.7	0.0	91.1	0.6	0.0	0.7	5.8	21
White cheek	NSL 7#	Townsville, QLD	27-Jul-99	0.0	0.5	0.0	90.6	4.5	0.0	2.0	2.4	15
Spot-tail	NSL 9#	"	"	0.0	0.4	0.0	94.5	1.5	0.0	1.7	1.9	39
Blue	NSL 18	Cairns, QLD	25-Aug-99	0.0	4.6	0.5	93.6	0.5	0.0	0.4	0.4	43
Whaler	NSL 19#	"	"	0.0	3.0	0.0	89.2	4.0	0.0	1.4	2.4	56
Whaler	NSL 20	"	"	0.0	0.1	0.0	99.4	0.1	0.0	0.3	0.2	32
Pacific white tip	NSL 21	"	"	0.0	0.3	0.4	97.7	0.0	0.0	0.8	0.8	40
Spot-tail	NSL 22	Townsville, QLD	26-Sep-99	0.0	0.6	0.0	97.3	0.6	0.0	0.5	1.0	54
Spot-tail	NSL 24#	"	"	0.0	1.0	0.0	91.8	0.8	0.0	0.7	5.6	33
Weasel	NSL 37#	Harvey Bay, QLD	30-Oct-99	0.0	1.9	0.0	23.0	18.6	0.0	6.3	50.3	9
Silky	NSL 52	South Headland, WA	15-Jul-00	0.0	0.0	0.0	98.5	0.6	0.0	0.0	0.9	59
	NSL 53	"	"	0.0	0.0	0.0	98.9	0.5	0.0	0.2	0.4	74
	NSL 54	"	"	0.0	0.0	0.0	98.7	0.6	0.0	0.2	0.4	73

Table 2 (continued). Lipid class composition of liver oils from northern Australian sharks

Species	Sample	Location	Date collected	Percentage composition								Oil yield
				HC	WE	DAGE	TAG	FFA	Other	ST	PL	(%,ww)
Thick skin	NSL 55	"	15-Jul-00	0.0	0.0	0.0	98.9	0.5	0.0	0.3	0.3	46
	NSL 56	"	"	0.0	0.0	0.0	98.4	0.7	0.0	0.4	0.5	47
	NSL 58*	"	"	0.0	0.0	0.0	98.8	0.5	0.0	0.3	0.4	64
Pig eye	NSL 60	"	15-Jul-00	0.0	3.2	0.0	89.3	1.9	2.2	2.0	1.4	26
	NSL 61	"	"	0.0	0.0	0.0	99.3	0.5	0.0	0.0	0.3	64
School Shark	NSL 42	Esperance, WA	26-Jun-00	0.0	0.0	0.0	97.5	1.2	0.6	0.2	0.5	46
	NSL 43	"	"	0.0	0.0	0.0	99.6	0.0	0.0	0.0	0.4	68
	NSL 44	"	"	0.0	0.0	0.0	96.3	1.5	0.5	0.4	1.3	43
Gummy Shark	NSL 45	"	26-Jun-00	0.0	0.0	0.0	99.6	0.0	0.0	0.0	0.4	53
	NSL 46	"	"	0.0	0.0	0.0	98.1	0.5	0.0	0.6	0.8	46
	NSL 47	"	"	0.0	0.0	0.0	98.3	0.8	0.3	0.3	0.3	61
Milk shark	NSL 62#	Howard Springs, NT	10-Oct-00	0.0	0.6	0.0	96.3	0.8	0.0	0.3	1.9	58
	NSL 63#	"	"	2.2	0.9	0.0	95.0	1.0	0.0	0.5	0.4	61
Whaler	NSL 64	"	10-Oct-00	1.6	0.7	0.0	95.8	0.3	0.0	0.5	1.0	34
	NSL 65	"	"	0.0	0.8	0.0	98.1	0.0	0.0	0.3	0.8	59
Spot-tail	NSL 68	"	10-Oct-00	0.0	0.0	0.4	98.6	0.0	0.0	0.4	0.5	46
	NSL 69	"	"	0.0	0.6	0.5	98.1	0.0	0.0	0.0	0.8	52
Handle bar	NSL 76	"	10-Oct-00	0.0	3.5	0.0	95.2	0.1	0.0	0.3	0.9	46
	NSL 77	"	"	0.0	0.0	0.0	97.8	1.2	0.0	0.1	0.9	55

ww denotes wet weight of liver; * NSL 58 unidentified; # denotes extracted using Bligh and Dyer (1959) method, all other samples obtained by blending, heating and separation of oil. Abbreviations: HC, hydrocarbon; WE, wax ester; DAGE, diacylglycerol ether; TAG, triacylglycerol; other, includes diacylglycerol; ST, sterol; PL, polar lipid; n/a, not available..

Table 3. Lipid class composition of liver oils from Northern Australian sharks - oils supplied by fishers.

Species	Sample	Location	Date collected	Percentage composition							
				HC	WE	DAGE	TAG	FFA	Other	ST	PL
Hammerhead	NSO 1	Esperance, WA	01-Jul-99	0.0	0.0	0.0	98.0	0.7	0.0	0.9	0.3
Hammerhead	NSO 2	Townsville, QLD	"	0.0	0.0	0.0	98.0	0.7	0.0	0.9	0.3
Blacktip	NSO 3	"	"	0.0	0.0	0.0	99.2	0.0	0.2	0.2	0.4
Blacktip	NSO 14	"	20-Sep-99	0.0	0.4	0.0	97.8	0.8	0.0	0.0	0.9
Blacktip	NSO 15	"	"	0.0	0.0	0.0	99.5	0.0	0.0	0.0	0.5
Hammerhead	NSO 16	"	"	0.0	0.0	0.0	99.3	0.0	0.0	0.0	0.7
Blacktip	NSO 17	"	"	0.0	0.0	0.0	99.4	0.0	0.0	0.0	0.6
Blacktip	NSO 18	"	"	0.0	0.0	0.0	99.5	0.0	0.0	0.0	0.5
Blacktip	NSO 19	"	"	0.0	0.0	0.0	98.8	0.0	0.0	0.0	1.2
Blacktip	NSO 20	"	"	0.0	0.0	0.0	98.8	0.0	0.0	0.0	1.2
Whaler	NSO 22	Ballina, NSW	22-Mar-00	1.8	0.0	0.0	97.2	0.0	0.0	0.0	1.0

HC, hydrocarbon; WE, wax ester; DAGE, diacylglycerol ether; TAG, triacylglycerol; other, includes diacylglycerol; ST, sterol; PL, polar lipid.

Table 4. Lipid class composition of liver oils from tiger sharks

Species	Sample	Location	Date collected	Percentage composition							
				HC	WE	DAGE	TAG	FFA	Other	ST	PL
Tiger	NSL 51	South Headland, WA	15-Jul-00	0.0	0.0	63.4	35.5	0.7	0.0	0.0	0.4
Tiger	NSO 21	Ballina, NSW	22-Mar-00	0.0	0.0	59.6	40.4	0.0	0.0	0.0	0.0
Tiger	NSO 23	Ballina, NSW	31-May-00	0.0	0.0	57.0	29.6	0.0	0.0	0.0	13.4

Abbreviations as for Table 3.

Table 5. Fatty acid composition of blacktip/school (*C. tilstoni/C. limbatus*) shark liver oils, Harvey Bay, QLD

	Percentage composition		
Fatty acid	NSL 38	NSL 39	NSL 40
14:0	1.0	0.9	1.2
15:0	0.3	0.3	0.3
16:1ω9	0.0	0.0	0.0
16:1ω7	27.2	25.9	24.5
16:1ω7t	0.2	0.1	0.0
16:0	33.4	33.8	37.3
i17:0	0.0	0.0	0.0
a17:0	0.7	0.7	0.6
17:1	1.2	1.1	0.9
17:0	0.4	0.5	0.5
18:4ω3	1.1	1.2	1.3
i18:0	0.3	0.3	0.4
18:2ω6	0.0	0.0	0.0
18:1w9	26.2	27.0	25.0
18:1ω7c	1.3	1.1	1.2
18:0	4.7	5.2	5.0
20:4ω6	0.0	0.0	0.0
20:5ω3	0.3	0.3	0.3
20:4ω3	0.0	0.0	0.0
20:2ω6	0.0	0.1	0.3
20:1ω11	0.3	0.1	0.0
20:1ω9	0.1	0.1	0.1
20:0	0.1	0.2	0.1
22:5ω6	0.0	0.0	0.0
22:6ω3	0.0	0.1	0.0
22:4ω6	0.0	0.0	0.0
22:5ω3	0.0	0.0	0.0
22:1ω9	0.2	0.2	0.3
24:1	0.0	0.0	0.0
24:0	0.1	0.4	0.2
Other	0.5	0.4	0.5
Total	100.0	100.0	100.0
Sum SAT	41.4	42.4	45.8
Sum MUFA	57.2	55.8	52.3
Sum PUFA	1.4	1.8	2.0
Sum ω3 PUFA	1.4	1.6	1.7
Sum ω6 PUFA	0.0	0.1	0.3
Ratio ω3/ω6	>100	11.1	5.8

Other: 12:0, 14:1, i15:0, a15:0, i16:0, 16:1ω5, 18:1ω5, 19:1, 20:1ω5, C21&23PUFA, 22:3ω3, 22:0

Table 6. Fatty acid composition of whiskery shark liver oils, Esperance, WA

	Percentage composition					
	collection 1-Jul-99			collection 26-June-00		
Fatty acid	NSL 2	NSL 3	NSL 6	NSL48	NSL49	NSL50
14:0	1.7	1.4	2.1	2.5	2.4	1.3
15:0	0.6	0.5	0.6	0.8	0.6	0.7
16:1ω9	0.4	0.4	0.5	0.5	0.4	0.3
16:1ω7	5.9	9.6	10.9	10.0	12.5	4.8
16:0	21.1	21.8	27.4	31.8	34.7	36.0
i&a17:0	0.5	0.5	0.5	0.9	0.6	1.3
17:1	1.0	0.9	1.1	1.5	1.1	1.0
17:0	1.4	1.1	1.3	2.1	1.4	3.4
18:3ω6	0.0	0.0	0.1	0.5	0.8	1.2
18:4ω3	0.6	0.5	0.3	0.5	0.2	0.6
18:3ω3	0.1	0.1	0.7	0.6	0.5	0.6
18:2ω6	0.7	0.6	0.0	0.0	0.0	0.0
18:1ω9	17.3	21.0	23.5	22.9	25.5	19.9
18:1ω7c	3.7	3.3	3.7	5.4	4.1	5.0
18:0	4.4	3.8	4.8	6.9	6.0	12.6
20:4ω6	7.0	6.0	3.8	1.5	1.0	0.0
20:5ω3	6.4	6.1	3.1	0.8	0.3	0.0
20:4ω3	0.5	0.3	0.2	1.2	1.6	4.5
20:2ω6	0.8	0.6	0.8	0.7	0.4	0.4
20:1ω11/ω9/ω7	3.4	2.9	3.2	4.5	3.1	4.9
20:0	0.2	0.2	0.2	0.2	0.2	0.3
22:5ω6	0.7	0.6	0.3	0.0	0.0	0.0
22:6ω3	13.9	12.1	5.9	0.8	0.1	0.0
22:4ω6	2.2	1.5	1.0	0.4	0.3	0.0
22:5ω3	2.9	2.1	1.1	0.3	0.1	0.0
22:3ω3	0.2	0.2	0.2	0.2	0.2	0.0
22:1ω11/ω9	0.5	0.5	1.1	0.9	0.5	0.7
24:1	0.2	0.2	0.5	0.4	0.2	0.3
Other	1.7	1.5	1.1	1.6	1.2	0.2
Total	100.0	100.0	100.0	100.0	100.0	100.0
Sum SAT	30.1	29.4	37.1	45.3	46.1	55.5
Sum MUFA	33.2	39.6	45.2	47.1	48.4	37.1
Sum PUFA	36.6	31.0	17.7	7.6	5.4	7.4
Sum ω3 PUFA	24.6	21.3	11.4	4.5	3.0	5.7
Sum ω6 PUFA	11.8	9.5	6.2	3.2	2.5	1.6
Ratio ω3/ω6	2.1	2.3	1.9	1.4	1.2	3.5

Other:12:0,14:1,i&a15:0,i16:0,16:1ω5,18:1ω5,19:1,20:1ω5,20:3ω6,C21&23PUFA, 22:3ω3, 22:0

Table 7. Fatty acid composition of Australian blacktip shark livers, Townsville (NSL 11-30) and Hervey Bay (NSL33), QLD

	Percentage composition					
Fatty acid	NSL 11	NSL 12	NSL 27	NSL 28	NSL 30	NSL 33
14:0	3.5	2.4	3.0	4.4	4.3	2.3
15:0	1.3	0.9	1.1	1.2	1.8	1.0
16:1ω9	0.3	0.2	0.3	0.3	0.3	0.3
16:1ω7	5.7	5.9	6.8	4.6	5.8	2.8
16:0	24.2	26.7	23.5	25.4	23.5	19.9
i17:0	0.6	0.4	0.5	0.5	0.5	0.5
a17:0	0.4	0.2	0.2	0.3	0.4	0.3
17:1	0.5	0.4	0.8	0.4	0.8	0.5
17:0	1.8	1.4	1.3	1.7	1.7	1.7
18:3ω6	0.1	0.1	0.1	0.0	0.2	0.9
18:4ω3	0.7	0.6	0.3	0.3	0.6	0.3
18:3ω3	0.2	0.1	1.2	1.3	1.3	1.0
18:2ω6	1.1	1.1	0.0	0.0	0.0	0.0
18:1ω9	11.0	10.5	13.7	12.2	11.0	8.5
18:1ω7c	3.7	4.8	3.5	4.0	3.9	3.7
18:0	8.8	7.8	7.1	9.8	9.0	11.4
20:4ω6	3.9	3.5	3.8	3.8	4.2	4.5
20:5ω3	5.3	5.2	4.9	3.5	4.8	4.1
20:3ω6	0.3	0.2	0.2	0.3	0.3	0.3
20:4ω3	0.6	0.4	0.5	0.5	0.5	0.6
20:2ω6	0.4	0.3	0.4	0.4	0.4	0.4
20:1ω11	0.7	0.2	0.4	0.5	0.6	0.0
20:1ω9	0.8	0.8	0.7	1.0	0.8	2.1
20:1ω7	0.4	0.3	0.2	0.4	0.4	0.3
20:0	0.4	0.2	0.3	0.3	0.3	0.6
22:5ω6	1.9	2.3	2.1	2.6	2.4	1.7
22:6ω3	14.3	17.9	16.3	13.3	12.0	16.8
22:4ω6	1.6	1.0	1.3	1.8	2.1	1.7
22:5ω3	2.3	2.1	2.5	2.4	2.6	2.8
22:1ω11	0.1	0.0	0.0	0.0	0.1	4.7
22:1ω9	0.1	0.1	0.2	0.2	0.1	1.0
24:1	0.2	0.1	0.2	0.2	0.2	0.4
24:0	0.1	0.0	0.1	0.2	0.1	0.2
Other	2.7	1.8	2.2	2.0	2.9	2.6
Total	100.0	100.0	100.0	100.0	100.0	100.0
Sum SAT	41.4	40.4	37.6	44.2	42.1	38.4
Sum MUFA	25.1	24.4	28.3	25.1	25.8	26.0
Sum PUFA	33.4	35.2	34.2	30.7	32.1	35.6
Sum ω3 PUFA	23.4	26.3	25.8	21.3	21.8	25.6
Sum ω6 PUFA	9.3	8.6	7.9	8.9	9.7	9.4
Ratio ω3/ω6	2.5	3.1	3.3	2.4	2.2	2.7

Other: 12:0,14:1,i&a15:0,i16:0,16:1ω5,18:1ω5,19:1,20:1ω5,C21&23PUFA, 22:3ω3, 22:0

Table 8. Fatty acid composition of hammerhead shark livers, Townsville and Mooloolaba, QLD and NT

	Percentage Composition							
	Townsville			Mooloolaba			Nth Territory	
Fatty acid	NSL 15	NSL 25	NSL 26	NSL 34	NSL 35	NSL 41	NSL 74	NSL 75
14:0	3.3	2.7	1.7	1.6	1.9	1.1	0.9	2.1
15:0	1.1	1.5	0.8	0.8	0.8	0.3	0.5	1.4
16:1ω9	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2
16:1ω7	6.7	3.9	3.7	2.7	4.8	21.8	2.1	4.5
16:0	31.2	24.7	22.5	23.3	23.7	34.8	22.1	26.1
i17:0	0.4	0.4	0.7	0.7	0.9	0.1	0.7	0.8
a17:0	0.2	0.2	0.4	0.4	0.5	0.4	0.6	0.4
17:1	0.4	0.6	0.5	0.4	0.4	0.7	0.3	0.6
17:0	1.8	1.6	2.1	1.9	1.8	0.5	1.8	2.3
18:3ω6	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1
18:4ω3	0.4	0.3	0.3	0.3	0.5	1.8	0.0	0.2
i18:0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
18:2ω6	1.1	1.1	0.7	1.3	1.1	0.1	0.6	1.0
18:3ω3	0.0	0.0	0.4	0.0	0.0	0.0	0.2	0.0
18:1ω9	10.8	8.6	9.6	7.4	10.0	23.7	9.6	5.9
18:1ω7c	4.9	4.7	6.8	6.3	6.1	2.5	7.4	5.6
18:0	8.3	7.0	12.5	10.9	10.8	5.9	12.5	10.8
20:4ω6	3.1	3.6	5.8	5.0	4.3	0.3	5.7	4.8
20:5ω3	4.4	4.4	2.9	2.7	1.9	0.3	1.7	3.2
20:3ω6	0.2	0.2	0.3	0.2	0.3	0.0	0.3	0.3
20:4ω3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3
20:2ω6	0.3	0.4	0.8	0.8	0.8	0.3	0.7	0.4
20:1ω11	0.2	0.0	0.0	0.6	1.1	0.0	0.4	1.0
20:1ω9	0.6	0.9	1.9	1.4	1.3	0.7	1.9	0.5
20:1ω7	0.0	0.2	0.4	0.3	0.4	0.0	0.3	0.4
20:0	0.2	0.2	0.3	0.3	0.4	0.3	0.2	0.3
22:5ω6	1.8	3.1	1.9	3.5	2.9	0.2	3.9	3.3
22:6ω3	13.5	23.3	12.9	17.8	13.3	1.0	14.0	14.7
22:4ω6	0.7	1.2	2.8	2.9	3.1	0.1	5.1	2.6
22:5ω3	1.5	2.2	4.0	3.6	3.7	0.2	4.0	3.2
22:1ω11	0.0	0.0	0.3	0.1	0.1	0.0	0.0	0.1
22:1ω9	0.1	0.1	0.1	0.2	0.2	0.4	0.2	0.1
24:1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.2
24:0	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.2
Other	2.0	1.8	1.9	1.9	2.1	1.1	1.3	2.5
Total	100.0	100	100.0	100.0	100.0	100.0	100.0	100.0
Sum SAT	46.8	38.4	41.6	40.4	41.3	44.8	39.7	44.8
Sum MUFA	25.1	19.8	23.9	20.0	25.1	49.7	23.0	19.5
Sum PUFA	27.7	40.4	34.0	39.2	33.2	4.7	37.0	35.1
Sum ω3 PUFA	20.2	30.5	21.0	24.6	19.8	3.8	20.1	21.5
Sum ω6 PUFA	7.2	9.6	12.5	13.9	12.5	0.9	16.3	12.7
Ratio ω3/ω6	2.8	3.2	1.7	1.8	1.6	4.0	1.2	1.7

Other: 12:0, 14:1, i&a15:0, i16:0, 16:1ω5, 18:1ω5, 19:1, 20:1ω5, C21&CPUFA, 22:3ω3, 22:0

Table 9. Fatty acid composition of shark livers from the Townsville and Cairns regions, QLD

	Percentage composition									
Fatty acid	NSL 7	NSL 9	NSL18a	NSL18b	NSL 19	NSL 20	NSL 21	NSL 22	NSL 24	NSL 37
14:0	3.1	2.9	3.2	3.8	3.4	2.5	2.5	3.5	3.0	2.5
15:0	1.2	1.2	0.8	1.0	1.1	0.8	1.1	1.2	1.2	0.7
16:1ω9	0.3	0.2	0.6	0.6	0.4	0.5	0.4	0.3	0.2	0.2
16:1ω7	4.8	4.6	3.0	3.1	3.5	4.2	5.2	5.2	5.3	2.1
16:0	24.9	25.4	18.3	19.3	24.8	22.0	25.8	23.3	25.4	20.3
i17:0	0.6	0.8	0.2	0.2	0.2	0.3	0.2	0.4	0.7	0.4
a17:0	0.3	0.4	0.4	0.4	0.3	0.2	0.5	0.2	0.4	0.2
17:1	0.6	0.5	0.6	0.6	0.5	0.7	1.1	0.5	0.5	0.3
17:0	1.8	1.8	0.9	1.0	1.5	0.9	1.8	1.5	1.7	2.6
18:3ω6	0.1	0.0	0.0	0.0	0.2	0.0	0.1	0.2	0.1	0.2
18:4ω3	0.5	0.5	0.4	0.4	0.7	0.5	0.2	0.4	0.3	0.2
18:3ω3	0.2	0.2	0.5	0.6	1.6	0.9	1.0	1.6	1.1	0.6
18:2ω6	1.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18:1ω9	12.2	8.3	14.0	13.7	11.7	30.3	18.8	10.4	8.0	4.9
18:1ω7c	3.5	3.9	2.7	2.7	3.2	3.8	3.0	3.4	4.0	3.5
18:0	9.2	9.7	5.0	4.7	7.9	5.9	6.8	7.5	8.2	16.7
20:4ω6	4.0	3.6	4.2	4.0	2.9	1.9	2.4	4.1	4.2	7.9
20:5ω3	3.1	3.2	4.4	4.6	3.1	1.9	3.2	4.2	3.4	6.6
20:3ω6	0.3	0.2	0.2	0.2	0.5	0.2	0.1	0.3	0.3	0.2
20:4ω3	0.5	0.3	0.4	0.5	0.8	0.7	0.4	0.6	0.3	0.2
20:2ω6	0.4	0.4	0.8	0.7	0.5	0.5	0.3	0.4	0.4	1.0
20:1ω11	0.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
20:1ω9	0.9	0.7	7.2	6.7	3.3	7.1	2.1	1.0	0.7	3.0
20:1ω7	0.3	0.4	0.4	0.4	0.2	0.4	0.1	0.2	0.4	0.2
20:0	0.4	0.4	0.3	0.2	0.3	0.2	0.2	0.2	0.3	0.2
22:5ω6	3.0	3.8	2.6	2.5	2.9	1.0	2.5	2.5	3.5	1.1
22:6ω3	13.8	15.4	20.8	20.2	17.2	6.7	15.7	19.5	16.3	15.7
22:4ω6	2.1	2.7	1.7	1.7	2.3	0.9	0.6	1.7	2.6	2.3
22:5ω3	2.9	3.2	2.4	2.4	2.5	1.6	1.5	3.6	3.2	2.7
22:1ω11	0.1	0.1	0.6	0.6	0.2	1.2	0.3	0.0	0.1	0.4
22:1ω9	0.1	0.1	1.3	1.1	0.4	0.8	0.2	0.1	0.2	0.6
24:1	0.4	0.4	0.8	0.8	0.4	0.7	0.3	0.2	0.3	0.3
24:0	0.2	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.1
Other	2.6	2.6	1.3	1.3	1.5	0.7	1.5	1.9	2.6	2.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sum SAT	42.1	43.3	29.1	30.5	39.9	32.8	39.2	38.2	41.6	44.1
Sum MUFA	25.4	21.5	32.2	31.4	24.8	50.3	32.6	22.6	21.8	16.5
Sum PUFA	32.6	35.2	38.7	37.9	35.3	16.9	28.2	39.2	36.5	39.4
Sum ω3 PUFA	20.9	22.8	29.0	28.7	25.8	12.4	22.0	29.8	24.6	26.1
Sum ω6 PUFA	10.9	11.7	9.5	9.1	9.3	4.5	6.1	9.1	11.2	12.6
Ratio ω3/ω6	1.9	1.9	3.1	3.2	2.8	2.7	3.6	3.3	2.2	2.1

* 7, white cheek; 9,22,24, spot-tail;18, blue; 19, whaler; 20, whaler; 21, Pacific white; 37, pick handle.
Other: 12:0,14:1,i&a15:0,i16:0,16:1ω5,18:1ω5,19:1,20:1ω5,C21&23PUFA,22:3ω3,22:0

Table 10. Fatty acid composition of shark liver oils from South Headland, WA

	Percentage composition							
Fatty acid	Silky NSL52	Silky NSL53	Silky NSL54	Thick skin NSL55	Thick skin NSL56	Unid* NSL58	Pig eye NSL60	Pig eye NSL61
14:0	1.3	6.1	6.4	3.7	2.9	4.0	3.8	3.9
15:0	0.0	0.7	0.9	1.3	1.1	1.3	1.1	1.3
16:1ω9	0.0	0.4	0.4	0.6	0.6	0.5	0.5	0.7
16:1ω7	6.8	10.0	0.9	0.6	0.5	7.2	4.4	8.3
16:0	21.3	30.2	35.6	33.9	31.3	29.5	29.9	31.9
i17:0	5.8	0.3	0.4	0.4	0.5	0.6	0.7	0.5
a17:0	0.0	0.2	0.3	0.2	0.3	0.2	0.3	0.2
17:1	0.0	0.4	0.6	0.9	1.0	0.8	0.5	0.8
17:0	1.2	1.2	1.7	2.2	1.9	2.0	2.2	1.8
18:3ω6	0.0	0.3	0.4	0.7	0.2	0.2	0.2	0.3
18:4ω3	0.0	0.4	0.2	0.4	0.1	0.1	0.3	0.1
18:2ω6	0.9	1.2	0.9	0.7	1.0	1.2	0.9	1.1
18:1ω9	23.0	20.7	24.4	27.2	29.0	21.5	19.1	22.0
18:1ω7c	6.6	5.6	6.7	5.4	5.1	5.5	5.5	5.1
18:0	9.3	8.3	10.0	13.2	11.0	10.8	15.5	9.7
20:4ω6	2.2	1.6	1.1	0.2	1.4	1.7	0.9	1.5
20:5ω3	1.9	2.5	1.5	0.0	0.6	0.7	0.4	1.1
20:3ω6	0.0	0.2	0.2	0.0	0.3	0.3	0.3	0.2
20:4ω3	1.2	1.3	0.7	2.6	0.8	0.6	0.9	0.9
20:2ω6	0.0	0.2	0.2	0.3	0.4	0.5	0.4	0.3
20:1ω11	5.7	0.5	0.0	0.4	1.2	1.1	1.6	0.6
20:1ω9	1.3	1.1	1.8	2.1	2.2	1.5	2.2	1.3
20:1ω7	0.0	0.3	0.4	0.5	0.4	0.5	0.6	0.3
20:0	0.0	0.4	0.4	0.5	0.5	0.5	0.7	0.3
22:5ω6	1.0	0.5	0.3	0.0	0.5	0.7	0.4	0.3
22:6ω3	5.7	1.4	0.7	0.0	1.1	1.4	0.8	2.1
22:4ω6	1.2	0.5	0.4	0.0	0.9	1.2	1.0	0.5
22:5ω3	1.8	0.8	0.6	0.0	0.6	1.0	0.5	0.6
22:1ω11	0.0	0.1	0.0	0.2	0.2	0.1	0.2	0.0
22:1ω9	0.0	0.2	0.1	0.3	0.3	0.2	0.5	0.2
24:1	0.0	0.2	0.2	0.4	0.3	0.3	0.6	0.2
24:0	1.9	0.1	0.1	0.2	0.2	0.0	0.3	0.0
Other	0.0	2.3	1.3	0.9	1.5	2.2	2.7	1.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sum SAT	40.6	48.0	56.3	55.8	50.1	49.3	55.1	49.9
Sum MUFA	43.4	40.9	36.4	39.2	41.5	40.6	37.2	40.9
Sum PUFA	15.9	11.1	7.3	5.1	8.4	10.1	7.8	9.2
Sum ω3 PUFA	10.6	6.7	3.8	3.4	3.2	4.0	3.3	4.9
Sum ω6 PUFA	5.3	4.5	3.5	1.9	4.8	5.8	4.2	4.2
Ratio ω3/ω6	2.0	1.5	1.1	1.8	0.7	0.7	0.8	1.2

Other: 12:0,14:1,i&a15:0,i16:0,16:1ω5,18:1ω5,19:1,20:1ω5,C21&23PUFA,22:3ω3,22:0

Table 11. Fatty acid composition of shark liver oils from school and gummy sharks, WA

	Percentage composition					
Fatty acid	School NSL 42	School NSL 43	School NSL 44	Gummy NSL 45	Gummy NSL 46	Gummy NSL47
14:0	2.6	3.2	3.6	1.0	2.9	1.5
15:0	1.3	1.1	1.3	0.7	0.9	0.5
16:1ω9	0.6	0.5	0.6	0.5	1.1	0.5
16:1ω7	6.1	4.1	6.6	4.8	9.2	17.6
16:0	28.2	21.5	26.0	15.4	26.8	22.4
i17:0	0.7	0.5	0.5	0.5	0.4	0.4
a17:0	0.4	0.3	0.3	0.4	0.3	0.4
17:1	0.8	0.5	1.0	0.9	1.0	1.0
17:0	1.7	1.1	1.4	0.8	1.2	0.5
18:3ω6	0.4	0.2	0.2	0.3	0.4	0.5
18:4ω3	0.2	0.4	0.4	0.4	0.3	0.1
18:2ω6	1.3	1.3	1.5	1.8	1.3	0.5
18:1ω9	21.9	21.7	25.4	14.5	25.2	22.3
18:1ω7c	6.9	5.6	5.1	5.7	5.4	4.9
18:0	8.2	5.4	6.5	3.8	5.3	3.4
20:4ω6	1.0	0.7	1.2	2.5	1.3	1.3
20:5ω3	1.0	1.1	1.8	2.1	1.3	1.0
20:3ω6	0.2	0.0	0.1	0.2	0.1	0.1
20:4ω3	1.4	1.3	1.1	0.5	1.2	0.7
20:2ω6	0.6	0.4	0.4	0.8	0.5	0.3
20:1ω11	0.0	1.0	0.0	0.0	0.0	0.0
20:1ω9	5.3	14.8	3.5	4.1	5.1	4.3
20:1ω7	0.5	0.6	0.3	0.3	0.2	0.3
20:0	0.3	0.2	0.2	0.1	0.1	0.2
22:5ω6	0.4	0.3	0.4	1.5	0.2	0.1
22:6ω3	2.6	3.3	4.8	12.5	3.2	1.2
22:4ω6	0.5	0.3	0.3	2.5	0.5	0.2
22:5ω3	0.9	1.1	1.0	4.6	0.9	0.5
22:1ω11	0.5	3.5	0.4	6.9	0.6	5.3
22:1ω9	0.6	1.2	0.4	2.4	0.5	2.4
24:1	0.6	0.7	0.6	1.9	0.2	1.2
Other	2.3	2.0	2.9	5.4	2.1	4.5
Total	100.0	100.0	100.0	100.0	100.0	100.0
Sum SAT	11.5	8.6	12.5	12.6	14.4	24.7
Sum MUFA	48.2	39.3	42.9	33.1	41.9	35.8
Sum PUFA	38.0	49.2	40.9	53.3	40.6	37.9
Sum ω3 PUFA	6.0	7.3	8.9	20.2	6.9	3.6
Sum ω6 PUFA	4.3	3.2	4.3	9.5	4.3	3.0
Ratio ω3/ω6	1.4	2.3	2.1	2.1	1.6	1.2

Other: 12:0,14:1,i&a15:0,i16:0,16:1ω5,18:1ω5,19:1,20:1ω5,C21&23PUFA,22:3ω3,22:0

Table 12. Fatty acid composition of shark livers oils from the NT

	Percentage composition									
Fatty Acid	Milk	Milk	Whaler	Whaler	Spot-tail	Spot-tail	Blacktip	Blacktip	Handle bar	Handle bar
	NSL62	NSL63	NSL64	NSL65	NSL68	NSL69	NSL70	NSL71	NSL76	NSL77
14:0	3.0	3.7	4.6	3.8	4.4	2.8	4.0	2.5	3.3	2.9
15:0	1.0	1.2	1.0	1.5	1.6	0.9	1.5	0.8	1.4	1.1
16:1ω9	0.3	0.3	0.4	0.4	0.5	0.3	0.3	0.3	0.3	0.3
16:1ω7	4.1	6.1	6.2	6.5	6.8	5.8	5.0	2.9	5.3	4.4
16:0	24.0	22.4	25.6	26.3	37.2	24.0	24.2	21.6	27.8	25.3
i17:0	0.5	0.8	0.6	0.5	0.8	0.5	0.5	0.5	0.6	0.8
a17:0	0.2	0.3	0.3	0.3	0.3	0.2	0.3	0.2	0.4	0.3
17:1	0.3	0.6	0.4	0.6	0.7	0.5	0.5	0.3	0.5	0.4
17:0	2.0	1.9	1.6	1.8	2.6	1.7	1.9	1.8	1.7	1.9
18:3ω6	0.0	0.2	0.2	0.0	0.5	0.1	0.2	0.0	0.2	0.0
18:4ω3	0.2	0.0	0.2	0.3	0.0	0.3	0.4	0.0	0.3	0.2
18:2ω6	1.1	1.4	1.4	1.3	1.1	1.3	1.2	1.0	1.3	1.1
18:1ω9	7.7	9.6	12.1	11.1	13.4	11.0	9.5	10.2	8.9	7.1
18:1ω7c	4.4	5.2	5.1	4.2	5.2	4.2	4.1	4.1	5.6	6.5
18:0	12.2	10.5	9.8	9.6	14.0	9.7	11.3	13.9	9.1	9.9
20:4ω6	4.1	6.2	4.0	3.5	0.8	3.8	3.9	5.3	3.3	4.0
20:5ω3	3.7	4.6	3.1	3.1	0.4	3.4	3.4	2.9	3.7	4.0
20:3ω6	0.3	0.4	0.4	0.3	0.0	0.3	0.4	0.3	0.3	0.3
20:4ω3	0.3	0.4	0.4	0.5	1.0	0.4	0.4	0.3	0.4	0.3
20:2ω6	0.3	0.5	0.4	0.3	0.2	0.4	0.3	0.4	0.3	0.4
20:1ω11	0.6	0.4	0.9	0.5	0.6	0.5	0.8	0.7	0.4	0.6
20:1ω9	0.7	0.7	0.7	1.0	1.0	1.1	0.8	0.9	0.8	0.5
20:1ω7	0.3	0.3	0.3	0.2	0.4	0.3	0.4	0.3	0.3	0.3
20:0	0.4	0.3	0.3	0.3	0.4	0.3	0.4	0.5	0.3	0.2
22:5ω6	3.3	2.1	2.5	2.1	0.3	2.6	3.4	3.7	2.3	2.7
22:6ω3	16.7	10.7	9.7	12.2	1.0	14.3	12.3	15.5	14.9	17.2
22:4ω6	2.3	2.7	2.4	1.8	0.3	2.1	2.4	2.8	1.4	2.0
22:5ω3	2.8	4.0	3.0	4.1	0.5	4.1	3.2	3.4	2.7	3.2
22:1ω9	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.0
24:1	0.5	0.2	0.3	0.2	0.5	0.5	0.5	0.7	0.2	0.1
24:0	0.3	0.0	0.2	0.0	0.2	0.2	0.2	0.4	0.0	0.0
Other	2.2	2.2	1.9	1.5	3.4	2.4	2.1	1.6	2.1	2.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sum SAT	44.1	41.7	44.5	44.3	62.1	40.7	44.8	42.5	44.8	42.8
Sum MUFA	20.2	24.6	27.2	25.8	31.2	25.8	23.1	21.2	23.3	21.0
Sum PUFA	35.5	33.5	28.1	29.7	6.4	33.3	31.7	35.9	31.4	35.7
Sum ω3 PUFA	10.1	11.6	9.6	7.7	1.9	8.8	10.3	12.1	7.5	9.0
Sum ω6 PUFA	35.5	28.4	25.2	27.9	19.4	30.1	30.1	34.9	30.4	33.8
Ratio ω3/ω6	0.3	0.4	0.4	0.3	0.1	0.3	0.3	0.3	0.2	0.3

Other: 12:0,14:1,i&a15:0,i16:0,16:1ω5,18:1ω5,19:1,20:1ω5,C21&23PUFA,22:3ω3,22:0

Table 13. Fatty acid composition of liver oils from northern Australian sharks - oils supplied by fishers

	Percentage composition										
Fatty acid	Hammerhead		Blacktip	Hammer Head	Blacktip						Whaler
	NSO1	NSO2	NSO3	NSO 16	NSO 14	NSO 15	NSO 17	NSO 18	NSO 19	NSO 20	NSO 22
14:0	2.8	3.2	3.1	2.1	3.9	4.0	3.1	3.6	2.9	3.3	4.4
15:0	1.0	1.2	1.1	1.2	1.4	1.5	1.1	1.2	1.1	1.3	1.1
16:1ω9	0.4	0.4	0.5	0.0	0.3	0.3	0.4	0.4	0.3	0.4	0.5
16:1ω7	3.2	4.5	4.6	4.3	4.4	4.4	5.5	5.8	6.3	7.0	7.7
16:0	16.2	22.3	24.6	24.9	25.3	25.4	23.7	23.2	23.5	25.9	27.9
i17:0	0.2	0.5	0.5	0.9	0.0	0.3	0.4	0.4	0.4	0.4	0.3
a17:0	0.3	0.3	0.2	0.0	0.0	0.3	0.0	0.3	0.3	0.3	0.3
17:1	0.3	0.6	0.6	0.5	0.5	0.5	0.6	0.6	0.7	0.8	0.6
17:0	1.1	1.8	1.8	2.3	1.9	1.9	1.8	1.8	1.5	1.7	1.4
18:3ω6	0.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
18:4ω3	2.0	0.7	0.7	0.0	0.5	0.4	0.4	0.4	0.3	0.3	0.4
18:3ω3	0.0	0.1	0.1	0.9	1.0	1.0	1.2	1.3	1.1	1.1	1.2
18:2ω6	1.9	2.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18:1ω9	8.4	12.5	13.6	6.7	10.8	10.7	13.6	13.6	13.5	14.0	18.7
18:1ω7c	3.5	3.6	3.6	6.0	3.1	3.0	3.7	3.9	3.5	3.6	4.3
18:0	5.3	8.4	9.3	9.4	9.3	9.2	9.1	8.6	7.5	8.1	6.9
20:4ω6	1.4	4.1	3.6	5.1	4.0	4.0	3.9	3.9	3.7	3.2	2.2
20:5ω3	7.5	3.7	3.9	3.8	4.8	4.7	4.7	4.6	4.4	3.9	2.0
20:3ω6	0.1	0.5	0.3	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.3
20:4ω3	0.9	0.6	0.5	0.0	0.4	0.4	0.4	0.4	0.4	0.4	0.5
20:2ω6	0.5	0.5	0.4	0.5	0.3	0.3	0.4	0.4	0.4	0.4	0.4
20:1ω11	0.0	0.3	0.4	1.3	0.4	0.4	0.7	0.5	0.5	0.8	0.5
20:1ω9	1.3	0.8	0.8	0.7	1.1	1.1	0.9	0.9	0.8	0.7	1.6
20:1ω7	0.1	0.2	0.2	0.0	0.4	0.4	0.0	0.3	0.3	0.3	0.4
20:0	0.1	0.3	0.3	0.0	0.3	0.3	0.4	0.4	0.4	0.4	0.3
22:5ω6	1.2	2.1	2.2	3.4	2.5	2.4	2.1	2.0	2.3	1.8	2.4
22:6ω3	35.3	16.7	14.4	17.6	19.0	18.7	15.5	14.4	17.0	13.6	6.5
22:4ω6	0.4	1.6	1.5	2.7	1.1	1.1	1.6	1.5	1.4	1.2	1.7
22:5ω3	2.2	2.7	2.5	2.8	1.9	1.9	2.6	2.5	2.7	2.2	2.7
22:1ω11/ω9	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.5
24:1	0.2	0.2	0.2	0.0	0.4	0.4	0.5	0.5	0.3	0.3	0.6
24:0	0.0	0.1	0.1	2.1	0.0	0.0	1.0	0.0	0.2	0.9	0.2
Other	1.9	2.7	2.1	0.7	0.9	0.9	0.7	2.3	2.0	1.3	1.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sum SAT	27.4	39.0	41.8	43.0	42.2	43.0	40.8	40.0	38.1	42.5	43.1
Sum MUFA	29.2	41.6	44.6	39.0	40.9	40.5	44.8	45.0	42.2	45.0	50.0
Sum PUFA	54.0	36.4	32.2	36.8	35.5	35.0	32.7	32.2	34.7	28.7	20.8
Sum ω3 PUFA	46.0	23.8	21.4	25.1	27.2	26.7	24.4	23.3	25.7	21.3	12.9
Sum ω6 PUFA	7.6	12.1	10.4	11.7	8.3	8.3	8.3	8.5	8.3	7.2	7.5
Ratio ω3/ω6	6.0	2.0	2.1	2.1	3.3	3.2	3.0	2.8	3.1	3.0	1.7

Other: 12:0,14:1,i&a15:0,i16:0,16:1ω5,18:1ω5,19:1,20:1ω5,C21&23PUFA,22:3ω3,22:0

Table 14. Fatty acid composition of tiger shark liver oil

	Percentage composition		
Fatty acids	NSL51	NSO 21	NSO23
14:0	3.6	3.0	3.7
15:0	0.7	0.6	0.8
16:1ω9	0.7	1.0	1.2
16:1ω7	0.6	8.1	7.3
16:0	27.1	24.9	24.1
i17:0	0.8	0.8	1.1
a17:0	0.4	0.4	0.4
17:1	0.7	0.6	0.7
17:0	1.4	1.5	1.1
18:3ω6	0.0	0.1	0.0
18:4ω3	0.6	0.8	0.2
18:2ω6	1.9	1.6	1.5
18:1ω9	30.1	23.6	23.1
18:1ω7c	10.0	6.8	6.6
18:0	6.7	5.9	5.4
20:4ω6	1.0	0.7	0.8
20:5ω3	0.4	1.6	0.7
20:3ω6	0.2	0.2	0.1
20:4ω3	0.3	0.4	0.3
20:2ω6	0.0	0.0	0.2
20:1ω11	1.9	0.6	1.0
20:1ω9	0.0	2.7	3.3
20:1ω7	0.3	0.3	0.3
20:0	0.0	0.2	0.2
22:5ω6	0.2	0.4	0.4
22:6ω3	0.7	2.6	2.6
22:4ω6	0.6	0.6	0.8
22:5ω3	0.4	1.0	0.9
22:1ω11/ω9	0.4	1.2	1.4
24:1	1.9	1.5	2.3
24:0	0.0	0.0	0.5
Other	6.3	6.5	7.3
Total	100.0	100.0	100.0
Sum SAT	41.5	37.9	38.1
Sum MUFA	51.3	51.6	52.7
Sum PUFA	7.6	13.4	10.4
Sum ω3 PUFA	2.5	6.4	4.7
Sum ω6 PUFA	3.9	3.6	3.8
Ratio ω3/ω6	0.6	1.8	1.2

Other: 12:0,14:1,i&a15:0,i16:0,16:1ω5,18:1ω5,19:1,20:1ω5,C21&23PUFA, 22:3ω3,22:0

Table 15. Glyceryl ether diol composition of tiger shark liver (tissue and oil)

	Percentage composition		
Glyceryl ether diol	NSL51	NSO 21	NSO23
14:0	2.9	2.2	1.4
br 15:0	0.3	0.8	0.3
15:0	0.9	1.6	0.7
i16:0	1.7	1.2	2.8
16:1?9c	1.2	1.1	1.5
16:1?7c	8.8	8.8	7.7
16:1?5c	1.2	3.0	2.5
16:0	17.0	20.7	14.4
i17:0	0.8	1.1	1.0
a17:0/17:1	1.9	2.9	2.1
17:0	0.8	1.2	1.2
i18:0	0.4	1.0	1.0
18:1?9c	51.8	41.9	50.4
18:1?7c	3.0	3.4	3.9
18:0	7.2	8.8	8.9
20:0	0.1	0.2	0.3
Total	100.0	100.0	100.0

Table 16. Vitamin composition of selected shark livers oils

Sample	Species	Retinol (mg/100g)	a-Tocopherol (mg/100g)
NSL 15	Hammer head	37.2	14
NSL 20	Whaler	60.9	16
NSL 21	Pacific white tip	4.3	10
NSL 22	Spot-tail	23.6	45
NSL 27	Blacktip	10.3	23
NSL 30	Blacktip	43	22
NSL 39	Blacktip/School	0.03	0.4

13. Appendices

APPENDIX 1:

INTELLECTUAL PROPERTY

The project has generated interest from various client groups. During the project, we received numerous requests for data on shark species that to our knowledge had not been previously analysed.

The intellectual property generated during the project includes detailed oil compositional data on shark liver derived oils. Without specific details being provided, some of these data already have been reported at national and international conferences, and provided to clients in report form (Appendix 3).

Interpretation of the oil compositional results has included examination of possible relationships between various biological and other parameters as indicated in Section 7. Further intellectual property will be generated through similar use of the results from Project 99/369 by CSIRO and other researchers as the data set becomes more widely available. At this stage, no commercial return is envisaged from other users of the project database. However, it may be appropriate to at least recover costs incurred for the provision of these data to other users.

APPENDIX 2:

STAFF

Dr. Peter Nichols	Snr. Prin. Res. Sci.	BSc (Hons), PhD	10%
Dr. John Stevens	Snr. Prin. Res. Sci..	BSc (Hons), PhD	5%
Mr. Mark Rayner	Exp. Sci.	Cert Chem Tech	25%

APPENDIX 3:

CSIRO Marine Research

GPO Box 1538 Hobart TAS 7001 Australia
Castray Esplanade Hobart Tasmania
Telephone (03) 6232 5222 Int +61 3 6232 5222
Facsimile (03) 6232 5090 Int +61 3 6232 5090
Web site: http://www.marine.csiro.au
Chief: Dr Nan Bray

20 July 1999

Paul Hayler
PO Box 2425
SOUTH HEDLAND WA 6722

Dear Paul

Further to our phone discussion, I will put together a sampling parcel for you to send to Hobart when ready. We are keen for liver and oil samples from all the species you have access to. We would appreciate separate liver and flesh samples from 3-4 specimens of each species.

With the sampling gear, the larger bags will be for livers, the small bags for flesh muscle, and the tubes are for the oil – if you are able to produce an oil. It is important for the specimens to be identified and other details provided (date of collection, sex, length, etc). The bags and tubes should be labelled to distinguish species. We have put water in one of the bags to demonstrate their use after you tear off the top.

For species available in "commercial" quantities year round, we are keen to look at seasonal changes. For this we would collect samples every 2-3 months and will send you further sample containers in the future.

We look forward to working with you on this new FRDC funded initiative on northern Australian sharks. Please contact either myself (03 6232 5279) or Mark Rayner (03 6232 5290) should you have any questions or comments.

Thanks in advance for your help.

Yours sincerely

Peter Nichols

Samples – Summary of Requirements

All species, if possible 3 – 4 specimens in separate bags, fill bag.
Details needed: species name, collection location and date, length, sex

- Liver in larger bag, fill bag
- Liver oil in tubes, fill tube
- Muscle (for species confirmation), in smaller bag – 1 cm^3 is enough

Transport to Hobart

- Return by air courier, address label supplied
- Freeze samples and blue ice and send in esky
- If possible, provide Mark Rayner or Peter Nichols notice of shipment. Do not send on Fridays.

Reports Prepared for Industry

Nichols, P., Stevens, J. and Rayner, M. (2000) A pilot investigation of northern shark liver oils: characterization and value-adding. Milestone Report prepared for FRDC, January 2000.

Rayner, M. and Nichols, P. D. (2000) Oil composition of a northern shark liver oil. Internal Report 2000-CMR1.

Rayner, M. and Nichols, P. D. (2000) Oil composition of a northern shark liver oil. II. Internal Report 2000-CMR3.

Nichols, P. and Stevens, J. (2001) A Pilot Investigation of Northern Shark Liver Oils: Characterization and Value-Adding. Summary flier prepared for distribution at industry meetings. FRDC 99/369: Cairns and Darwin, November, 2001 (see p 44).

Publications, Presentations and Media Contact

October 1999. Sci-Files 99-10. "Health giving oils from fish waste" Interview produced by CSIRO and Pegasus Media and distributed to ABC radio.

Nichols, P. (1999) Recent developments with Australian marine oils. Invited 12th G. I. Feutrill Memorial Lecture, Melbourne University Chemistry Department, August, Melbourne.

Nichols, P. (1999) The good oil. Invited lecture to AMRAD Pharmaceuticals, August, Melbourne.

Nichols, P., Lewis, T., Elliott, N., Virtue, P. (2001) Marine souces of omega-3 polyunsaturated oils. Omega workshop. Wollongong, February, Abstracts.

Nichols, P. The good oil. (2001) Tasmanian Aquaculture and Fisheries Institute. Invited lecture, March.

Nichols, P. D., Mooney, B. D. and Elliott, N. G. (2001) Value-adding to Australian Marine Oils. More Efficient Utilization of Fish and Fish Products, Kyoto, Japan, October, Abstracts

FRDC 99/369: A Pilot Investigation of Northern Shark Liver Oils: Characterization and Value-Adding

PROJECT LEADERS: Peter Nichols and John Stevens
CSIRO Marine Research, Hobart, Ph 03 62325279

OBJECTIVES

- Characterise liver oils from northern sharks (NT, WA, Qld), including examining changes with location, season and other factors. The key components to be examined will be the omega-3 PUFA and vitamins.
- Provide initial comment on the potential commercial usefulness of these liver oils.

OUTCOMES

Liver oil profiles were obtained for northern sharks. The profiles indicate new sources are available for omega-3 and diacylglyceryl ether oils. These two types of oils have been manufactured over the last 5 years in Australia from fisheries by-catch and by-products. The scope may exist to utilize the northern shark fishery as a new source for these valuable oils.

FURTHER DETAILS

The content and composition of liver oil from around twenty species of northern Australian sharks were examined. The discovery of PUFA-containing and DAGE-rich liver oils in northern sharks demonstrate that suitable raw material is available and the potential exists with the research capability and industry expertise available in Australia for products to be developed. With the acknowledged problem that fish oil resources may be limiting in the near future, and that fish oils from northern hemisphere waters may be contaminated by organochlorines and other deleterious materials, the potential for "clean and green" Australian omega-3 products is further enhanced. Possible applications for omega-3 oils include in nutraceuticals (health products) and feeds (aquaculture and livestock), with DAGE also used in nutraceuticals. Industry needs include co-ordination of collections and preparation of oil from livers, and forming links to marine oil producers.

KEYWORDS

northern sharks, *Carcharhinus tilsoni*, *Carcharhinus sorrah*, *Galeocerdo cuvier*, liver oils, triacylglycerols, diacylglyceryl ethers (DAGE), omega-3 polyunsaturated fatty acids (PUFA), purification, health applications, aquaculture feeds

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Fisheries Waste & By-catch

Opportunities: new source(s) of oils for use in aquaculture feeds and other health product applications

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