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**FINAL REPORT**

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# The Quality of Under-utilised Deep-water Fish Species

The National Food Centre
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Contents

# THE QUALITY OF UNDER-UTILISED DEEP-WATER FISH SPECIES

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## SUMMARY

The quality of twenty-three frozen under-utilised fish species was examined. The species were spot samples of deep-water fish caught near the Rockall Trough by the Fisheries Research Centre. Their basic composition was 80.8 - 86.4% water, 9.8 - 25.2% protein, 0.18 - 16.2% lipid and 0.7 - 2.0% ash. Lead, cadmium and mercury concentrations were determined for six species and were much lower than the maximum levels set in 1992. Ammonia levels were unacceptably high in three shark species.

Sensory analysis showed that as fillets, taste panellists preferred six species to cod, while, presented as nuggets and fish-cakes, ten and eight species, respectively, were preferred to cod. Orange roughy, black scabbard, morid cod and Portuguese dogfish scored particularly well for acceptability. Some of the species that were very tough or soft as fillets, scored much better as nuggets, perhaps because their texture was improved by mincing. Skinless deep-water flying squid was preferred to commercially sourced squid (*Illex coindetti*), due to its texture and flavour.

Some of the fish species had high weight loss on cooking and very high levels of drip loss on thawing, indicative of freezing damage. Cryoprotectants (polysaccharides, dairy proteins and trehalose) reduced freezing damage in fish minces or in fillets.

This study has highlighted that many under-utilised deep-water fish species are highly acceptable. If deep-water fishing gear is not prohibitively expensive and marketing is managed well, then there will be good potential for commercial gain from deep-water fishing.


## INTRODUCTION

### History of Irish deep-water fishing

Irish fishing trials for deep-water species commenced in 1988 (McCormick, 1995) as a response to restrictive quotas and dwindling stocks associated with traditional in-shore species. The first species targeted were blue whiting and greater argentine, but a rapid decline in argentines, coupled with damage to the costly fishing gear, terminated this fishery in 1990. Further deep-water trials in

1992-1993 demonstrated that there was a viable trawl fishery for grenadiers. From the mid 1990s there has been a continued interest in deep-water species and stock assessments have continued. There have been increasing numbers of commercial Norwegian, Icelandic, French and Faeroes vessels deep-water trawling and longlining (Anonymous, 1996). Markets have been developed in France, Spain and the US, giving considerable potential for deep-water fishing.

## Management of deep-water stocks

Many scientists believe that deep-water species are long-lived and slow to mature (Connolly and Kelly, 1997) which makes them vulnerable to over-fishing. These concerns have led to international interest in collating biological data so that stocks can be assessed. The Fisheries Research Centre of the Marine Institute and the Irish Sea Fisheries Board have been carrying out deep-water fish surveys since the late 1980s. The information they have collected on population sizes, distribution, age, maturity and reproduction will help in future management of deep-water fishing.

## Objectives of the current study

A prediction of which fish will be successful in the marketplace is required, so that efforts can be put into developing the fishery without too high a risk of market failure. However, there has been relatively little European work on the flavour and texture characteristics of the fish and even less on their suitability for a range of added-value fish products. At The National Food Centre, in collaboration with the Fisheries Research Centre, previous studies on food applications of deep-water under-utilised fish have concentrated on argentine (Gormley *et al*, 1991; Gormley *et al*, 1993) or a relatively small number of other deep-water species (Gormley *et al*, 1994; Maier *et al*, 1997). The current study was designed to add to the previous work by assessing more species and carrying out sensory tests on more product types.

The aim was to provide the fishing industry with indications of the quality of many under-utilised fish species. Quality encompassed not only sensory analysis of flavour, colour and texture of the fish and fish products, but also nutritional composition, spoilage, drip and cook losses and damage from freezing. In addition, selected heavy metals have been quantified for six species.

*A range of deep-water fish and fish products.*

## THE FISH

Fish were caught for the project by the Fisheries Research Centre in two deep-water survey trips of the eastern slopes on the Rockall Trough in August 1997 (Clarke *et al*, 1999) and in October/November 1997 (Connolly *et al*, 1999). The fish were gutted, filleted and frozen at sea; then stored frozen at -25°C at the Fisheries Research Centre and The National Food Centre until required. Twenty two species (Table 1) were provided with masses varying from 1 to 42 kg. These should be regarded as spot samples. Bord Iaschaigh Mhara (the Irish Sea Fisheries Board) provided samples of blue whiting which were caught in April and May 1998.

Table 1 shows latin and common names of the fish species but throughout the report, the common names are used. To avoid confusion, it is advisable to refer to the latin names when comparing these results with other studies.

Fresh cod (*Gadus morhua*) fillets, frozen long-finned common squid (*Loligo vulgaris*) and squid from Taiwan (*Illex coindetti*) were used as controls to compare against the deep-water species. They were frozen at -30°C in an air-blast freezer, then stored at -25°C until required.

Table 1: Under-utilised fish species used in this project

| Latin name | Common name | Date caught |
|---|---|---|
| SELACHI | SHARKS | |
| *SQUALIDAE* | *DOGFISH SHARKS* | |
| Centrophorus squamosus | Leafscale gulper shark | 08/97 |
| Centroscymnus coelolepis | Portuguese dogfish | 08/97 |
| Centroscymnus crepidater | Longnose velvet dogfish | 08/97 |
| Deania calceus | Birdbeak dogfish | 11/97 |
| Etmopterus princeps | Greater lantern shark | 08/97 |
| *CHIMAERA* | *RABBITFISH* | |
| Chimaera monstrosa | Rabbitfish | 08/97; 11/97 |
| Hydrolagus affinis | Small-eyed rabbitfish | 08/97 |
| CEPHALOPODA | CEPHALOPODS | |
| *DIBRANCHIA DECAPODA* | *SQUID* | |
| Todarodes sagittatus | Flying squid | 11/97 |
| PISCES | BONY FISH | |
| *ALEPOCEPHALIDAE* | *SMOOTHEADS* | |
| Alepocephalus bairdii | Baird’s smoothead | 10/97 |
| *ARGENTINIDAE* | *ARGENTINES* | |
| Argentina silus | Greater argentine | 10/97 |
| *MACROURIDAE* | *GRENADIERS* | |
| Coryphaenoides rupestris | Roundnose grenadier | 10/97 |
| *GADIDAE* | *COD FISHES* | |
| Mora moro | Morid cod | 08/97 |
| Molva dipterygia | Blue ling | 08/97 |
| Molva molva | Ling | 08/97 |
| Brosme brosme | Tusk | 08/97 |
| Phycis blennoides | Forkbeard | 08/97; 11/97 |
| Micromesistius poutassou | Blue whiting | 04/98; 05/98 |
| *TRACHICHTHYIDAE* | *TRACHICHYDIS* | |
| Hoplostethus atlanticus | Orange roughy | 11/97 |
| *TRICHURIDAE* | *SCABBARD FISHES* | |
| Aphanopus carbo | Black scabbard | 10/97 |
| *SCORPAENIDAE* | *SCORPION FISHES* | |
| Helicolenus dactylopterus | Bluemouth rockfish | 11/97 |
| *GEMPYLIDAE* | *SNAKE MACKERELS* | |
| Nessiarchus nassutus | Snake mackerel | 11/97 |
| *ANARHICHADIDAE* | *WOLF FISHES* | |
| Anarhichas lupus | Wolf-fish | 11/97 |

# SENSORY ANALYSIS OF FISH AND FISH PRODUCTS

Twelve taste panellists were used to score the acceptability of the fish as fillets, nuggets, fish-cakes and smoked fillets by marking a 6 cm line on which 0 was least acceptable and 6 was most acceptable. The mean scores are given in Table 2, in which the fish have been sorted into order of preference according to the fillet acceptability scores.

**Table 2:** Mean acceptability scores from 12 taste panellists for fish and fish products

| | Acceptability scores[a] | | | |
|---|---|---|---|---|
| Species | FILLET | NUGGET | CAKE | SMOKED |
| Orange roughy | **3.9** | **4.7** | 2.7 | |
| Morid cod | **3.9** | **4.2** | **3.7** | |
| Black scabbard | **3.9** | **3.8** | **3.6** | |
| Greater argentine | **3.9** | | **3.4** | |
| Portuguese dogfish | **3.8** | **4.1** | 2.8 | |
| Snake mackerel | **3.8** | | 2.7 | |
| Cod | 3.6 | 3.7 | 3.0 | 3.5 |
| Roundnose grenadier | 3.5 | **4.0** | | 1.6 |
| Baird's smoothead | 3.4 | **4.1** | 2.3 | 2.1 |
| Wolf-fish | 3.4 | **4.1** | **3.4** | 2.4 |
| Bluemouth rockfish | 3.3 | 3.4 | **3.5** | |
| Redfish | 3.3 | | | |
| Greater lantern shark | 3.2 | 3.1 | 3.0 | **3.7** |
| Ling | 3.1 | **4.0** | **3.3** | 1.8 |
| Tusk | 3.0 | **4.0** | **3.3** | 2.9 |
| Forkbeard | 3.0 | 3.0 | 2.5 | 1.4 |
| Blue whiting | 3.0 | | **3.2** | |
| Leafscale gulper shark | 2.8 | **4.1** | 2.7 | 3.0 |
| Blue ling | 2.8 | 3.7 | 2.9 | |
| Longnose velvet dogfish | 2.7 | 3.2 | 2.8 | |
| Birdbeak dogfish | 2.6 | 1.8 | | |
| Small-eyed rabbitfish | 2.3 | 1.4 | | |
| Flying squid | 1.7 | 1.9 | | |
| Rabbitfish | 1.6 | 1.0 | | |
| No. of species tasted[b] | 24 | 20 | 18 | 9 |
| No. of species preferred to cod | 6 | 10 | 8 | 1 |

[a] 0 = least acceptable; 6 = most acceptable.

Scores in **bold** are those greater than the corresponding score for cod

[b] including cod

Presented as fillets, six species were preferred to cod (Table 2) and ten other under-utilised species received a mean score of 3.0 or more (*i.e.* at least 50% along the score line). This result suggests there is good potential for establishing a market for deep-water fish.

Taste panellists indicated that ling and cod were particularly bland in flavour, while some of the shark species had a sweet flavour. A strong smell of ammonia from the rabbitfish sample was detected by many panellists.

Presented as nuggets, (made from minced fish, shaped, battered and crumbed) ten species were preferred to cod (Table 2) and a further five species had a mean score of at least 3.0. Most species received higher scores as nuggets than as fillets. Many of the species which scored much better as nuggets than as fillets had particularly low (leafscale gulper shark) or high (tusk, blue ling) shear values as cooked fillets. Mincing the flesh may have improved the texture and hence the acceptability. The three species (birdbeak dogfish, small-eyed rabbitfish and rabbitfish) that scored much more poorly as nuggets than as fillets had high ammonia levels. This may have increased yet further during nugget production, which involved several freeze-thaw cycles. It is suggested that fish samples with high ammonia levels are not suitable for further processing.

Maier *et al* (1997) found that greater argentine was very acceptable as a nugget (score = 4.4), but in their study the most preferred species was Greenland halibut, which was not examined in the present study.

Presented as fish-cakes (made from flaked cooked fish and mashed potato), eight species were preferred to cod which scored just 3.0. The fish-cake recipe introduced two flavours, lemon and smoke. This might explain why ling, which was described as bland as a fillet, scored better as a fish-cake.

The species selected for smoking were those that received lower mean acceptability scores than cod in taste panels for cooked fillets. However, when smoked, only the two shark species scored well, the other species scored poorly (less than 3.0); the main complaint was that they were too salty and/or too dry.

## DEEP-WATER SQUID

Because the European flying squid was so different from cod it was also compared to other squid species. Results from taste panels indicated that it was equally acceptable to common or Taiwan squid. However, when a layer of skin was removed, toughness was reduced (Table 3) and taste panellists considerably preferred the flying squid to Taiwan squid with regard to both texture and flavour. The flavour of the flying squid was described as savoury, whereas the Taiwan squid was salty and had a stronger seafood flavour.

It was concluded that, as long as the flying squid had its skin removed before cooking, it was a highly acceptable squid species and thus could be suitable for commercialisation.

**Table 3:** Effect of cooking method, skin and species on squid shear value

| | | Flying squid (N/20 g)[a] | Taiwan squid (N/20 g)[a] |
|---|---|---|---|
| Boiled | With skin | 1020 | 1390 |
| | Without skin | 750 | 940 |
| Fried | With skin | 1410 | 1380 |
| | Without skin | 750 | 1420 |

[a] Newtons required to shear 20 g sample

## COLOUR AND TEXTURE OF FISH FLESH

The colour of fish flesh is important both at point of purchase and consumption. The colour of the raw flesh was measured with a Minolta Chroma Meter (CR-331), using D65 illumination and the Hunter Lab colour scale. The fish were cooked in a microwave oven then cooled to room temperature. The colour was re-measured for each species and values are listed in Table 4.

The shark species and Baird's smoothead were particularly white, both when raw and cooked but yellowness increased during cooking. Redfish was the

Table 4: Colour[1] of raw and cooked fish flesh and toughness of cooked fish

| Species[2] | Raw | | | Cooked | | | Shear |
|---|---|---|---|---|---|---|---|
| | L | a | b | L | a | b | (N/50 g) |
| Leafscale gulper shark | 78 | -2.8 | 1.5 | 78 | -2.9 | 4.1 | 474 |
| Flying squid | 72 | 0.7 | 2.3 | 73 | 0.4 | 7.0 | 1520 |
| Portuguese dogfish | 70 | -1.4 | 3.2 | 78 | -0.4 | 5.0 | 1330 |
| Greater lantern shark | 70 | -0.4 | 3.2 | 86 | -1.2 | 7.3 | 625 |
| Longnose velvet dogfish | 69 | -0.4 | 2.4 | 70 | -1.0 | 6.8 | 1420 |
| Orange roughy | 69 | 0.9 | 7.0 | 75 | 0.0 | 10.2 | 1010 |
| Snake mackerel | 69 | 1.4 | 11.5 | 73 | 0.9 | 10.5 | 1550 |
| Baird's smoothead | 68 | -1.5 | 1.7 | 75 | -1.7 | 7.5 | 976 |
| Wolf-fish | 66 | 0.6 | 10.1 | 73 | 0.3 | 11.4 | 741 |
| Small-eyed rabbitfish | 65 | -2.7 | 2.5 | 72 | -1.3 | 10.5 | 2060 |
| Black scabbard | 64 | 0.1 | 8.9 | 75 | -0.4 | 9.1 | 1090 |
| Birdbeak dogfish | 62 | -1.8 | 2.6 | 71 | -1.9 | 5.7 | 539 |
| Roundnose grenadier | 62 | -1.0 | 6.0 | 69 | -0.8 | 9.0 | 1333 |
| Greater argentine | 61 | -3.7 | 6.4 | 84 | -1.9 | 10.7 | 675 |
| Tusk | 60 | -1.6 | 4.3 | 82 | -0.6 | 9.2 | 1610 |
| Cod | 59 | 0.0 | 4.7 | 72 | -1.3 | 6.5 | 800 |
| Morid cod | 59 | 0.6 | 5.1 | 73 | 0.0 | 8.1 | 816 |
| Blue ling | 58 | 0.9 | 3.4 | 77 | 0.1 | 7.3 | 1550 |
| Rabbitfish | 57 | -0.4 | 3.3 | 74 | -1.6 | 7.1 | 426 |
| Bluemouth rockfish | 56 | 1.4 | 7.3 | 70 | 0.5 | 10.9 | 1140 |
| Forkbeard | 55 | 1.1 | 4.7 | 68 | 0.0 | 7.0 | 825 |
| Blue whiting | 54 | 0.1 | 7.2 | 63 | -0.4 | 9.4 | 1220 |
| Redfish | 54 | 3.9 | 7.3 | 62 | 2.4 | 9.5 | 1250 |
| Ling | 53 | -0.8 | 2.0 | 77 | -0.9 | 7.8 | 1300 |

[1] L = whiteness, +a = redness, -a = greenness; b = yellowness; values are the mean from 5 measurements

[2] Species sorted into order according to L values for raw flesh, from highest to lowest.

most red species, reflecting its name. A pinkish colour was also noticed for wolf-fish, while snake mackerel had brownish coloured flesh, hence relatively high Hunter a and b values.

Pieces (50 g) of the cooked, cooled flesh (from above) were sheared in a Kramer style shear press. Two samples were tested and the mean force

*The leafscale gulper shark has soft flesh.*

required to shear 50 g was determined (Table 4). Fish texture was more influential than colour on fish acceptability. The three least tough species scored 3.0 or less for fillet acceptability, as did the most tough species. Snake mackerel was the only exception: it was tough but very acceptable, perhaps because of its high fat content.

Forkbeard, roundnose grenadier and blue whiting all had a spongy structure with fibres of fish being surrounded by unbound liquid. This may have been due to damage from ice crystals tearing the sarcolemma of the myofibrils during freezing. All the fish were frozen in the same way so it seems that these species are particularly prone to freezing damage.

## AMMONIA CONCENTRATIONS AND MICROBIAL LOADS

Levels of ammonia were established by titration of free nitrogen. Eleven species (Table 5) had more than 15 mg N/100 g, with rabbitfish and bluemouth rockfish having extremely high levels. Oehlenschläger (1997)

Table 5: Ammonia and microbial loads in fish

| Species | Ammonia[1] | Bacteria[2] | Species | Ammonia[1] | Bacteria[2] |
|---|---|---|---|---|---|
| Baird's smoothead | 8.1 | 5.0 | Wolf-fish | 6.7 | 4.8 |
| Black scabbard | 14.8 | 5.4 | Greater argentine | 11.2 | 4.0 |
| Tusk | 17.8 | 3.5 | Leafscale gulper shark | 9.7 | 2.6 |
| Portuguese dogfish | 10.6 | 1.7 | Longnose velvet dogfish | 10.9 | 3.0 |
| Rabbitfish | 207.0 | 4.8 | Roundnose grenadier | 30.3 | 5.0 |
| Birdbeak dogfish | 76.0 | 2.0 | Greater lantern shark | 8.7 | 1.8 |
| Bluemouth rockfish | 209.0 | 3.5 | Orange roughy | 9.7 | 5.7 |
| Small-eyed rabbitfish | 99.7 | 5.4 | Blue whiting | 7.2 | 3.0 |
| Blue ling | 15.5 | 4.5 | Ling | 18.4 | 1.5 |
| Morid cod | 20.8 | 2.5 | Snake mackerel | 9.7 | 3.2 |
| Forkbeard | 27.0 | 3.3 | Redfish | 9.8 | 3.3 |
| Flying squid | 18.6 | 4.0 | | | |

[1] Ammonia concentration (mg N/100 g)

[2] Total viable microbial count ($log_{10}$ colony forming units / g)

stated that ammonia is only a poor indicator of freshness, except for elasmobranch (cartilaginous) fish (*i.e.* sharks) in which it is formed during storage. Indeed, most of the species with high ammonia levels were sharks (dogfish and rabbitfish). Additional samples, caught on different days, were tested and a low ammonia level was found for rabbitfish. If the sample with little ammonia had been tasted it would have scored better for acceptability. Fishermen need to be aware of which species are prone to high ammonia levels and take preventative or corrective action.

Table 5 also shows total viable counts for the raw fish. Only five species had more than 100,000 bacteria per gram but none had more than 600,000 bacteria per gram. Species with very little microbial contamination were sharks and ling. These species received less handling before freezing so there was less chance of the flesh becoming contaminated with bacteria from the gut.

## LEAD, CADMIUM AND MERCURY CONCENTRATIONS

Some deep-water fish are long-lived and orange roughy of over 100 years have been found (Clark, 1995). This poses the concern that, with time, metals could accumulate to unacceptably high levels. Freeze-dried samples of six species were analysed for contaminating heavy metals (Table 6). Lead and cadmium were determined by digestion and atomic absorption, while mercury was analysed by oxidation and atomic fluorescence.

Mercury is the only heavy metal for which there is an EC maximum limit for fishery products (0.5 µg/g wet weight). Some species accumulate mercury more readily than others and so have a higher EC acceptable limit of 1.0 µg/g wet weight; these include black scabbard, Portuguese dogfish, redfish, blue ling and wolf-fish.

For lead and cadmium, there are no EC standards; however a number of Contracting Parties to the Oslo and Paris Conventions (OSPAR) have developed standards and guidance values for contaminants in marine foodstuffs. The strictest of these are shown in Table 6. All the fish tested in the current study were well within the standards. It should be noted, however, that this was a small study of only six fish of unknown age. A more in-depth study on contaminants of deep-water fish is underway at the Fisheries Research Centre, Dublin.

**Table 6:** Lead, cadmium and mercury concentrations of selected fish species

| Species | Lead[1] | Cadmium[1] | Mercury[1] |
|---|---|---|---|
| Black scabbard | 0.0058 | 0.0043 | 0.0002 |
| Greater argentine | 0.0146 | 0.0034 | 0.0001 |
| Portuguese dogfish | 0.0101 | 0.0056 | 0.0024 |
| Roundnose grenadier | 0.0050 | 0.0069 | 0.0001 |
| Orange roughy | 0.0039 | 0.0034 | 0.0002 |
| Morid cod | 0.0060 | 0.0018 | 0.0005 |
| **Standard** | **0.5**[2] | **0.1**[2] | **0.5**[3] |

1 Concentration (µg/g wet weight) calculated using water contents shown in table 7

2 Dutch standard, which is the strictest maximum limit used by countries participating in the Oslo and Paris Conventions

3 EC maximum limit, but a higher value of 1.0 is set for some species including black scabbard and Portuguese dogfish

## PROXIMATE ANALYSIS

Water content was determined by oven drying, protein content by a Leco nitrogen analyser and salt (sodium chloride) by titration of the reconstituted ash. Lipids were extracted and analysed by Fourier transform infra red spectroscopy. The results are shown in Table 7.

Water contents of the different species ranged from 80.8 to 86.4% and were similar to that reported for frozen cod steaks, 83.9% (Holland *et al*, 1991). The

**Table 7:** Composition of flesh of under-utilised fish species

| Species | Water % | Protein % | Lipid % | Ash % | Salt % |
|---|---|---|---|---|---|
| Baird's smoothead | 80.8 | 12.9 | 4.3 | 1.0 | 0.4 |
| Birdbeak dogfish | 82.8 | 25.2 | 0.2 | 0.9 | 0.2 |
| Black scabbard | 84.0 | 19.5 | 1.1 | 1.2 | 0.4 |
| Blue ling | 81.6 | 16.4 | 0.3 | 0.8 | 0.2 |
| Blue whiting | 82.3 | 9.8 | 0.6 | 2.0 | 1.3 |
| Bluemouth rockfish | 82.6 | 19.5 | 0.7 | 1.2 | 0.4 |
| Flying squid | 83.0 | 16.8 | 0.4 | 1.4 | 0.4 |
| Forkbeard | 82.6 | 17.1 | 1.1 | 1.3 | 0.7 |
| Greater argentine | 85.4 | 17.9 | 0.6 | 1.4 | 0.7 |
| Greater lantern shark | 82.7 | 21.5 | 0.3 | 1.2 | 0.4 |
| Leafscale gulper shark | 82.7 | 22.0 | 0.6 | 0.8 | 0.3 |
| Ling | 82.2 | 18.3 | 0.3 | 1.3 | 0.2 |
| Longnose velvet dogfish | 83.0 | 23.5 | 0.6 | 1.0 | 0.1 |
| Morid cod | 82.5 | 17.3 | 0.4 | 1.1 | 0.2 |
| Orange roughy | 82.9 | 16.4 | 7.2 | 1.0 | 0.4 |
| Portuguese dogfish | 82.0 | 22.4 | 0.5 | 0.9 | 0.3 |
| Rabbitfish | 83.0 | 15.1 | 0.6 | 1.5 | 0.7 |
| Redfish | 83.2 | nd | nd | 1.2 | 0.4 |
| Roundnose grenadier | 82.7 | 15.2 | 0.5 | 1.1 | 0.5 |
| Small-eyed rabbitfish | 82.2 | 20.3 | 0.7 | 1.3 | 0.6 |
| Snake mackerel | 86.4 | 16.4 | 16.2 | 1.2 | 0.4 |
| Tusk | 82.7 | 19.6 | 0.4 | 0.9 | 0.2 |
| Wolf-fish | 82.8 | 13.5 | 6.1 | 1.9 | 0.5 |

% = percentage content of the wet weight

nd = not determined

values are for thawed fish and are likely to be lower than for fresh fish due to water migration during frozen storage and drip loss during thawing.

Protein contents varied from 9.8 to 25.2%; for bony fish they were similar to that of cod (15.6% [Holland et al, 1991]), except that blue whiting was exceptionally low (9.8%) in protein. The protein contents listed for shark species were higher (~22%) but this is partly because sharks contain a high proportion of non-protein nitrogen (Holland et al, 1991) which was measured as protein in the assay used here.

Lipid content was less than 1.1% for 18 species but ranged from 4.25 to 16.2% for four species. Salt contents ranged from 0.1 to 0.7%, except for blue whiting which had 1.3% salt. This species came from a different supplier and it is possible that the salt concentration was increased by storing the fish in refrigerated sea-water. Carbohydrate contents were zero or negligible.

Gormley *et al* (1993) determined water, protein and fat contents of five frozen deep-water fish species. The main differences were that, for Baird's smoothead, the water content was higher (91%) and the protein (6%) and fat (1.8%) were lower than in the present study, while, for black scabbard, the water content was lower (74%) and fat content much higher (7%) (2.7% in an unpublished study), and for forkbeard, the fat content was a little lower (0.1%) than in the present study. The differences in water and protein contents are likely to be due to variation in water content caused by water migration and drip loss. Fat contents are known to vary considerably with season and location for fatty fish like mackerel and perhaps this is also true for black scabbard. It would be interesting to investigate this variation in fat content as fat can have a big influence on taste acceptability and shelf-life.

Other factors, such as flavour, texture and stock density, are, and will be, far more influential on the selection of deep-water fish species for exploitation, than the fish composition. Nevertheless, this nutritional information is vital for species that may be commercialised.

## LIPID COMPOSITION

Consumption of marine polyunsaturated fatty acids (PUFAs) induces beneficial changes in blood plasma lipids, and is associated with the low incidence of coronary heart disease in Greenland and Japan (Ahmad, 1998).

Measurement of ω–3 PUFAs was done to allow an assessment of the contribution that deep-water fish could make to dietary intake of ω-3 PUFAs. None of the species were rich sources of ω-3 PUFAs. Most species had low fat levels (below 1.1%) and so even the species with more than 50% of their lipids as ω-3 PUFAs (tusk, blue whiting, ling and flying squid) had lower levels per gram of fish than cod (about 0.3%). The highest concentrations of ω-3 PUFAs per gram of fish (1.15% for snake mackerel, 0.69% for wolf-fish and 0.66% for orange roughy) were in species with high fat levels. However, salmon, for example, can have more than 5% of ω-3 PUFAs.

Snake mackerel and orange roughy contained high levels of indigestible wax esters. Spark and deWit (1980) reported that fish of high wax ester content were not permitted for sale in Japan. Although wax esters are not of nutritional benefit they have many other industrial uses and 1000 tons of orange roughy oil per year have been produced in New Zealand (Body *et al*, 1985).

## YIELD FROM FROZEN FISH

Drip loss on thawing, yield of mince flesh from the frozen fillets and cook loss were determined for each species (Table 8). Drip loss on thawing ranged among the species from 1% to 40% while cook loss ranged from 6% to 54%. Drip loss is an indicator of tissue damage. Many of the deep-water species had much higher drip loss values than cod (~1%) and four species lost more than 20% (w/w) as drip. Baird's smoothead had particularly high drip and cook losses and Gormley *et al* (1994) previously found that it had a poor water holding capacity.

Mince yield ranged from 16% for wolf-fish to 78% for forkbeard and flying squid. The mince yield values varied considerably between replicates (this is why individual results are shown in Table 8) because they had different proportions of skin and bone. The shark species tended to have poor yields because their cartilage was not removed on the boats; species with high drip loss also had poor mince yields. Filleting yield is a more useful measurement for fish processors, but this was not possible in this study as whole fish were not provided.

**Table 8:** Drip loss, mince yield and cook loss of deep-water fish

| Fish species | Drip loss[1] (%) | Mince yield[2] (%) | Cook loss[1] (%) |
|---|---|---|---|
| Baird's smoothead | 39 | 30 (36, 24) | 54 |
| Wolf-fish | 40 | 16 (16, nd) | nd |
| Black scabbard | 9 | 50 (67, 33) | 22 |
| Greater argentine | 3 | 63 (63, nd) | nd |
| Tusk | 8 | 60 (64, 55) | 28 |
| Leafscale gulper shark | 24 | 39 (54, 24) | 22 |
| Portuguese dogfish | 11 | 37 (44, 31) | 25 |
| Longnose velvet dogfish | 19 | 39 (55, 39) | 26 |
| Rabbitfish | 1 | 68 (79, 57) | 17 |
| Roundnose grenadier | 24 | 37 (53, 20) | 30 |
| Birdbeak dogfish | 7 | 42 (50, 34) | 6 |
| Greater lantern shark | 12 | 40 (60, 20) | 30 |
| Bluemouth rockfish | 9 | 47 (65, 29) | 24 |
| Orange roughy | 13 | 54 (63, 46) | 27 |
| Small-eyed rabbitfish | 14 | 31 (39, 23) | 43 |
| Blue whiting | nd | nd | 28 |
| Blue ling | 16 | 58 (67, 49) | 25 |
| Ling | 1 | 32 (48, 17) | 24 |
| Morid cod | 4 | 77 (90, 64) | 24 |
| Snake mackerel | nd | nd | 23 |
| Forkbeard | 9 | 78 (89, 67) | 16 |
| Redfish | nd | nd | nd |
| Flying squid | 5 | 78 (82, 73) | 15 |

[1] mean of 2 determinations
[2] mean of the 2 determinations shown in brackets
nd = not determined

## EFFECTS OF MULTIPLE FREEZING OF FILLETS

Re-freezing of fish is not recommended to the general public as it can spoil fish quality and increase the risk of food poisoning, but when carried out properly by commercial fish processors it can be a useful technique. However, freezing can damage fish structure and some fish species are more susceptible than others.

Portions of five fish species were thawed at 4°C for 24 h and drip loss, centrifugal liquid loss and shear value were measured. The remaining fish was refrozen in an air-blast freezer at –30°C for 2 h. The thawing, testing and freezing procedure was repeated twice, except that there was no final freezing step. The fish used in the final tests therefore had, since capture, been frozen three times.

For all species, drip loss occurred for every thawing, but the amount (as a percentage of the weight) decreased on each thaw. For four species (Portuguese dogfish, leafscale gulper shark, roundnose grenadier, forkbeard), drip loss after the first thaw was high (~20%), but was much less (~6%) after the second thaw and just 2% after the third thaw. Black scabbard, however, lost much less (9%) during the first thaw but then lost slightly more than the other species during the second and third thaws.

The loss of additional liquid when a force is applied to the fish has relevance for fish products made from compressed blocks of fillets or mince. When centrifugal force was applied, the liquid loss was particularly high for roundnose grenadier after its first thaw despite the fact that it had already lost a lot of liquid as free drip. Leafscale gulper shark had the lowest liquid loss during centrifugation which suggests that it was the most suitable of the five species for use in a compressed form.

From a consumer's point of view a large drip loss is undesirable, so fish that has been frozen twice would look better than that which has been frozen only once. However, toughening caused by a second or third freeze-thaw cycle may be unacceptable. For roundnose grenadier, forkbeard and black scabbard the shear value increased after every thawing.

After the final testing, the remaining fish were de-skinned, de-boned and the flesh was minced in a food processor and then used to make sausages that were cooked to form gels. The gel sausages were stored at 4°C overnight, then allowed to equilibrate to room temperature (*ca*. 20°C) before their texture (cohesiveness, elasticity and firmness) and colour were assessed.

For Portuguese dogfish, forkbeard and black scabbard the cohesiveness (compressive force) was significantly greater for gels from fish frozen and thawed three times compared to gels from fish frozen and thawed once. Triple freeze-thawed leafscale gulper shark gels were significantly firmer than the single freeze-thawed ones but there was no significant effect for the other

*A fish gel sausage.*

species. No significant effects on gel elasticity (springiness) of any of the species were found. The colours (Hunter L/b) of the gels were significantly affected by the triple freeze-thawing but for some species the whiteness increased while for others it decreased. It is concluded that freeze-thaw cycles did not reduce the gelling potential of the fish minces, instead it increased gel strength which might be beneficial in the manufacture of some fish products.

## USE OF CRYOPROTECTANTS TO REDUCE FREEZE DAMAGE IN FISH MINCE

Fish mince is more vulnerable to freezing damage than fish fillets (Gormley *et al*, 1991). If freezing damage to fish mince could be reduced, it would increase flexibility in the manufacture of added-value fish products.

Cryoprotectants were added to minced fish with the aim of reducing freezing damage by reducing ice crystal growth and migration of water molecules from the fish proteins. Sodium caseinate, whey protein concentrate (Carbelac), pectin and carrageenan were added (1% or 8% by weight) to minced flesh of six fish species (leafscale gulper shark, Portuguese dogfish, roundnose grenadier, forkbeard, blue ling and black scabbard) and were assessed for their cryoprotective activity on triple-frozen fish.

All of the cryoprotectants tested were effective in increasing the water holding capacity of the fish minces. Sodium caseinate was the most effective but resulted in very viscous mixtures which were difficult to handle. Also, sodium caseinate reduced the strength of fish gels made from the triple-frozen mixtures. Carbelac was the only ingredient that significantly increased gel strength of both shark species, and it made very strong gels with blue ling. Pectin and carrageenan either decreased gel strength or had no effect, depending on the fish species. The strength of fish gels is a useful indicator of the suitability of fish species for use in fish products (Maier *et al*, 1997). Anese and Gormley (1996) found that ingredients that increased fish gel strength were those that reduced water holding capacity of the fish mince. In the absence of cryoprotectants, Portuguese dogfish gave gels with the highest L/b colour ratio and blue ling gave the lowest. Gel colour was affected by the cryoprotectants, with most of the combinations of fish and cryoprotectant resulting in a decrease in L/b ratio (*i.e.* loss of whiteness). However, carrageenan increased the L/b value for both shark species and roundnose grenadier. Pectin was found to introduce a reddish hue to the gels, which could be undesirable in fish products.

The effectiveness of the different ingredients as cryoprotectants was measured by determining the amount of unfreezable water in fish mince. The unfrozen water contents of frozen minces of five fish species (leafscale gulper shark, Portuguese dogfish, forkbeard, tusk and orange roughy) with cryoprotectants were determined using a differential scanning calorimeter. Four dairy ingredients (sodium caseinate, Carbelac, calcium caseinate and milk protein isolate, at an 8% [by weight] inclusion rate) and three polysaccharides (pectin, 1%; carrageenan, 1%; sorbitol 8%) were assessed. All three polysaccharides caused a large increase in unfrozen water content per dry matter for cod; other particularly effective combinations were pectin with tusk or orange roughy, carrageenan with leafscale gulper shark or tusk and sorbitol with forkbeard. Overall, the dairy ingredients were poor with respect to increasing the unfreezable water. Cod was the only species that increased in unfreezable water content with all the dairy ingredients and in particular with milk protein isolate. For the deep-water species (with dairy ingredients), forkbeard with calcium caseinate was the most effective combination.

## USE OF TREHALOSE TO REDUCE FREEZE DAMAGE IN FISH FILLETS

Trehalose, a non-reducing disaccharide sugar, can function in cells as a substitute for water but does not evaporate or freeze; it is thought to act as a barrier that protects the cell structure from deformation (Roser, 1991). It was hoped that introducing trehalose into fish would render it less prone to freezing damage. This was tested by soaking fish in a concentrated trehalose solution so that osmosis resulted in an uptake of trehalose and a loss of water A piece (10 x 5 x 2 cm) of orange roughy flesh was osmotically treated in 50% (w/v) trehalose solution for 1 h at 4°C. The effects of freezing (-35°C), thawing (overnight at 4°C) and cooking (in a sealed bag in a water bath at 80°C) on the sample, compared to an unsoaked control piece, were quanitified by measuring drip loss, cook loss, colour (Minolta chroma meter, Hunter Lab scale) and texture (shear value for 80 g of cooked flesh). Water content was determined after each process step.

The osmotic treatment increased fish mass (due to trehalose uptake) and reduced water content but did not reduce drip loss on thawing or cooking. It had little effect on the whiteness of raw or cooked fish, but it decreased shear value considerably. This is of potential benefit as toughening during freezing and thawing can lead to adverse consumer acceptability.

## CONCLUSIONS

- Fourteen of the twenty-three under-utilised species tested were preferred to cod as fillets, nuggets, fish-cakes or smoked fillets.
- Five other fish species scored at least 3.0 (on a scale of 0 to 6) in taste panels.
- Flying squid was preferred to other commercialised squid species.
- Twenty out of twenty-three species have potential value for the fishing industry.
- The most acceptable species were orange roughy, black scabbard, morid cod and Portuguese dogfish.
- Many species which were very soft or tough as fillets scored much

better as nuggets.

- Orange roughy and snake mackerel lipids were high in wax esters.
- Omega–3 polyunsaturated fatty acid levels were relatively low in the species examined.
- Many species had high drip loss on thawing.
- Freezing damage was reduced by the addition of cryoprotectants.
- The choice of cryoprotectant should be made for each species individually to optimise the desired effect.
- Lead, cadmium and mercury concentrations were low in six species examined.
- High levels of ammonia were found in some species.

It must be stressed that the results recorded in this study are based on spot samples due to the high cost of exploratory deep-water fishing. Successful exploitation of deep-water fish species can only occur if there is a combined effort to develop fishing and processing technology and market demand.

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