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UTILIZATION OF THE RESOURCES OF THE SEA

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(with two text-figures and five tables)

SUMMARY

In a hungry world, we are looking to the sea to provide much of the animal protein needed to feed our ever-increasing population. Fishing has developed in many parts of the Northern Hemisphere to such an extent that further increases in the catch are not possible. In the Southern Hemisphere appreciable increases are still possible but if they are not to be wasted, post-catch utilization must be efficient and effective.

Seafoods are highly perishable products, and it is necessary to process them to extend the shelf life. This paper describes traditional methods of preserving fish, such as freezing, curing, smoking, canning and fermenting; it also considers new methods which make more efficient use of resources and reduce wastage. The advantages of producing fish meal and comminuted fish are also discussed.

The paper looks at the prospects for future growth in the fishing industry and stresses the importance of introducing modern handling and processing techniques.

The relevance of these future developments to the Australian industry and their implications for future product development are considered.

INTRODUCTION

The oceans of the world are an ecosystem consisting of a series of interrelated food chains linking the autotrophic and heterotrophic marine organisms. As in any ecosystem, the sun's energy is trapped by the photosynthesis of plants. The energy fixed by these plants supports a large population of herbivorous and carnivorous animals, ranging from the small krill of the zooplankton to large carnivorous fish and mammals. This ecosystem can be represented as a triangle of decreasing biomass, decreasing because with every step in the food chain there is a significant loss of the energy originally fixed by the plants. Human beings, invaders from outside the aquatic environment, are making increasing use of the plants and animals in the sea.

MAN'S USE OF THE BIOLOGICAL RESOURCES OF THE SEA

Of the world's fish catch, 69% is consumed directly as edible fish products, while most of the remainder (29.5%) is reduced to fish meal and oil. The meal is fed to animals which are subsequently slaughtered and eaten whilst the oil finds many uses in industry, ranging from margarine production to cosmetics.

There is some interest in the possibilities of using fish in other industries. Glue, dyes and leather, for example, have traditionally been made from fish and shellfish, but a lot of research is now being carried out into the possibilities of extracting pharmaceutical products from sea creatures. The juice of abalone, for example, has powerful antibiotic properties and the toxin from puffers is being used in open heart surgery. A small amount of the available seaweed (0.9 million tonnes a year) is harvested, mostly by the Japanese. This is often eaten without further treatment or alternatively it can be processed to yield sodium alginate, a compound used in industries as diverse as icecream manufacture and welding.

Overwhelmingly, our main use of marine organisms is in food production, and it is this field I want to discuss more fully.

PROBLEMS OF UTILIZATION

Fish is one of the most perishable of foodstuffs. Once removed from the water, marine animals are put under severe stress and soon die. When death occurs, the fish is highly susceptible to spoilage from autolysis and bacterial attack. Autolysis occurs when catheptic enzymes released from the lysosomes in the cells begin to hydrolyze protein, and also when the digestive enzymes in the gut begin to attack the walls of the body cavity. Bacteria are confined to the skin, gut and gills of living fish and spread to the flesh after death. Lowering the temperature slows down the rate of reproduction of bacteria and therefore reduces the spread of bacterial decay. A new development called radurization involves treating the fish on board the vessel with radiation to reduce the initial load of bacteria.

Spoilage like all biological phenomena depends on chemical processes, and therefore the rate of spoilage is dependent on temperature. Lowering the temperature by storing the fish in refrigerated sea water or ice slows down the rate of spoilage.

On larger fishing vessels which may stay at sea for a considerable period, fish can be frozen on board and held in that state.

METHODS OF PRESERVATION OF FISH FOR HUMAN CONSUMPTION

A number of processes have been developed for the preservation of fish, and the popularity of the various methods is reflected in the annual statistics of fish utilization for 1972 (table 12).

TABLE 12

UTILIZATION OF THE WORLD FISH CATCH, 1972

Usage	Weight (Million tonnes)	Percentage
Total	64.6	100
Total direct human consumption	45.2	70
Fresh	19.5	30
Freezing	10.8	17
Curing	8.1	12.5
Canning	6.8	10.5
Reduction to meal	19.4	30

Source : FAO (1973)

Reduction of temperature is an obvious way to limit spoilage. Fish can be held in ice at $0^{o}C$ for a maximum of 18 days after catching. This period can be extended to several months or years by lowering the temperature below $-30^{o}C$. Freezing is not a new method of preserving fish. The first British patent for freezing fish was taken out in 1842, and in America commercial fish freezing began in the 1860s. Technological developments since World War II have made it possible to produce a product that is indistinguishable from fresh iced fish. Thus a more regular supply of fish is facilitated. In 1972, 16% of the world's fish catch was processed into frozen products.

It should be noted, however, that the usage of frozen fish is dependent on sophisticated technology requiring refrigerated transport and refrigerated storage at the retail outlet. Thus this method of preservation is useful only in more advanced economies.

Curing is a more traditional way of preserving fish. In 1972, 12% of the world's fish catch was processed in this way. Since the three main methods of curing operate by the same mechanism, i.e. lowering the water activity of the flesh, a brief description of the principle involved will be given.

All living organisms require water for growth and reproduction and spoilage microorganisms are no exception. The chemical activity of water, (A_w), can give an indication of the stability of a product to attack by microorganisms (Scott 1957). The limitations placed on the growth of various classes of microorganisms is shown in table 13.

TABLE 13

APPROXIMATE WATER ACTIVITY VALUES BELOW WHICH GROWTH OF ORGANISMS DOES NOT OCCUR

Organism	A_w
Bacteria	0.9
Yeasts	0.88
Moulds	0.80
Halophilic Bacteria	0.75
Xerophilic Bacteria	0.65
Osmophilic Yeasts	0.61

Source : Mossel and Ingram (1955).

The water activity can be determined from the following formula:

$$\text{Water Activity } (A_w) = \frac{\text{Moles of Water}}{\text{Moles of Water + Moles of Solute}}$$

for example if we add 1 mole of glucose (198 g) to 1000 g of water (55.5 mole)

$$A_w = \frac{55.5}{55 + 1}$$

$$= 0.98$$

It is obvious from the above equation that removal of water without any equivalent removal of solute, or addition of solute without any equivalent increase in water will lead to a decrease in A_w.

Drying foods reduces the number of moles of water without removing the compounds in solution and so lowers the A_w. This increases the stability of food to bacterial attack.

Dried Fish Products

For thousands of years man has known how to preserve fish by drying. Traditional methods of drying usually involve exposing the flesh in the open air to the effects of wind and sun.

This results in a strongly flavoured product that is unattractive in appearance due to enzymic and non-enzymic browning and that may often be rancid due to the oxidation of fats. Improvements have resulted from the introduction of mechanical drying which has enabled the processor to control the rate of drying and has made him independent of the prevailing weather.

Salt Cured Fish Products

Salt curing of fish involves removal of water from the fish into a strong salt solution, and absorption of salt into the fish tissue. This is done by burying split fish in salt or immersing fish in strong salt solution. Body fluids are drawn out of the fish and salt is progressively taken up. This lowers the water activity and inhibits growth of spoilage microorganisms. The fish may be stored in strong salt solutions in airtight barrels, which is known as pickle curing. In dry salting (also known as kench salting) the free liquid is progressively drained off, thus leaving a hard, dry product with a high salt content.

In addition to the preservative effects brought about by drying, the high salt content of the cured fish is toxic to many types of bacteria, and the exclusion of air in pickle curing prevents the growth of aerobic bacteria; hence the process gives a stable product.

Such products, however, have grossly altered textural and taste properties from the original fish. The fish must be soaked in water to reconstitute and to wash out the salt, and so is inconvenient to prepare. In humid climates, the salt will re-absorb water from the atmosphere, raising the water activity and permitting the growth of some yeasts and moulds. For these reasons, salt curing as a method of preservation is being progressively replaced by freezing as the technology of freezing becomes more widely known.

Smoked Fish

Traditionally, smoking was used in association with heavy salting and drying as a means of preserving fish. Most of the preservative effects came from the salting and drying; the chemicals in the smoke, mainly phenols, sterilized only the surface of the fish. The flavour of smoked fish products was better than that of salted and dried products. Today smoking is used to impart this characteristic taste rather than to preserve the fish. Modern smoked products are subjected to less drying and have a lower salt content (2-3%); refrigeration is used to maintain keeping quality.

The traditional smoke kiln is essentially a chimney with a fire in the bottom and racks of fish strung up above. The draught up the chimney and the heat produced by the fire dry the fish. Fish must be rotated from the top to the bottom of the kiln to ensure an even rate of drying; this is a laborious procedure. If the temperature of the smoke in the kiln is allowed to rise to about 77^{o}C the fish is cooked. This process is called hot smoking. If the temperature of the smoke is restricted to below 30^{o}C the flesh will not cook; this is known as cold smoking.

The traditional kiln is very susceptible to changes in climatic conditions, especially relative humidity. A mechanical kiln developed by the Torry Research Station in Aberdeen is now finding wide acceptance. Air is mixed with smoke from external hearths and is blown horizontally along a tunnel containing trolleys of fish. The temperature and relative humidity of the air are artificially controlled and the trolleys are rotated to ensure even smoking. The method reduces the amount of labour required, and eliminates problems of climate.

More precisely controlled smoking can be obtained by dipping the fish in a solution of extracted smoke. Fish are partially dried, dipped in dye to give the characteristic colour, then dipped in liquid smoke. Control of smoking to produce the desired product can be provided by regulating the dipping time.

It has long been known that the carcinogenic chemicals, 3,4-benzpyrenes, are present in smoke, and the use of liquid smoke facilitates the removal of these substances before smoking.

Canned Fish

The two types of spoilage, autolytic and bacterial, can be prevented by heat denaturation of enzymes and destruction of microorganisms. If the material thus heat treated is sealed against re-infection from external sources it can be stored indefinitely. Canning is a process in which a foodstuff is hermetically sealed in a container that is resistant to corrosion from both inside and outside; container and contents are then sterilized to destroy bacteria and autolytic enzymes.

A substantial amount of preparation of fish is necessary before canning. The technology of these processes is well developed and machinery is available which reduces labour costs.

Canning necessarily involves a complete denaturation of the product; the contents of the can are cooked and so this is not merely preservation of the fish but conversion to a different, more stable form.

Fermented Fish

For thousands of years, fish has been preserved by fermentation. The popularity of fermented fish products in Europe reached a peak in Graeco-Roman times but waned with the decline in Roman influence (Badham 1854). Fermentation of fish in the Western world is now restricted to delicacies such as Scandinavian 'tidbits' and French anchovies.

Fermented fish is of real dietary significance now only in Asia, where the people are poor and the hot, humid climate makes wastage of fish due to spoilage a formidable problem. Amano (1962) has estimated that in Vietnam, where daily intake of fish sauce is 40g/head, 7.5% of nitrogen intake is provided by fermented fish sauce alone. The importance of fermented fish products increases in the poorer sectors of society.

The first stage in fermentation of fish is partial curing. The fish may be either gutted or left whole and sufficient salt is added to prevent gross bacterial spoilage (about 13%). Autolysis of the fish protein by digestive and catheptic enzymes produces free amino acids. Restricted growth of microorganisms is permitted to occur as fermentation proceeds. The fish and salt is stored under anaerobic conditions for periods ranging from a few months to years. Sometimes a carbohydrate source such as honey or cereal is added to lower the pH by the formation of organic acids and prevent spoilage. The sauce, called '*nuoc-nam*' in Vietnam, is progressively drained off, one part fish yielding from two to six parts sauce.

These sauces contain appreciable amounts of the breakdown products of proteins, amino acids, creatine, ammonia, trimethylamine and urea. Ammonia and trimethylamine, usually measured as ammoniacal nitrogen, are bacterial spoilage products, and an index of the quality of a sauce can be gained by comparing free amino acid nitrogen with ammoniacal nitrogen; the amino acid content should be high and the ammoniacal content low.

MODERN METHODS OF FISH PROTEIN UTILIZATION

It has been estimated (Moiseev 1973) that a potential increase of 20 million tonnes is possible in the world fish catch. Of this, 1-2 million tonnes is expected to be caught in the seas between Australia and New Zealand. In the year 1972-73, Australia caught only 59,000 tonnes of fish in comparison with about 63,000 tonnes of invertebrate species. Australia heavily exploits its relatively limited stocks of prawns, abalone, scallops and rock lobster to supply the lucrative export market, while relying on imports of cheaper fish products to satisfy local demand. The potential increase referred to above is for demersal species but large schools of pelagic fish will also be exploited. If Australia is to benefit from this increase, it is vital that we develop modern methods of bulk handling and processing of fish. This will require larger vessels, improved docking facilities, and new processing plants tailored to meet the requirements of local species. It will result in development of new products, and substitution of local species for some of the products that are presently imported. We shall now discuss some of the new techniques of utilization that may be adopted.

Utilization of Fish for Animal Feeding

Much of the fish protein available from a food fishing industry is either wasted or not exploited. The offal and scraps from fish filleting operations contain valuable protein. Some species of fish are unpalatable or small and difficult to handle, and therefore are never exploited. Other species are not exploited as fully as they might be. In recent years, a considerable effort has been put into developing processes to convert this wasted fish into a stable feed for livestock.

The fish is converted into dry granules called fish meal, a product that is easily transported and stable to attack from bacteria. The fish oil is separated out, thus yielding a valuable by-product and reducing the likelihood of any rancidity occurring in the meal.

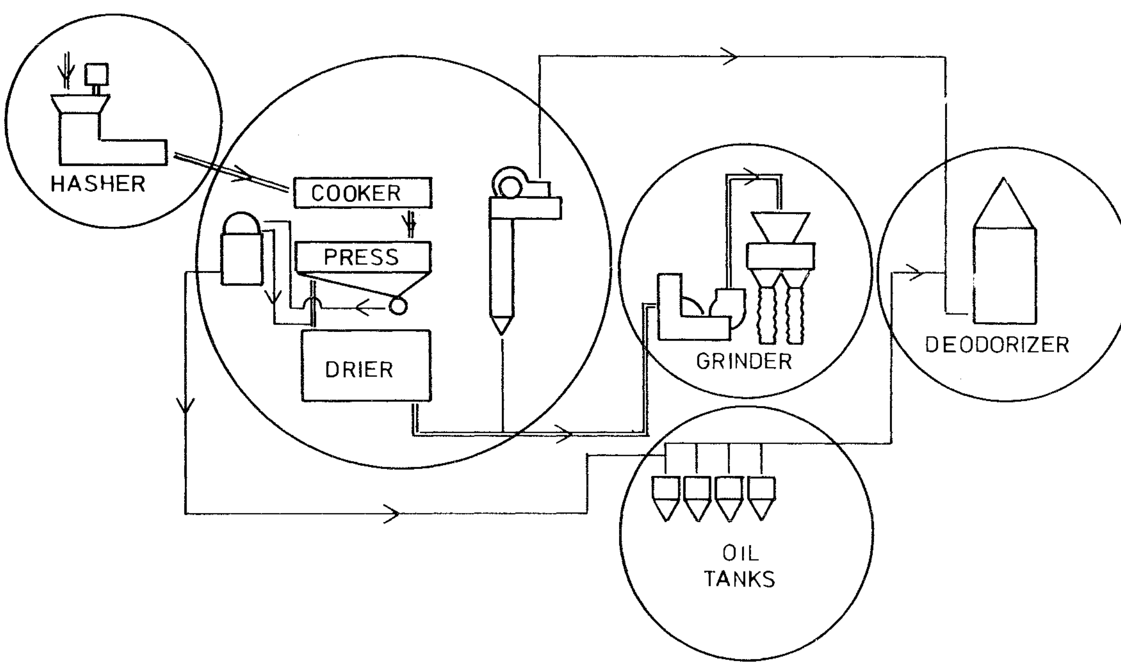

FIG. 34. - Schematic diagram of a fish meal plant.

A typical fish-meal manufacturing process is shown schematically in figure 34.

For a fish meal operation to be successful it is essential to have a reliable supply of cheap raw material. This resource should be readily available in large quantities, highly prolific and suitable for mechanical handling. Some local pelagic species such as jack mackerel are very suitable for this purpose.

TABLE 14

COMPARISON OF THE CHEMICAL COMPOSITION OF RAW FISH AND FISH MEAL

	Raw Fish	Fish Meal
Water (%)	65-70	6-10
Fat (%)	10-15	5-12
Protein (%)	15-20	60-75
Minerals ash etc. (%)	4- 6	10-20

Fish meal is much richer in protein than raw fish (table 14) because most of the water has been removed and this protein is of high nutritive value, being rich in the essential amino acids lysine, methionine and cystine. Because of this rich amino acid content, fish meal can be used to enrich other, poorer quality meals such as feather meal and cereals, which would be less effective or totally unsuitable as feeds by themselves. These blended feeds have proved very successful and consequently the world demand for fish meal is very high, for example in 1971-72, Australia imported 27000 tonnes of fish meal worth A$4 million.

The use of fish meal enables us to use previously under-utilized protein. It can be easily stored and transported to inland areas and then by feeding to livestock, can be converted into a form of food suitable for humans. If fish meal is fed to poultry, 30% of the protein content is ultimately passed on to man. The return from farmed fish fed on meal is higher still, of the order of 40% (Barlow and Burton 1973). The return to man from direct consumption of fish meal would of course be 100%. In order to render fish meal fit for human consumption, it is further refined. This is done by extracting the remaining fat with organic solvents to reduce further any problems of rancidity and extracting the high levels of fluoride which is a constituent of the skeleton. An odourless, flavourless, stable product called fish protein concentrate (FPC) is produced. Unfortunately, early extraction methods produced FPC Type A which although nutritious, had very few functional properties. Further work was then done to develop a process which would produce a protein concentrate that would retain both nutritive and functional properties (Bligh *et al.* 1973). This product is called functional fish protein (FFP). The protein in FFP readily re-hydrates, emulsifies easily, and coagulates on heating. It could find wide application in the food industry, for example as a meat extender in sausages.

There are compelling arguments in favour of development of a fish meal industry. In normal preparation of edible fish products up to 50% of the fish is lost in heading, gutting and filleting. Fish meal can utilize this waste or alternatively whole fish can be used. Such whole fish, if from unexploited or underexploited species, constitute a very real increase in the protein supply of mankind. Fishing for these species, usually referred to as "Industrial Fishing" involves highly sophisticated catching and handling methods, usually carried out by machinery to increase efficiency and reduce labour costs. The expertise gained in adoption of these methods is often of use in the food fish industry. Exports of fish meal can be a valuable source of foreign exchange; in Peru for example, export of fish meal in 1970 earned $US340 million, 32% of the country's foreign exchange earnings. At the same time, such an export industry can take protein out of a developing country where it is needed, to produce poultry and pork for the affluent Western nations.

Utilization

Some developing countries, such as India, prefer to encourage the development of an efficient industry based on small boats. It is argued (George 1973) that such an industry employs labour in an economy where unemployment is high, thus helping to distribute wealth; moreover, small boats can deliver fresh fish to a nearby market without the need for the expensive port handling facilities used by the larger industrial vessels. However, because of the decentralized nature of such an industry, it is often not feasible to set up a fish meal plant to process waste and valuable protein is lost because of the lack of storage facilities. It may be possible to preserve these proteins by making silage. This is a relatively simple process which could be easily applied at the village level. Lowering of the pH can inhibit the spoilage of protein. The pH of fish waste can be lowered to about 3.7 either by the direct addition of acid or by mixing with a source of carbohydrate and innoculating with bacteria which produce lactic acid. In Hobart for example, the CSIRO has succeeded in making a silage from abalone viscera using malted barley or waste from apple processing as a carbohydrate source (Anon 1972).

The demand for edible fish products is increasing, however, and today fish is "the gourmet's delight rather than the poor man's food" (Bligh *et al* 1973). Fish meal manufacturers will be facing increasing competition for raw material as development of edible fish products such as comminuted fish bring more species into the category of food fish.

COMMINUTED FISH PRODUCTS FOR HUMAN CONSUMPTION

Attention has already been drawn to the high wastage of protein in the preparation of edible fish products by conventional means such as filleting and steaking.

In recent years machines have been developed to separate flesh from bones of whole fish or 'frames' (the skeleton after filleting). Such machines produce minced or comminuted fish paste and substantially improve recovery of flesh from fish (table 15).

TABLE 15

YIELD OF MINCED FLESH AND FILLETS FROM SOME PACIFIC OCEAN SPECIES

Species	Yield of Edible Flesh (Percent)	
	Minced	Filleted
English Sole	60	30
Starry Flounder	47	31
Lingcod	43	23
Pacific Cod	38	29

Source : Steinberg (1972)

Minced fish can be used to make a variety of products tailored to suit the consumer such as fish cakes, fish fingers and fish sausage.

Because of the small particle size of the flesh in the product, the processor has the opportunity to use additives to good effect without the problems of penetration that are usually encountered in more solid fish products. Antioxidants can be used to stabilize the product; succulence can be controlled by regulating the moisture content with additives such as polyphosphates; texture can be controlled by regulating particle size, binder, and blending of species; flavour can be controlled by blending species and adding synthetic flavours.

Species which are not presently exploited because they have unacceptable properties can be blended with other species to produce a product that has properties intermediate between the species.

The development of comminuted fish products will increase the available supply of edible fish products. Present markets will be expanded, and by developing new products, new markets will be opened. Fish which is used for fertilizer or animal feed at the present time, will be used directly in the human diet.

Whilst substantial quantities of seafoods are imported into Australia in retail packs (table 16), nearly a quarter of our marine imports (23.5%) come in large wholesale packs, which are broken down and often further processed before distribution to consumers. These fish blocks are often converted into fish fingers, to take one example.

There are good prospects for replacing some of these imported fish with Australian species. With the assistance of a grant from the Fishing Industry Research Committee, the Tasmanian Food Research Unit of the CSIRO Division of Food Research is carrying out investigations aimed at increasing the use of Australian species in comminuted fish products. It should be possible to extract meat from white-fleshed fish, too bony for ordinary use, in order to produce fish blocks and fish fingers.

In addition to research on comminuted fish, it is hoped to demonstrate that there are more profitable ways of utilizing the fish we are exploiting at present. Most of the tuna taken by Australia is canned. If this fish is carefully handled, however, it can be sold to the lucrative raw fish (sashimi) trade in Japan.

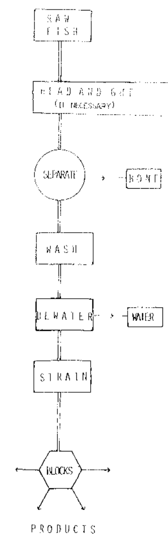

FIG. 35. - Schematic diagram of a process for manufacturing comminuted fish products.

TABLE 16

PRINCIPAL AUSTRALIAN IMPORTS OF MARINE PRODUCE IN 1972-73

	$A'000	Percentage
Fresh or Frozen Products		
Whole Fish	1,667	3.3
Fillets (Retail Pack)	2,015	4.0
Comminuted (Retail Pack)	3,600	7.2
Wholesale Packs (500 g)	11,800	23.5
Crustaceans and molluscs	2,671	5.3
Canned Products		
Fish	14,728	29.3
Crustaceans and molluscs	2,200	4.4
Preserved by Other Means	8,000	15.9
Fish Meal	2,052	4.1
Other	1,453	2.9

Source : Anon (1973b)

FUTURE TRENDS IN FISH PROCESSING

The last 100 years have been a period of rapid growth and development in the fishing industry. Sophisticated processing methods have been introduced for long term storage to augment salting, drying and smoking. Before this time fresh fish was expensive, except at fishing ports, because of the high cost of ice. A complex industry, using the modern technologies of canning and freezing, has grown up to supply high quality seafood products; in addition, a major portion of the increased catch is now being made into useful stockfeed. As demand for seafood increases technologists will make future efforts to use more of the raw material of fish meal production for human feeding. Such developments will be accompanied by more exploration and experimental fishing in regions that are not at present productive, in order to find new kinds of industrial fish and more fish for human consumption. Species and quality will determine the end use but there are also geographical limitations and difficulties in harvesting resources which are known to exist. Fish caught far from available markets are more likely to be converted into fish meal which is relatively easy to transport, than processed for human consumption.

The major known fishing areas are apparently being exploited at their maximum potential. Any new fishing areas will probably yield different species, and present technology will have to be adopted to facilitate the processing of these species into forms that are acceptable to the essentially conservative demand for seafood. The consumer is resistant to change, and although there will always be a demand for high quality fish at ever-increasing prices, the major fishing companies will have to work hard to persuade their customers to buy new species. Recently the British Government, faced with restrictions on fishing around Iceland, has funded research into deep water trawling off the west coast of Ireland (Anon 1973a). The commercial potential of some of the species landed has been demonstrated but the fish were unusual in appearance. There was considerable public aversion when these species were shown on television followed by statements from at least two of the largest fish-processing companies that they would not mislead the public by incorporating these species in their comminuted product (Anon 1974). Some of these fish are extremely palatable, although others are jelly-like or bitter. This incident shows how the conservative tastes of the public can impede development and how big business, in order to avoid short-term problems in the market place, can react in a way that is inimical to its own long-term interests.

Guidelines for future research in fish-processing technology were discussed at length during the FAO Technical Conference on Fishery Products in Tokyo in December 1973. The concensus was that major developments over the next few years will include an increase of fish canning. Such a development will provide safe and convenient products for people in developing countries where refrigeration is unavailable. Canned fish will replace rather than supplement the traditional temperature-stable products. Pelagic species such as jack mackerel are expected to fulfill this market requirement.

The most important development, however, will be the increase in production of re-formed fish products from comminuted fish flesh. The technology needed for this has already been described. Any new products in this range must have high quality and good storage life before they can be introduced commercially. Strong market resistance to unfamiliar products can be expected. The fish technologist is in a difficult position; he attempts to make full use of the available resources to alleviate food shortages whilst he is subject to criticism from a public suspicious that food additives and processed food products are adversely affecting the quality of life. It is not easy to equate these points of view but in any case it will be the marketing man who will have to convince the public that they should eat large quantities of fish that has been mechanically separated, minced, mixed with additives, treated with chemicals, compressed, frozen, thawed, and fried before being served.

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