〈Review〉

Developments and Trends in Fisheries Processing: Value-Added Product Development and Total Resource Utilization

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Changing concepts in fishery science increasingly are recognizing depletion of traditional stocks, utilization of alternate(non-traditional) species, demand for high quality products, and a total resource utilization approach. Innovative practices are occurring in fisheries processing wherein solid and liquid discharges are no longer treated as "waste," but rather as valuable feedstocks for recovery of a variety of value-added ("value enhanced") by-products. Among these are protein hydrolysates, soluble proteins and amino acids, proteolytic enzymes, flavor and flavor extracts, pigments, and biopolymers such as chitosan. Properties and applications of this deacetylated derivative of chitin are noted. Crustacean processing by-products are discussed in terms of their serving as materials for generation of natural flavors and flavor extracts, and products such as fish sauces using contemporary enzymatic techniques. Various food and feed applications of fisheries processing by-products are illustrated with increased usage seen in formulated diets for an expanding aquaculture market. Examples are given of aquaculture becoming increasingly significant in global fisheries resource projections. Critical issues in the international seafood industry include those of seafood quality, processing quality assurance (HACCP), and recognition of the nutritional and health-related properties of fisheries products. A variety of current seafood processing research is discussed, including that of alternate fish species for surimi manufacture and formulation of value-added seafood products from crawfish and blue crab processing operations.

Increasing emphasis is being placed on international aspects of global fisheries and the role of aquaculture in such considerations. Coupled with the need for the aquatic food industry to develop innovative seafood products for the 21st century is that of total resource utilization. Contemporary approaches in seafood processing recognize the need to discard the traditional concept of processing "waste" and adapt a more realistic, and economically sound, approach of usable by-products for food and feed application. For example, in a period of declining natural fishery resources it is no longer feasible to discard fish frames following fillet removal when a significant amount of residual valuable flesh is present that can be readily recovered and properly utilized in a variety of mince-based formulated seafood products.

World Fisheries and Seafood Processing

We can note various particular factors that relate to the changing world of fisheries. These include the high cost of many fishery products, the trend toward fresh products, innovations in processing and packaging, specific changes in processing that involve by-product recovery and manufacture of value-added fishery prducts, growth in global aquaculture, and of great importance, the present declining state of major fish stocks. Added to this list is recognition of the nutritional value of fish and an increased per captita consumption.

The terms "*total resource utilization*", "*by-product recovery*" and "*value-added product*" will be expressed throughout this lecture, and together form the nucleus of a modern fishery effort. Growth in world aquaculture is of particular importance since scientists project that by the turn of the century global aquaculture output will exceed 20million tons, comprising approximately 25% of our total harvestable fishery resource. With particular stocks, such as marine shrimp, this percentage will increase significantly due in large part to the commercial success of penaeid shrimp culture in various regions of the world. By the year 2000, farm-raised shrimp may comprise as much as 50% of the world shrimp market, representing 1.5million tons. Vast marine shrimp culture operations are widespread in Asia, particularly in countries such as Indonesia and Thailand, and in Latin American countries such as Ecuador where the shrimp culure industry comprises a significant portion of the national economy.

Significant changes have occurred in terms of fishery harvests, based on fishing regions as well as in catch of particular species. Fishery and seafood scientists now recognize that the sea is no longer an infinite supply of an expanding resource of wild stock. The maximal sustained yield has been met with various fish species, and exceeded with some, in different regions of the world oceans. Various documentations report that all of the world's major fishing grounds are at, or beyond, their harvestable limits and many have suffered ecologically serious declines. Out of 15 major fishing regions, productivity in all but two has fallen. In four of the hardest hit areas the northwest, west-central, southeast Atlantic, and the east-central Pacific, total fishery catch has shrunk by 30%(Table 1). Eighteen fisheries have seen their productivity reduced by more than 100,000 tons each. Five of these are noted in Table 2. Together, these drops represent a fall of nearly 30 million tons, more than one-third of the 1992 marine catch ! This current status of the world's fisheries clearly supports the premise of total resource utilization, certainly our taking a more prudent look at wasteful fishery practices.

The following table lists what I perceive as major critical issues in the global seafood processing industry, (Table 3). Certainly, others could be added. Note the emphasis placed on product quality and nutritional/health-related properties, concepts present throughout contempory food science. These are items of great importance as governmental re-

Table 1. Change in catch for major marine fishing regions, peak year to 1992*

Region	Peak Year	Peak Catch	1992 Catch	Change
		(...Million	Tons...)	(Percent)
Atlantic Ocean				
Northwest	1973	4.4	2.6	−42%
East Central	1990	4.1	3.3	−20%
Southeast	1973	3.1	1.5	−53%
Pacific Ocean				
Northwest	1988	26.4	23.8	−10%
East Central	1981	1.9	1.3	−31%
Southeast	1989	15.3	13.9	− 9%

*Adapted from World Watch Paper 120. P. Weber. Net Loss: Fish, Jobs, and the Marine Environment, July, 1994.

Table 2. Fishery declines of more than 100,000 tons, peak year to 1992*

Species	Peak Year	Peak Catch	1992 Catch	Decline	Change
			(....Million Tons....)		
Alaskan Pollock	1986	6.8	5.0	1.8	−26%
Japanese Pilchard	1988	5.4	2.5	2.9	−54%
Peruvian Anchovy	1970	13.1	5.5	7.6	−58%
Atlantic Herring	1966	4.1	1.5	2.6	−63%
Atlantic Cod	1968	3.9	1.2	2.7	−69%

*Adapted from World Watch Paper 120. P. Weber. Net Loss: Fish, Jobs, and the Marine Environment, July, 1994.

gulatory pressures lead to ultimate mandatory seafood inspection. Seafood safety and quality assurance are major issues relative to ultimate consumer acceptance of the fishery product. Such considerations are equally significant in projected food use of fishery processing by-products.

Table 3. Critical issues in the global seafood processing industry

Seafood Quality
Prpcessing Quality Assurance (HACCP)
Seafood Inspection
Nutritional/Health-Related Properties of Fisheries Products
Processing by-Producy Recovery
Value-Added Seafood Product

Seafood Safety

It is necessary to be increasingly aware of quality-control measures such as HACCP(Hazard Analysis Critical Control Point), now becoming widespread throughout food industries in the United States. Efforts are in progress to implement a national HACCP-based mandatory seafood safety inspection program. At a 1993 international conference on "Quality Control and Quality Assurance for Seafood, representatives from U.S. regulatory agencies stressed that HACCP-based principles ultimately will guide seafood inspection and that seafood safety may be evolving toward a single global standard. Both processors and importers will be required to adhere to Food and Drug Administration "Hazards and Control Guides" with certification that seafood plants are following HACCP guidelines. A date of June 1, 1995 has been set as the schedule for opening all such plants in the Unitd States to HACCP inspection. It should be noted that 55% of all seafood in the United States is imported, and seafood plants at *points of origin* eventually will be required to adhere to standards similar to those for U.S. seafood facilities.

In development of quality processing by-products for ultimate food use, the raw material must be properly handled in the same approximate manner as fresh seafood. Uniform standards of identity of fishery by-products can be expected. Among critical factors involved in effective utilization of seafood processing by-products are quality assurance as well as economic condiderations. Innovative development of new and competitive products that can enhance the total operational efficiency of the particular processing facility is needed. Similarly, factors such as total resource availability and ease of recovery and logistical problems of collection and handling must be considered in projected use of fishery processing by-products. Characteristics of the latter are of great importance, especially in seafood flavorant recovery where compound lability may negate proper recovery of a high quality product.

Surimi Manufacturing

All of us are familiar with surimi manufacturing and the impact it has had on fishery processing and innovative seafood product development. In 1990, the United States produced approximately 300 million pounds of surimi, mainly from the Alaskan pollock. For every 10 pounds of surimi produced, about one pound of soluble proteins is lost in the wash water during product preparation. Since current market factors, especially resource limitations, may affect future surimi development from pollock, researchers are looking at blends of pollock with other fish such as arrowtooth flounder and whiting in terms of characteristics of final gel formation. Current usage of stocks such as Alaskan pollock may change as demand increases for more profitable food use of th resource. Clearly, all fisheries are in a period of potential dynamic changes.

Trends of importance in the surimi industry germane to this lecture include utilization of flesh from fish frames as well as recovery of proteinaceous material from the surimi process water. Such recovery also allows clarification of the discharge stream for its subsequent re-use within the processing operation. The proteinaceous product can then be added back to the surimi, utilized as a marine protein for fish meal, or as a dietary ingredient in various aquaculture diets. These options will depend on growth in aquaculture as well as emphasis on particular species and their need for sources of marine protein.

Investigations are focusing on possible use of minced flesh from pollock frames for incorporation into food-grade formulated fish products. Such frames usually are discarded after recovery of the fillet during mechanical filleting. In 1993, landings of three billion pounds of round Alaskan pollock for surimi manufacturing resulted in over 900 million pounds of potentially usable frames for food-grade flesh recovery. Such recovery could amount to as much as 35% or 315 *million pounds*, of usable mince. Unquestionably, there will be a notable increase in fish minced-based products, especially those intended for specialty markets or for various ethnic consumers.

In surimi manufacturing, as much as 30~40% of the protein is lost during the washing and de-watering operations. As noted, current research is being directed toward recovery of such material as a valuable proteinaceous by-product as well as a means of reducing the organic load (BOD) of the processing discharge stream. Research has indicated that the amino acid composition of the recovered protein is similar to that of the pollock and surimi itself. Addition of up to 10% of this recovered protein to surimi rsulted in no measurable decrease in the gel strength, elasticity, color, or water-holding capacity. Furthermor, the protein is reported to be highly soluble, with significant amounts of actomyosin and other myofibrillar proteins. Filtration approaches for recovery of the protein and reconditioned water are being developed. It is reported that proteins collected by microfiltration are highly functional and exhibit properties comparable to proteins found in regular surimi.

Fishery Processing By-Products

There are at least three major concepts that must be considered, including that of value-added by-products, total resource utilization, and increased use of underutilized or unutilized species. No longer can we think of material from processing operations as "waste".

A few of such products are noted in the following table (Table 4). Applications include use in

Table 4. Various products from fisheries processing operations

Fish/Crab Minces*
Chitin/Chitosan Biopolymers
Protein Hydrolysates
Soluble Proteins/Amino Acids
Flavor Compounds

*From Fish Frames/Crab Claws and Body Parts for Food Use.

aquaculture feeds and a variety of livestock and pet foods as well as in food products for human consumption (Tabel 5). Ancillary treatment is seen in biotechnological approaches in which selected proteolytic enzymes may be used to treat the raw product under controlled conditions for further product generation, such as production of protein hydrolysates, protein concentrates, or a liquefied fish silage. Currently, commercial proteolytic enzymes are being tested and examined for development of more controlled silage products.

Table 5. Uses of various fisheries processing "wastes" (solids and discharge streams)

● Seafood Flovor Enhancers	⇨ Food Use
● Fish/Crab Minces	⇨ Formulated Seafood Products
● Natural Pigments	⇨ Aquaculture
● Protein Hydrolysates	⇨ Silage
● Natural or Commercial Enzymes	⇨ Further Value-Added Products (Soup Stocks, Microbiological Media, Peptides, Amino Acids)
● Dried Means or Protein Concentrates	⇨ Aquaculture Diets

Fish meal is a major ingredient in aquaculture diets, especially those for carnivorous fish. High-value carnivorous species require feeds containing 40% or more of protein, usually supplied in the form of fish meal. Cost and supply of high quality fish meal has resulted in increased attention being given to alternate sources of plant and animal protein as a partial or complete replacement for fish meal. Soybean meal has been particularly examined for this purpose. In this regard, fishery proteinaceous processing by-products have particular application in aquaculture feeds in regions where availability of fish meal is limited or present in only low grade forms.

As increased levels of plant proteins are used in aquaculture feeds, levels of proteins of marine origin will be used for their palatability value to stimulate feed ingestion. An example of this can be seen in the Korean squid processing industry. Use of processing by-products such as squid meal and squid liver oil find ready application in aquatic diets, especially those for penaeid shrimp. Similar use can be projected in carnivorous fish diets to provide a proper palatability to the feed.

Fish Sauces

Work is in progress on use of proteolytic enzymes i.e., trypsin and chymotrypsin, for production of traditional fish sauces widely used in Southeast Asia. Under controlled fermentation conditions, an acceptable fish (herring) sauce product can be produced with a reduction in fermentation time of from as long as 6~12 months to approximately two months, without compromising product quality. This is but one example of converting a underutilized fish species into a value-added product based on current technologically available approaches.

More and more, fishery by-product development will involve such controlled use of proteolytic enzymes for specific product formulation. As noted subsequently, this approach is being used for production of seafood flavors, especially those from crustacen processing by-products.

Aquaculture and Product Quality

A brief mention of aquaculture-raised products is in order especially in view of the current impact of commercial fish and crustacean culture on seafood commodities worldwide.

As aquaculture increases in global importance, demand is acceleration for high quality feeds most of which contain marine proteinaceous ingredients, especially fish meal. There has been a dramatic increase in demand for aquaculture feed, i.e., from approximately 4.2 million metric tons in 1989 to a projected 14 million metric tons by the year 2000. Value of such feed also has tripled to an estimated $6.6 billion dollars. In 1990 alone, approximately one million tons of feed for farm-raised shrimp was produced. Clearly, fishery processing by-products will play a major role in supplying proteinaceous ingredients for feed used to cultivate a variety of fish, especially marine species.

Apart from actual production, the quality of the aquaculture product is of particular importance. More and more, specific sensory attributes are inherent in farm-raised fish compared with wild stock. These include improved texture, milder and less robust fish flavor, and desired differences in the color/appearance of the skin or flesh. With farmed salmonids (trout, salmon). proper color of the flesh is essential for favorable consumer acceptance. In view of the imporance of fat levels present in the diet and deposition in the fish, considerable focus has been on factors affecting fat levels in farmed fish. Such attention is particularly evident in the channel catfish industry in the United States where a critical quality assurance program has been established. All of these aspects assume significance as fishery-processing by-products are being increasingly used in aquaculture.

Shrimp and Other Crustacean Meals

Crustacean meals, especially crab meal, have been used as a source of the biopolymers chitin and chitosan. Over the years, chitosan has received considerable attention for its proposed application in chemical, biochemical, and food industries. Presently, major commercial applications are used as a coagulant in industrial wastewater treatment and recovery of proteinaceous material from food processing plant discharges. Recently, this approach has been applied successfully on a laboratory basis to wastewater from the Korean tofu manufacturing industry, making possible reduction and recovery of proteinaceous solids from the tofu processing water.

Certainly, recovery and use of shrimp processing by-products has a long history, especially its application as a proteinaceous ingredient in aquaculture shrimp diets. Such use is widespread throughout the extensive shrimp farming industry in Southeast Asia. Properly processed shrimp meal provides (Tabel 6) protein, chitin and minerals, all needed in various degrees by the farmed crustacean. Shrimp head meal itself is especially desirable in view of its high protein level.

Crustacean processing by-products are increasingly being considered as feedstocks for generation of natural seafood flavors and flavor extracts using enzymatic techniques. Examples of raw seafood 'wastes' examined for flavorant recovery include those of clam, lobster, shrimp, crab, and crawfish. Earlier work specifically focused on clam juice recovered from clam processing operation and its proposed use in commercial clam chowder formulations. Numerous flavor-active compounds from various seafood sources have been identified, including free amino acids, sugars, nucleotides, and single compounds such as betaine.

The following discussion of crab and crawfish processing by-products represents research conducted in our laboratories over the past decade. The objective was to develop a more integrated approach wherin recovery of more than a single by-product was possible. Such a composite approach provides operations, especially one in which more than one application is feasible. A further, and significant, advantage is combining efforts that lead to options of both feed and food usages.

Table 6. Protein and chitin (shell) composition of various shrimp meals*

Source	% Protein	% Chitin	% Protein
Dehydrated	37.3	20.6	28.5
Shrimp Hulls	45.9	54.2	22.6
Sun-Dried	51.7	9.0	47.8
Shrimp Heads	58.2	11.1	53.5

*From Meyers, S. P., Utilization of Shrimp Processing Wastes. Infofish Marketing Digest No. 4/86.

Blue Crab Processing By-Product Utilization

The blue crab processing industry in the United States generates as much as 180 million pounds of by-product. This material, comprising about 11% of the live animal weigh, has been traditionally discarded in landfills or further processed into a crab meal. Other uses are its serving as a source of chitin for chitosan production. Studies have shown that mechanical extraction of mixed meat from traditionally discarded by-products recovers a significant amount of edible food-grade product. Allied investigations have focused on undersized blue crab claws using a mechanical meat/shell separator. As much as 60% valuable food-grade mince from picking table by-products and 49% from undersized claws has been documented. Primary attention has been directed to inclusion of the crab claw mince in a crab cake product, sparing use of the expensive whole crab meat. Certainly, other applications are possible.

A schematic of the approach is shown in the following figure (Fig. 1). This allows separation of food-grade and feed-grade by-products, wherein the latter could be used as a source of chitin for chitosan production. The approach warrants serious consideration in other crustacean processing industries in which large amounts of valuable food-grade meat is being treated as waste for disposal purposes.

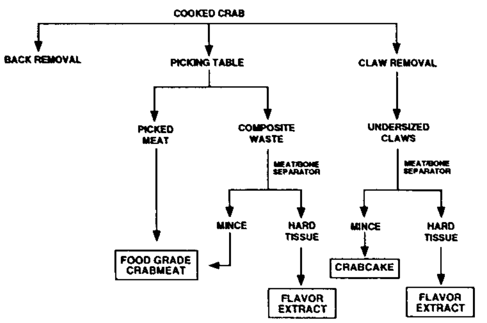


*Figure adapted from Lee, Meyers, and Godber, Minced meat crabcake from blue crab processing by-products development and sensory evaluation. J. Food Sci. 58(1): 99-103. 1993.

Fig. 1. Product recovery from blue crab processing.

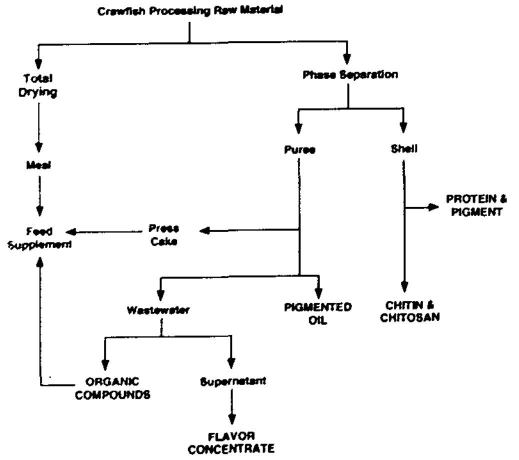
Researchers in our department have focused on use of the fresh crab processing by-product as a substrate for generation of desirable crab flavors. Crab meat itself has been studied to provide a base of identification for volatile compounds that contribute to the authentic crab flavor. It has been found that the majority of volatile compounds in freshly picked crab meat also are present in the fresh processing by-proudct which is hand-separated at the picking tables.

Crawfish By-Product Recovery and Utilization

The Louisiana crawfish culture industry comprises the largest localized concentration of freshwater crustacean aquaculture in the United States with and annual production in excess of one hundred million pounds. Processing plants in the region annually generate more than 80 million pounds of peeling by-product during recovery of the 15% (by weight) edible tail meat. The residue, representing 85% of the biomass, was traditionally discarded in land fills or used at an inexpensive fertilizer. Over the past decade, a series of investigations at Louisiana State University have demonstrated the feasibility of utilization of this renewable resource, especially as a valuable natural source of the carotenoid astaxanthin used in aquaculture as a flesh and integument color enhancer. This one ingredient alone, used in salmonid culture, comprises a multi-million dollar industry.

The composite approach to total product recovery is illustrated in the following schematic (Fig. 2). The spent meal itself is now being utilized, especially in Southeast Asia, as a proteinaceous component in diets for aquaculture-raised shrimp. In Louisiana, the meal is finding application in crawfish baits in traps within the pond system where it serves as a chemosensory-active component to attract the crustaceans. Recently, we have found that portions of the oil extractant can serve as a valuable fish attractant and this is now being used as a commercial product in the sport fishing industry in the United States.

Other studies from the Food Science Department at Louisiana State University have focused on use of fresh crawfish processing by-product as a source of volatile flavor compounds. Ancillary work has applied proteinaceous enzymes for preparation of a suitable flavor concentrate. Analysis of the volatile flavor have documented the presence of a variety of salty and meaty aromas. Among these, thermally generated aromas such as pyrazines make a significant contribution to the characteristic crawfish flavor. In other investigations from our laboratories, we have found the crawfish hepatopancreas to be a rich source of proteolytic enzymes that can be used effectively for extraction of desired flavor compounds.



*From No and Meyers, Utilization of crawfish processing wastes as carotenoids, chitin, and chitosan sources. J. Korean Soc. Food Nutr. 21(3): 318-326. 1992.

Fig. 2. Total utilization of crawfish processing by-products.

Summary

Clearly, results from various seafood processing industries indicate that significant quantities of economically valuable by-products can be recovered and utilized for both feed and food purposes. Markets for such products, especially in aquaculture, are rapidly growing. However, realistic considerations to achieve economically-viable goals must be based on availability of a localized large volume of fresh processing material that can be recovered in an economically-sound manner. Certainly, emphasis in seafood processing must be geared toward a complete resource utilization concept in which the term "*by-product*" replaces that of the traditional "*waste*" designationl. With this approach, the outlook for more innovative and effective fishery processing technology and by-product recovery will become increasingly promising in the coming decade.

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