TOWARDS SUSTAINABLE AND EFFICIENT USE OF FISHERY RESOURCES; PRESENT AND FUTURE TRENDS.

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ABSTRACT.

Present production of wild fish resources is around 85 millions tonnes per year, and the maximum long-term potential of marine capture fisheries of some areas and fisheries has been reached. However, not all that is obtained from the sea is adequatelly used and three clearly differentiated factors can be taken into account to explain this fact: discards, wastes on board and byproducts and wastes ashore. Although some efforts has been employed for changing this situation a more efficient and inteligent use of the natural resources extracted from sea and wasted is needed.

In this article the present utilization of discards and fishery wastes and the future trends and the expected future of fishery industry are presented.

INTRODUCTION

Fishing is an ancient activity and has played an important role to many human societies since the dawn of civilization. As human societies became more organized and adquired technological knowledge their fishing activity changed accordingly. However, it was during the 19th century, and especially during the 20th century, when fishing activity exhibited an expectacular and dramatical change driven by several facts: the invention of freezing technology, the increase in fishing effort by the introduction of steam trawling and all the improvements in fishing gears. Some concern about the decrease of some fish stocks of coastal waters emerged as early as 1885 (Kreuzer, 1974), when in McIntosh's book "*Resources of the sea*" the established idea of the inexhaustibility of the sea was regarded as erroneous, prompting the need to conserve fish stocks.

The state of capture fisheries has been monitored since the creation in the early 1960's of FAO Fishery Resources Division. As a result of these studies, it was observed that the total world marine capture fish production was increasing at a rate of 6% per year since 1950 (19.3 million tonnes) up to 1970 (around 60 million tonnes). The estimations for maximum potential for traditionally exploited marine species, excluding cephalopods, was of 80-100 million tonnes per year, time and further studies have supported these estimations. This amount was overpassed in 1989 with more than 100 million of tonnes and 2002 with 134 million of tonnes. The contribution of marine captures to this production was very high, around 86%, although during the last decades this contribution has diminished thanks to the faster expansion of marine and inland water aquaculture (FAO, 2005).

The present production of wild fish resources of the oceans is 85 millions tonnes, almost the 63% of the total world fish production, giving to the aquaculture an important role in this total production (around 30%) (FAO, 2005). This situation is explained by the changes suffered in highly productive areas and some stocks, where fishing captures suffered stagnation, suggesting that the maximum long-term potential of marine capture fisheries has been reached with these areas and stocks being overfished or some stocks not producing their full expected potential (FAO, 2005).

However, not all that is obtained from the sea is adequatelly used and we can mention three clearly differentiated aspects: discards, wastes on board and byproducts and wastes at land.

Discards

The non intended capture of non-target fish species is a well-known feature of fisheries. This is usually called by-catch and some organisms are retained for sale while others are thrown back to the sea because of either low value or legal requirements (Harrington, Myers & Rosenberg, 2005). It is widely accepted that ecological impacts of by-catch are significant (Kelleher, 2005).

In particular, discarded by-catch is a serious conservation problem because valuable living resources are wasted, populations of endangered species are threatened, stocks already heavily exploited are further impacted and ecosystem changes in the overall structure of trophic webs and habitats may result (Morgan & Chuenpagdee, 2003).

Discards estimation is a very difficult task, some studies were regarded as inaccurate mainly because they were based in data from the 1980s and early 1990s (17.9-39.5 million tonnes/year). More recent estimations based on focused discard studies give lower values (7.3. million tonnes/year) (Kelleher, 2005).

Discards also promote a significant waste of potential food resources. Since global marine fisheries catches are declining (Watson & Pauly, 2001) and competition for depleted stocks is increasing, the ecological, social and economic arguments to decrease by-catch have received greater attention from policy makers, industry and the general public (FAO, 2005).

In this sense, some measures have been taken for the reduction of by-catch, such as the use of more selective fishing gears, the introduction of bycatch and discard regulations, the improvement in the enforcement of regulatory measures, the reduction of effort in some major trawl fisheries and the increased retention of bycatch for direct utilization (market opportunities, fishmeal, silage etc..), etc. However, it is foreseen that the existence of by-catch will continue and, since the future trend for international regulations is directed towards the zero discards, means to convert discards into landed products will be neccesary, developing new markets and proccesing techniques for this type of material.

Wastes on board

In terms of fishing capacity, nowadays there is an important part of the fishing fleet processing the captures on board, generating subproducts (heads, guts, skins, etc.) which are sent back to the sea. Besides partially wasting a natural resource, these practices can generate some impacts such as ecological problems (changes in the ecosystem structure), environmental problems (keeping at sea toxic compounds derived from land: PCBs, dioxines, heavy metals, etc.) and toxicological problems (spreading parasites present in fish viscera, such as Anisakis).

Subproducts and wastes at land

Actual trends are, in one hand, a bigger elaboration and processing of fishery products generating a bigger quantities of wastes at land, and in the other, a bigger concentration of them due to implantation of new larger industries rather than smaller ones, and less and better fish auctions.

Although much of these wastes are being already managed, either for the fish meal and oil production or treated as urban solid waste, it is considered that this kind of utilization/management is poorly efficient and that, with the present technological development, a more smart and profitable use of them is possible.

PRESENT UTILIZATION OF FISH RESOURCES

Fish catches are used mainly for human consumption and other minor uses include meal production, bait, and miscellaneous purposes. Fish for human food represents around 78%, both in developed and developing countries, leaving about 21% for non food uses (Vannuccini, 2004). Therefore, fish and its derived byproducts are considered important from the nutritional point of view, being world average fish consumption of 16 Kg/ person/ year, this is especially true for some areas where the fish consumption per capita is relatively high (James, 1984; Kent, 1987; Sikorski, Kolakowsky, & Pan, 1990).
Fish and parts of fish can have a variety of applications, figure 1 shows some of the uses and potential uses of different parts of fish.

Fish meal

Fish meal is one of the main products obtained from fish waste, bycatch and other abundant species, like anchovy (*Engraulis* sp.), menhaden (*Brevoortia* sp.) and capelin (*Mallotus villosus*) (Hevr∅y, Sandnes & Hemre, 2004). Fish meal is a relatively dry product composed mainly of protein (70%), minerals (10%), fat (9%) and water (8%), it can have different qualities, in terms of aminoacid profile, digestibility and palatability, depending on the raw material used for its production and the type of process employed for obtaining the meal (Gildber, 2002). Fish meal is mostly employed as ingredient in feed of fish and crustaceous. Differences in fish meal quality can affect the growth and feed efficiency ratios (Aksnes & Mundheim, 1997). Fresh raw material and stale raw material can produce significant differences in the content of biogenic amines, such as cadaverine, in the fish meal, reducing feed intake and feed efficiency. Proccess conditions also affect the meal quality, protein digestibility is one of the parameters used to test it, and in general high processing temperature reduces protein digestibility. Therefore, although traditional fish meal was focused in the production of an ingredient for feed from any kind of waste, the trend now is to focus in a better use of marine bycatch and discards and produce a better quality fish meal.

Fish minces and restructurated products

Muscle is the most often used part of the fish since is the edible portion of it. But fish can be dressed before, by hand or using mechanical filleters, and the resulting fillet can constitute the main product, leaving some parts like trimmings, etc. which can be used for different products like minced, restructurates, etc.

Restructured fishery products are products made from minced or chopped muscle. Fish-restructured product have been developed using different binding agents and techniques. The use of transglutaminase as a binding agent is widely extended in food industry to induce covalent cross-linking of proteins, joining pieces of fish muscle (Uresti, Tellez-Luis, Ramirez & Vazquez, 2004).

Surimi products are based upon techniques used traditionally in Japan, and usually the resulting products could have a variety of forms and textures, imitating the characteristics of natural products (Borderias & Perez-Mateos, 2005). Surimi is a paste formed by myofibrillar proteins which is obtained from mechanical deboned fish flesh washed with salt solutions to remove sarcoplasmic proteins and stabilized with the inclussion of cryoprotectants. It is an intermediate product used in a variety of products such as the traditional Japanese *kamaboko* or different preparations of shellfish substitutes (crab legs, crab meat, young eel, etc.).

Collagen and gelatines

Skin, bones and fins are produced as a consequence of the preparation of different fishery products such as fillets, sashimi (sliced raw fresh fish) etc., representing around 30% of the fish fillet processing waste. Fish skin therefore is an important byproduct of the fish-processing industry, causing wastage and pollution. Skins and bones are a rich source of gelatins and collagen, collagen is the major structural protein found in skin and bones of animals, and gelatines are collagen degradation products. Several studies were carried out to obtain collagens from skins, bones, scales, fins of different fish species, and invertebrates, that otherwise may be dumped as waste (Morimura, Nagata, Uemura, Fahimi, Shigematsu & Kida, 2002, Senaratne, Park & Kim, 2006). Nagai & Suzuki (2000) reported the obtention of high yield of collagen from fish skin, bone and fins (about 36-54%). The collagen obtained has potential use for a variety of applications: edible casings for the meat processing industries, cosmetics as it has good moisturizing properties (Swatschek, Schatton, Kellerman, Muller & Kreuter, 2002) and biomedical materials or pharmaceutical applications which includes production of wound dressings, vitreous implants or carriers for drug delivery (Takeshi & Suzuki, 2000). Furthermore, Morimura et al. (2002) found that the hydrolysates derived from fish bone would be suitable as a food additive due its high anti-radical activity.

The outbreak of mad cow disease and the necessity to meet religious requirements (Jewish and Muslim markets), has resulted in an increased attention for fish gelatine, however nowadays the fish gelatine production is still minor, yielding about 1% of the annual world gelatine production of 250,000 tons (Arnesen & Gildberg, 2006). Neverthless, the amount of gelatine used in the food industry worldwide is increasing annually (Montero & Gomez-Guillen, 2000).

Extraction of gelatine has been reported for cod (Gudmundsson & Hafsteinsson, 1997), tilapia (Grossman & Bergman 1992, Jamilah & Harvinder 2002), shark, lungfish and carp skin (Ward & Courts, 1977), snapper (Jongjareonrak, Benjakul, Visessanguan, Prodpran, & Tanaka, 2006), Alaska pollock (Zhou & Regenstein, 2005), Yellowfin tuna (Cho, Gu & Kim, 2005), Sin croaker and Decapterus macrosoma (Cheow, Norizah, Kyaw & Howell, 2006), Cod head (Arnesen & Gildberg, A. 2006).

Choi & Regenstein (2000) found that fish gelatin has similar properties to pork gelatin, but its lower melting point, compared with pork or beef, together with the fact that fish gelatin has a better release of aroma and gives a stronger flavor, could offer new opportunities to product developers. Gómez-Guillén, Turnay, Fernandez-Diaz, Ulmo, Lizarbe & Montero (2002) made a comparative study of the structural and physical properties of gelatin extracted from different marine species, they concluded that the best gelatin preparations regarding the viscoelastic properties and gel strength were those obtained from sole (*Solea vulgaris*) and megrim (*Lepidorhombus boscii*).

Furthermore, the study of Surh, Decker & McClements (2006) provides information about the potential applications of fish gelatins as emulsifiers in food products, demonstrating that fish gelatin stabilized emulsions, remained moderately stable to droplet aggregation and creaming, after being subjected to changes in temperature, salt concentration and pH.

Jongjareonraka et al. (2006) studied and characterized the skin gelatin from two snapper species, finding that strong and transparent edible films could be prepared successfully with these gelatins.

Fish silage and Fish protein hydrolysates

Viscera of fish include the digestive tissues (stomachs, pyloric caeca, intestines, liver, pancreas, etc.) and some other organs like spleen and gonads.

Viscera wastes were used to obtain fish protein hydrolysates (FPH) and fish silages. FPH and silages constitute a broadly accepted nitrogen source for rats, pets, aquaculture, bacteria and other commercially grown organisms (Clausen, Gilberg & Raa 1985; Fagbenro & Jauncey 1998; Coello, Montiel & Concepcion, 2002, Martone, Borla & Sanchez 2005), reducing the cost of nitrogen supply in feeds and culture media (Dufosse, De la Broise & Guerard 2001). Vazquez, Gonzalez & Murado (2004) found that hydrolysates from fish viscera wastes can substitute other peptones for culture of lactic acid bacteria, permitting the production of biomass and bacteriocins, with equal or superior qualities than those obtained with common commercial media. Vidotti, Viegas & Carneiro (2003) evaluated the amino acid composition of silages produced from fish as suplement in fish feeds, as the nutritional value of aquaculture fish diet is determined basically by its amino acid composition. Authors concluded that silages made from fish wastes materials are adequate to be used as an ingredient in balanced diets.

Enzymes

Digestive organs of viscera were investigated to see the possibilities offered by enzymes, mostly proteases, present in them. Applications include biotechnology, clinical applications, diagnosis and physiological processes (Batista & Pires, 2002). The digestive proteolytic enzymes studied include pepsin, trypsin, chymotrypsin, gastricins and elastase. Marine digestive proteases are especially interesting for the food industry due its unique properties, which include high catalytic efficiency at low reaction temperatures, lower thermostability, and cold stability (Simpson, 2000). The specific characteristics which make marine proteases different from terrestrial have emerged by the adaptation of marine animals to special environment conditions, particularly to cold temperatures. In some cases, and it seems to be the trend in the future, enzymes and other recovered products, are obtained from waste material from the fishing industry (Almas 1990, Raa 1990, Haard 1992)

Fish oils

Fish oils can be extracted from the whole fish, skins or livers (in the case of some species). Fish oils are rich sources of polyunsaturated fatty acids, especially eicosapentaenoic acid (EPS) and docosahexanoic acid (DHA), these two compounds have shown different interesting bioactivities. Among the properties of omega-3 fatty acids the best known are: prevention of atherosclerosis (Schacky, 2000), reduction of blood pressure (Appel, Miller, Seidler & Whelton, 1993), protection against arrhytmias (Christensen, Korup, Aaroe, Toft, Moller & Rasmusen, 1997).

Squalene is a lipid found in large quantities in shark liver oil. The large bycatch of shark in fishing industry around the world provides a useful source for fish oils whose value, can be substantially increased by processing it to obtain fractions such as the squalene. Bakes & Nichols (1995) analyzed the liver oils from several deep-sea sharks to describe their composition. For almost all species studied, it was found a high squalene content (50-80% of oil), suggesting that oil from sharks will be suitable for industrial uses. In a more recent study, Catchpole, Grey & Noermark (2000), reports the fractionation of fish oils using supercritical extraction with CO_2 and CO_2 with ethanol mixtures, recovering specific fractions such as squalene. Squalene is an interesting bio-active oil and it has been reported its application in diabetes treatments, cancer and tuberculosis, it also has antifungal and antioxidative properties (Archer, Watson & Denton, 2001).

FUTURE TRENDS IN THE TOTAL UTILIZATION OF FISH

It is clear that the situation of utilization of wastes and discards have changed dramatically from that of the 1950's: now there are more possibilitties for enhancing returns by extraction and utilization of fishery byproducts (Gildberg, 2002), but still there are more to come. In this section we will mention some of these new compounds which can be obtained from fish and that can constitute an incipient industry or the possibility to become so.

Bio-active compounds

New biological active compounds have been isolated from fishery discards, one example is the discover of the antifungal and antibacterial properties of the epidermis, epidermal mucus of different fish species, liver, intestine, stomach, and gills of some fish species (Richards, O'Neill, Thibault & Ewart, 2001; Lijima, 2003) and the blood and shell of some crustaceans.

Fish mucus is known to have important biological functions acting as an immunological barrier (Fletcher & Grant 1969, Austin & MacIntoch 1988; Fouz, Devesa, Gravningen, Barja & Tranzo, 1990; Ingram 1980). A variety of biologically active compounds are responsible for these functions: proteinases, peptides, or polypeptides with high molecular weight, as well as the presence of immunoglobulin, lysozyme or precipitin in the epidermal mucus were reported as fundamental in the avoidance of colonization by bacteria, fungi and other aquatic parasites (Ourth 1980, Smith, Fernandes, Jones, Kemp & Tatner, 2000; Braun, Arnesen, Rinne & Hjelmeland, 1990; Takahashi, Itami & Kajiwaki 1992, Park, Park, Kim & Kim,1998; Nagashima, Kikuchi, Shimakura & Shiomi, 2003).

In another recent study, Patat, Carnegie, Kingsbury, Gross, Chapman & Schey (2004) reported relevant data indicating that shrimp hemocyte histone proteins present antimicrobial activity, representing a defense mechanism for these organisms.

Chitin is a polysaccharide, one of the major components from crustacean shell wastes, and has been found to be a potential source of antimicrobial substances, due the high percentage that shrimp wastes represent at a global scale. Chitosan has strong antimicrobial activity against a variety of microorganisms, and its properties, non-toxic, biocompatible and biodegradable, make it adequate for its applications as a food ingredient and in medical applications, (Tsai & Hwang 2004; Sudarshan, Hooever & Knorr, 1992; Chen, Liau & Tsai, 1998; Fang, Li & Shin, 1994). Suzuki, Owaga, Okura, Hashimoto & Suzuki (1982, 1984) found that chitosan could be used for protection of animals against *Candida albicans* and *Staphylococcus aureus* infections. Also, it was found that chitosan could activate macrophages and cytotoxic T lymphocytes and therefore protecting mice against bacteria infections (Nishimura, Nishimura, Nishi, Saiki, Tokura & Azuma, 1984; Tsai & Su, 1999). It has also some antitumor properties revealed both in vitro and in vivo (Jeom & Kim, 2002). Besides the antimicrobial effect, chitosan has also been identified as effective in reducing LDL-cholesterol levels in liver and blood (Kanauchi, Deuchi, Imasato, Shizukuishi & Kobayashi, 1995), the mechanism suggested is that these compounds act as fat scavengers, removing fat and cholesterol in the digestive tract and promoting their excretion (Ikeda, Suganoi, Yoshida, Sasaki, Iwamoto & Hatano, 1993).

Chitooligosaccharides also exhibited scavenging activity on hydroxyl and superoxide radicals, these being dependent on their molecular weight (Park, Je & Kim, 2003), this property make them potential additives for the inhibition of lipid oxidation in food, but also to prevent some pathological processes associated with free radical modification of cellular compounds, such as atherosclerosis, arthritis, diabetes, inflammatory disorders, and neurological disorders such as Alzheimer’s disease (Frlich & Riederer, 1995).

Other applications of chitin and chitosans are their use as an ingredient of toothpaste, shampoo, hand and body cream, for cell immobilization, and material for production of contact lens (Sugano, Watanabe, Kishi, Izume & Ohtakara, 1988; Shahidi & Synowiecki, 1991).

Pigments

Valuable pigments have been found in a variety of fish raw materials, especially in seafood wastes. Various studies have reported the presence and recovering of pigments such astaxanthin and its esters, β-carotene, lutein, astacene, canthaxanthin and zeaxanthin in crustacean waste.

Carotenoids are a group of fat-soluble pigments that can be found in many plants, algae, micro-organism and animals, and are responsible for the colour of several shellfish. Carotenoids have been extracted using shrimp waste, from processing head and shell of *Penaeus indicus,* applying different organic solvents (Sachindra, Bhaskar & Mahendrakar, 2005). Carotenoids were also extracted from fish eggs as reported Li, Tyndale, Heath & Letcher (2005), and from fish scales waste (Stepnowski, Olafssón, Helgason & Jasturff, 2004). These valuable pigments would be a cheaper alternative applicable to a wide variety of industrial needs such as coloration of some surimi based products or aquaculture feed formulation.

Furthermore, some pigments like asthaxanthin are important in medical and biomedical applications due its high antioxidative effects and to the fact of being a precursor of vitamin A.

Antifreeze proteins

Antifreeze proteins (AFPs), which are found in diverse species of marine fishes, are characterised by their ability to prevent ice from growing upon cooling below the freezing point. This is a protecting method of polar fishes against freezing. Evans & Fletcher (2004), found that snailfish skin tissue contains antifreeze activity that can be purified by chromatography techniques. Some work has also been carried out on the extraction of AFPs from winter flounder (*Pseudopleuronectes americanus*), cunner (*Tautogolabrus adspersus*), sea raven (*Hemitripterus americanus*), and shorthorn sculpin (*Myoxocephalus scorpius*). AFPs have a main application as cryoprotectants since they can prevent freezing damage by their lowering freezing point capacity and the inhibition of ice recystallisation. Some studies revealed that the addition to meat or injection to animals of AFP reduce the damage due to frozen storage of their meat (Payne & Young, 1995).

Lectins

Lectins are sugar-binding proteins that agglutinate cells and/or precipitate glycoconjugates by establishing stable complexes. Lectins are widely found in reproductive cells, eggs and sperms, because of its role in fertilization. The ability of lectins to bind with carbohydrates makes them a suitable alternative for antibiotics, since they can bind the carbohydrate layer in bacterial walls making pathogens unable to cause disease (Kim & Mendis, 2006).

Fish leather

Another use for the fish skin is to process it in leather. The aquatic source of skin would be desirable in areas where green pastures are scarce leading a lack of cattle. Fishes can be converted into leather by similar methods than those already applicable to skins from land animals (Flick & Martin, 2000).

CONCLUDING REMARKS

The main problems to face when trying to implement and enforce management measures in fishery activities, are those related with the infrastructure needed both on board vessels and ashore. Regarding the high perishability of most fish species, immediate processing is needed. This leads to the necessity to establish and implement protocols of by-product separation, classification and storage, as well as proposals for conservation or preprocessing alternatives when possible, either on board or in land, so to maintain the materials in the appropriate processing conditions.

Some of the main obstacles to implement the technology for obtaining benefits from discards and by-catch are the following:

- Scarce investment in new technologies applied to discards and by-catch to obtain higher added-value products.
- Limited storage facilities of trawlers and preference to maximize storage of species with high commercial value, than those discards or by-catch which currently have lower price in markets.
- Lack of a global policy framework and severe legislation regarding discards and by-catch.

The states should enhance good-fishery-practices, and promote standards of conduct in every sector involved in fishery practices, leading the progress of awareness of environmental protection, encouraging the crew to be involved in educational programmes focused on responsible fishing and sustainable development practices.

The implementation of the practices, procedures and machinery to fishing fleets, fish auctions and related industries will induce a substantial degree of innovation inside the related sectors, improving the sustainability of marine resources, the rational exploitation of fisheries, the reduction of pollution, and new employment opportunities and economic activities.

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