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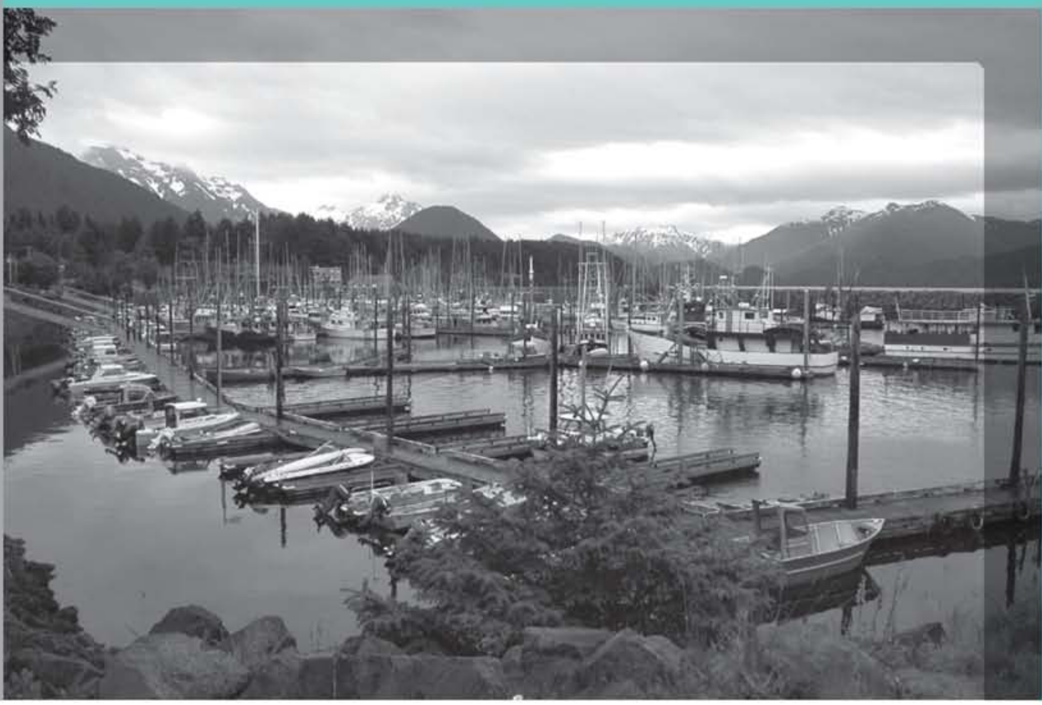
ISSN 2070-6103

Second International Congress on Seafood Technology on Sustainable, Innovative and Healthy Seafood

FAO/The University of Alaska
10–13 May 2010
Anchorage, the United States of America



UNIVERSITY of ALASKA
Many Traditions One Alaska

FAO FIAT PANIS

Cover photo:
Image of Sitka Harbor, Alaska; courtesy of Murat O. Balaban.

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Second International Congress on Seafood Technology on Sustainable, Innovative and Healthy Seafood

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Edited by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2012

ISBN 978-92-5-107108-3

Preparation of this document

These proceedings contain the submitted manuscripts from the Second International Congress on Seafood Technology on Sustainable, Innovative and Healthy Seafood held in Anchorage, the United States of America, from 10 to 13 May 2010. All papers have been reproduced as submitted.

The University of Alaska organized the meeting in collaboration with the FAO Fisheries and Aquaculture Department, and the congress was hosted by The University of Alaska and held at the Hotel Captain Cook in Anchorage.

Abstract

These proceedings contain the manuscripts from the Second International Congress on Seafood Technology on Sustainable, Innovative and Healthy Seafood held in Anchorage, the United States of America from 10 to 13 May 2010. The University of Alaska organized the meeting in collaboration with the FAO Fisheries and Aquaculture Department.

The congress reviewed developments related to:

- international seafood trade;
- consumer trends, consumption and health benefits;
- regulations for market access in international trade;
- recent trends in certification in the seafood sector;
- value-added products and new technologies;
- packaging;
- seafood quality and safety;
- education at college/university level;
- economics; and
- fishmeal and fish oil.

The meeting included a range of views regarding the opportunities and the recent developments in sustainable, innovative and healthy seafood. These included thoughts from government officials, business representatives and academia and highlighted that the seafood industry is in a position to take advantage of the many positive aspects that consumption of seafood offers to consumers, while recognizing that there are still challenges ahead to realize fully the potential that seafood can achieve in international and national trade and in meeting consumer expectations.

Ryder, J.; Ababouch, L.; Balaban, M.
Second International Congress on Seafood Technology on Sustainable, Innovative and Healthy Seafood.
FAO/The University of Alaska. 10–13 May 2010, Anchorage, the United States of America.
FAO Fisheries and Aquaculture Proceedings. No. 22. Rome, FAO. 2012. 238 pp.

Contents

Foreword

Fisheries and aquaculture, as food production industries, have been advancing rapidly in recent decades. Fish is now the most internationally traded food product, with some 37 percent by volume being traded across national borders. This can be traced to the fact that fish is now a popular food commodity with a positive health image and that it generally carries low tariffs. Aquaculture has become a major success story, with more than 250 species in production, and now globally furnishes some 48 percent (2008) of all fish for human consumption. To help boost the demand for fishery products is the increasingly strong evidence with regard to the positive health effects of fish consumption, despite the fact that some fish can carry various contaminants, such as polychlorinated biphenyls (PCBs), dioxins and mercury.

In the last few decades, there have been significant developments in food processing technology that have opened up various new possibilities for more value-added products, longer shelf-life, and more secure distribution of fresh food, to name only a few. This is particularly important for fish and fishery products because of their inherent short shelf-life and their highly oxidative polyunsaturated lipids. Thus, fish are not only some of the most perishable of protein foods of animal origin, but also the sheer number of the very diverse species that are commercially utilized makes fish a very challenging raw material when it comes to processing and distribution.

In recent decades, developing countries have achieved remarkable results in supplying the international market with fish and fishery products. Despite the stringent technical and hygienic demands of the major importers, they now supply more than 50 percent of all imports. FAO has, through various programmes over the years, been heavily involved in assisting developing countries in meeting these demands, not the least of which is the now the internationally accepted Hazard Analysis and Critical Control Point (HACCP) approach. In the past, FAO has convened various conferences and congresses on seafood technology. More recently, an International Congress on Seafood Technology was held from 18 to 21 May 2008 by the Faculty of Fisheries of Ege University in Turkey. FAO joined forces with the co-organizers of that congress, i.e. the University of Alaska, to organize this Second International Congress on Seafood Technology.

The main objective of this Congress was to review the best available knowledge in the main technological fields relating to seafood processing, shelf-life extension and distribution. The most significant progress made in the last 10–15 years in the various fields of seafood processing was reviewed by commissioned papers, in line with the objectives of the FAO Code of Conduct for Responsible Fisheries, Article 11, which relates to post-harvest practices and trade.

Acknowledgements

The Second International Congress on Seafood Technology on Sustainable, Innovative and Healthy Seafood was held in Anchorage, the United States of America, from 10 to 13 May 2010. It was organized by the University of Alaska in collaboration with the FAO Fisheries and Aquaculture Department in Rome, Italy.

The Organizing Committee consisted of:

- Lahsen Ababouch, Food and Agriculture Organization of the United Nations, Rome, Italy.
- Murat Balaban, University of Alaska, United States of America.
- Sukran Cakli, Ege University, Turkey.
- Paula Cullenberg, Alaska SeaGrant Marine Advisory Program, United States of America.
- Kevin O'Sullivan, Office of Fisheries Development for the State of Alaska, United States of America.
- Randy Rice, Alaska Seafood Marketing Institute, United States of America.
- Hart Schwarzenbach, Peter Pan Seafoods, United States of America.
- Grimur Valdimarsson, Food and Agriculture Organization of the United Nations, Rome, Italy.

The task of the Scientific Committee was to select speakers for the individual papers and to ensure that the quality of these is in conformity with expected standards. The composition of the Scientific Committee was as follows:

- Lahsen Ababouch, Food and Agriculture Organization of the United Nations, Rome, Italy.
- Murat Balaban, University of Alaska, United States of America.
- Takashi Hirata, Kyoto University, Japan.
- Hordur Kristinsson, University of Florida, United States of America.
- Chengchiu Liu, Shanghai Ocean University, China.
- Grimur Valdimarsson, Food and Agriculture Organization of the United Nations, Rome, Italy.

The Congress was funded by the Regular Programme of FAO through a Letter of Agreement with the University of Alaska.

The object of the symposium was to bring together leading experts on seafood trade-related issues in order to identify the opportunities and challenges that lie ahead in the sector.

Thanks are extended to all those who made presentations and chaired sessions, with special thanks to those who prepared papers for publication in these proceedings.

Appreciation is also extended to Gloria Loriente of FAO Fisheries and Aquaculture Department for the layout design of this publication.

Welcome address

Dear Colleagues,

On behalf of the Organizing Committee, we are pleased to welcome you to the Second International Congress on Seafood Technology being held from 10 to 13 May 2010 in Anchorage, Alaska, United States of America.

Building on the success of the First Congress in 2008, the 2010 Congress will address state-of-the-art information and innovation regarding handling, processing, preservation, storage and transportation of seafood. World experts will present on key issues addressing the seafood industry such as products and health, safety and quality, integrated traceability, novel products and technologies, education, research and innovation.

The high level panel of guest speakers and the organization of the Congress around key themes will enable you to capture the breakthrough advances of the last decades and envision the broad opportunities and possibilities that exist for more value-added products, longer shelf-life, and more secure distribution of seafood.

In addition, the most recent research results will be presented in concurrent sessions, and in poster sessions during the Congress. This will be an excellent opportunity to interact, network, and exchange information, ideas and business opportunities because this Congress has brought together not only scientists, technologists, seafood processors, but also importers and exporters of seafood, business developers, government administrators responsible for policy development, NGOs and other interested parties from around the globe.

We believe it is most opportune to hold this Seafood Congress in Alaska. The state has been the shining example of sustainable policies, practices, and science-based decision-making for decades and has a long experience and leadership in seafood processing and exporting, clean technologies, value addition, research, and teaching.

We welcome you to the 2nd International Congress on Seafood Technology.

Murat Balaban, Ph.D.
Director and Professor
Fishery Industrial Technology Center
School of Fisheries and Ocean Sciences
University of Alaska Fairbanks

Grimur Valdimarsson, Ph.D.
Director
Fish Products and Industry Division
Fisheries and Aquaculture Department
Food and Agriculture Organization of the United Nations

Programme

Monday, 10 May 2010

08:00 – 17:00	Registration Desk Open
09:00 – 09:15	Opening Ceremony
09:15 – 09:45	Global fish production, utilization and trade. *Lahsen Ababouch*
09:45 – 10:15	Consumer perspectives and expectations. *Jonathan Banks*
10:15 – 10:30	Break / Poster Showcase
10:30 – 11:00	Advances in the development and use of fish processing equipment. *Sveinn Margeirsson*
11:00 – 11:30	Developments in automation of processing equipment. *Kristinn Andersen*
11:30 – 12:00	Heat treated fishery products. *V. Venugopal*
12:00 – 13:30	Lunch
13:30 – 14:00	Processing molluscs, shellfish and cephalopods. *Irineu Batista*
14:00 – 14:30	Vacuum packaging and modified atmosphere. *Jerry Stillinger*
14:30 – 15:00	Sashimi and Sushi products. *Yoko Murata*
15:00 – 15:10	Break / Poster Showcase
15:10 – 15:40	Seafood consumption and health benefits. *Linda Chaves*
15:40 – 16:00	Marine oils and related products. *Schuichi Abe*
16:00 – 16:20	Application of short path distillation to produce human grade Pollock oil. *Alexandra Olivera*
16:30 – 18:30	Welcome Reception and Poster Showcase

Tuesday, 11 May 2010

07:30 – 17:00	Registration Desk Open
07:30 – 08:30	Poster Showcase
08:30 – 09:00	Consumer perceptions of the risks and benefits of farmed fish and fish farmer in Europe. *Anne Katrin Schlag*
09:00 – 09:30	Alternatives to antibiotics in aquaculture. *Iddya Karunasagar*
09:30 – 10:00	Farmed fish welfare during slaughter and automation of selected unit operations in subsequent processing line. *Ulf Erikson*
10:00 – 10:30	Break / Poster Showcase
10:30 – 11:00	Market based standards and certification schemes. *Melanie Siggs*
11:00 – 12:00	Education and training in seafood science and technology. *Murat Balaban*
12:00 – 13:30	Lunch / Poster Showcase Open
13:30 – 14:00	The EU regulatory perspective of seafood safety. *Alan Reilly*
14:00 – 14:30	Regulatory perspective: US FDA safety requirements. *Tim Hansen*
14:30 – 15:00	Bioactive substances from fish waste. *Se-Kwon Kim*
15:00 – 15:20	Break / Poster Showcase
15:20 – 15:40	Utilization of Alaska fish processing by-products. *Peter Bechtel*
15:40 – 16:00	Fish protein hydrolysates as novel ingredients for cryoprotection of frozen fish. *E.C.Y. Li-Chan*
16:00 – 16:20	Bioactive peptides derived from aquatic sources. *H. Kristinsson*
16:20 – 17:00	Final Chance to Visit Posters

Wednesday, 12 May 2010

07:30 – 17:00	Registration Desk
08:30 – 09:00	Economics of value addition for fish and fishery products. *Gunnar Knapp*
09:00 – 09:30	Future of fish meal and fish oil technology. *Jonathan Shepherd*
09:30 – 10:00	Surimi, state of the technology. *Tyre Lanier*
10:00 – 10:20	Break
10:20 – 10:50	Functional Benefits of Marine Phospholipids. *K. Takahashi*
10:50 – 11:10	Optimization of extraction, nanostructure and physical properties of channel catfish skin gelatin. *Yifen Wang*
11:10 – 11:30	Extraction and characterization of collagen from skin, bone and muscle of a trash fish, leatherjacket. *R.J. Shakila*
11:30 – 11:50	Comparison of phospholipids and DHA containing molecular species from the liver of marine and river fish. *Chengchu Liu*
11:50 – 12:10	Traceability technology solution overview. *Paul Lavery*
12:10 – 12:30	Closing session

Breakouts	*Session I*	*Session II*
13:30 – 13:50	Traceability of fish and fish products in Egypt. *Necla Demir*	Contribution of polyphenols and flavonoids to antioxidative capabilities of ethanol extracts from 20 species of marine algae. *Chengchu Liu*
13:50 – 14:10	Seafood authenticity testing systems using PCR -RFLP and bioanalyzer technology. *Lenore Kelly*	Reducing the fat content of fried seafood. *Angee Hunt*
14:10 – 14:30	Rapid and reliable detection of *Salmonella enterocolitica* seravarsin shrimp by multiplex PCR assay. *Geevaretnam Jeyasekaran*	Determining quality changes of salted anchovies produced from previously frozen raw material for a year. *Sevim Kose*
14:30 – 14:50	Microbial risk assessment and process standardization for partially processed value added fish. *DD Namburidir*	Effects of chitosan coatings incorporated with garlic oil on quality characteristics of shrimp. *Emine Asik*
14:50 – 15:10	Break	Break
15:10 – 15:30	Antilisterial properties of liquid smokes applied to seafood products. *Naim Montazeri*	Fat quality variations monitoring in covered Kilka with sodium alginate. *Mina Seifzadeh*
15:30 – 15:50	Effects of individual quick freezing on salmonella recovery and texture of shrimp. *Kathleen Rajkowski*	Production of salted cod from farmed and wild cod. *Cristol Solberg*
15:50 – 16:10	Biogenic amine content of traditional fish products of European and Turkish origin. *Sevim Kose*	Proposed mechanisms of water holding in cooked surimi gels. *Tyre Lanier*
16:10 – 16:30	Break	
16:30 – 17:30	Closing ceremony and announcement of next ICST	

Thursday, 13 May 2010

Various	Optional Tours

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PAPERS PRESENTED AT THE CONGRESS

Fish utilization and trade

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INTRODUCTION

From very ancient times, fisheries have been an important source of food and also a provider of livelihoods and economic benefits for those engaged in harvesting, culturing, processing and trading of fish. Because of their nutritional and health attributes, taste and easy digestibility, fish and seafood are much sought after by a broad cross-section of the world's population, particularly in developing countries. For example, fisheries and aquaculture supply over 1.5 billion people with almost 20 percent of their average animal protein intake and 3 billion people with at least 15 percent of their average animal protein intake (FAO, 2010).

Likewise, fish and seafood are commodities that have been preserved and traded since the Bronze Age. According to FAO (2010), around 32 to 40 percent of fish globally harvested entered international trade over the last 40 years, increasing in value from a mere US$8 billion in 1976 to an estimated export value of US$102 billion in 2008. Developing countries contribute almost 50 percent of the value of world exports of fish and fishery products and their net receipts of foreign exchange (i.e. deducting imports from the value of exports) increased from US$1.8 billion in 1976 to US$27.2 billion in 2008. This is greater than the net exports of other agricultural commodities such as rice, coffee, sugar, tea, banana and meat altogether.

But fish and seafood are highly perishable. Immediately after capture, several chemical and biological changes can take place in the fish flesh and lead to rejection for human consumption because of spoilage. Unfortunately, these fish post-harvest losses remain important, especially in coastal areas of developing countries. Estimated at 10 to 12 million tonnes, they account for more than 8 percent of global fish production, but can reach over 30 percent in some developing countries (Ward, 2007). Understanding the causes of post-harvest losses and the options for their prevention can assist in the choice of the most appropriate and cost effective preservation and utilization methods.

The following sections are analyses of fish and aquaculture production, utilization, economics and trade and of the main issues that need to be addressed to promote responsible fish utilization and trade for a sustainable social and economic development of the fishing and aquaculture communities, while preserving food security and the environment.

FISH PRODUCTION, UTILIZATION AND TRADE

This section is based mainly on the data compiled globally and published by FAO (FAO, 2010).

Production

The world production from capture fisheries and aquaculture remains very significant for global food security and food trade, providing an apparent per capita supply of 17.2 kg (LWE) in 2009. It averaged at 138.2 million tonnes per year during the period 2000 – 2009, with a record high of 145.1 million tonnes in 2009 (Table 1).

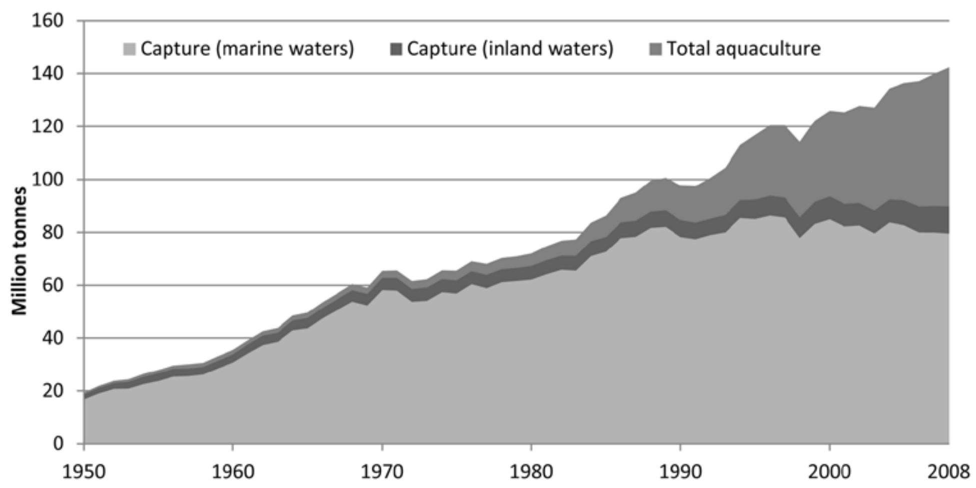
TABLE 1
World fisheries and aquaculture production and utilization 2004–2009

	2004	2005	2006	2007	2008	2009*
				(million tonnes)		
PRODUCTION						
Inland						
Capture	8.6	9.4	9.8	10.0	10.2	10.1
Aquaculture	25.2	26.8	28.7	30.7	32.9	35.0
Total inland	33.8	36.2	38.5	40.6	43.1	45.1
Marine						
Capture	83.8	82.7	80.0	79.9	79.5	79.9
Aquaculture	16.7	17.5	18.6	19.2	19.7	20.1
Total marine	100.5	100.1	98.6	99.2	99.2	100.0
Total capture	92.4	92.1	89.7	89.9	89.7	90.0
Total aquaculture	41.9	44.3	47.4	49.9	52.5	55.1
Total world fisheries	134.3	136.4	137.1	139.8	142.3	145.1
UTILIZATION						
Human consumption	104.4	107.3	110.7	112.7	115.1	117.8
Non-food uses	29.8	29.1	26.3	27.1	27.2	27.3
Population (Billions)	6.4	6.5	6.6	6.7	6.8	6.8
Per capita food fish supply (kg)	16.2	16.5	16.8	16.9	17.1	17.2

Note: Excluding aquatic plants. * FAO Data for 2009 are provisional estimates.
Source: SOFIA, 2010.

While fish production from capture fisheries has stagnated at around 90 to 92 million tonnes over the years, the demand for fish and fishery products has continued to rise (Figure 1). Consumption has more than doubled since 1973. The increasing demand has been steadily met by a robust increase in aquaculture production, estimated at an average 8.3 percent yearly growth during the period 1970–2008, while the world population grew at an average of 1.6 percent per year. As a result, the average annual per capita supply of food fish from aquaculture for human consumption has increased tenfold, from 0.7 kg in 1970 to 7.8 kg in 2008, at an average growth rate of 6.6 percent

FIGURE 1
Global fisheries and aquaculture production 1950–2008

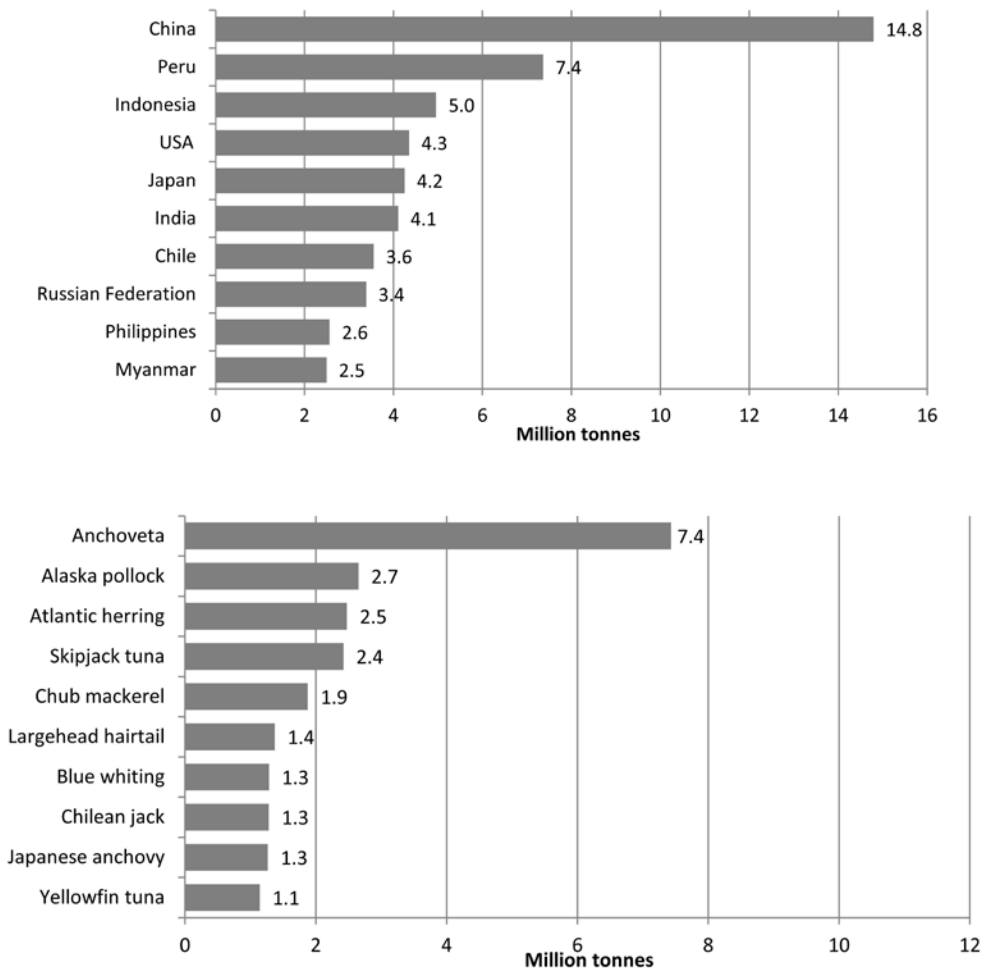


Source: SOFIA, 2010.

per year. This trend is projected to continue, with the contribution of aquaculture to fish food supply estimated to reach 60 percent by 2020, if not before.

Global capture fisheries production in 2008 was about 90 million tonnes, comprising about 80 million tonnes from marine waters and a record 10 million tonnes from inland waters (Table 1). World capture fisheries production has been relatively stable in the past decade, with the exception of marked fluctuations driven by catches of anchoveta – a species extremely susceptible to oceanographic conditions determined by the El Niño Southern Oscillation – in the Southeast Pacific. Fluctuations in other species and regions tend to compensate for each other to a large extent. In 2008, China, Peru and Indonesia were the top producing countries. China remained by far the global leader with production of about 15 million tonnes (Figure 2).

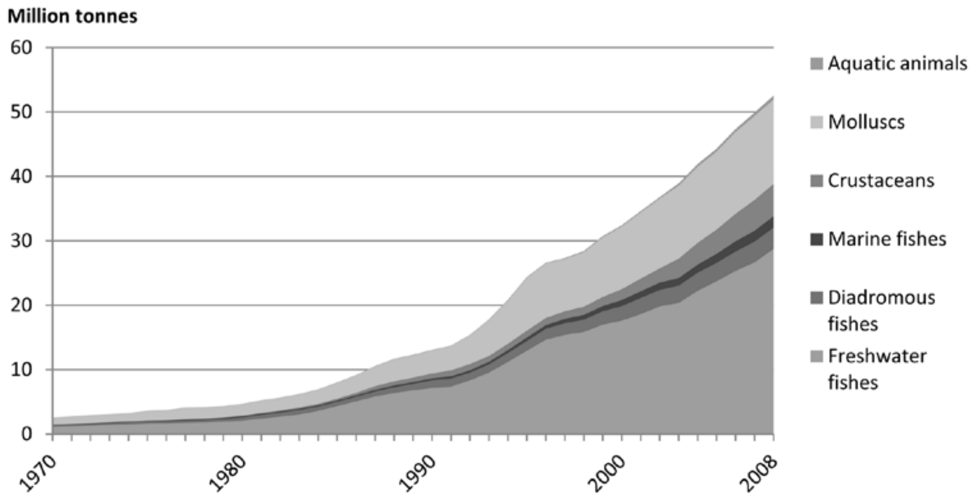
FIGURE 2
Global capture fisheries production in 2008: top ten producers and 10 species



Source: SOFIA, 2010.

From a production of less than one million tonnes per year in the early 1950s, aquaculture grew dramatically to reach 68.3 million tonnes in 2008, including 15.8 million tonnes of aquatic plants. The Asia–Pacific region is the main aquaculture production area, accounting for 89 percent of production in volume and 79 percent in value, China alone accounts for 62 percent by volume and 51 percent by value of total global production (Figure 3 and Table 2).

FIGURE 3
Trends in world aquaculture production: major species group



Source: SOFIA, 2010.

TABLE 2
Top 15 aquaculture producers in 2008

	Production ('000 tonnes)			Average annual rate of growth (Percentage)		
	1990	**2000**	**2008**	**1990-2000**	**2000-2008**	**1990-2008**
China	6 482	21 522	32 736	12.7	5.4	9.4
India	1 017	1 943	3 479	6.7	7.6	7.1
Viet Nam	160	499	2 462	12.0	22.1	16.4
Indonesia	500	789	1 690	4.7	10.0	7.0
Thailand	292	738	1 374	9.7	8.1	9.0
Bangladesh	193	657	1 006	13.1	5.5	9.6
Norway	151	491	844	12.6	7.0	10.0
Chile	32	392	843	28.3	10.1	19.8
Philippines	380	394	741	0.4	8.2	3.8
Japan	804	763	732	-0.5	-0.5	-0.5
Egypt	62	340	694	18.6	9.3	14.4
Myanmar	7	99	675	30.2	27.1	28.8
United States of America	315	456	500	3.8	1.2	2.6
Korea, Republic of	377	293	474	-2.5	6.2	1.3
Taiwan Province of China	333	244	324	-3.1	3.6	-0.2

Notes: Data exclude aquatic plants.
Source: SOFIA, 2010.

However, the growth rates for aquaculture production are slowing, reflecting the impact of a wide range of factors. They also vary greatly among regions. Latin America and the Caribbean showed the highest average annual growth rate (21.1 percent) in the period 1970–2008, followed by the Near East (14.1 percent) and Africa (12.6 percent). During the same period, China's aquaculture production increased at an average annual growth rate of 10.4 percent, although it has declined to 5.4 percent per annum in the new millennium. This is significantly lower than in the 1980s (17.3 percent) and 1990s (12.7 percent). In Europe and North America, the annual growth rate has decreased substantially since 2000 to 1.7 percent and 1.2 percent, respectively. The once-leading countries in aquaculture development, such as France, Japan and Spain, have seen declining production in the past decade. It is expected that, while world aquaculture production will continue to grow in the coming decade, the rate of increase in most regions will slow.

Economics

The fisheries and aquaculture sectors contribute significantly to national economies, income and to the livelihood for millions of people around the world. In 2008, the first sale value of capture fisheries was estimated at US$93.9 billion and that of aquaculture at US$105.8 billion, including US$7.4 billion of aquatic plants. This harvest undergoes primary and secondary processing and distribution, generating additional value at each subsequent step, estimated in 2007 at US$60 billion, US$120 billion and US$120 billion respectively for primary processing, secondary processing and distribution (Gudmundsson, Asche and Nielsen, 2006). This value addition is also accompanied by employment opportunities, especially for women employed in primary and secondary processing in developing countries.

Employment in fisheries and aquaculture has grown substantially in the last three decades, with an average rate of increase of 3.6 percent per year since 1980. It is estimated that, in 2008, 44.9 million people were directly engaged, full time or part time, in capture fisheries and aquaculture, and at least 12 percent of these were women. This represents a 167 percent increase since 1980 (16.7 million people) and also represents 3.5 percent of the 1.3 billion people economically active in the broad agriculture sector worldwide in 2008, compared with 1.8 percent in 1980.

It is also estimated that, for each person employed in capture fisheries and aquaculture production, about three jobs are generated in subsequent activities, for a total of more than 180 million jobs in the fisheries and aquaculture sector. On average, each jobholder provides for three dependants or family members. Thus, the sector is likely to support the livelihoods of a total of about 540 million people, or 8 percent of the world population.

In 2008, 85.5 percent of fishers and fish farmers were in Asia, followed by Africa (9.3 percent), Latin America and the Caribbean (2.9 percent), Europe (1.4 percent), North America (0.7 percent) and Oceania (0.1 percent). China is the country with the highest number of fishers and fish farmers, representing nearly one-third of the world total. Although the highest concentration of people employed in the primary sector is in Asia, the average annual production per person there is only 2.4 tonnes, whereas it is more than 18 tonnes in North America and almost 24 tonnes in Europe. This reflects the degree of industrialization of fishing activities, but also the key social role played by small-scale fisheries in Africa and Asia. The difference is even more evident in the aquaculture sector, where, for example, fish farmers' average annual production in Norway is 172 tonnes per person, as compared with 72 tonnes in Chile, 6 tonnes in China and 2 tonnes in India.

Fish utilization

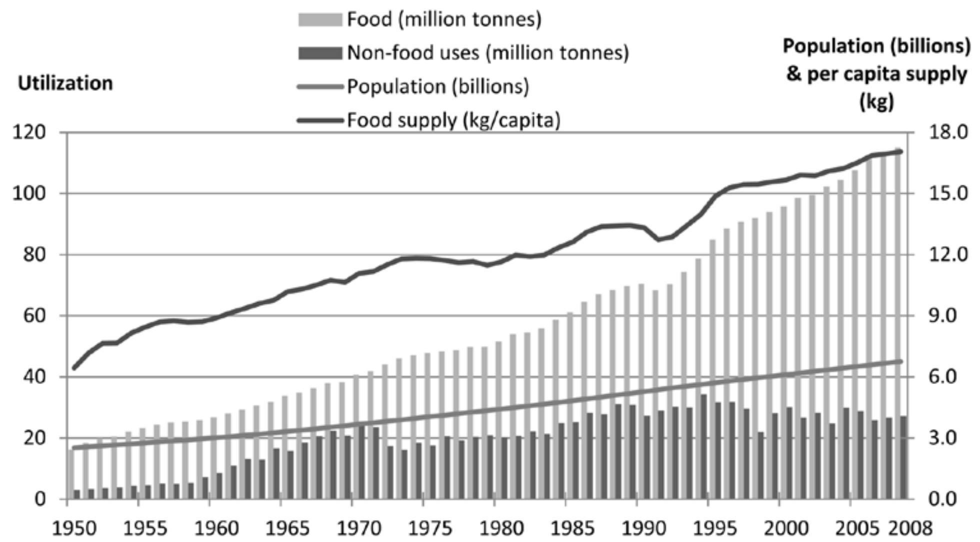
As a highly perishable commodity, fish is often processed to conserve its nutritional properties and prolong its shelf-life. It is estimated that over 1 200 fish and seafood species are harvested commercially worldwide, with a wide variation in appearance, taste and price, although their nutritional attributes are broadly similar, particularly with reference to their protein content (OECD, 1995).

Fish can be processed in a great variety of ways to provide product forms. Fish is generally distributed as live, fresh, chilled, frozen, heat-treated, fermented, dried, smoked, salted, pickled, boiled, fried, freeze-dried, minced, powdered or canned, or as a combination of two or more of these forms. These many options for processing fish cater to a wide range of tastes and presentation preferences, making fish one of the most versatile food commodities. Yet, unlike many other food products, processing does not necessarily lead to a greater value than that of premium fresh fish. In fact, for many finfish species, premium fresh gutted fish can fetch the highest price.

During the period from 2004 to 2009, 104.4 to 117.8 million tonnes, representing on average 80 percent of the annual world fish production, were used for direct human consumption (Table 1). The remaining 27 to 30 million tonnes were destined for non-food products, in particular for the manufacture of fishmeal and oil.

The data in Figure 4 show that the proportion of fish used for direct human consumption has grown since the mid 1990s, mainly because more fish is used as food and less for producing fishmeal and fish oil. Also, the proportion of fish marketed in live/fresh form worldwide increased more significantly over the years compared with other products.

FIGURE 4
Utilization and supply of world fisheries and aquaculture production (1950–2008)

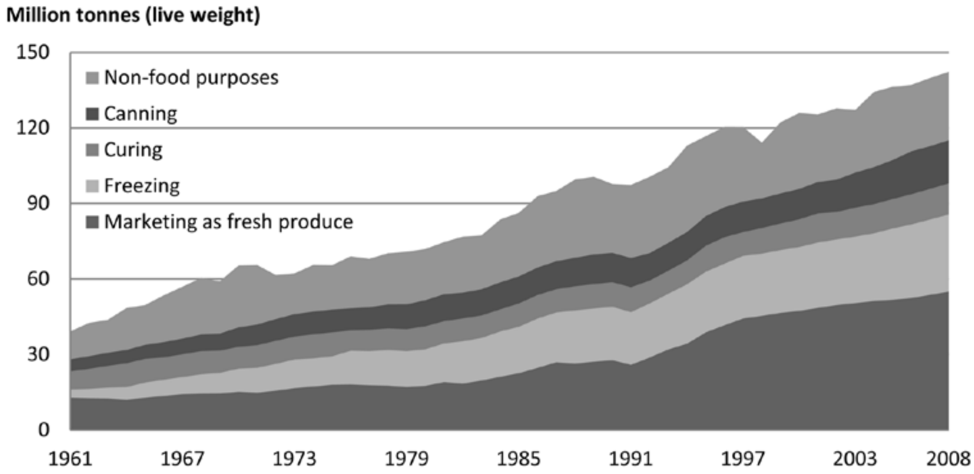


Source: SOFIA, 2010.

Small pelagics, in particular anchoveta, are the main species used for the production of fishmeal and fish oil. The El Niño phenomenon significantly affects anchoveta catches, which have experienced a series of dramatic peaks and drops in the last few decades. Since the peak of 30.2 million tonnes (LWE) in 1994, anchovy catches have fluctuated significantly. In the last three years, they have stabilized at around 21 million tonnes per year.

Of the fish destined for direct human consumption, fish in live or fresh form was the most important product, with a share of 49.1 percent, followed by frozen fish (25.4 percent), prepared or preserved fish (15.0 percent) and cured fish (10.6 percent). Live and fresh fish increased in quantity from 45.4 million tonnes in 1998 to 56.5 million tonnes in 2008. Processed fish for human consumption increased from 46.7 million tonnes in 1998 to 58.6 million tonnes in 2008. Freezing represents the main method of processing fish for human consumption and it accounted for a 49.8 percent share of the total processed fish destined for human consumption and a 20.5 percent share of total fish production in 2008 (Figure 5).

FIGURE 5
Utilization of world fisheries and aquaculture production (1960–2008)



Source: SOFIA, 2010.

However, these general data mask significant differences between continents, regions, countries and even differences within countries. The highest percentage of fishmeal is produced by Latin American countries (47 percent of the total). The proportion of cured fish is higher in Africa (14 percent of the total) compared with other continents (the world average is 8.6 percent). In Europe and North America, more than two-thirds of fish used for human consumption is in frozen and canned forms.

In developing countries of Africa, Asia and Latin America, a large proportion of fish is marketed in live or fresh forms representing 60.0 percent of fish destined for human consumption in 2008. Live fish is particularly appreciated in Asia (especially by the Chinese population) and in niche markets in other countries, mainly among immigrant Asian communities. However, notwithstanding technical changes and innovations, many of these countries still lack adequate infrastructure, especially properly equipped landing centres with access to electricity, potable water, roads, ice plants, cold rooms and refrigerated transport. These factors, combined with tropical temperatures, lead to a high percentage of post-harvest losses and quality deterioration. Market infrastructure and facilities are often limited and congested, increasing the difficulty of marketing perishable goods.

It is worth noting in the last few years that developing countries have experienced a growth in the share of frozen products (18.4 percent in 2008, up from 7.7 percent in 1998) and of prepared or preserved forms (11.8 percent in 2008, compared with 7.8 percent in 1998).

Notwithstanding these differences and limitations, globally the fish industry has been dynamic during the last two decades. Fish utilization and processing have diversified significantly, particularly into high value fresh and processed products, fuelled by changing consumer tastes and advances in technology, packaging, logistics and transport. Processing is becoming more intensive, geographically concentrated, vertically integrated and linked with global supply chains. These changes reflect the increasing globalization of the fisheries value chain, with the growth of international distribution channels controlled by large retailers. More and more producers in developing countries are being linked with, and coordinated by, firms located abroad. The practice of outsourcing processing has gained significance, its extent depending on the species, desired products and cost of labour and transportation. For example, whole fish from Europe and North America are sent to Asia (China in particular, but also India and Viet Nam) for filleting, packing and re-export. In Europe, smoked and marinated products are processed in Central and Eastern Europe, in particular in Poland and in the Baltic countries. European shrimp is peeled in North Africa and tuna loins or canned tuna are prepared in many African and Latin American countries. For some commodities, an entire industry has been delocalized over the years from the developed to the developing world. For example, the preparation of salted anchovies has been moved from Southern European countries to North Africa, mainly Morocco (Ababouch and El Marrakchi, 2009). The further outsourcing of production to developing countries is restricted specifically by sanitary and hygiene requirements that can be difficult to meet. At the same time, processors are frequently becoming more integrated with producers, with large processors in Asia, Africa and Latin America relying on their own fishing vessels or aquaculture farms for the supply of groundfish, salmon, catfish and shrimp to improve the product mix, obtain better yields and respond to evolving quality and safety requirements of importing countries.

In developed countries, innovation in value addition is mainly focused on further development of convenience foods and a wider variety of high value-added products, mainly in fresh, frozen, breaded, smoked or canned forms. These require sophisticated production equipment and methods and, therefore, access to capital. The resulting fish products are commercialized as a variety of branded ready-to-eat meals.

In developing countries on the other hand, because of cheaper labour, manual processing is still widespread for filleting, salting, canning, drying and fermentation, thus providing livelihood opportunities for large numbers of people in coastal areas in these countries. But, in several developing countries, fish processing is evolving towards more value adding processes such as breading, cooking, vacuum packaging or individual quick-freezing. Some of these recent developments are also driven by demand in the domestic retail industry, especially in countries with an expanding middle class, or by a shift in cultured species.

Finally, important innovations have also been achieved in the utilization of fish waste derived from the fish processing industry. Chitin and chitosan obtained from shrimp and crab shells are now used in water treatments, cosmetics and toiletries, food and beverages, agrochemicals and pharmaceuticals. The skin of fish such as shark, salmon, ling, cod, hagfish, tilapia, Nile perch, carp and seabass is used as a source of gelatin as well as for the production of leather to make clothing, shoes, handbags, wallets and belts. Fish collagen is used in the pharmaceutical industry, as are carotenoids and astaxanthins – pigments that can be extracted from crustacean waste. Fish silage and fish protein hydrolysates obtained from fish viscera are finding applications in the pet feed and fish feed industries. A number of anticancer molecules have been discovered following research into marine sponges, bryozoans and cnidarians. These molecules are now chemically synthesized, while research on how to cultivate these sponge species is ongoing. Procedures for the industrial preparation of biofuel from fish waste as well as from seaweeds are being developed and their economic feasibility assessed.

Fish consumption

For many countries, the sector of fisheries and aquaculture is vital for food security, not only for subsistence and small-scale fishers who rely directly on fisheries for food and incomes, but also for consumers who can have access to an excellent source of animal protein that contains all the essential amino acids. It is estimated that one portion of 150 g of fish provides about 50–60 percent of the daily protein requirements for an adult. Fish is also a source of essential micronutrients, including various vitamins and minerals and highly unsaturated fatty acids with well established health benefits (Lewin *et al.*, 2005; Mozaffarian and Rimm, 2006). Although in many countries, especially in developing countries, the average per capita fish consumption is low, fish consumption, even in small quantities, can significantly improve the quality of dietary proteins by complementing the essential amino acids that are often absent or present only in low quantities in vegetable based diets.

Total and per capita fish food supplies have expanded significantly in the last five decades. Total food fish supply has increased at an annual rate of 3.1 percent since 1961, while the world population has increased by 1.7 percent per year in the same period. Annual per capita fish consumption grew from an average of 9.9 kg in the 1960s to 17.2 kg in 2009 (Table 1 and Figure 5).

Table 3 shows the per capita consumption and the difference between countries and regions reflecting the different levels of availability of fish and other foods, diverse food traditions, tastes, income levels, prices and seasons. Annual per capita apparent fish consumption can vary from less than 1 kg in one country to more than 100 kg in another. Differences are also evident within countries, with consumption usually higher in coastal areas.

TABLE 3
Fish food supply by continent and economic grouping in 2007

	Total fish food supply (million tonnes LWE[1])	Per capita fish food supply (kg/year)
World	113.1	17.0
World excluding China	78.2	14.6
Africa	8.2	8.5
North America	8.2	24.0
Latin America and the Caribbean	5.2	9.2
Asia	74.5	18.5
Europe	16.2	22.2
Oceania	0.9	25.2
Industrialized countries	27.4	28.7
Other developed countries	5.5	13.7
Least developed countries	7.6	9.5
Other developing countries	72.6	16.1
LIFDC[2]s	61.6	14.4
LIFDCs ex China	26.7	9.0

[1] Live weight equivalent.
[2] Low-income food-deficit countries.
Source: SOFIA, 2010.

Countries in the sub-Saharan Africa region have experienced static or decreasing fish consumption, whereas countries of the former Soviet Union in Eastern Europe and Central Asia experienced major declines in the 1990s. The most substantial increases in annual per capita fish consumption have occurred in East Asia (from 10.8 kg in 1961 to 30.1 kg in 2007), Southeast Asia (from 12.7 kg in 1961 to 29.8 kg in 2007) and North Africa (from 2.8 kg in 1961 to 10.1 kg in 2007). China, in particular, has seen dramatic growth in its per capita fish consumption, with an average growth rate of 5.7 percent per year in the period 1961–2007, owing to the substantial increase in aquaculture production. If China is excluded, in 2007, annual per capita fish supply was about 14.6 kg, slightly higher than the average values of the mid 1990s, and lower than the maximum levels registered in the mid 1980s.

The total amount of fish consumed and the species composition of the fish food supply vary according to regions and countries,

In terms of regions, of the 111 million tonnes available for human consumption in 2007, consumption was lower in Africa (8.2 million tonnes, with 8.5 kg per capita), while Asia accounted for two-thirds of total consumption, with 74.5 million tonnes

(18.5 kg per capita), of which 39.6 million tonnes was consumed outside China (14.5 kg per capita). Likewise, per capita consumption was 25.2 for Oceania, 24.0 for North America, 22.2 for Europe, 9.4 for Central America and the Caribbean, and 9.1 kg per capita for South America.

Because of their increasing reliance on fish imports, apparent fish supply rose from 16.7 million tonnes live weight equivalent (LWE) in 1961 to 33.0 million tonnes in 2007 in developed countries and this is forecast to continue because of the increasing demand and the decreasing fisheries production (down 16 percent in the period 1998–2008) in these countries. Apparent fish consumption in developed countries grew from 17.2 kg per capita per year in 1961 to 24.3 kg in 2007. However, the share of fish to animal protein intake, after consistent growth up to 1984, declined from 13.3 percent in 1984 to 12.0 percent in 2007, because of higher consumption of other animal proteins.

Regarding species groups, annual per capita availability of crustaceans grew substantially from 0.4 kg to 1.6 kg and that of molluscs (including cephalopods) from 0.8 kg to 2.5 kg during the period 1961–2007, although consumption of these highly priced species is concentrated mainly in affluent economies. The increasing production of salmon, trout and selected freshwater species has led to a significant growth in annual per capita consumption of freshwater and diadromous species, up from 1.5 kg in 1961 to 5.5 kg in 2007. In the last few years, no major changes have been experienced by the other broader groups. Consumption of demersal and pelagic fish species has stabilized at about 3.0 kg per capita per year. Demersal fish continue to be among the main species favoured by consumers in Northern Europe and in North America (8.5 kg and 7.0 kg per capita per year, respectively, in 2007), whereas cephalopods are mainly preferred by Mediterranean and East Asian countries. Of the 17.0 kg of fish per capita available for consumption in 2007, about 75 percent came from finfish. Shellfish supplied 25 percent (or about 4.1 kg per capita), subdivided into 1.6 kg of crustaceans, 0.6 kg of cephalopods and 1.9 kg of other molluscs. Freshwater and diadromous species accounted for about 36.4 million tonnes of the total supply. Marine finfish species provided about 48.1 million tonnes, of which 20.4 million tonnes were pelagic species, 20.0 million tonnes were demersal fish, and 7.7 million tonnes were unidentified marine fish.

In terms of health benefits, in addition to the provision of high quality animal proteins, fish and fisheries products are a unique sources of the long chained omega-3 fatty acids – docosahexaenoic acid (DHA), essential for an optimal development of the brain and neural system, and eicosapentaenoic acid (EPA), well known to prevent coronary heart disease (CHD) in the adult population (Lewin *et al.*, 2005; Mozaffarian and Rimm, 2006). DHA is a major building block of the human brain where it is mainly incorporated during the period starting at the third trimester of a pregnancy and expanding over the two first years after birth (Martinez, 1992; Lewin *et al.*, 2005). Likewise, a pooled analysis of 19 different studies has shown a 36 percent risk reduction on CHD mortality with a daily consumption of 250 mg/day of long chained omega-3 fatty acids (Mozaffarian and Rimm, 2006). The role of fish consumption in mitigating mental disorders, such as depression and dementia, is increasingly recognized (FAO, 2010).

Furthermore, fish and fisheries products are among the best sources of essential micronutrients. Micronutrient deficiencies are affecting hundreds of million people, particularly women and children in the developing world. More than 250 million children worldwide are at risk of vitamin A deficiency, 200 million people have goitre, and 20 million are mentally retarded as a result of iodine deficiency, 2 billion people (over 30 percent of the world's population) are iron deficient, and 800 000 child deaths per year are attributable to zinc deficiency (WHO, 2007, 2009; De Benoit *et al.*, 2008). Many rural diets in many countries may not be particularly diverse, and thus, it is vital to have access to food that can provide the essential nutrients. Improving access and consumption of fish and seafood could help in combating micronutrient deficiencies. Essential minerals, such as calcium, iodine, zinc, iron and selenium are widely found in fish products, particularly in small species that are consumed whole. Seafood is almost the only natural source of iodine, and iron and zinc are found in significant amounts, particularly in fish species eaten whole such as the small indigenous fish Chanwa pileng (*Esomus longimanus*) from Cambodia. Only 20 grams of this species eaten whole can be one of the best sources of dietary minerals such as iron and zinc, meeting the daily need of iron and zinc of a child (Roos *et al.*, 2007).

Vitamins A, D and the B vitamin complex are found in significant amounts in many fish species such as the small indigenous fish species from Bangladesh, mola (*Amblypharyngodon mola*), which is reported to contain over 2 500 µg Retinol Activity Equivalent of vitamin A in 100 g of fish; making it possible for 140 g of this fish to cover a child's weekly need of vitamin A (Roos *et al.*, 2007).

However, there is a growing public concern regarding the presence of chemical contaminants in fish. This concern has become more apparent in recent years, while during the same period the multiple nutritional benefits of including fish in the diet have become increasingly clear. Some fish species are known to contain contaminants such as methyl mercury and dioxins. While the levels of such contaminants in seafood are well below the maximum levels established for their safe intake, some long-lived predator species can contain levels of these contaminants that exceed the levels regarded as safe for consumption.

The evolving science in this field has led to questions about how much fish should be eaten, and by whom, in order to minimize the risks of chemical exposures and maximize the health benefits. National authorities have been faced with the challenge of communicating complicated and nuanced messages to consumers and also with questions on regulating maximum levels of these chemical contaminants in fish and other foods.

A recent FAO/WHO Expert Consultation on the Risks and Benefits of Fish Consumption reviewed data on nutrient and specific chemical contaminant levels in a range of fish species, as well as recent scientific literature covering the risks and benefits of fish consumption (FAO, 2010). The review was used to consider risk–benefit assessments for specific end points of benefits and risks, including for sensitive groups of the population. The output is intended to provide guidance to national food safety authorities and the Codex Alimentarius Commission in their work on managing risks, taking into account the existing data on the benefits of eating fish.

The consultation concluded that:

- Consumption of fish provides energy, protein, and a range of other important nutrients, including the long chain n-3 poly unsaturated fatty acids (LCn3PUFA).
- Eating fish is part of the cultural traditions of many peoples and in some populations is a major source of food and essential nutrients.
- Among the general adult population, consumption of fish, particularly oily fish, lowers the risk of CHD mortality. There is an absence of probable or convincing evidence of CHD risks of methyl mercury. Potential cancer risks of dioxin-like compounds (DLCs) are well below established CHD benefits.
- When considering benefits of LCn3PUFA versus risks of methyl mercury among women of childbearing age – maternal fish consumption lowers the risk of suboptimal neurodevelopment in their offspring compared with women not eating fish in most circumstances evaluated.

- At levels of maternal DLCs intake (from fish and other dietary sources) that do not exceed the provisional tolerable monthly intake (PTMI) of 70 picograms/kg bodyweight/month established by JECFA, neurodevelopmental risk for the foetus is negligible. At levels of maternal DLCs intake (from fish and other dietary sources) that exceed the PTMI, neurodevelopmental risk may no longer be negligible.
- Among infants, young children, and adolescents, the available data are currently insufficient to derive a quantitative framework of health risks and benefits of eating fish. However, healthy dietary patterns that include fish and that are established early in life influence dietary habits and health during adult life.
- In order to minimize risks in target populations, the Consultation recommended a series of steps that member states should take to better assess and manage the risks and benefits of fish consumption and to more effectively communicate with their citizens.
- Member states should acknowledge fish consumption as an important food source of energy, protein, and a range of essential nutrients and part of the cultural traditions of many peoples.
- Emphasis should be given to the benefits of fish consumption on reducing CHD mortality for the general adult population.
- Emphasis should be given to the neurodevelopment benefits provided to offspring owing to fish consumption by women of childbearing age, particularly pregnant women and nursing mothers and the neurodevelopment risks to offspring of such women not consuming fish.
- Existing databases on specific nutrients and contaminants, particularly methyl mercury and DLCs, in fish consumed in their region should be developed, maintained, and improved.
- Risk management and communication strategies that both minimize risks and maximize benefits from eating fish should be developed and evaluated.

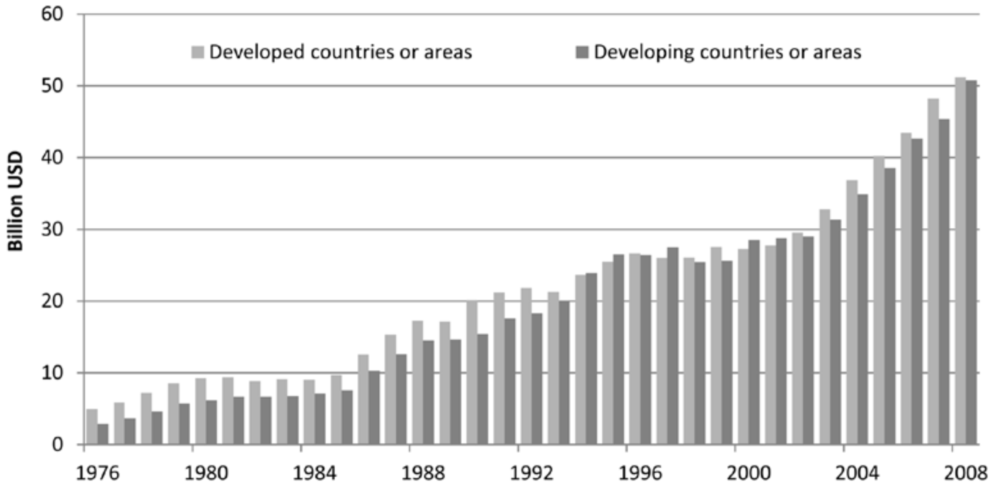
Fish trade

Total world trade of fish and fishery products has seen an important increase during the last three decades, going from a mere US$8 billion in 1976 to a record export value of US$102 billion in 2008, at an average annual growth rate of 8.3 percent in value (Figure 6).

Trade in fish and fishery products is characterized by a wide range of product types and participants. In 2008, 197 countries reported exports of fish and fishery products. Fish exports are important for many economies, in particular for developing nations where they generate foreign currency earnings. In addition the sector has a significant impact on employment, income and food security. In a few cases, fishery exports are crucial for the economy. For example, in 2004 they accounted for a half or more of the total value of merchandise trade for St. Pierre and Miquelon, Maldives, Federal States of Micronesia, Iceland, Panama and Kiribati.

The 2008 world fish exports figure of US$102 billion is a record, 9 percent higher than 2007, and nearly double the US$51.5 billion corresponding value in 1998. This represents about 10 percent of total agricultural exports and 1 percent of world merchandise trade. In real terms (adjusted for inflation), fish exports grew by 11 percent in the period 2006–08, by 50 percent between 1998 and 2008 and by 76 percent between 1988 and 2008. In quantity terms (LWE), exports were 55 million tonnes in 2008, representing an increase of 28 percent since 1995 and of 104 percent since 1985, although some slight decline is observed since 2005. This decline was mainly because of a fall in production of and trade in fishmeal (down 10 percent in the period 2005–08), but also to the first signs of contraction in demand as a consequence of the food price crisis, which affected consumer confidence in major markets.

FIGURE 6
Global export of fish and fishery products (1976–2008)



Source: FAO Fisheries and Aquaculture Statistics and Information Service. 2010. Commodities production and trade 1976-2008. FISHSTAT Plus - Universal software for fishery statistical time series [online or CD-ROM]. Food and Agriculture Organization of the United Nations. Available at: www.fao.org/fishery/statistics/software/fishstat
Note: Fishery statistical data presented in the above table exclude the production for marine mammals, crocodiles, corals, sponges, shells and aquatic plants.

Similarly to other food commodities, prices of fish and fishery products were also affected by the food price crisis of 2006 to 2008 when they reached record levels. The FAO Fish Price Index indicates an increase from 93.6 in February 2007 to 128.0 in September 2008. This represents the highest value reached since 1994 (with the base year 1998–2005 = 100). Prices for species from capture fisheries increased more than those for farmed species (which reached 137.7 versus 117.7 in September 2008, with 2005 as base year = 100) because of the larger impact from higher energy prices on fishing vessel operations than on aquaculture operations.

Following the economic recession of September 2008, food prices fell dramatically. The FAO Fish Price Index reported a drastic drop from 128.0 in September 2008 to 112.6 in March 2009, before recovering to 119.5 in November 2009. Provisional data for 2010 indicate that there have been increasing signs that fish trade is recovering in many countries, and the long term forecast for fish trade remains positive.

Table 4 shows the top ten exporters and importers of fish and fishery products in 1998 and 2008. China, Norway and Thailand are the top three exporters. Since 2002, China has been by far the leading fish exporter, contributing almost 10 percent of world fish export, estimated at US$10.1 billion in 2008 and at US$10.3 billion in 2009, although this represents a mere 1 percent of its total merchandise exports. China is also the sixth-largest importer, with an import value estimated at US$5.1 billion in 2008, as compared with US$1 billion in 1998. This increase in imports reflects the lowered import duties following China's accession to the World Trade Organization (WTO) in late 2001, the rising imports of raw material for reprocessing, as well as the growing domestic consumption of high value species that are not available from local sources.

Viet Nam has also experienced significant growth in fish exports, up from US$0.8 billion in 1998 to US$4.6 billion in 2008, when it became the fifth largest exporter in the world. Its growing exports are linked to its flourishing aquaculture industry, in particular to the production of Pangasius and of both marine and freshwater shrimps and prawns.

TABLE 4
Top ten exporters and importers of fish and fishery products

	1998	2008	APR
	(US$ millions)	(US$ millions)	(Percentage)
Exporters			
China	2 656	10 114	14.3
Norway	3 661	6 937	6.6
Thailand	4 031	6 532	4.9
Denmark	2 898	4 601	4.7
Viet Nam	821	4 550	18.7
United States of America	2 400	4 463	6.4
Chile	1 598	3 931	9.4
Canada	2 266	3 706	5.0
Spain	1 529	3 465	8.5
Netherlands	1 365	3 394	9.5
Top ten subtotal	23 225	51 695	8.3
Rest of world total	28 228	50 289	5.9
World total	51 453	101 983	7.1
Importers			
Japan	12 827	14 947	1.5
United States of America	8 576	14 135	5.1
Spain	3 546	7 101	7.2
France	3 505	5 836	5.2
Italy	2 809	5 453	6.9
China	991	5 143	17.9
Germany	2 624	4 502	5.5
United Kingdom	2 384	4 220	5.9
Denmark	1 704	3 111	6.2
Republic of Korea	569	2 928	17.8
Top ten subtotal	39 534	67 377	5.5
Rest of world total	15 665	39 750	9.8
World total	55 199	107 128	6.9

Note: APR refers to the average annual percentage growth rate for 1998–2008.
Source: SOFIA, 2010.

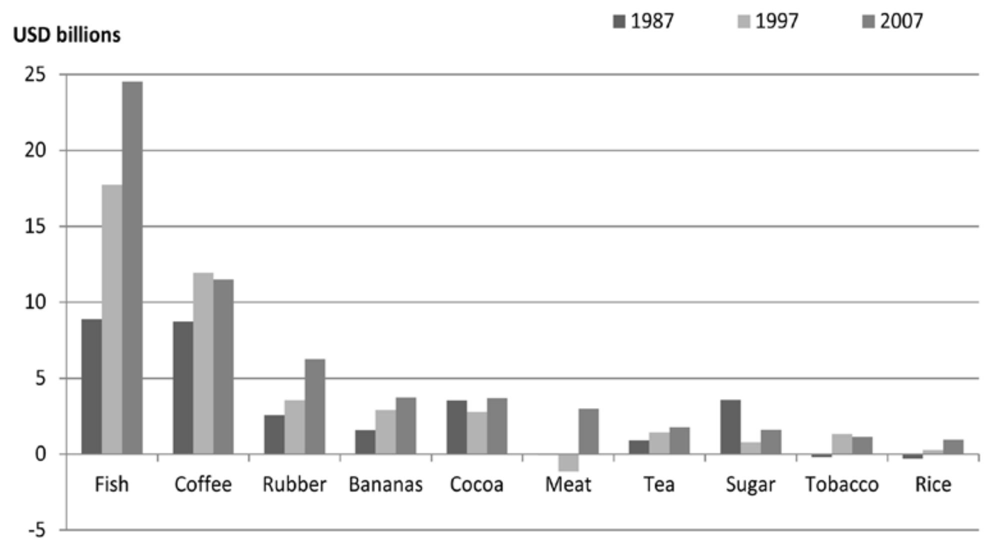
In addition to China, Thailand and Viet Nam, many other developing countries play a major role in global fish exports. In 2008, developing countries accounted for 80 percent of world production. Their fish export accounted for 50 percent (US$50.8 billion) of world fish export in value terms and 61 percent (33.8 million tonnes) in quantity. Fishmeal represented 36 percent by quantity, but only 5 percent by value of developing countries export in 2008. However, developing countries have also considerably increased their share of the quantity of world fish exports destined for human consumption, from 46 percent in 1998 to 55 percent in 2008.

A major barrier to fish exports by developing countries is the stringent quality and safety standards and buyers' requirements for animal health, environmental issues and social responsibility concerns. In addition, the increasing power of large retail and restaurant chains in seafood distribution is shifting negotiating power towards the final stages in the value chain, and retailers are also imposing more and more private or market based standards and labels on exports from developing countries. All the above are making it more difficult for small-scale fish producers and operators to penetrate international markets and distribution channels.

On the other hand, developing countries rely heavily on imports from developed countries to supply the processing industry, including raw material for re-export, and to supply the domestic markets (mainly low-priced, small pelagic species as well as high value fishery species for emerging economies). In 2008, out of 75 percent (in value) of fish exports from developing countries directed to developed countries, a growing share used imported raw material for further processing and re-export. In 2008, in value terms, 40 percent of the imports of fish and fishery products by developing countries originated from developed countries.

Net export revenues of fish and fish products (i.e. value of fish exports minus value of fish imports) are particularly important for many developing countries, being higher than those of several other agricultural commodities such as rice, meat, sugar, coffee and tobacco combined (Figure 7). They have increased significantly in recent decades, growing from US$2.9 billion in 1978 to reach US$9.8 billion in 1988, US$17.4 billion in 1998, and US$27.2 billion in 2008, including US$8.3 billion for low-income food-deficit countries (LIFDCs) (out of US$11.5 of LIFDC net export revenues). World imports of fish and fish products reached a new record of US$107.1 billion in 2008, up 9 percent from 2007 and up 95 percent since 1998.

FIGURE 7
Net exports of selected agricultural commodities by developing countries



Source: SOFIA, 2010.

Japan, the United States of America and the European Union (EU) are the major markets, with a total share of about 69 percent in 2008. Japan is the world's largest single national importer of fish and fishery products, with imports worth US$14.9 billion in 2008, a growth of 13 percent compared with 2007, followed by a decrease of 8 percent in 2009. The EU is by far the largest fish importing market. However, it is extremely heterogeneous, with markedly different conditions from country to country. In 2008, imports by the EU reached US$44.7 billion, up 7 percent from 2007, and representing a share of 42 percent of total world imports. However, if intraregional trade among EU countries is excluded, the EU imported US$23.9 billion from non-EU suppliers. This still makes the EU the largest market in the world, with about 28 percent of the value of world imports (excluding intra EU trade). Figures for 2009 indicate a downward trend in EU imports, with a 7 percent decrease in value recorded.

RESPONSIBLE FISH UTILIZATION, TRADE AND MARKET ACCESS

With the globalization of the economy and the ever increasing concern over fisheries and aquaculture sustainability, fish utilization and trade are not considered anymore under the prism of technical and economic feasibility of processing and investment projects only, but they are more and more integrated in the policies of government and the corporate social responsibility strategies of fish and food companies.

Food security

A first major issue that faces policy makers, especially in developing countries, is the necessity to balance food security and export promotion objectives owing to the impact of fish trade on food security. In 1996, the World Food Summit declared that food security is considered to exist "when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preference for an active healthy life".

Fish is an important source of both direct and indirect food security in many developing countries. Many of the concerns on issues relating to fish and food security focused on the dimension of fish for consumption. Consequently, when fish exports are examined, the focus has been primarily on how it reduces fish availability for domestic consumption. Fish imports, on the other hand, are mostly seen as a means to increase local availability. In actual fact, the relationship between trade (exports and imports) and food security is more complex.

Production for exports to lucrative markets can enhance the income of poor fishers substantially and thus achieve greater food security. This is especially beneficial for non or low fish eating communities, for example, in Mauritania, Mali and Burkina Faso, or vegetarian fishermen in India. On the other hand, exports may deprive a section of the domestic consumers of a variety of fish, leading to a potential loss of food security for them. This is particularly so when fish is an integral part of the culturally conditioned diet of a population.

Fish imports for human consumption can help to stabilize or reduce fish prices for poorer fish consumers. However, this can have an adverse effect on the income of fishers in the importing country thus lowering their food security. As a response, they may begin to exploit the local fish stocks heavily endangering resource renewal. But it can be positive for the food security of countries such as Nigeria or Egypt that import large quantities of highly nutritious but low price small pelagic fish such as herring and mackerel for national consumption. Alternatively, women working in fish processing may have more employment opportunities and secure more income to spend on household food security. Imports may also be destined for re-export after processing. In this case, new employment is generated in processing facilities for fish workers from urban and rural areas. Their increased incomes will contribute to household food security.

These examples illustrate that a single answer regarding the impact of international fish trade on food security is not possible and that it is essential to analyse very specific case studies in a variety of country contexts. In this respect, an FAO/Norway study (Kurien, 2005) examined the impact of international fish trade on food security both at the global level and through 11 national case studies in Nicaragua, Brazil, Chile, Senegal, Ghana, Namibia, Kenya, Sri Lanka, Thailand, Philippines and Fiji. The evidence drawn from this study indicates that, globally and in 8 of the 11 countries, international trade has had a positive impact on food security. This assessment was based on outcomes related to national impacts, impacts on fishers, workers, consumers and resources. International fish trade was, however, found to have a negative impact on the fish resources for all the countries, highlighting the urgent need for more effective management regimes. Consequently, the study cautions that sustainable resource management practices are a necessary condition for sustainable international trade and that fish export promotion needs to be coupled with a sustainable resource management policy. Ecolabelling and certification is an attempt to link market access and resource sustainability (Washington and Ababouch, 2011). The study also highlights the need for free and transparent trade and market policies to ensure that the benefits from international fish trade are equitably enjoyed by all segments of society. The study underscores the FAO's Code of Conduct for Responsible Fisheries recommendation that States consult with all stakeholders – industry, as well as consumer and environmental groups – in the development of laws and regulations related to trade fish trade.

Post-harvest losses

The generally acknowledged limits of production from capture fisheries and the widening gap between fish supply and demand reaffirms that post-harvest losses are an unacceptable waste of scarce natural resources. Post-harvest losses of fish occur in various forms (Ward and Jeffries, 2000). The physical loss of material is caused by, for example, discarding fish or bycatch (accidentally or voluntarily) and predation by birds, other animals or insects. Quality losses occur when spoilage or physical damage of fish result in a decrease in value or when there is a need to reprocess cured fish, raising the cost of the finished product. In addition, inadequate handling, processing and storage can reduce nutrients, leading to nutritional loss. Similarly, the conversion of large quantities of fish catches into animal feeds can be considered, under certain conditions, as a "loss" for human food security.

Post-harvest losses in small-scale fisheries can be among the highest for all the commodities in the entire food production system. Fish losses caused by spoilage are estimated at 10 to 12 million tonnes per year, accounting for over 8 percent of the total production from capture fisheries and aquaculture. Appropriate preservation methods can significantly reduce this loss, including from glut catches when the processing, distribution and marketing system cannot cope with the exceptional quantities of fish that are sometimes landed because of seasonal or inter-annual variations of availability or abundance.

A large part of fisheries post-harvest losses occur because of inadequate or lack of proper landing sites and related equipment. Fishing ports and landing sites are key infrastructures at the interface between the harvesting of fish and its utilization. The type and size of fishing ports greatly influences the rate at which a country's fisheries resources will be exploited, whereas the basic port and landing site infrastructure, including administration setup and services, will contribute to the way resources will be utilised, including opportunities to add value to the harvests. Fishing ports and landing sites vary in size, organization and complexity depending on many factors. They can range from relatively informal artisanal landing sites to relatively organized and formalized locations. Moreover, these harbours may be found along the coastlines of fresh and marine bodies of water (Sciortino, 2010).

To overcome these difficulties, investment is needed to physically upgrade and rehabilitate landing sites and fishing harbours in conformity with sanitary and hygienic requirements and to develop human capacity and administrative and management structures for effective utilization and maintenance. In addition to improving fish utilization and reducing post-harvest losses, improved harbour and landing site infrastructure and administration can contribute to an easing of pressure on fish resources.

However, it is critical that improved physical infrastructure be planned within the framework of proper governance, policy and management of fisheries. Indeed, because production from capture fisheries is limited, it is vital that fisheries policies and management are in place to ensure that fishers can focus on maximizing the value of the fish they catch instead of having to focus on maximizing the amount of fish they catch.

Physical loss also results from the discarding of bycatch. This type of loss is especially significant in shrimp trawl fisheries where the proportion of other species caught incidentally is very high and can reach 95 percent of the total material taken on board. Bycatch contains a variety of fish sizes and species and is sometimes discarded at sea. However, in densely populated areas of several developing countries, it is largely used for local consumption. Chilled or frozen storage facilities on board the trawlers are limited and are mostly kept for the main target species. Sorting the bycatch would require additional crew time further reducing the financial incentive.

An FAO study to update fishery by fishery the quantity of discards in global marine fisheries estimated that in the 1992 to 2001 period, annual average discards were 7.3 million tonnes (Kelleher, 2005). Trawl fisheries for shrimp and demersal finfish accounted for over 50 percent of the total estimated discards while representing approximately 22 percent of the total landings recorded in the study. Tropical shrimp trawl fisheries have the highest discard rate and account for over 27 percent of total estimated discards. Demersal finfish trawling account for 36 percent of the estimated global discards. Most purse seine, handline, jig, trap and pot fisheries have low discard rates. Small-scale fisheries generally have lower discard rates than industrial fisheries. Small-scale fisheries account for over 11 percent of the discard database landings and have a weighted discard rate of 3.7 percent.

The study revealed a substantial reduction in discards in recent years. The major reasons for this are a reduction in unwanted bycatch and increased utilization of catches. Bycatch reduction is largely a result of the use of more selective fishing gears, introduction of bycatch and discard regulations and improved enforcement of regulatory measures. Increased retention of bycatch for human or animal food is the result of improved processing technologies and expanding market opportunities for lower-value catch.

The study discusses a number of policy issues to reduce discards. These include a “no-discards” approach to fisheries management, the need for balance between bycatch reduction and bycatch utilization initiatives and concerns arising from incidental catches of marine mammals, birds and reptiles. The study also advocates the development of more robust methods to estimate discards, the allowance for discards in fishery management plans, the development of bycatch management plans and the promotion of best practices for bycatch reduction and mitigation of incidental catches. Global discard estimates could achieve greater precision through additional studies at national and regional levels.

Finally, about 15 to 20 percent of the total fish production is still processed into fishmeal and fish oil, using mainly small pelagic oily fish such as herrings, sardines, mackerel, anchovies, pilchards, sand eel, menhaden and offal from the processing of more valuable species (e.g. tuna). While conversion of fish to fishmeal and oil can be an acceptable and efficient fishing strategy, it can also be considered a “loss” from a food security perspective. Ideally, reduction into fishmeal and oil should only occur when it is not economical or practical to utilize fish for direct human consumption.

Reducing post-harvest losses requires a wiser use of resources, the reduction of spoilage and discards and the conversion of low-value resources that are available on a sustainable basis into products for direct human consumption. Reducing spoilage requires improved fish handling at all stages of the value chain, on board the boat, during landing, processing and preservation and during transportation, all of which are particularly deficient in small-scale fisheries. With increasing fish scarcity, the problem of discards tends to resolve itself, at least partially, as new species previously deemed commercially inferior are progressively integrated into markets and into consumer consumption habits. This is insufficient, however, and proactive efforts are needed to use more appropriate technologies systematically, such as square mesh and bycatch excluder devices.

Duties, quotas and tariff escalation

The World Trade Organization (WTO) classifies fish as an industrial product which carries lower import duties as compared with agricultural products. Furthermore, the Doha round of negotiations decided that "tariff escalation" for fish and fishery products would be reduced. This means that import duties for value added products will be lowered thus creating new opportunities, not the least for developing countries.

In addition, stagnant domestic fishery production and the growing demand in developed markets that rely on imports to cover increasing consumption have reduced import duties on fish to a current average of around 4.5 percent. As a result, fishery products from developing countries are able to gain increased access to developed country markets without facing prohibitive custom duties similar to those applied to agricultural products.

Over the last decade, however, both as a result of the WTO negotiations and of bilateral trade agreements, many tariffs on processed products have been reduced. Consequently, the transfer of value addition technologies, know-how and investment capital to developing countries has increased, generating further employment and hard currency earnings from processing and value addition. Part of this production has been distributed in emerging economies, mainly in Asia, but also in Africa and Latin America.

However, despite the availability of technology, not all projects in value addition for export from developing countries have been successful. In particular, due consideration was not always given to quality assurance, marketing and distribution issues before embarking on the value addition process. For example, new value added products have encountered difficulty accessing supermarket shelves without substantial investment in marketing and publicity. Some operators have circumvented the problem by using the label and distribution system of the importer or retailer, giving up some benefits that accrue downstream from marketing and distribution in the value chain (O'Sullivan and Bengoumi, 2008).

An important issue is the study of the distribution of costs and benefits to understand how and where in the fish value chain revenues are accumulated, values are added, profits are generated and to understand what are the principal barriers against adding more value to exported seafood products in the country of origin or destination. Preliminary studies indicate that the distribution of benefits is not always equitable, especially in developing countries where upstream operators, especially small-scale fishermen, do not always receive adequate benefits that in turn increase their vulnerability (Gudmundsson, Asche and Nielsen, 2006).

Safety and quality requirements

The food and feed scares of the last decades (bovine spongiform encephalopathy (BSE), dioxins, avian flu, severe acute respiratory syndrome (SARS) and foot and mouth disease) have exposed the weakness in traditional food control systems. Likewise, the increased globalization of fish trade has highlighted the risk of cross-border transmission of hazardous agents and the rapid development of aquaculture has been accompanied by the emergence of food safety concerns, in particular residues of veterinary drugs. These developments have led to the need for the development of a food safety strategy applicable throughout the entire fish food chain – from "farm or sea to table". This strategy needed to be scientifically based, adaptive and responsive to changes in the food production chain. It had to be elaborated around the use of risk analysis to develop food safety objectives and standards and be based on the implementation of Hazard Analysis Critical Control Points (HACCP) systems.

FAO/WHO has identified the following five needs for a strategy in support of a food chain approach to food safety, including for fish and fishery products:

- Fish safety and quality from a food chain perspective should incorporate the three elements of risk analysis – assessment, management and communication – ensuring an institutional separation of science-based risk assessment from risk management;
- Tracing techniques (traceability) from the primary producer (including animal feed and medicines used in aquaculture), through post-harvest treatment, processing and distribution to the consumer must be improved;
- Harmonisation of standards, implying increased development and wider use of internationally agreed, scientifically based standards is necessary;
- Equivalence in food safety systems – achieving similar levels of protection against fish-borne hazards and quality defects whatever means of control are used – must be further developed;
- Increased emphasis on risk avoidance or prevention at source within the whole food chain – from farm or sea to plate.

The implementation of the food chain approach requires an enabling policy and a regulatory environment at national and international levels with clearly defined rules and standards, establishment of appropriate food control systems and programmes at national levels, and provision of appropriate training and capacity building. Development and implementation of Good Aquaculture Practices (GAP), Good Hygienic Practices (GHP) and HACCP are required in the food chain step(s). Government institutions should develop an enabling policy and a regulatory environment, organize the control services, train personnel, upgrade the control facilities and laboratories and develop national surveillance programs for relevant hazards. The industry should adopt good practices and train personnel to implement GAP, GHP and HACCP. The support institutions (academia, trade associations, private sector, etc.) should upgrade skills of personnel involved in the food chain, conduct research on quality, safety and risk assessments, and provide technical support to stakeholders. Finally, consumers groups and other Non Governmental Organizations (NGOs) should promote consumer education and information and play a counter-balancing role to ensure that safety and quality policy is science based and not driven by political or economical considerations.

The globalization and further liberalization of world fish trade, while offering many benefits and opportunities, also presents emerging safety and quality challenges. Improved scientific tools must be adopted and novel flexible approaches to safety must be sought to ensure that responsibility for consumer protection is effectively shared along the food chain and that regulations and standards reflect the most current scientific evidence. This requires significant resources which are not always available, especially for small-scale operations in developing countries.

Fish safety and quality assurance at the beginning of this third millennium requires enhanced levels of international cooperation in promoting transparency, harmonisation, equivalency schemes and standards setting mechanisms based on science. The SPS/TBT agreements of the WTO and the benchmarking role of Codex Alimentarius provide international references in this respect.

LABELLING AND CERTIFICATION

Certification and labelling have become important competitive parameters to access international fish markets. Not only must suppliers adhere to the regulatory requirements of importing countries, but additional labels or certificates may also be required by the importer for commercial and marketing reasons. In the same way, the supplier may also choose to apply particular labels or undergo voluntary certification programmes in order to target specific segments of consumers, thereby gaining a competitive advantage in market niches.

Similarly, companies may choose to produce according to specific requirements that permit them to label their products as environmentally friendly or produced with respect to certain social values. Examples of such labelling include: "organic production" labels, "fair trade" labels", "dolphin-safe tuna" labels or ecolabels such as those of the Marine Stewardship Council (MSC) or Friend of the Sea (FoS). An ecolabel is a tag or label placed on a product that certifies that the product was produced in an environmentally friendly way. The label provides information at the point of sale that links the product to the production process.

In fisheries, the increased interest in ecolabels results from the concerns about the dramatic state of the world's marine resources. The perceived failure of governments to effectively manage marine resources has led to the development of alternative mechanisms for protecting marine life and promoting sustainability. These are aimed at influencing the purchasing decisions of consumers and the procurement policies of retailers. Ecolabels are one such mechanism. Organizations developing and managing an ecolabel develop standards against which applicants wishing to use the label will be judged. They also manage the accreditation and certification process and market the label to consumers to ensure recognition and demand for labelled products.

Other mechanisms used by NGOs include:

- Publicity campaigns or organized boycotts of certain species deemed to be threatened such as the "Give Swordfish a Break" campaign in the United States in the late 1990s;
- Consumer guides to influence consumers purchasing decisions, such as the "Best Fish Guide" of the New Zealand Royal Forest and Bird Protection Society or "The Sustainable Seafood Guide", produced by Eartheasy, Canada;
- Putting pressure on retailers to introduce sustainable procurement policies for fish and seafood. This is perhaps most developed in the United Kingdom where Greenpeace is working with large retailers and produces an annual league table, "Ranking of the sustainability of supermarkets' seafood". Greenpeace also uses "naming and shaming" strategies such as media-savvy protests outside retail outlets.

These strategies can be seen in terms of a continuum from more reactive mechanisms that highlight and "shame" bad practice, to more proactive activities such as encouraging consumers to purchase fish from sustainable stocks and working with retailers to improve their procurement policies, as well as rewarding those that do with positive publicity. Buyers and retailers have in turn responded by imposing private standards and certification back through the supply chain, especially on producers and processors. These developments have resulted in the proliferation of certification bodies and schemes designed to trace the origin of fish, its quality and safety, and the environmental and/or social conditions prevailing during fishing, aquaculture production, processing and distribution (Washington and Ababouch, 2011).

But as standards, certification schemes and labels proliferate, both producers and consumers are questioning their value. Producers in particular question whether these private standards and certification schemes duplicate or complement government work. In addition, consumers ask if private schemes really provide better protection for them and the environment and/or contribute to social equity.

Many producers and exporting countries hold the view that sanitary standards represent unjustified restrictions to trade, especially where they introduce measures which duplicate those already applied by government authorities of the exporting country. This raises the issue of how to define boundaries between public regulations dealing with food safety, animal health, environmental and social protection on the one hand and private market standards on the other? And who is responsible for what and accountable to whom? While governments that are seen to use standards as trade barriers can be challenged through the rules of WTO, what international mechanism, or agreement, could be invoked to challenge private companies whose standards are judged to create technical barriers to trade between countries? Several countries and industry associations have raised serious concerns about the potential for private standards to have trade limiting or trade distorting effects (WTO, 2008).

Proponents of private standards and certification schemes claim that they encourage suppliers to force the use of responsible practices in fisheries and aquaculture. Opponents of such standards see them as a private sector attempt to replace/duplicate governmental policy in fisheries and aquaculture. The key issue is how private standards and certification schemes, if needed, can be reconciled with the public sector's responsibility to regulate the use of responsible practices in fisheries and aquaculture, throughout the food chain.

These issues require a concerted international effort. Improved knowledge is a precondition for an international understanding and an approach to dealing with this issue. More must be known about the effects of private standards and certification schemes. Such knowledge may make it possible to propose solutions that will ensure coherence of private standards with WTO trade measures.

It is also necessary to analyze if and how private standards are duplicating or complementing the work of government authorities. Such an analysis will have a particular focus on the effects that private standards and certification schemes are having on developing countries' capacities to access markets.

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Grocery consumers in the recession

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INTRODUCTION

There are some myths and misconceptions surrounding consumer behaviour during the current downturn. It is very easy to believe all of the gloom and doom published in the media. However, it is preferable to base understandings on data and the insights they provide.

At The Nielsen Company, key methods of observing consumer behaviour include:

1. Scanning data from store checkouts
2. Household panel data (access to over ½ million homes around the world)
3. Consumer research
   - Regularly asking consumers in over 50 countries about their thoughts and concerns on issues related to their purchasing activity;
   - Media consumption and online behaviour. This helps build a picture of what consumers see, and what they buy;
   - Resulting in an understanding of what is being done, where, by whom and most interestingly of all, why.

BACKGROUND

There are several large geodemographic changes occurring which are worth exploring.

The population is growing. Currently there are 7 billion people on the planet. This number will continue to grow until 2050 when it is predicted that it will level off at about 9.2 billion. This is 1 billion fewer than was being predicted 5 years ago. Much of this decline is caused by the rapid lowering of fertility rates, especially in Latin America. This is owing to increasing levels of wealth, and, as more women receive more education, they enter careers of their own, marry later, and have their first children at an older age. Also, lower infant mortality means parents can be more confident that their offspring will survive childhood.

Average life expectancies continue to rise. Around the world there are large variations in life expectancy. Most Europeans can expect to live until they are nearly 80, that is 10 years more than the global average. At the other end of the scale, people in many African countries have low life expectancies. In Swaziland, it is just 32. This is as a result of:

- lower levels of wealth. There is a high degree of correlation between wealth and longevity
- the presence of HIV Aids in over a quarter of the adult population.

In most countries, women can expect to live 5 years longer than men.

The world's wealth is unevenly dispersed. It is tempting, but a little inaccurate, to over simplify this by saying that there is a rich North and a poor South. Over the last 60 years there has been a great increase in the number of people classified as middle class. This is because of political and technological changes, many of which have occurred in just the last 30 years:

- 1981 – the first personal computer – from IBM
- 1985 – the launch of Windows
- 1989 – the Berlin Wall falls

- 1990 – Nelson Mandela is released; so is Windows 3.0
- 1991 – the first web site – at CERN in Switzerland
- 1993 – the first Browser

Deregulation and the opening up of economies to foreign investment help improve gross domestic product (GDP), although protectionism and criminality prevent economies reaching their full potential. Table 1 demonstrates that there is much further growth potential for some already large growth economies. Many are not yet matching their share of the world's GDP to their share of the world's population.

TABLE 1
Comparison of share of global population and GDP for selected countries

Country	Population (%)	GDP (PPP) (%)	Index (%)
Singapore	0.1	0.3	506
United Arab Emirates	0.1	0.3	381
Japan	1.9	6.5	340
Taiwan	0.3	1.1	307
Korea, South	0.7	1.8	251
Malaysia	0.4	0.5	145
Chile	0.2	0.4	143
Argentina	0.6	0.8	132
Mexico	1.6	2.1	125
South Africa	0.7	0.7	98
Brazil	2.9	2.8	96
Thailand	1.0	0.8	81
China	19.9	10.7	53
Egypt	1.2	0.6	51
Indonesia	3.5	1.3	36
Philippines	1.4	0.5	32
India	17.0	4.6	27
Pakistan	2.6	0.6	24

Source: Global Online Surveys, 2009.

So is all this extra wealth making consumers feel more financially confident? The evidence suggests not.

CONSUMER CONFIDENCE

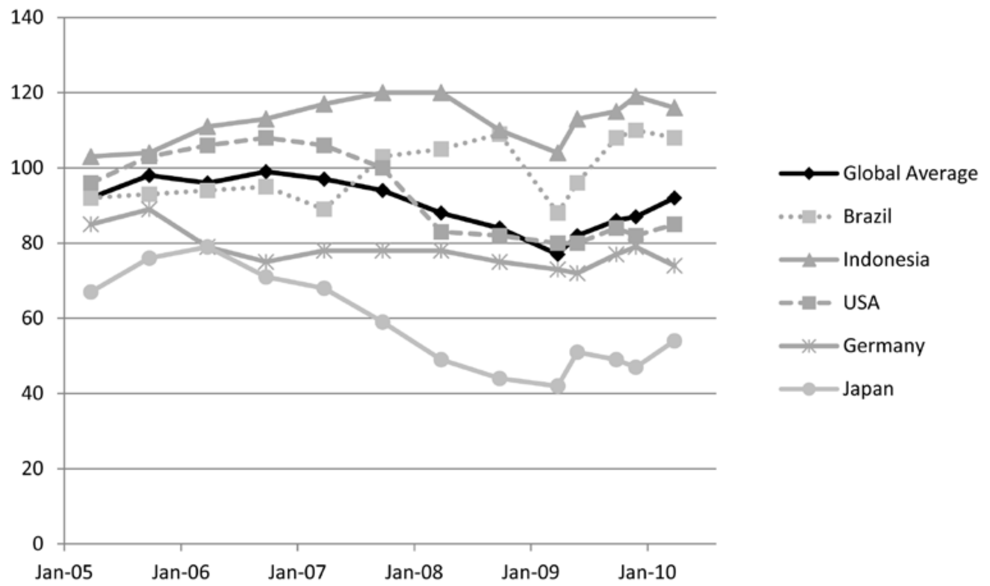
The Nielsen Company undertake global research to understand consumers' attitudes to various aspects relating to their shopping and consumption behaviour. Quarterly surveys conducted in over 50 countries ask respondents:

- Do you think job prospects in your country over the next 12 months will be: (Excellent, good, not so good, bad, don't know);
- Do you think the state of your own personal finances in the next 12 months will be: (Excellent, good, not so good, bad, don't know);
- Considering the cost of things today and your own personal finances, would you say at this moment the time to buy the things you want and need is: (Excellent, good, not so good, bad, don't know).

Amalgamating the answers allows the construction of a Consumer Confidence Index. A score above 100 means people are confident about their future finances and below 100 means they are pessimistic about their prospects.

Figure 1 shows how consumer confidence has changed leading into and during the current downturn.

FIGURE 1
Consumer Confidence Index



Note: A score above 100 means people are confident about their future finances and below 100 means they are pessimistic about their prospects.
Source: Global Online Surveys, 2009.

The Consumer Confidence Index numbers for the 54 countries in which the research is carried out show that some of the least financially confident countries have been some of the richest (as measured by per capita GDP). Currently (March 2011), only 6 countries record a score that is significantly positive (above 110): India, Saudi Arabia, Indonesia, Australia, Philippines and Switzerland.

CONSUMER CONCERNS

In the past, in most countries, health and work/life balance were normally in the top 3 concerns when people were asked "What is your biggest, and second biggest, concern in the next 6 months?". Financial worries have changed that (Table 2).

TABLE 2
Largest and second largest consumer concerns

The concern	Percentage of respondents giving the concern as their largest or second largest concern
The economy	32
Job security	23
Health	20
Work / life balance	20
Increasing utility bills	15
Increasing food prices	13
Debt	13
Children's education and/or welfare	12
Parents' welfare and happiness	9
Increasing fuel prices	6
Global warming	6
Crime	6
Political instability	6
Terrorism	4
War	3
Immigration	2
Lack of understanding of other cultures	2
No concerns	2

Source: Nielsen Global Online Survey: global totals, December 2009.

It is disappointing to see only 6 percent of respondents give 'global warming' as a major concern. In fairness, the question is "What is your biggest/2nd biggest concern in the next 6 months?" If the question asked was what the biggest concern is for the next 20 years, "global warming" would probably score higher.

Large variations are seen in the different consumer concerns from country to country. For example, 'Crime' is cited as a major concern in South Africa, Argentina, Italy and Denmark given its prevalence in those areas. Similarly, 'Terrorism' scores highest in India and Turkey because of recent events and the frequency of attacks there.

When looking at the evolution of these concerns over the last 4 years, financial concerns now dominate social and environmental issues, with the exception of 'health'.

UNEMPLOYMENT

Unemployment is increasing around the world. Spain has been hit particularly hard given the importance of three recession-sensitive industries there: automotive, construction and tourism. The German economy has not been run as irresponsibly as some others, but still suffers as the ability to export is curtailed.

If one is made redundant, then for that person and their family it is potentially catastrophic, but it is worth noting that for example, even in Spain, the vast majority (79 percent) of the workforce is employed.

It remains to be seen whether the historic levels of fiscal stimulus being injected into economies around the world have been sufficient. This, together with the government debt accrued in bailing out the failed financial institutions, means that countries have national debt levels that are painful to sustain. On a brighter note, in many countries, consumers are beginning to learn that if they buy something, they have to pay for it! Personal savings levels are still arguably too low, though they are increasing. In the future, there may be more people that have sustainable debt levels and sufficient pension provision.

PROTECTIONISM

The results shown in Table 3 indicate that despite the fact that restrictions on free trade make people worse off (on average), with higher prices and reduced choice, in many countries there are more votes for the politicians to restrict imports than to have open access.

TABLE 3

Protectionism. Response to the question "To stimulate economic growth your government should place trade restraints on foreign imports"

The Crtieria	Percentage responding
Strongly agree	6
Agree	26
Neither agree nor disagree	38
Disagree	24
Strongly disagree	6

Note: Compiled from 25,420 respondents from 53 countries – results shown here are total global average.
Source: Nielsen Global Online Survey, April 2009.

CONSUMER BEHAVIOUR

Table 4 shows a summary of recent grocery shopping behaviour, based on 12 countries that make up 70 percent of the world's GDP – Brazil, Canada, China, France, Germany, Hong Kong, India, Italy, Spain, Taiwan, United Kingdom and the United States of America.

TABLE 4
Grocery shopping behaviour trends based on data from the 12 countries that make up 70% of the world's GDP

The Behaviour	May 09	Jun 09	Jul 09	Aug 09	Sep 09	Oct 09
Nielsen market Index – Volume	⇨	⇨	⇨	⇨	⇧	⇨
Nielsen Market Index – Value	⇧	⇧	⇧	⇧	⇧	⇧
Are consumers moving to store brands?	⇨	⇨	⇨	⇨	⇨	⇧
Are shoppers shifting to value channels?	⇧	⇧	⇧	⇧	⇧	⇧
Are retailers selling more on promotion?	⇨	⇧	⇧	⇧	⇧	⇧⇧
Are consumers shopping more frequently?	⇩	⇩	⇩	⇩	⇨	⇨
Are consumers spending more per trip?	⇨	⇨	⇨	⇨	⇨	⇨
Nielsen Global Consumer Confidence		⇩⇩			⇨	

Key:
⇧⇧ Very Strong Growth: Greater than or equal to +5%
⇧ Strong Growth: Between +1% and +4%
⇨ Neutral: between -1% and +1%
⇩ Negative: Between -1% and -4%
⇩⇩ Very Negative: Less than or equal to -5%
Source: Nielsen Global Online Survey: global totals, December 2009.

Volume levels are largely static, and the growth in value is mainly because of inflation, as opposed to trading up. Discussion about the growth of store brands (private labels) will follow in the next section. The growth of value channels – discounters like Aldi, Lidl and Dia, and Dollar Stores in the US – has more to do with their increased store numbers than constraints on household expenditure. The increases observed in promotional expenditure may be because shoppers were seeking out 'bargains', but these offers can be a false economy. 'Buy one get one free' (BOGOF) promotions are now giving way to single pack price reductions, as the additional purchase on the 'BOGOF' often ended up in the bin. The increases seen at the start of last year may also have been caused by an increase in the number of promotions being put in front of shoppers. In other words, if the head office buyer in a retailer thinks that, in a downturn, shoppers will want to buy more on promotion, and as a result provides more promotions, it can become a self-fulfilling prophecy that more is sold on promotion. Much of our research shows that shoppers "want what they get" – as opposed to "getting what they want". Shopping behaviour is greatly influenced by the environment and the infrastructure in which shoppers find themselves.

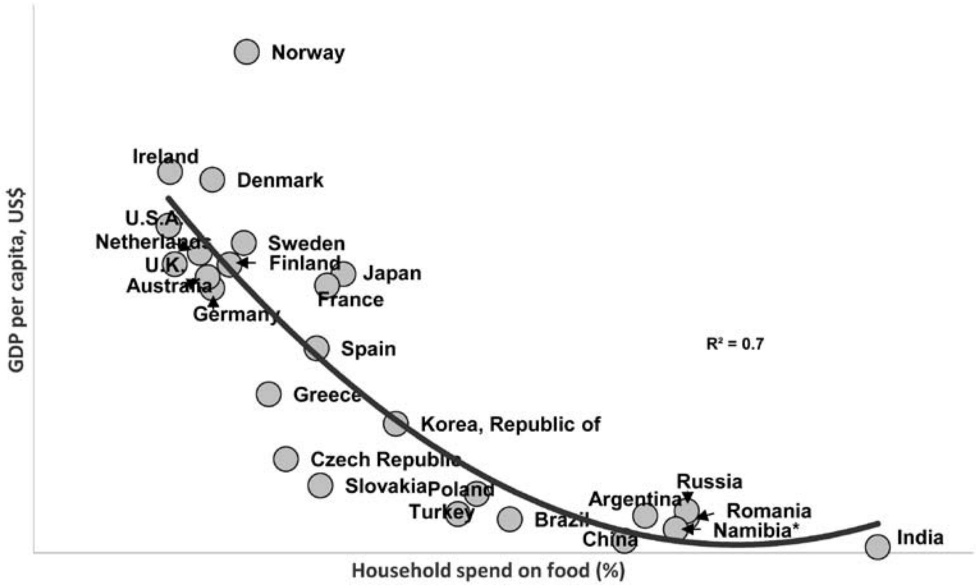
To save money, some households are shopping more frequently, buying just what is needed for the next meal or two, thereby spreading expenditure and reducing waste. More often households are shopping slightly less often – two completely different tactics to achieve the same objective!

The reason that for so many people it is 'business as usual' is that whilst a new car or exotic foreign holidays are not needed every year, we do have to eat. Food is now cheaper than it has ever been before, so despite the recession, all of the gloom and doom in the media is not reflected in our data. Figure 2 provides the reason.

A peasant in India, earning less than US$1 per day, would probably spend all of that income on food. In richer western countries about 15 percent of our household expenditure goes on food. So even after significant food inflation, only a small part of our income is spent on groceries.

People in employment may now even have more disposable income as they reduce their spending on big-ticket items like cars and holidays, and see interest rates on their mortgages at their lowest levels.

FIGURE 2
GDP per capita vs household spend on food across countries



Note: Country abbreviations are standard ISO 3166-1 alpha-2 codes.
Source: Global Online Surveys, 2009.

A crucial thing for the food industry to understand is that whilst the industry is not recession-proof, it is definitely recession-resistant. Sales levels are not declining; the majority of categories measured are either static or growing. There is undoubtedly pressure on categories and the value and profit they generate as a result of creeping commoditisation. This is caused by:

- the growth of discounters;
- increased reliance on promotional activity; and
- the growth of private label.

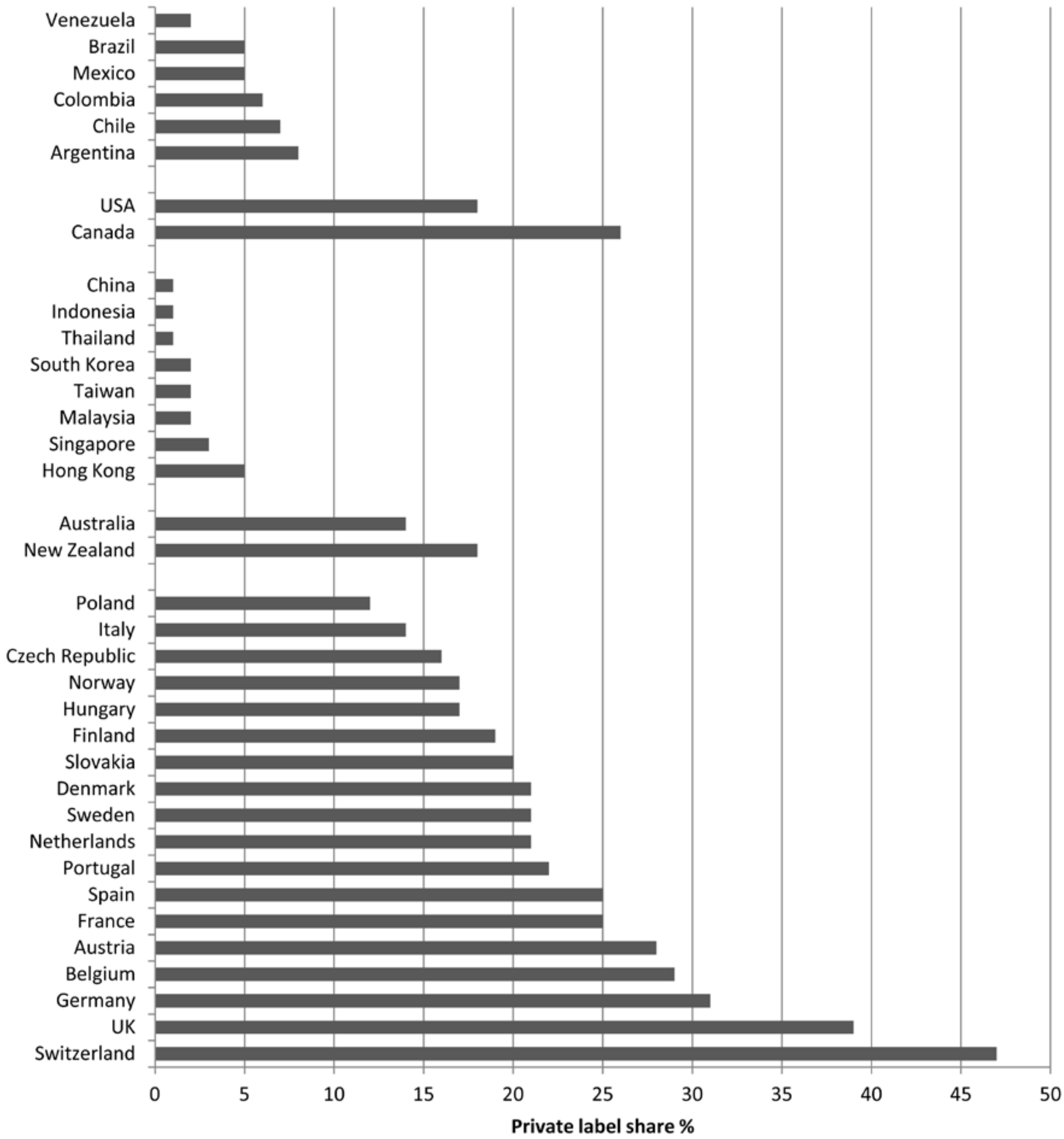
PRIVATE LABEL

Private label's growth is not so much driven by the economic downturn, but is more a function of increasing consolidation of store ownership. This results in head office buyers increasingly finding that they have the critical mass needed to make more private label "Stock Keeping Units" viable. As their most important Key Performance Indicator will often be the percentage profit on return achieved, decreasing brands' share is often seen as a high priority in the management of the category. Private label's share varies by country (Figure 3).

Private label is increasingly supported by professionally marketed initiatives. It evolves from being just a cheaper copy of the brand to a more differentiated offering with category leading innovations and often sold at a premium to the brand.

FIGURE 3

Private label share – by country and grouped by continent



Source: Global Online Surveys, 2009.

BRAND OWNERS' RESPONSE

Having studied thousands of categories in many countries over a long period of time, it is evident that brand owners can be the masters of their own destiny and mitigate the downward pressures on their categories and margins. Private label does not cause brands to be weak, but if brands are weak, private label will take over.

So the question then becomes – "how do you stop your brand from being weak?" The answer is to understand the drivers of your brand's equity and watch for early warning signs of weakening:

- Is your innovation record poor?
- Is your Research and Development budget no longer large enough?
- Are you becoming more reliant on promotional activity to support your volume?

- Are you charging an unjustifiably high premium for your brand?
- Are you spending enough on good advertising?
- Is there spare capacity in your market?

There is much you can do to add value. Despite the economic downturn, consumers are still willing to spend more money on products that align with these mega-trends:

- Health and well-being
- Indulgence and pleasure
- Convenience and practicality
- Ethical

If vendors can bring products to market that tick all four of these boxes then they are likely to be able to charge quite significant premiums!

THE FUTURE

Going forward, the most important of these mega-trends is the last – ethical. It means different things to different people, and might include:

- Local
- Animal welfare
- Sustainably sourced (e.g. paper or fish products; recyclable packaging)
- Organic
- Fair trade
- Low carbon emissions

Consumers are learning to live in a financially more sustainable manner. That means, in increasing numbers, they will:

- Make their cars last longer
- Have fewer foreign holidays and take more vacations locally
- Reduce debt levels, and save more
- Have greater concern for the environment

The respondents in our Global Online Survey[1], which covers over 50 countries, claim to be concerned about the environment. It is surprising, therefore, that there is not 100 percent agreement with the question: "How strongly do you agree or disagree the statement 'I am concerned about the global environment' ". In fact, 51 percent agree with the statement and 29 percent strongly agree, leaving 20 percent as undecided or disagreeing.

Do these concerns translate in to actions? Shoppers' perception of ethical consumption varies greatly (Table 5). Table 6 then provides the buying claims of respondents.

TABLE 5

Response to the question: "In the last six months, in response to my concerns about climate change, I have changed my daily behaviour"

Criteria	Percentage responding
Strongly agree	12
Agree	39
Neither agree nor disagree	32
Disagree	13
Strongly disagree	4

Source: Global Online Surveys, 2009.

[1] *Source:* Nielsen Global Online Survey, April 2009.

TABLE 6
Consumer stated preferences for grocery products addressing sustainability issues.

Product category	Percentage of those who actively buy the product
Energy efficient products or appliances	53
Locally made products	51
Products in recyclable packaging	45
Products bought from a Farmers' market	42
Organic products	35
Products with little or no packaging	31
Fairtrade products	27
Products that haven't travelled long distances to get to the store	27
Ethically produced or grown products	25
Products that have not been tested on animals	23

Source: Global Online Surveys, 2009.

There is probably a degree of over-claiming here – however, at worst, this shows a propensity to want to do the right thing.

When trying to consume groceries in a more sustainable manner, there is much confusion. Many column inches have been devoted to 'food miles'. However, a better concept is carbon emissions. This is because carbon audits often reveal counter intuitive findings. Products transported from far away may have lower carbon emissions than local ones – sometimes depending on the time of year or mode of transport. The carbon emissions from the energy inputs needed to grow and process a product in the country of consumption can be much higher than those associated with transportation of imported products, as with these examples in Europe:

- New Zealand lamb
- New Zealand apples in winter
- Kenyan roses

Some products declare on their packaging the carbon emissions associated with their production. Knowing that, for instance, 85g of carbon were emitted in the production of a 35g pack of crisps does not tell the consumer whether that is good, bad, or indifferent[2]. It does, however, demonstrate that the manufacturer is bothered enough about this to a) measure it, and then b) try to reduce it. After all, you can only effectively manage what you measure.

The idea that certain fruits and vegetables have seasons and cannot be expected to be available all year round is also gaining wider acceptance. Consumers need manufacturers and retailers to do 'choice editing' for them and provide sustainably sourced products.

Some consumers 'get it' more than others (Table 7).

TABLE 7
"Within the next 10 years, how do you think your quality of life will be affected by the impacts of climate change?"

Criteria	Total percentage
It will improve greatly	4
It will improve slightly	15
It will neither worsen nor improve	32
It will worsen slightly	38
It will worsen greatly	11

Source: Global Online Surveys, 2009.

[2] www.walkerscarbonfootprint.co.uk/walkers_carbon_footprint.html

At a country level (Table 8), the most concerned about climate change are countries in Latin America, with the exception of Greece.

TABLE 8
Responses to the question "Within the next 10 years, how do you think your quality of life will be affected by the impacts of climate change?"

Country	Percentage responding to:		Total thinking their quality of life will worsen (%)
	"It will worsen slightly"	"It will worsen greatly"	
Greece	52	35	87
Brazil	55	24	79
Argentina	57	22	79
Chile	48	30	78
Colombia	47	29	76
Mexico	47	27	74
Venezuela	48	25	73

Source: Global Online Surveys, 2009.

The global population will rise from its current 6.8 billion to between 9 and 10 billion in 2050. There has to be sufficient food, sustainably sourced, for everyone to eat. Perhaps the negative opinion over genetic modification may diminish as the population grows and the science is better understood.

FISH VERSUS MEAT

People are encouraged to eat less red meat to reduce carbon emissions[3] and fish has certainly gained in popularity as consumers are encouraged by health campaigns to regularly eat oily fish to improve intake of omega-3 and omega-6 essential fatty acids. Consumption levels vary hugely from country to country, but 92 percent of Nielsen's survey respondents claim to have eaten fish in the last year (Table 9).

TABLE 9
Responses to the question "On average how often do you eat fish (including seafood)?"

Country	Occasions per week	Country	Occasions per week	Country	Occasions per week
Philippines	3.3	Israel	1.6	Latvia	1.4
Malaysia	3.0	France	1.5	Belgium	1.3
Singapore	2.9	Ireland	1.5	Brazil	1.3
Portugal	2.8	Italy	1.5	Chile	1.3
Thailand	2.8	Poland	1.5	New Zealand	1.3
Hong Kong	2.7	Sweden	1.5	Switzerland	1.3
Indonesia	2.6	United Kingdom	1.5	Venezuela	1.3
Japan	2.6	Estonia	1.5	Canada	1.2
Spain	2.3	Lithuania	1.5	Turkey	1.2
Taiwan	2.3	Egypt	1.5	United States	1.2
Vietnam	2.1	Australia	1.4	Colombia	1.2
China	1.9	Austria	1.4	Netherlands	1.1
Norway	1.9	Finland	1.4	Czech Republic	1.1
Denmark	1.7	Germany	1.4	Pakistan	1.1
South Korea	1.7	Greece	1.4	Argentina	1.0
Russia	1.7	Mexico	1.4	India	0.9
United Arab Emirates	1.7	South Africa	1.4	Hungary	0.8

Source: Nielsen Global Online Survey, April 2008. Global average is 1.6.

Overfishing has led to the depletion of many species in the world's fisheries. Consumers are becoming more aware of the need to ensure that the fish they buy has

[3] www.supportmfm.org

been sustainably sourced. Consumer awareness of the issue is low, but growing. The split of those who 'strongly agree; or 'agree' with the question: "I am concerned about overuse of global fish stocks" is 17 percent and 36 percent respectively.

Table 10 shows the countries that are most concerned with this issue.

TABLE 10
Responses to the question "I am concerned about overuse of global fish stocks"

Country	Percentage responding:		Total agreeing (%)
	"Stongly agree"	"Agree"	
Greece	45	39	84
Indonesia	30	50	80
Thailand	34	45	79
Sweden	29	44	73
Switzerland	29	44	73
Spain	27	45	72
South Africa	34	37	71
France	29	42	71
Philippines	28	40	68
Mexico	28	35	63

Source: Global Online Surveys, 2009.

But who did consumers think should take responsibility for it? Table 11 provides the answer.

TABLE 11
Response to question: "Which of the following groups should assume responsibility for ensuring the sea's fish stocks are not overused?"

Group	Percentage responding
Governments of countries	67
The fishing industry	46
Fish manufacturers and processors	28
People who buy or eat fish	19
Non-governmental organisations	18
Retailers of fish products	16

Source: Global Online Surveys 2009.

There are a number of schemes in place to ensure that the fishing industry is behaving in a responsible manner, with perhaps the best known being the Marine Stewardship Council founded 10 years ago and whose logo appears on many products.

For most people, this kind of on-pack accreditation is at best a 'nice-to-have' and is only a 'must-have' for a minority (Table 12).

TABLE 12
"What level of influence do product labels declaring that fish is sustainably sourced have on your purchasing decision?"

Criteria	Total percentage
Very important	27
Important	43
No influence on purchase decision	30

Source: Global Online Surveys, 2009.

There is a variation by country with Table 13 showing the countries that are most heavily influenced by a product label declaring the sustainability of the source of fish and those that are least concerned.

TABLE 13
Country populations that are influenced by a product label declaring the sustainability of the source of fish

Country	Importance of product label declaring sustainability of the source of fish on purchase decision		
	Very important (%)	Important (%)	No influence (%)
Most influenced populations			
Vietnam	57	39	4
Philippines	50	40	10
Brazil	45	39	16
Colombia	45	37	18
Saudi Arabia	44	35	21
Mexico	41	38	21
India	38	41	21
Chile	37	40	23
Indonesia	35	47	18
United Arab Emirates	35	40	25
Least influenced populations			
Russia	16	37	47
Belgium	14	38	48
Czech Republic	14	37	49
Poland	12	40	48
Hungary	11	46	43
Netherlands	11	45	44
Finland	10	37	53
Norway	9	41	50
Estonia	9	36	55
Latvia	8	35	57

Source: Global Online Surveys, 2009.

If governments and the industry can work out how fisheries can be fully exploited but not over exploited, then, with help from aquaculture, perhaps fish can increase its 'share of stomach'. The fish industry still has other hurdles to overcome, as this research from an earlier Nielsen survey demonstrated (Table 14).

TABLE 14
Response to question: "What are the main reasons you don't eat fish?"

Response	Percentage of respondents (global average)
I don't like the taste	33
I don't like the smell	32
I don't like the bones	21
It's too expensive	17
I'm opposed to eating	15
I don't like the	14
I don't know how to	12
It's not easily available	8

Note: The base is those respondents who "rarely eat fish".
Source: Nielsen Global Online Survey, April 2008.

QUO VADIS?

Twenty years ago, when the world realised that chlorofluorocarbons were depleting the ozone layer, effective action was taken with the Montreal Protocol. That is a good precedent, but will a sense of inequality hamper negotiations, as most of the carbon in the atmosphere today has been put there by the wealthier nations? It might have been reasonable to expect consumers in emerging economies to want developed nations to contribute more to the savings needed. This is not necessarily what survey results showed. Table 15 shows the response to the question: "Which one of the following options do you believe should be adopted to reduce emissions of greenhouse gases?"

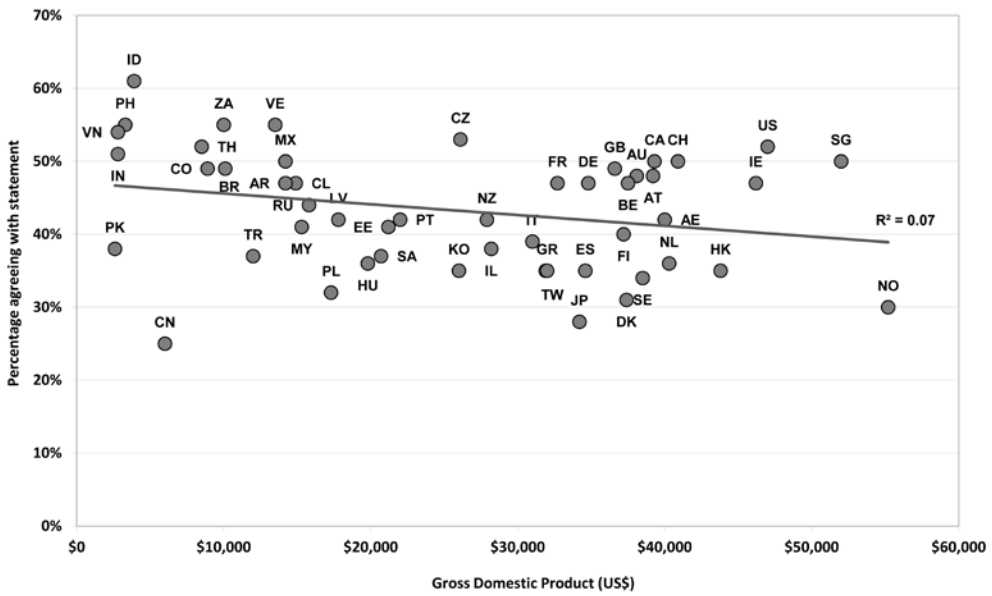
TABLE 15
"Which one of the following options do you believe should be adopted to reduce emissions of greenhouse gases?"

Answer to question	Total percentage
All countries should reduce their emission per person equally	41
Emission reductions based on country wealth – all countries reduce emissions and wealthy reduce their emissions the most	43
Emission reductions based on country wealth – emission reductions from poor countries are voluntary	5
Emission reductions based on country wealth – only wealthy countries should reduce their emissions	3
Don't know	7

Sources: Nielsen Global Online Survey, April 2009; GDP data – CIA Factbook.

Figures 4 and 5 show the country responses to the same questions. The low r^2 numbers show there is little correlation between a country's wealth and the response selected.

FIGURE 4
Response to question "All countries should reduce their emissions per person equally?"



Note: Country abbreviations are standard ISO 3166-1 alpha-2 codes.
Sources: Nielsen Global Online Survey, April 2009; GDP data – CIA Factbook.

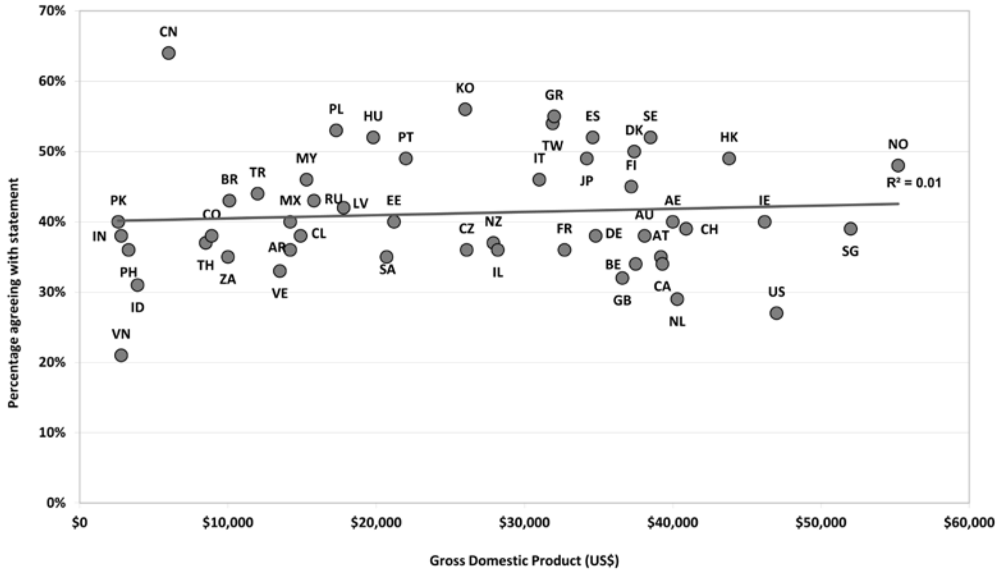
It is to be hoped that COP17[4] in Durban (Nov 28 2011) will help reduce emissions. Many political leaders in countries with high emissions show understanding of the issue and give signs of willingness to adopt policies based on the science (as opposed to a misunderstanding of the economics involved). Professor Stern[5] has persuasively demonstrated that the cheaper option is to attack this issue sooner rather than later.

[4] The 17th Conference of the Parties to the United Nations Framework Convention on Climate Change held in Durban, 28 November to 9 December 2011.

[5] Stern Review on the Economics of Climate Change. UK Treasury, 2006.

FIGURE 5

Response to question "Wealthy countries should reduce their emissions the most?"



Note: Country abbreviations are standard ISO 3166-1 alpha-2 codes.
Sources: Nielsen Global Online Survey April 2009; GDP data – CIA Factbook.

The food industry has much work to do in this area and needs to proceed with some urgency and, above all, integrity. Marketers should not be lazy and become beguiled by trying to achieve short-term gains with spurious claims. Similarly, when the organic farming industry claim that their product is "better for you, and better for the planet", they had better make sure that it is. Carbon emissions are often lower from the non-organic alternative[6].

The food industry is currently in a transition phase, where displaying your ethical credentials might be a differentiator in the fight for consumer loyalty. However, it is likely that very soon it will cease to be a differentiator – and just become a hygiene factor for manufacturers and retailers. So is the industry seriously addressing this issue in their businesses? Tackling carbon emissions will not only make businesses more attractive to customers (i.e. both retailers and consumers), but will also reduce energy bills. This in turn leads to higher profits – achieving the so-called 'triple-win' of people, planet and profits.

There is not a single 'magic bullet' that will solve the climate crisis, however if everyone takes action to reduce emissions, the worst may be avoided. Rabbi Tarfon put it rather well[7] "It is not your duty to finish the work...but neither are you free to ignore it."

CLOSING THOUGHTS

In the grocery arena, provenance and sustainability will gain in importance. Shoppers will be more discerning about why they are paying a premium for some products, and ponder the 'value for money' that more expensive products yield (e.g. organic or bottled water).

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[6] Shopping Trolley Report Manchester Business School, University of Manchester, 2007.

[7] Ethics of the fathers/Pirkei Avot. A compilation of the ethical teachings and maxims of the Rabbis of the Mishnaic period.

It may be hoped that this downturn finishes in a couple of years, after which there could be a recovery and a return to the consumer behaviour of the previous 10 years. Perhaps more consumers will 'press a reset button' and increasingly learn to make a permanent adjustment to sustainable financial and environmental purchasing behaviour.

Around the world, as the numbers of modern self-service supermarkets and hypermarkets increase, the economies of scale, especially from supply chain savings, will be passed on to consumers thereby retarding inflation. With total food bills becoming a smaller component of total household expenditure there will be plenty of opportunities for exciting, premium, value-added propositions on the shelves.

Now is a great time to develop and launch products! Advertising is probably cheaper than it has ever been before, and competitors may be engaged in a race to the bottom of the category – so keep adding value, and enhance brand equity. Studies show that increasing brand equity leads to higher market share – and profits.

Advances in the development and use of fish processing equipment. Use of value chain data

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SUMMARY

Advances in the development and use of fish processing equipment, with respect to the whole value chain, are discussed. The situation in Iceland is described briefly, especially in terms of how seafood production has increasingly taken a value chain perspective into account. Focus is put on how different modules have been linked together, allowing for constant monitoring of yield and economic performance of the catch and processing operations. The different data collection equipment, such as electronic logbooks, processing information systems and marketing information systems are discussed and as is how the data from each link are used for management within the link. Application of traceability is also discussed and how such an application can integrate data from different links in the value chain. When such integration is achieved, more information can be produced from the data. Such information include, for instance, processing related variables like nematodes in the fish and fillet yield and their connection to fishing grounds, as well as environmentally related variables such as oil usage. Future aspects of value chain management, including decision support, more efficient fisheries management and increased data collection to increase the fineness of the traceability granularity are also discussed.

INTRODUCTION

The value chain concept has been increasingly used in the Icelandic food industry in the last years and the management of seafood companies has changed accordingly. Today, managers in the seafood industry consider catching, processing and marketing simultaneously when making decisions. The fact that the same party often owns Icelandic fishing vessels, fish processing companies and marketing companies has also impacted on the value chain approach; the aim is to maximize the profit of the total chain – from catch to consumer – instead of only looking at an isolated link in the value chain.

Increased use of automatic data capturing methods, such as electronic logbooks and weighing machines onboard the vessels, has also enabled better inventory management based on the age and size of the raw material, and other factors considered useful for planning the processing. Use of RFID labelled fish tubs is also increasing, making inventory control and traceability more automated and accurate and therefore enabling different processing of raw material with different properties.

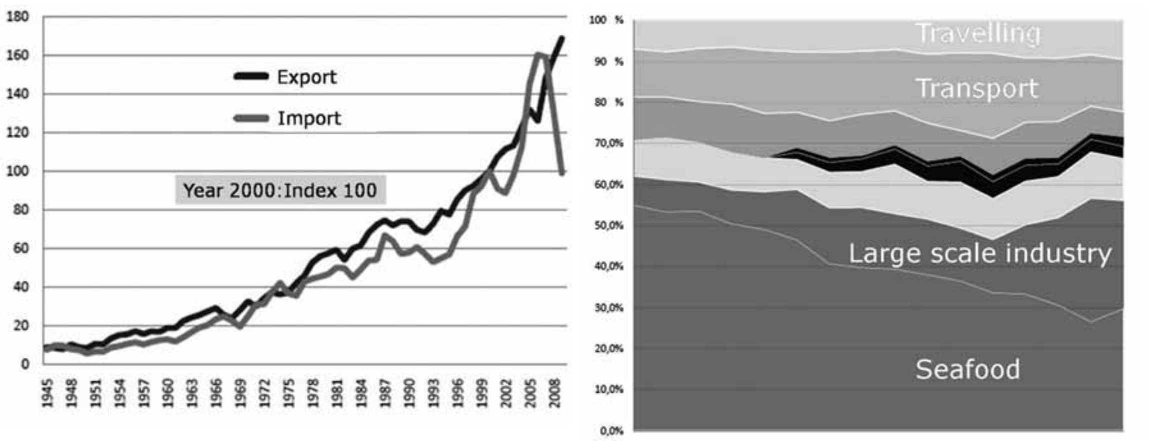
IMPORTANCE OF SEAFOOD PRODUCTION FOR THE ICELANDIC ECONOMY

Despite growth in other industry sectors, the seafood industry is the single most important industry for Iceland. It was estimated in 2004 that fisheries and seafood production, together with ancillary industries, accounted for at least 30 percent of domestic production (Árnason I, 2004). In 2007, this was still the case (Jóhannesson S, Agnarsson S, 2007).

The worldwide economic downturn has impacted negatively on Iceland. This is partly because Icelanders spent too much during 2004 to 2007, as apparent from Figure 1(a), but also because, apparently, the Icelandic banking industry has been badly mis-managed over the last decade. There are other reasons, of course. However, one of the consequences of the economic crash in Iceland in 2008 has been the increased importance of fisheries and seafood production for the country‘s economy. Seafood production is again considered the most important industry in Iceland, not only in terms of the export value (Figure 1(b)), but also in terms of growth opportunities. Companies like Marel (www.marel.com), Trackwell (www.trackwell.com) and Hampidjan (www.hampidjan.is) are all examples of innovative companies servicing Icelandic fisheries and seafood production and also exporting their products and services, contributing importantly to the Icelandic economy.

The export value of seafood in Iceland in 2009 was approximately 200 billion ISK (US$1.5 billion). This is approximately 30 percent of the country’s total export value (Statistics Iceland, 2010). The transportation sector is heavily reliant upon seafood production and accounts for approximately 10 percent of the export value of Iceland. Thus, altogether, seafood is responsible for at least one third of the export value of Iceland.

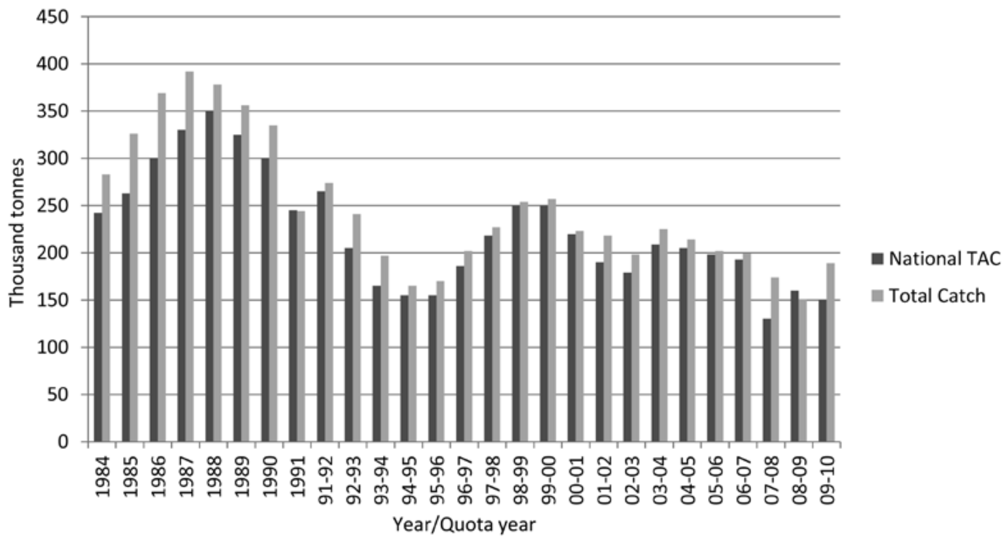
FIGURE 1
Export and import index from 1945–2009 and Proportional distribution of export value between industries in Iceland



Notes: Left figure - Icelandic export and import index from 1945–2009. Note the increase in imported goods from 2004–2007, much higher than the increase in value of exported goods. In 2009, the value of imported goods fell sharply, while the value of exported goods increased fast. Right figure - The proportional distribution of export value between industries in Iceland. Note the increase of the importance of seafood production from 2008 to 2009. The transport industry in Iceland relies heavily on the seafood production and therefore, seafood production account for even higher proportion of export value than appears at first.
Source: Statistics Iceland and the Federation of Icelandic Industries, 2010.

The most important species for value creation in Icelandic seafood production is cod. The Icelandic economic zone is in the north Atlantic Ocean, and there, as in many other waters, catch volumes have declined in the last decades. After attaining annual catch volumes of 300–400 thousand tonnes during the late 1980s, a sharp decline in catch volumes followed. In the decade after the onset of the Icelandic quota system in 1984 and again from 2000–2006, quite large differences between total allowable catch (TAC) and the actual total catch can be noticed (Figure 2).

FIGURE 2
Catch volume and quotas for cod in Icelandic waters from 1984–2010



Source: Sigurdsson, 2006.

Even though the cod stocks did recover to some extent, after the actual implementation of the fisheries management system that had been established in 1984, the high catch volumes of the 1980s are distant memories. Such a decrease in catch volumes called for new methods to maintain profitability of the fish industry. Therefore, in the 1990s, focus was put on improving the handling and processing of cod and the development of new and more valuable products. The first decade of the 21st century has led to the development of a more comprehensive management of the cod value chain as a whole.

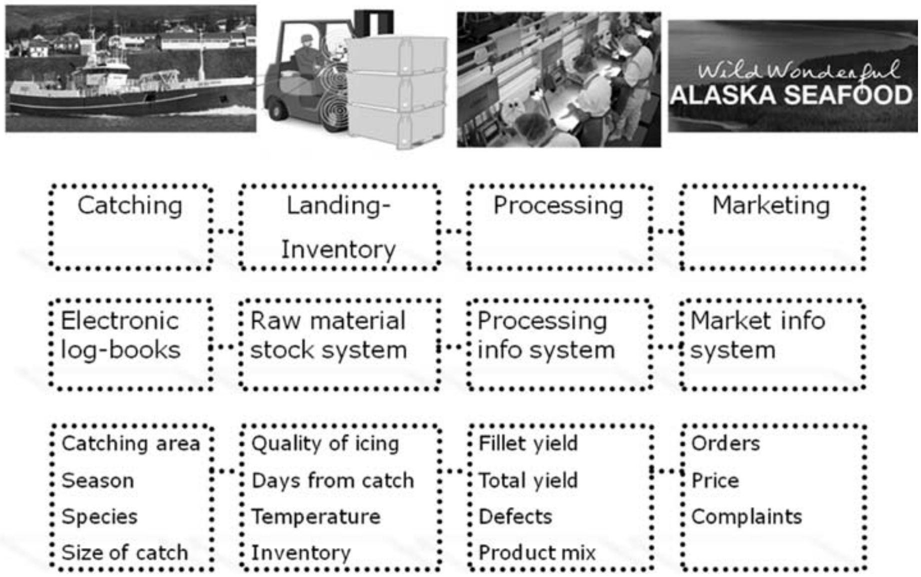
VALUE CHAIN PERSPECTIVE

The concept of the value chain (Figure 3) has been increasingly used in the Icelandic seafood industry in recent years and the management of seafood companies has changed accordingly.

Today, many managers in the seafood industry consider catching, processing and marketing simultaneously when making decisions. Many of the seafood companies have integrated value chain operations, so in fact the whole value chain is owned and operated by the same party. This has led to a more holistic approach to management by not only focusing on maximising the profit from one link in the value chain but looking at the value chain as a whole. It is now possible to estimate the properties of any catch, based on historical data, and to evaluate sailing times and the value of the catch because it has been shown that the properties of the catch and the corresponding value are both spatially and temporally dependent (Margeirsson, B. *et al.*, 2010; Margeirsson, S. *et al.,* 2007; Margeirsson, S. *et al.,* 2006).

Increased use of automatic data capturing methods, such as electronic logbooks and weighing machines onboard the vessels, has also enabled better inventory management based on the age and size of the raw material and other factors considered useful for planning the processing. The use of RFID labelled fish tubs, for instance, makes inventory control and traceability more automatic and precise and facilitates the use of different processing options for raw material with different properties.

FIGURE 3
The value chain of seafood



Note: The first layer (top) shows the operations within the value chain. The second layer shows the medium for data collection within each link and the third layer shows examples of data which are collected.

The amount of data recorded in the Icelandic cod industry has increased greatly in the last decade, in parallel with the decreased costs of acquiring data through automation and computer systems. Some companies have started to utilise the data for management purposes. Data can also be used to respond to consumers' demands for more information about their food products, such as origin, catching method and impact on the environment. This flow of data is based on traceability being in place in the value chain.

Traceability leads to transparency within the chain and is a key factor when linking data. Vertical integration and partnership relationships have increased the motivation within the food industry, as well as in other industries, to share information from one link to another in the value chain. Increased sharing of information and data has and will continue to improve decision making concerning catch and processing of cod in Iceland. Information on fillet yields, gaping and parasites and further analysis of that information has helped in managing the fleet of each company. The size of the catch is no longer only taken into account when choosing catching grounds, but also the properties of the catch for processing, time from catching ground to processing, oil cost and other economic related factors.

When information, such as grading and location data, are available for the catch, modern communication technology allows transmission of data to the processing companies, facilitating the organisation of the processing lines long before the catch is landed. The processing companies are then able to estimate how much and what kind of products they will be able to supply to retailers. This makes marketing more focused and more efficient.

THE ROLE OF TRACEABILITY

Traceability is a term that is often discussed in relation to seafood production and food production in general. Different definitions for traceability in the food sector exist, such as:

- The ability to trace the history, application or location of that which is under consideration. (ISO, 2000).

- The ability to trace and follow a food, feed, food producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution (Regulation EC No 178/2002 (EC, 2002)).
- The ability to follow the movement of a food through specified stage(s) of production, processing, and distribution" (Codex Alimentarius, (CAC, 2008)).
- The creation and maintenance of records needed to determine the immediate previous sources and the immediate subsequent recipients of food (U.S. Bioterrorism Act 2002 (PL107-188, 2002)).

No matter which definition is used, traceability can be used to trace products up and down the value chain. Most commonly, the value chain is seen as starting with raw material and ending with the consumer. The flow of goods defines the stream – downstream is in the direction to the consumer, upstream is in the direction to the raw material. Tracing products upstream (or backward) is often called tracing, whereas tracing products downstream (or forward) is called tracking. Tracing enables "source finding". It enables for instance health authorities to find the source of a particular problem (Bechini *et al.*, 2005; Deasy, 2002; Dupuy *et al.*, 2005; Frederiksen *et al.*, 2002; GS1, 2009; Olsson and Skjöldebrand, 2008; Schwägele, 2005). From the processing manager's point of view, it enables tracing the catching ground of a particular product and thereby linking the attributes of the product to the catching area. Such attributes might include water content, water holding capacity and other physical properties of fish muscle. They might also include analysis of the contribution margin of the product, thereby enabling the processing manager to choose catching areas based on expected contribution margins.

The captain, on the other hand, may be interested in tracking his catch. What happened to the catch? Was it properly utilised? Did all the quality arrangements onboard affect the price of the catch? Tracking is also used in a product recall. If, for instance, mercury contamination is found in a seafood product entering the EU market, it is necessary to trace its origin back to the source and when the source of the contamination is found, track all products that may have been contaminated in the same way.

Generally there are two categories of traceability. Internal traceability is the ability to trace the product information internally in a company and external traceability (or chain traceability) is the ability to trace the product information through the links in a value chain. It is important to note that traceability is not the product information itself. Traceability is the ability to trace and is, as such, only a tool that makes it possible to trace this information through the chain. This was emphasized by Olsen and Karlsen (2005).

A traceability system should, in the same way, not be understood as a system that holds all the data, but rather a system that enables an actor in the value chain to trace back or track forward. The systems that hold the data are referred to as information systems. Experience has shown that in complex food value chains, such systems must be electronic if they are to be effective. However, theoretically a traceability system might be based on pens and paper.

There may be numerous benefits of applying traceability. Traceability allows health authorities to trace and track contaminated foodstuff and reduces the risk and cost of food borne disease outbreaks (Hobbs, 2003). For the food industry, including seafood producers, the benefits occur at the market end and back to distribution and processing.

Some of the benefits of applying traceability are as follows:

1. Lower recall cost is probably the most widely accepted benefit. If contamination is found in seafood products and the producer cannot show that the problem is isolated to a small portion of his production, a full product recall may be the

result. For many producers, such recalls may mean an end to their business and therefore it is of utmost importance to isolate the problem and thereby reduce the cost of a recall. A rule of thumb is that the smaller the production lot, the smaller the recall cost. It is, however, important to estimate the risk of a recall, as having small lots may increase cost; for instance, by slowing down processing. It is therefore important, from an economic point of view, to take the whole value chain into account and weigh risks and costs when deciding on the methods used for traceability.

2. Related to this, benefits from the reduction of lawsuits may accrue. If a producer can show that problems with their products are not related to their operations but rather the operations of another processor, a transporting company, a retailer or even the consumer, then lawsuits may be avoided. This may save the producer from penalties and a possible loss of trade owing to a damaged reputation and a weakened brand (Can-Trace, 2007; Frederiksen *et al.,* 2002; Poghosyan *et al.,* 2004).
3. Market benefits may occur simply because, by being able to trace products, companies become compliant with EU and US regulations. There may also be some consumer requirements regarding traceability, especially at the high-value end of the market (Golan *et al.,* 2004).
4. Improved natural resource management is possible through analysis of the resource utilisation. In fisheries this may be an analysis of how well the natural resource (fish stocks) are utilised - if the catch is coming from a sustainable stock, if the utilisation of the catch is for human consumption, how much of the catch is utilised and how much is discarded, either before or after processing (as waste or byproducts).
5. Improved environmental management, for instance through Life Cycle Assessment (LCA) and calculation of carbon footprints. The use of LCA and carbon footprints may offer a viable way of expanding the discussion on the sustainability of seafood production and providing a more holistic view on the matter of sustainable seafood than that offered by the adoption of popular ecolabels, such as the Marine Stewardship Council (MSC).
6. There are numerous process improvements possible if traceability is applied. From the authors' point of view, this area has by far the most potential for economic benefits, excluding benefits from limiting food poisoning events. A more thorough discussion on the opportunities related to some of the benefits may be found later in the chapter, but the benefits may include:
   a) Improved supply chain management
   b) Improved company management
   c) Increased production efficiency
   d) Improved planning of processing
   e) Improved inventory management
   f) Lower cost of distribution
   g) More focused raw material acquisition
   h) Improved quality management
   i) More focused product development

USING INFORMATION SYSTEMS IN THE VALUE CHAIN

Different information systems are responsible for managing data in the different links of the value chain. Figure 3 (middle layer) shows how the information systems relate to individual links and what kind of data may be expected in each link. The following section discusses this in brief.

Information systems in catching

In Europe, reporting the catch of individual vessels has been required for some time. This reporting has been done by filling out so called logbooks. Electronic logbooks are widely used in Icelandic fisheries and are being adopted in more fisheries, such as in Norway and the Faroe Islands. Today, hundreds of vessels report their catch through electronic logbooks, or e-logbooks as they often are called. The e-logbooks are basically an electronic edition of the paper based logbooks that have been used for decades in those countries and more widely. The captain of the vessel enters the catch, by haul or days, depending on the fisheries. Catch reports are created with information on the size of the catch, relative size of each species, catch location, date, weather conditions and other factors, depending on the fisheries. The reports are received by the Directorate of Fisheries and the Marine Research Institute. The Marine Research Institute uses the reports for scientific purposes, for instance regarding calculations of fish stock sizes. The Directorate of Fisheries compares the data from the reports to landing data for fisheries management purposes.

The use of electronic logbooks has frequently been enhanced by new regulations. A good example is the law on fisheries management in Iceland, which now requires electronic logbooks if vessels are above a certain limit. Today, suppliers of seafood into the European Union must show that their supply is not coming from illegal, unreported, unregulated (IUU) fisheries. This will most probably further enhance the use of electronic logbooks. The electronic logbooks will create enormous volume of data concerning the catch. It is therefore important for all parties of the value chain to realize how they can benefit from the use of electronic logbooks.

The owners of the vessels also receive copies of the catch data. The owners of the vessels are often also the owners of processing factories and they use the data for management of their operations. Some examples of different kinds of analyses that help decision makers include:

1. Catch rates in different catching areas and seasons.
2. Species distribution (proportion of different species) in different catching areas and seasons.
3. Size distribution of the catch in different catching areas and seasons.
4. Comparison between different vessels, if companies use more than one vessel for catching.
5. Bait utilization, i.e. how different bait results in different catches, even mapped down to different catching areas and seasons.
6. Comparison of catching areas in terms of expected profit making, taking into account both revenues (sales) and costs (oil cost, for instance).
7. Analysis of vessel movements during fishing trips and catch, possibly taking into account environmental conditions such as salinity, currents and weather conditions.

Raw material stock systems

Raw material stock systems or information systems at landing include data such as quality of icing, temperature measurements and inventory levels. The information systems are normally not as advanced as those used in e-logbooks and may be a mixture of a database based software solution, spreadsheets and paper. Radio frequency identification (RFID) tags have been used as identifiers of storage units (most often for fish tubs) and even for data storage. However, the use of RFID tags in seafood production is not common yet because of the harsh conditions (cold and humid environment) that makes reading of RFID tags more difficult. The same applies for bar codes, which have also been used as identifiers. In Iceland, the most common method for identification is labelling the fish tubs with either the haul number or date. In some instances the label may even be the trip number.

Information from this link of the value chain can be used widely. Quality management of icing is one example. Many processing plants in Iceland pay a quality premium, because icing of the catch is vital for the quality and freshness and this premium quality opens up the possibilities that the processing plant has for further processing. Another example is scheduling of the processing workforce. By knowing the inventory level and details of the catch (size and age distribution, for instance) and adding data from the e-logbooks (incoming supply), the processing managers can organise the processing for the following days, determine if there is enough raw material to fulfil orders (and also determine if additional supplies are needed from the fish market) and, based on the market price of different products and the workforce available, schedule which products are to be produced and how – with the ultimate goal of profit optimization.

Information systems in processing

There are different processing information systems available. In Iceland, the most common systems are Wisefish from Maritech, Innova from Marel and SAP systems. All of these systems vary greatly, but have in common the feature to manage data from processing and sometimes from marketing. The utilisation of the data can take many forms. Marketing needs to know the product inventory. Processing managers may require different information from the systems. Contribution margin calculations are based on information from the systems, as well as monitoring of yield at different stages of processing. Defect monitoring is also important, as well as monitoring of quality. Connecting quality inspections to the single employees helps with staff education, but may also serve as part of a salary system, with higher salaries for higher quality work.

Information systems in marketing

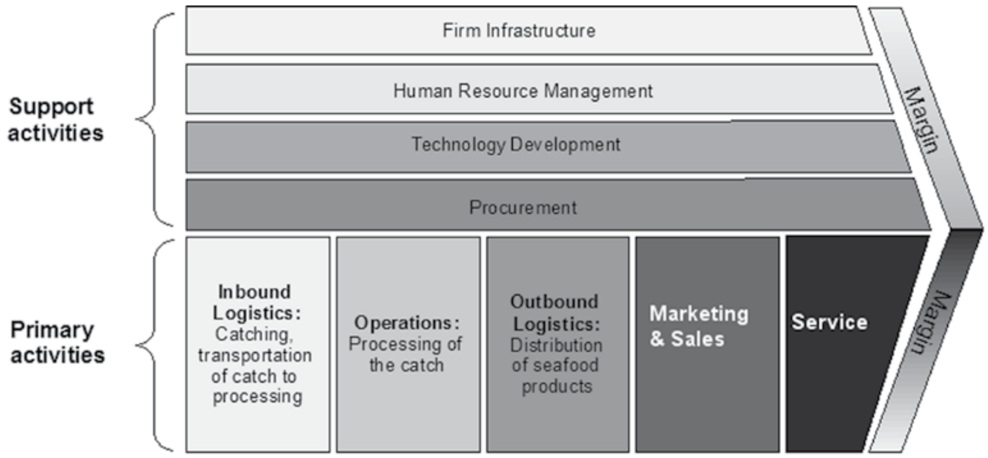
Information systems in marketing are often well connected to the processing information systems or at least to the product inventory. However, when it comes to displaying marketing information from the other parts of the value chain, no such system is available in the seafood industry. Thus data experts need to use raw data and manipulate and analyse this data to provide information of value to managers. With that in mind, at least an informal link exists between the marketing and processing parts of the value chain.

It is useful to look at the value chain using Porter's generic value chain model (Porter, 1985) to better understand the different activities throughout the chain (Figure 4). The primary value chain activities are:

- Inbound logistics: Receiving and warehousing of materials and their distribution to manufacturing.
- Operations: The processes of transforming inputs into finished products and services.
- Outbound logistics: The warehousing and distribution of finished goods.
- Marketing and sales: The identification of customer needs and the generation of sales.
- Service: The support of customers after the products and services are sold to them.

People are getting more and more conscious of the food they consume and discussion about genetic modification of foods has increased the demand for traceability, because consumers want to be able to obtain information about the food throughout the value chain. As a result, traceability can be used as a marketing tool, while recognising the limitations mentioned previously with regard to full chain data analysis when it comes to displaying marketing information from the other parts of the value chain.

FIGURE 4
Visualisation of Porter's Generic Value Chain



LINKING THE INFORMATION SYSTEMS

It is of extreme importance to link all the data collected in the value chain in order to make full use of the data. To illustrate the importance of this, one may look at the current typical method of determining catch location. This mostly involves the captains of vessels relying on their past experience and gut instinct with the aim of maximizing the catch, catch value and total earnings of each vessel. However the captain lacks hard information to consider the latter two factors, so the focus will mainly be on catch volumes. This method has proved remarkably successful but has some obvious shortcomings. The overall value of the catch, taking into account the value creation in processing is, for instance, not taken into account. A combination of the tacit knowledge of vessel captains and processing managers and a more scientific method would be a good option for decision making at sea. An optimization model based on work of Margeirsson *et al.* (2007) has been proposed (Olafsson *et al.*, 2010) for both long-term and short-term decision making for a fishery operating several vessels. A prototype of the software, called Fishmark, has been developed to support decisions in the seafood industry in Iceland and has been taken up by a number of Icelandic companies. The aim is to solve a multi-commodity network flow problem that describes the entire operation of a fishery. However, the shortcomings lie in the linking of data from different links of the value chain. An important part of such decision support systems is the statistical model, based on previous data, that gives indications on what kind of fish can be expected in a certain area at a certain time and helps in deciding the location for catching. This could surely be a very helpful tool but in the current situation, reliable and sufficient data are missing for the model to be of practical use.

The results of Olafsson *et al.* (2010) are, however, quite interesting. They showed that by linking data from electronic logbooks, onboard vessels and data from the information systems in processing, significant information can be created with a variety of possible uses. One application, for instance, might be the statistical analysis of size distributions of catches in order to highlight possible high-grading or at-sea discarding.

Another approach to linking information systems is being explored by an EC funded project called EcoFishman. The overall aim of the project is to develop and contribute to the implementation of a new integrated fisheries management system in Europe, based on results based management. The proposed method is to develop a geographical tool that will integrate relational databases containing the latest traceability tools with web based and geographical information system (GIS) technology. The geographical visualization tool / decision support system will provide a unique interface to view the interaction and interdependency of relevant data of different types.

The databases to be integrated are both proprietary, such as those described in previous chapters, and those that consist of data from three case studies where responsive fisheries management system (RFMS) will be designed and simulated. The different data sets to be collected include biological, social, legal and economic indicators. Because many of those indicators have a geographical component, the GIS technology is very applicable. The collected datasets will have an important role when it comes to predicting and simulating the effects of the RFMS.

Relevant sources of data include the numerous technological tools that are available for assisting in managing fisheries, such as logbooks, satellites, data systems for markets and processing, camera systems onboard vessels (CCTV), technological tools to mitigate bycatch and more.

DECISION SUPPORT: FLEET AND PROCESSING MANAGEMENT

In the case of the seafood industry, the total allowable catch is constrained by regulations. Therefore the revenues are determined by the price of the product and the production yield from the supply of raw material. With this in mind, one can see the importance of utilizing fish optimally as well as making sure that the properties and volumes of catches meet the demands from consumers.

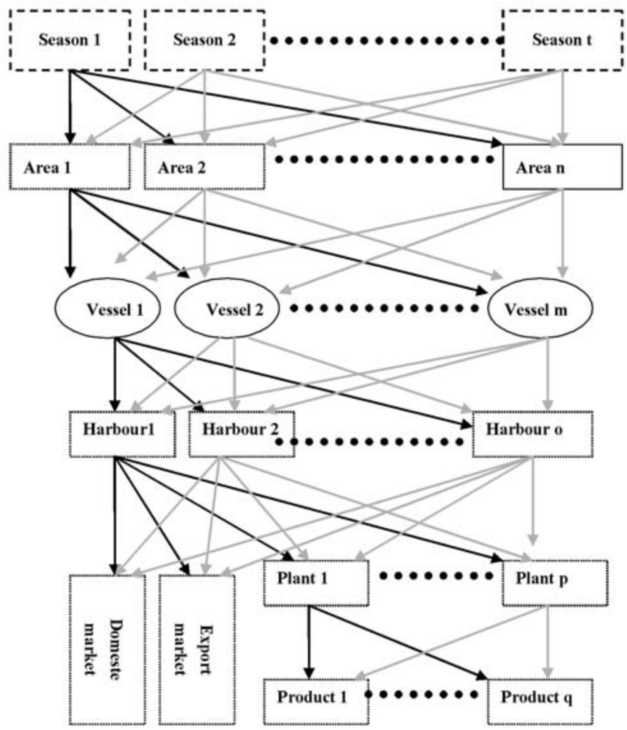
Activities included in the seafood value chain are dependent on each other. Decisions on fishing, processing, labour allocations, quota allocation and marketing may play an important role in the final quality of the final product and thus the revenue obtained. Decision support systems (DSSs) can play an important role in the industry. They have been defined as interactive and adaptable computer-based information systems and are especially developed for supporting managerial decision-making activities.

As an example of a DSS tool for the value chain, a linear optimization model, has been proposed (Margeirsson *et al.*, 2010) to solve the problem of choosing the right parameters for material acquisition. The model is a combination of an assignment problem and a production problem, where the objective is to assign vessels to fishing grounds and to determine the allocation of the expected catch. When constructing the model, the authors realized that good communication between the manager of the catch and the managers of processing and marketing is required to optimize the profits of the value chain as a whole. Four different data categories are taken into account:

1. Catching ground data: Catch volume, species composition, sailing distances, etc.
2. Catch properties in terms of processing properties: Age of the catch, size distribution, etc.
3. Operations expenses: Fishing, transport and processing.
4. Market data: Demand, price of fish from the vessels and price of fish products.

The proposed model may be described as a multi-commodity flow model, where fish is the flowing object. The flow is shown on Figure 5. Properties of the fish change as it moves through the network and the model needs to keep track of the properties of the fish and its associated costs and revenues.

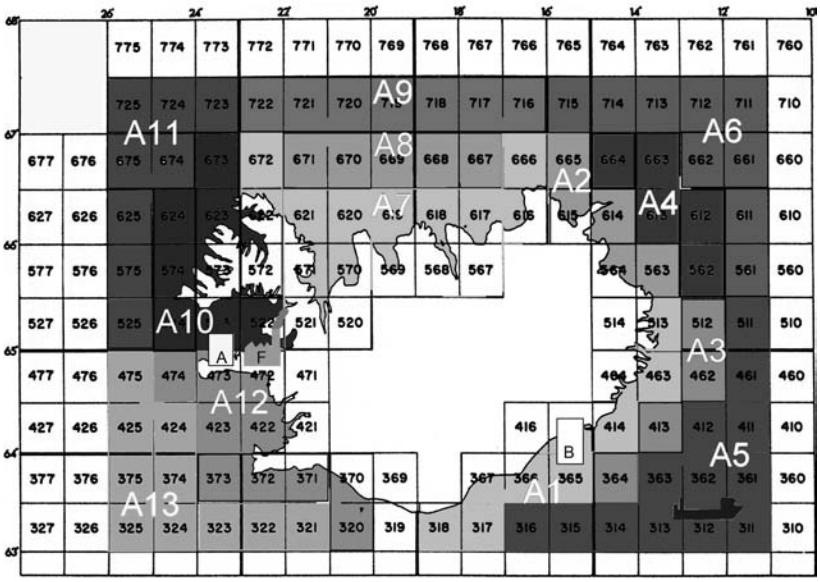
FIGURE 5
A network for one season that shows a flow of caught fish through the company's value chain



Icelandic fish processors are highly developed technically so that much of the information needed to make the correct decisions is already collected and available. Many of the processing plants have undergone radical changes in recent years, with installation of new processing equipment, such as Marel's concept of 'flowlines'. An important part of flowlines is a continuous weighing of fish parts at different unit operations of processing. The weight of the head, fillets, different products and byproducts can all be monitored. This allows processing managers to follow the yield through processing and, if traceability is applied, to map the yield to different catching conditions such as catching areas, seasons, towing times and other parameters. A few hypothetical, but still realistic, scenarios were constructed for a small company in Iceland. In one of the four scenarios, it was assumed that the company operated one trawler and one land-based fish processing plant and that the trawler could choose between two different harbours (A and B), as shown on Figure 6. Harbour A was located on the west coast of Iceland, close to the processing plant whereas harbour B was located on the east coast. The model assumed that fish landed in harbour B would be transported by land to the fish processing plant. The Icelandic waters were divided into 13 different areas and the year into four seasons.

The results show, for instance, that the most profitable catching areas would be A11 and A12 (see Figure 6). Another scenario revealed that if the processing took place in the south eastern part of Iceland (Harbour B location), the profits of the company would be higher than in the first scenario. From this it can be concluded that with traceability, fisheries can retrieve information on, for example, size distribution of the fish or fillet yield from different catching grounds. This confirms the value of traceability.

FIGURE 6
Partition of Icelandic waters into 13 different areas (A1-A13)



Note: The figure also shows the locations of two harbours A and B and the fish processing plant F. Harbours A and B are the harbours where the trawler of the company in the scenario can land. Fish processing plant F is owned by the company.

Moreover, the results show that creation of decision support systems in the form of linear programming models is viable. They require reliable and continuous data flow within the seafood value chain and that the data are accessible for analysis and modelling. Traceability must be applied to link the different actors in the value chain. When it comes to such linking, the high level of integration in Icelandic seafood value chains helps to ensure the data flow.

Decision support such as proposed here may be used to answer different "what-if" questions. Such questions may be about quota price, choice of catching areas and seasons for catching, location of processing plants and the possibility of responding to different market conditions. Historical data are important for the precision of the model, but new data on product price, as well as market forecasts may be of use.

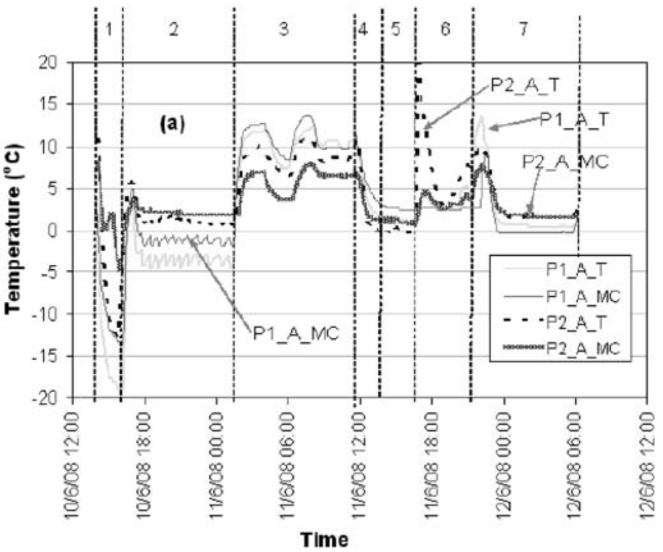
DECISION SUPPORT: COOLING CHAIN

It is of extreme importance that the cooling of the transported fish is well monitored, because the temperature of the fish throughout the value chain affects the quality of the product and, therefore, the revenue achieved. Freezing has for a long time been the most important preservation method in the seafood industry, especially in remote areas such as Iceland that require a longer periods to transport their products to the market. In the past decade or so, the importance of freezing has decreased while chilling has become more and more important. Icelandic consumers and consumers in Western Europe are the most important market for Icelandic seafood. In more recent times, these consumers have lost interest in frozen food, or put more accurately, they want their food in a fresh state if they can have access to it in that state. The economic crisis may have impacted on this to some extent, but this is the general trend. Many of the higher quality producers in Iceland and Norway have welcomed this because it has resulted in partial protection against double-frozen seafood that is processed in Asia and other low wage areas. This move to fresh fish has, however, demanded more efficient cooling because microbiological and enzymatic spoilage is much faster in chilled seafood compared with frozen seafood. In the first five years of the

21st century, this was solved mostly by transporting the fresh products to the market via airfreight, but environmental pressure as well as increasing fuel prices has necessitated the development of chilling techniques that allow sea freight to be used to meet the demands for chilled products. One such successful technique is superchilling. In superchilling, products are chilled below 0 °C, partially freezing the water contained in the products but doing it in such a way that the physical changes that occur when traditional freezing is used do not occur. Experiments have shown that the storage life may be prolonged by 4 to 6 days for both cod and arctic charr, which is approximately the time it takes to sail from Iceland to Western Europe. An important further benefit from superchilling, which takes place after filleting but before trimming and further processing, is an increased yield from the raw material, because the chilling treatment improves mechanical processing of the fillets. Superchilling combined with modified atmosphere packaging can result in further increases in shelf-life, to 14 to 20 days for cod fillets (Sivertsvik *et al.*, 2002).

However, it is not sufficient only to use superchilling during processing. Accurate control of the product temperature throughout the chill chain is essential in order to minimize cost and maximize product quality and thereby product value. This is unfortunately not always the case. Figure 7 shows an extreme example of what may be expected in terms of temperature fluctuations in air freight from Iceland to the United Kingdom.

FIGURE 7
Temperature fluctuations in an air freight transport of fresh fillets from Icelandic processor to further processing in United Kingdom



Source: Mai *et al.*, 2010.

The product temperature is affected by packaging and the ambient temperature. The fact that different transportation modes have various interfaces can cause problems in the chill chain, for example during loading, unloading, delivery operations and temporary storage. All of these stages can introduce delays and are normally not well monitored in terms of ambient temperature, at least not as well as the transportation links themselves. When ambient temperature rises, heat is transferred from the environment through the insulating packaging and starts affecting the product quality through stimulation of spoilage processes. The type of packaging used decides how serious this thermal load becomes, but factors such as air velocity and humidity also affect the transfer of heat from the environment through packaging. The effect of including frozen cooling packs inside fresh fish boxes has been studied (Margeirsson *et al.,* 2009; Margeirsson *et al.,* 2010). Their findings revealed that using cooling packs in fish boxes is an effective way to protect fresh fish fillets against temperature abuse. The same study showed that the insulating performance of expanded polystyrene boxes is significantly better than of corrugated plastic boxes, independent of usage of cooling mats, but the difference is even larger if cooling mats are used (Margeirsson *et al.,* 2010). Thus the management of the chilling chain can become more effective and efficient by taking into account all data from the value chain.

To retrieve the necessary information to monitor the temperature of the product, time-temperature indicators can be used. These are small devices or labels that can be attached to the food or the food package and are in close contact with the food. They show an easily measurable, time-temperature dependent change which must be irreversible and easily correlated to the food deterioration process and remaining shelf-life (Taoukis and Labuza, 1989). Because actual temperature measurements at all stages of the value chain of fresh fish may not be feasible, the use of time-temperature indicators has been suggested to enable estimation of the shelf-life of fresh seafood products (Kreyenschmidt *et al.,* 2010; Riva *et al.,* 2001; Taoukis and Labuza, 1989; Tsironi *et al.,* 2008).

ENVIRONMENTAL DECISION SUPPORT

The emphasis on the environment in the marketing of seafood products has increased greatly during the last decade. This has come about for at least two reasons. Firstly, pressure from non governmental organisations, consumer organisations and retailers has demanded it and, secondly, if seafood companies want to remain in business in the long term, they need to ensure a sustainable utilisation of fish stocks, otherwise they will have no raw material. Long term interests for an industry must be kept in mind at all times. For Icelanders, the crash in the herring stocks in the late 1960s, with the resulting economic crisis, was a tough lesson.

Life cycle assessment (LCA) evaluates the impacts that a product has on the environment over the entire period of its life cycle. One of the shortcomings of the method is, however, that it does not fully take into account the different origins of raw materials and the routes they take in the value chain. It is however widely used and may be among the most advanced tools available for environmental impact assessment.

In recent research, Guttormsdóttir (2009) studied two different value chains in Iceland; the catching of cod by long liners and by bottom trawlers. The environmental impacts of both catching methods were evaluated by applying LCA. Information from the processing phase was gathered and the product was followed from the processing plant to Sevilla in Spain were it was sold and consumed. The study revealed that fish caught by bottom trawling has a larger environmental impact than long line caught cod, within all categories assessed such as climate change, respiratory organics/inorganics, ecotoxicity, acidification and fossil fuel. The most environmentally unfriendly phase within both methods is the fishery phase, the reason being the heavy fossil fuel consumption. To elaborate, 1.1 litre of fuel was consumed by the trawler to obtain 1 kg of processed cod compared with 0.36 litres by the long liner to obtain the same amount of cod. Substantial environmental impact also arises from the processing phase, especially within the trawled cod product – this is mainly because of the refrigerants used in the processing plant. For long lined cod the second greatest environmental impact is the transportation with most of the environmental impact coming from the trucks that transport the product in Iceland and in the target country. Carbon footprints were also calculated. The trawled cod resulted in 5.14 kg CO2 equivalence while the long lined cod was calculated to be 1.58 kg CO2 equivalence. Much further research is needed to assess the environmental impact of a wider range of seafood products in different value chains so that catching, processing and transportation can become more environmentally friendly.

FURTHER WORK

The future of fisheries is based on the ability to maintain, or increase, production. However, this must be done in such a way that fish stocks are not overutilised, and that diversity and the well-being of the environment and society are maintained. One key to attain this is by ensuring traceability in the value chain and enhancing the use of it for managerial decision making. This is one of many important areas for future research and development in the seafood industry.

First of all, it is clear that the databases already maintained by many modern fisheries represent a great deal of untapped potential. Converting this data into useful information, through optimization models, statistical methods or any type of DSS could prove extremely useful for the decision makers. Moreover, regulatory authorities may also benefit from further utilization of the raw data collected over the years, including use of industry data. Still more data is needed as an input for DSSs and preferably this data should be collected automatically throughout the value chain.

Another issue that should be addressed in the near future is the sustainability of the seafood value chain. The value chain concept should be more tightly integrated in the day-to-day operations and information should be made available that will help companies to support the long term sustainability of their operations.

One may well foresee an extended version of LCA (call it LCA+) that uses traceability to allow even better analyses than are possible with current LCA methodology. This enhanced methodology will better incorporate ethical and socio-economic aspects. Moreover, LCA+ will allow its application to different food production chains to elicit differences with respect to sustainability attributes. It will enable Food Business Operators (FBOs) and other stakeholders to identify sustainability hot spots within production, processing, packaging and transportation, as well as allow for comparisons across various chains.

With the current use of DSS, most focus is put on financial outcome and optimisation of processes. However there is a need for a tool such as LCA+, or a system supporting decisions regarding environmental aspects of the value chain, which also takes economic factors into account. For an ideal DSS system to become useful the following data and parameters must be incorporated:

- Real-time traceability data;
- LCA+ results from analysis with the new parameters and data provision time-temperature indicators;
- Identified sustainability indicators;
- Expected consumer behaviour, if available. Consumer values of interest to FBOs relate thereby to increased demand or wider price margins for products meeting obvious consumer needs. They will support sustainable management with respect to their business operations.

By these means, managers within the respective chains will be able to use the DSS to aid decision making that can affect sustainability. Increased sustainability can then be achieved when informed decisions can be taken by the FBOs themselves and informed assessment can be performed by other stakeholders e.g. governmental agencies, certification agencies and NGOs.

Because the overall sustainability level of products consists of the sum of the sustainability of the operations throughout the production chain, an integrated approach is required. It is therefore necessary to increase the effort to utilise and disseminate information from all production processes in production chains – from catching the fish, through the value chain to the consumers buying the food in retail outlets or in a restaurant. A method such as LCA+ would be extremely useful for attaining these goals of transparency, traceability and improved decision making.

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Heat treated fishery products

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SUMMARY
Application of heat has an important role in the preservation of fishery products. Conventional heat-based processes for fishery products include boiling, drying, frying, baking and grilling. Thermal sterilization of fish on a commercial scale was initiated with the invention of canning. Conventional canning is being replaced by retortable pouch packaging because of its inherent advantages. Upcoming non-conventional thermal processes include microwave, radiofrequency and ohmic heating. Thermal processing makes foods more digestible, palatable and ensures their microbiological safety. However, high temperature processing has certain disadvantages such as loss of some vitamins, essential amino acids and unsaturated fatty acids as well as formation of some harmful compounds. These changes can be significantly minimized by combination of low heat with other techniques such as chilling, freezing, modified atmosphere packaging, high pressure, etc. Judicious combinations of these techniques help development of novel products, such as cook-chill and sous vide items, coated and grilled products, surimi based restructured products, heat/pressure processed products, etc. Advantages of combination techniques are saving of energy, reduced loss of nutrients, convenience in handling and enhanced consumer satisfaction. Analyses of merits of individual processes will be helpful for the successful value addition of fishery products.

INTRODUCTION
Heating is the oldest and most reliable method of preservation of food products including seafood. According to the Food and Agriculture Organization of the United Nations, in the year 2008, 115 million tonnes of fish was used for direct human consumption (FAO, 2010). Thermal processing was one of the important techniques used for their processing (FAO, 2008). Commercial scale heat processing of fishery products is supported by diverse equipments and machinery, depending upon the treatment. Heat processed fishery products may be grouped into three categories, depending on the intensity of thermal energy applied, as shown in Table 1.

The first category comprises conventional or traditional processes that depend on heat treatment below 100 °C and include cured products such as dried and smoked items. Products dried in the open sun, in general, have poor quality and hence limited consumer appeal. In contrast, drying of fishery products in cabinets by solar heat yields products having high hygienic properties. The second category relates to products that receive thermal treatment at temperatures above 100 °C. These products are those produced by canning, retort pouch packaging, extrusion cooking, as well as battered, prefried and grilled. Development of the third category of products is of recent origin and involves combination of mild heating with other processes such as chilling, uses of food additives including antimicrobial and antioxidant compounds, packaging, etc. These products are appealing, convenient to handle and hence have enhanced marketability. Applications of microwave, radio frequency and ohmic heating are yet to become commercialized. This article will deal with the major classes of heat-treated fishery products, their quality characteristics and merits of thermal processing.

TABLE 1
Thermal processes for seafood

Low temperature (treatment below 100 °C)	Conventional processes Drying (air, solar) Smoking (cold or hot smoking) Pasteurization Pickling Fermentation
High temperature (above 100 °C)	Canning Retort pouch packaging Extrusion cooking Battered, prefried and frozen products Grilled products
Combination processes involving moderate (not above 100 °C) heating	Cook-chill processing *Sous vide* processing Pasteurized and surface coated products using fish protein dispersion, chitosan etc.

TRADITIONAL PROCESSES

Curing is a combination of one or more processes such as salting, hot air drying, pickling, smoking and marinating (Venugopal and Shahidi, 1998). Thermal treatment during curing is through hot air drying (sun or solar) or contact of hot surfaces. While elevated temperatures enhance water evaporation, presence of salt (in the case of salted products), smoke components (smoked products), or pH (pickles and marinades) in the product provide barriers against growth of microorganisms. A combination of barriers efficiently prevents microbial growth through 'hurdle technology' (Leistner, 1992). The sensory properties of dried fish deteriorate during storage because of the oxidation of lipids, browning reactions, and formation of rust, subsequently leading to a hard texture of the dried tissue. Some novel treatments have potential to control such losses of quality. For example, dehydrated steaks from the freshwater fish rohu (*Labeo rohita*), which can give crispy products upon frying in oil, were developed by initial tenderization of fresh steaks with papain, salting the treated steaks in an equal volume of 5 percent brine followed by drying at 60 °C in a tunnel or a solar dryer. Tenderization enhanced rehydration capacity of the steaks (Smruti *et al.*, 2003). Squid, when subjected to semi-drying followed by roasting, gave a brown acceptable product (Fu *et al.*, 2007).

Smoking is the process of the penetration of volatile compounds resulting from incomplete burning of wood into fresh, ideally salted fish. Smoke is generated by burning sawdust or chips of wood such as maple, oak etc. Storage stability of smoked fish is owing to a combination of factors, namely, (i) salting, which lowers water activity resulting in reduced microbial growth; (ii) elevated temperature drying, which provides a physical surface barrier to the passage of microorganisms, (iii) deposition of antimicrobial substances such as phenols; and, (iv) deposition of antioxidant substances from smoke, delaying rancidity development. The process of smoking may be 'cold' or 'hot' depending upon the temperature of the treatment. Cold (temperature between 30 °C to 40 °C) smoked fish, containing about 5 percent salt and exposed to smoke for 7 hours can be kept for about 2 months at refrigerated temperatures, although, these products may pose microbial risks. Hot smoking is carried at temperatures in the range of 50 °C to 90 °C. The hot smoked products are rapidly cooled and stored at temperature below 4 °C or frozen. Smoke flavourings or liquid smoke have been applied to fishery products because of their advantages over conventional smoking (Hattula *et al.*, 2001). Vacuum, modified or controlled atmosphere packaging or canning can increase the shelf-life of the smoked products (Bannerman and Horne, 2001). A characteristic flavour is the most typical feature of smoked products. Smoked seafood may contain up to 0.5 g of smoke constituents per 100 g tissue, which include volatile carbon compounds including hydrocarbons, furans, nitrogen oxides, sulphur and other compounds, some of them being carcinogenic and hence responsible for health hazards. Improvements in fish smoking relating to temperature control, electrostatic filtration, and development of liquid smoke have been made to enhance the quality of the products. One of the most popular smoked fish species is salmon (Rora *et al.*, 1998). Salmon meat, usually discarded after oil extraction, could be preserved using a combination of smoking and acidification with lactic acid bacteria. The smoked shelf stable product is a source of protein and high-value fatty acids (Bower *et al.*, 2009). Dried fishery products frequently suffer severe losses because of infestation by flies, beetles and mites, particularly during storage under tropical conditions of high storage temperature and humidity (IAEA, 1989). Fumigants such as ethylene dibromide (EDB) have been used to control insects and nematodes in these products. However, these chemicals are being phased out for health reasons. Low doses of gamma radiation can inactivate most of the insects and their larvae (IAEA, 1989). However, the technology is yet to be commercially accepted.

HEAT STERILIZED PRODUCTS

Canning

Thermal treatment of fish in sealed metallic cans eliminates bacterial as well as autolytic spoilage, giving products with shelf lives of 1 to 2 years at ambient temperatures. The unit operations for finfish canning include skinning, filleting, separation of fish parts after evisceration and trimming of fins, scales and other inedible parts, brining, cooking, exhausting, hot filling, and sealing (Horner, 1992). The filling medium, usually brine or oil, accelerates heat transfer to the fish and avoids overcooking at points closest to the can walls. Sterilization of the filled can is done at 121 °C (a steam pressure of 2.0 bar would give a temperature of 120.2 °C) to attain commercial sterility. Inadequate thermal treatment is a risk factor because of possible survival of heat resistant *Clostridium botulinum* that can produce a lethal toxin. The generally recognized minimum heating time to contain the problem is exposure of the coldest spot in the can to a temperature of 121 °C for 3 min (F_o value of 3). High acid fishery products such as marinades and pickles, which contain acetic, citric or lactic acids require heat treatment at a lower temperatures (e.g. 90 °C), while fish canned in tomato juice and low acid (pH3) products require full sterilization at 121 °C. Computer simulation of heat transfer is increasingly used in the process development and ensures better product quality and safety (Ansorena *et al.*, 2010). During cooking, leaching of water soluble vitamins and soluble proteins into cooking liquors is increasingly recognized as the major source of loss of nutrients (Horner, 1992; Farkas and Hale, 2000**).** The equipment required for canning as well as its economic aspects has been discussed by Zugarramurdi *et al.* (1995).

Canning has been employed to preserve marine pelagic fish such as anchovy, herring, mackerel, sardine, scad, sprat, pilchard, a variety of shellfish and molluscs (Skipnes, 2002). In Europe, headed and gutted small sardines and sprat canned in oil or tomato sauce are available, while canned herring products are popular in Germany. Some fish such as sprats may be briefly smoked prior to canning. The U.S tuna industry annually processes several thousand tonnes of fish, with skipjack tuna being the most important raw material. Popular canned products include tuna canned in oil, brine, or vegetable broth, tuna salad with garden vegetables, tuna salad in Italian sauce, tuna in sweet and sour sauce and tuna spread (Subasinghe, 1996). Freshwater and farmed fish such as carp, chub and rohu are suitable for canning. (Raksakulathai, 1996). Canning has also been employed to preserve fish balls, pastes and spreads from freshwater bream. For these products, the fish is thoroughly cooked, chopped and mixed with ingredients to give a spreadable consistency. Incorporation of a gelling agent such as gelatin may be required to develop a paté that is sliceable and spreadable (Balange *et al.*, 2002). The two popular shrimp species, the white shrimp and black tiger, are also suitable for canning (Sriket *et al.*, 2007).

Retortable pouch packaging

The conventional canning in metal containers is being replaced by the retort pouch. The technology is aimed at producing high water activity (>0.85) low acid (pH>4.5) foods that are stable at ambient temperatures. Several types of retortable pouches are available that suit consumer choice and convenience. While conventional pouches are generally pillow style, the new stand-up flexible pouches are capable of erect positioning on shelves by virtue of a flat base and hence have a better ability to display their contents (Brody, 2008). The advent of retort pouch processing technology has made the availability of shelf-stable ready-to-eat (RTE) foods a reality. Other commercial retort pouch packaged products include vegetable curries, pudding in tubes, as well as coffee and dairy beverages (Brody, 2008). Although the costs associated with retort pouch processing are significantly higher than for canning, the comparatively low cost of the pouch compared with aluminium cans allows for lower freight costs attributed to the lighter weight and smaller volume of pouches. Higher consumer demand makes the technology cost effective. The retort pack allows shorter thermal processes in comparison to canning. Furthermore, unlike the metallic cans, the boil-in-bag facility offers the potential of warming the food in the pouch immediately before consumption. The required qualities of a retortable pouch are its ability to withstand a temperature as high as 133 °C, good seal integrity with a seal strength of 2 to 3.5 kg/100 mm, bond strength of 150–500 g/10 mg and burst strength of 7.5 kg/15 mm seal (Devadasan, 2001). The pouch is a laminate of three materials, an outer layer (normally 12 µm thick) of polyester, a middle layer of aluminium foil and an inner layer of polypropylene. The outer layer protects the foil, provides strength and also a surface for printing details of the contents. The aluminium layer functions as a barrier for moisture, odour, light and gas, while, the inner layer is the heat seal and food contact material. The following are the general requirements for retortable pouch packaging:

1. Resistance to temperature up to 133 °C;
2. Low gas permeability and no oxygen permeability;
3. Inertness in interaction with food components;
4. Low water vapour transmission rate. Ideal moisture vapour transmission rate, nil;
5. Heat sealability, bond strength and resistance to burst;
6. Physical strength to resist any handling during manufacturing and distribution;
7. Good aging properties;
8. Printability.

The critical factors involved in the development of retort=pouched products include product consistency, filling capacity/drained weight, perfection in sealing, temperature distribution and control, container orientation, residual headspace gas, processing and racking systems, processing medium, pouch thickness and the pressure applied (Beverly *et al.*, 1990). Because of their limited seal strength, pouches are unable to support internal pressure developed by heat induced expansion of gases, therefore during processing the retort pressure is carefully controlled by steam/air mixtures. After the sterilization process, the pouch is rapidly cooled to avoid overcooking (Silva *et al.*, 1995**)**. During treatment, monitoring of surface thermal conductance of pouches allows determination of process time, mass average sterilizing value and nutrient retention (Bhowmik and Tandon, 1987; Simpson *et al.*, 2004). There are three essential rules for the safety of retort pouch processed products, namely, pouch seal integrity, adequate thermal processes to eliminate the most dangerous and heat resistant microorganisms including *Clostridium botulinum* spores, and post-process hygiene. Retort pouch packaged products generally require reheating before consumption of the packaged food items (Rangarao, 2004). Table 2 compares retort pouch technology with conventional metallic canning.

TABLE 2
Comparison of retort pouch technology with conventional metallic canning

Features	Retort pouch	Can
Feasibility	Highly suitable for delicate products such as seafood, sauces	Good for products having tough texture such as beef, pork, etc.
Product development	Slower filling, thermal processing more complex	Convenient production line including filling and thermal processing
Sterilization time	Less	More
Product quality	Superior product quality, with more natural colour, flavour and texture	Intense cooking results in loss of natural sensory attributes.
Shelf-life	Comparable with canned products	Comparable with retort pouch products
Convenience in handling	Less weight, needs less storage space	More weight, requires more space for storage
Convenience in consumption	Can be easily opened by tearing across the top at a notch in the side seal or by cutting with scissors	May require a can opener
Capital investment	High	Medium level of capital investment
Marketing	Trade and consumers need to be familiarized with handling the pouches	Established technology and hence, minimum consumer education needed

An optimization technique has been developed for thermal processing of jack mackerel in cone frustum shaped pouches demonstrating the comparatively low cost of the pouch compared with aluminium cans (Simpson *et al.*, 2004). Seafood including salmon, tuna, crab, clams, shrimp, mussel and oyster, and products such as fish sausage, smoked fish, fish paste and other items have been successfully subjected to retort packaging (Srinivas Gopal, 2003). Curried seer fish (*Scomberomorus guttatus*) packaged in a retort pouch of polyester/aluminium foil/cast polypropylene, had acceptable sensory characteristics for more than a year in storage (Vijayan *et al.*, 1998). Prawn in 'kuruma' (essentially an extract of mixed spices), using white shrimp (*Fenneropenaeus indicus*), was packaged in retort pouches. Thermal processing required significantly less time compared with that of conventional aluminium cans and the resulting pouch products were superior to canned products in terms of quality attributes (Mohan *et al.*, 2008). Similar results have been reported for sardine based products. An increase in thermal treatment times resulted in loss of textural properties of both canned and pouch packaged fish (Ali *et al*, 2005). Salmon in various forms, such as flavoured roasted fillets, smoked chowder as well as spread, pickled products, paté, croquettes, lunch meat, pasties, low fat burgers, sausages and smoked and marinated tenderloins, have been retort packaged in stand-up flexible pouches (Venugopal, 2006). A novel pouch material, aluminium oxide coated polyethylene terephthalate (PET)/nylon/cast polypropylene (CPP) (ALOX) has recently been reported for packaging of salmon (Byun *et al.*, 2010). Smoked yellowfin tuna (*Thunnus albacares*) steaks were packed in retort pouches with refined sunflower oil or 2 percent brine as the filling medium. Processing was done at a F_o value of 10 in an overpressure autoclave with a facility for rotation. A slow rotation of the product up to 8 rpm during thermal treatment significantly enhanced heat penetration in the product requiring lower process time. (Bindu and Srinivas Gopal, 2008). Retort pouch packaged mussel meat was acceptable up to one year of storage at ambient temperature (Bindu *et al.*, 2004).

Consumer interest in retort pouch products are attributed to changes in lifestyles, lack of sufficient culinary knowledge (to prepare meals from scratch), interest in products having exotic tastes, better hygienic quality, and convenience in handling. Therefore, the global consumption of retort pouches has increased from 7 billion in 2002 to 10.1 billion in 2006 and is projected to be 18.8 billion in 2011 (McQuillen, 2007). In India, production of ready-to-eat (RTE) foods has exceeded an annual value of about US$20 million (Rangarao, 2004). The Natick Soldier Research, Development & Engineering Center (NSRDEC) in the United States has developed RTE meals for soldiers (Halford, 2010). Retort pouch packed fishery products have become a recent addition to seafood trade.

Extrusion cooking

Extrusion technology has been used for several decades, particularly for the development of cereal based breakfast items. Food extruders are high temperature (130–180 °C) short-time (HTST) machinery that can transform a variety of raw ingredients into modified intermediate and finished products (Harper, 1981). The process involves forcing a mixture of starch and other ingredients, at low moisture content (15 to 45 percent), through a barrel under variable conditions of temperature and pressure. This results in the melting and gelation of starch, facilitating its binding with other ingredients. The movement of the material through the barrel can be through single, twin, or multiple screw conveyors that provide high or low shear on the product. When the product emerges from the extruder, it expands because of the sudden drop in pressure. A suitable die at the end of the barrel allows different shapes of the emerging product to be formed. Twin screw extruders have better mixing ability, uniform shear rate, good heat transfer, and can operate at higher moisture contents, compared with their single screw counterparts and are therefore finding increased applications for chemical modification of food ingredients to create tailor-made products.

The application of extrusion technology for protein rich products is possible, at higher moisture levels. Extrusion of protein products at moisture contents of up to 80 percent facilitates emulsification, gelation, restructuring, microcoagulation, and/or fiberization of the specific protein constituents (Areaas, 1992; Cheftel *et al.*, 1992). Texturization of surimi using a twin screw extruder at a screw speed of 150 rpm, a barrel temperature of 160–180 °C, a feed rate of 30 kg per hr and a die temperature of about 10 °C gave a product having a texture comparable with that of lobster, crab, and squid. The equipment required long dies with cooling, which helped to partially solidify the material. Surimi from Alaska pollock, sardine, and salmon were used in these processes. An extruded crab analogue prepared from Alaska pollock surimi is in commercial production in Japan (Cheftel *et al.*, 1992). Extrusion processing of fish has scope for the development of products from underutilized species, bycatch and also meat recovered from filleting operations, for the production of fibrous value-added products. The system is capable of making products in a wide range of shapes (ropes, flakes, cubes and patties) with different physical properties (e.g. smooth, rough, shiny or marbled surface appearance with light to dark coloration). Ingredients such as flavourings, preservatives, colorants, oils and vitamins can be added. Development of products incorporating proteins from soybean and surimi has been attempted with some success (Choudhury and Gautam, 2003; Gautam *et al.*, 1997).

Coated, prefried products

Battered, prefried and then frozen products are an important category in the ready meals market. Because of their convenience, these items are liked by most consumers, indicated by the volume of global trade in such products. Sophisticated machinery is available for the operations. Predust usually is a fine, dry material composed of wheat flour, gums, proteins and often flavours, which is sprinkled on the moist surface of the frozen or fresh seafood. It improves the adhesion of the batter. Batters are of two types, adhesive and tempura. The adhesive batter contains starch, salt, seasonings, polysaccharides (e.g. xanthan), proteins, fat/hydrogenated oils, and preferably a leavening agent such as sodium carbonate to favour expansion during frying. The proportion of batter and water is usually in the ratio of 1:2. Gums such as xanthan are used in the control of viscosity and water holding capacity. Corn flour is important in tempura batters. The characteristic property of the batter is its viscosity, which determines its performance during frying and quality of the finished product. (Joseph, 2003; Fiszman and Salvador 2003). 'Breading' uses a cereal based coating, often of breadcrumbs. Texture, mesh size, porosity and absorption are the major factors contributing to the texture of the coating. The major functional characteristics of breading are its volume to unit area, browning rate, moisture absorption, oil absorption, colour and texture. According to the normal manufacturing process, frying is carried out at 180–200 °C in refined oil for about 30 sec, followed by freezing the product. By keeping the coated product in the fryer for a relatively short time, heat transfer to the product is restricted to the coating surface, while the core of the product, such as fish, remains frozen. Limited quality is lost because the product is frozen immediately after frying. However, the high temperatures associated with frying may cause oxidative losses of vitamins such as vitamin E. The coating technology has been described by Joseph (2003). Battering and breading techniques have contributed significantly to value-addition of fish fillets, shellfish and molluscs. Some of the products include butterfly shrimp, squid rings, stuffed squid rings, fish cutlets and fish burgers. The coating technology has further improved with the development of the surimi industry. The popular 'fish finger' or 'fish stick' is a coated product from finfish species such as cod, haddock, pollock, perch and catfish, among others (Sasiela, 200l).

Grill-marked and sauce coated fillets appeared in the market in the 1990s. The use of a flavoured sauce over the grilled fish enhances its flavour. The sauce is generally composed of water (40–60 percent), vegetable oil (10–50 percent), seasoning (5–25 percent) and gum thickener (0.2–1 percent). Popular sauce flavours include lemon pepper, Polynesian (pineapple sauce sprinkled with toasted coconut), smoked barbecue and tomato. The sauce is applied to the grilled seafood using conventional batter recirculating equipment. The sauced fish are individually packaged in pouches using skin-sealing trays. These products are generally well accepted throughout the world (Mermelstein, 2000).

COMBINATION PROCESSES INVOLVING MODERATE THERMAL TREATMENTS

The increased demand for convenient, fresh-like, ready-to-eat or ready-to-prepare products has encouraged the development of techniques combining mild heating with other techniques such as refrigeration, use of preservatives, etc.

Cook-chill products

Moderate heating in conjunction with chilling helps retain freshness and enhances user convenience of foods such as vegetables. These are called 'minimally processed foods' and are characterized by a water activity (a_w) above 0.85 and pH above 4. They include ready-to-eat meals and chilled prepared foods (Ohlsson and Bengtsson, 2002). Such foods are processed by a mild heating not exceeding 100 °C followed by refrigerated storage and distribution (FLAIR, 1997).The Codex Alimentarius Commission classifies these foods as low acid type foods, (pH>4.6) having high water activity (>0.92) that are heated (or processed using other treatments) to reduce their original microbial population and are intended to be refrigerated during their shelf-life to retard or prevent proliferation of undesirable microorganisms, and have an extended shelf-life of more than five days. These foods are packaged, not necessarily hermetically, before or after processing, and may or may not require heating prior to consumption (Codex, 1993). 'Cook-chill catering' is defined as a 'catering system based on the full cooking of food followed by fast chilling and storage at controlled low temperatures above freezing point (0–3 °C) and subsequent thorough heating by the consumer (or person serving the consumer) before consumption' (Light and Walker, 1990) The minimum unit operations of the process are cooking, chilling, packaging and chilled storage. The term, 'pasteurized chilled foods' is also used to refer to these foods. Pasteurization temperatures usually range between 65 °C and 95 °C. Preservatives are usually avoided in order to convey a fresh or home-made appeal to consumers. The safety of the products depends on limited refrigerated storage (normally 5 days) to prevent the growth of any hazardous microorganisms. Flexible packaging is an integral part of the process to prevent microbial contamination. The packaging also controls moisture vapour transfer and displays the product in an attractive way (Cleland, 1996). Time-Temperature Integrator devices are useful to monitor storage temperatures. A special barcode with a time-temperature indicator that changes colour can also give information on temperature abuse during storage (Brody, 2008). The food may be subjected to reheating, generally to 70 °C for a few minutes before consumption. The low cooking temperature and refrigerated storage retain high sensory and nutritional qualities. The disadvantages of cook-chill catering include possible abuse of storage temperatures enhancing microbiological risks, product instability during extended storage and the need for high capital investment for the technology. The limited chilled shelf-life of cook-chill products could be extended by incorporation of additional processing steps, such as brining. The U.S. National Food Processors Association recommends incorporation of multiple (at least two) barriers or hurdles (in addition to refrigeration) into the product formulation to ensure microbial safety (NFPA, 2002; IFT/FDA, 2003). Examples of such microbial barriers include acidification, reduced water activity, preservatives, protective cultures and modified atmosphere packaging. Modifications may also include *sous vide* (cooked under vacuum), hot-fill and hygienic and aseptic packaging. Additional treatments such as low dose irradiation and/or modified atmosphere packaging could be employed (Scott, 1989). Integration of Good Manufacturing Practices/Good Hygienic Practices (GMP/GHP) and of Hazard Analysis Critical Control Points (HACCP) can enhance safety of these foods. During the decade from 2000 to 2010, chilled foods worth GBP8 708 million per annum were marketed, showing a value growth of 83 percent during the period (UK Chilled Foods Association, 2010).

Cook-chill processes involving multiple microbial barriers including chill temperature have been reported for extending the refrigerated shelf-life of fishery products. The processes for two commercially important fishery products, namely white pomfret (*Stromateus cenereus*) and shrimp (*Penaeus indicus*), include polyphosphate dip treatment, brining, steaming, rapid chilling followed by chilled storage. Polyphosphates improve the water holding capacity of the product, while the brining stage enhanced flavour, sensitized microorganisms to heat and provided an additional antimicrobial barrier. The products had an extended shelf-life of 25 days, as shown by microbiological and sensory evaluations (Venugopal, 1993). The process for shrimp is shown in Figure 1. The process could be extended to other fishery products. Table 3 summarizes the merits of cook-chill technology.

FIGURE 1
Cook-chill process for shrimp. Adapted from Venugopal, 1993

Fresh shrimp
↓
Peel, devein
↓
Wash, drain
↓
Immerse in equal volume of aqueous (10%) (w/v) sodium chloride for 1 h
↓
Drain
↓
Gently stir in 5% (w/v) aqueous sodium tripolyphosphate (TPP)(Ratio of shrimp to solution, 5:1)
↓
Drain
↓
Steam for 15 min
↓
Cool to 0-2 °C for 15 min
↓
Package in polypropylene pouches
↓
Store at 3 °C

TABLE 3
Merits of cook-chill technology

Advantages	Disadvantages
Processing	Microbiological risks require strict process and storage control
Central production unit	Product instability during prolonged storage
Production is separate from consumption point	Environmental issues with respect to packaging material
Bulk buying power	Limited chilled distribution channels
Higher productivity	High energy requirement for storage
Better equipment	Need for capital investment
Lower storage costs, because temperature is not below freezing	
Heating is rapid. Microwave oven can be used	
Facility for HACCP	
Less equipment needed	
Less space	
Less skilled and unskilled staff	
Less waste of raw material	
Possibility for varied food product formulary	
Packaging	
Less food waste (flexible packaging size)	
Convenience and flexibility	
Protection from recontamination	
Vacuum retards spoilage processes	
'Sealing in' juice and flavours	
Labelling information	

Adapted from Rodger (2004).

Sous vide (meaning, 'under vacuum') cooking is defined as cooking of raw materials under controlled conditions of temperature and time inside heat-stable pouches under vacuum, followed by rapid chilling. (Gonzales-Fandos *et al.* 2004). Heat treatment equivalent to 90 °C for 10 min to obtain a substantial reduction in the numbers of the pathogenic microorganism *Clostridium botulinum* has been recommended (FLAIR, 1997). The European Chilled Food Federation's 'Botulism Working Party' determined a need for additional effective preservation factors for *sous vide* foods, where a 6D reduction of non-proteolytic *C. botulinum* cannot be guaranteed (Gould, 1999). The flavour and texture of *sous vide* foods are comparable to those of conventional cook-chill and conventionally cooked foods (Chirife and Favetto, 1992) Rainbow trout processed by the *sous vide* method (involving heating to maintain a core temperature 90 °C for 3.3 min) resulted in substantial microbial reduction in the product. (Gonzales-Fandos *et al.* 2004). The *sous vide* process for farmed blue mussels (*Mytilus edulis*) includes cleaning, filling in pouches in presence of desired sauces, packaging under vacuum and pasteurization at 100 °C for 17 to 35 min, followed by immediate cooling. The product has a shelf-life of 14 days at 0–5 °C. Instead of chilled storage, the seafood can also be frozen at -18 °C. Vacuum packed, cooked, frozen molluscs, having a shelf-life of 21 days at 4 °C are gaining popularity as a gourmet item. (Gorski, 1990). The shelf-life for *sous vide* processed cod, cod fillets and salmon stored at 0 °C, 3 °C and 4 °C were 28, 21 and 15–21 days, respectively (FLAIR,1997). *Sous vide* processing of salmon has been reported by Bergslien (1996).

Other combination techniques

Heating can be combined with high hydrostatic pressure (HHP) treatment, modified atmosphere packaging and use of preservatives such as antimicrobials, antioxidants, etc. Treatment at an optimum HHP of 150 MPa for 15 min significantly reduced microorganisms in Atlantic salmon. There was no significant change in fatty acid profile (Yagiz *et al.*, 2009). The possibility to improve the microbial quality of blue fish burgers incorporating thymol (110 ppm), GFSE (100 ppm) and lemon extract (120 ppm) in combination with MAP has been reported. The product had a shelf-life of 28 days at 4 °C. (Del Nobile *et al.*, 2009; Venugopal, 2010).

Meat from low cost fish can be converted to a thermostable water dispersion that can have various applications as protein coatings to preserve valuable fishery products. The dispersion is prepared by thorough washing of fish meat, as in the case of surimi. The washed meat is homogenized in water at 3 percent protein concentration. The pH of the homogenate is lowered to about 4 by a few drops of acetic acid, followed by heating of the homogenate. The dispersion contains proteins, which remain soluble even at 100 °C (Venugopal, 2006). The dispersion could be used as an edible coating to enhance the shelf-life of fresh fish, because, as it has a slightly acidic pH, the dispersion prevents bacterial proliferation on the surface (Smruti and Venugopal, 2004). The dispersion, when applied to mince of fatty fish such as mackerel, can prevent lipid oxidation as well as drip loss during frozen storage (Kakatkar *et al.*, 2004). Another promising area is using chitosan from shrimp shell waste to give coatings to high value fishery products. Chitosan, because of its well recognized antimicrobial and antioxidant activities, has the potential to extend refrigerated shelf-life of fishery products (Venugopal, 2010).

NON CONVENTIONAL HEATING TECHNIQUES

Non conventional, rapid heating techniques are increasingly becoming popular in food processing because of their recognized advantages. The upcoming technologies include microwave (MW), radiofrequency (RF) and ohmic heating. Both MW (915-24125 MHz) and RF waves (13 kHz to 40 MHz) are part of the electromagnetic spectrum that result in heating of dielectric materials by induced molecular vibration as a result of dipole rotation or ionic polarization (USFDA, 2009). Commercialized food applications of MW and RF heating include blanching, pasteurization, sterilization, drying, selective heating, disinfestations, etc. Technological challenges in these applications include process equipment design to achieve the desired effects, such as microbial destruction and enzyme inactivation, temperature and process monitoring, and achieving temperature uniformity. Other issues relate to the use of packaging materials in in-package sterilization applications, package/container concerns in domestic MW ovens, receptor technology for creating dry-oven conditions, modelling and time-temperature process integrators. There is also the issue of non-thermal and enhanced thermal effects of microwave heating on destruction kinetics (Ramaswamy and Tang, 2008).

Continuous flow microwave sterilization is an emerging technology that has the potential to replace the conventional heating processes for viscous and pumpable food products (Kumar *et al.*, 2007). Mathematical modelling of heat transfer has been developed using fish meat gel to study the heating mechanisms of seafood products inside a microwave oven, and employed fibreoptic probes to measure the temperature elevation at various positions of the foodstuff (Hu and Mallikarjun, 2004). MW heating for a few seconds could enhance puffing and improve the crispness of vacuum packaged fish slices (Chang *et al.*, 2007).

Radio frequency (RF) heating is a promising technology for food applications because of the associated rapid and uniform heat distribution, large penetration depth and lower energy consumption. Because of their lower frequency levels, RF waves have a larger penetration depth than microwave heating and hence could find better application in larger size foods. RF heating is influenced principally by the dielectric properties of the product when other conditions are kept constant (Chong *et al.*, 2004). The frequency level of the waves, temperature and properties of food, such as viscosity, water content and chemical composition affect the dielectric properties and thus the RF heating of foods (Piyasena *et al.*, 2003). Radio frequency heating has been successfully applied for drying, baking and thawing of frozen meat. An 18 MHz RF processor applied approximately 0.5 kV/cm electric field strength to liquids, and was capable of pasteurizing the liquids provided that cooling was minimized. There were no non-thermal effects of RF energy detected on various microorganisms including *Escherichia coli* K-12, *Listeria innocua*, or yeast in various food products (Geveke *et al.*, 2002; Wang *et al.*, 2003).

Ohmic heating has been applied to fishery products. Pacific whiting surimi gels having 78 percent moisture and 2 percent NaCl when heated slowly in a conventional water bath exhibited poor gel quality, while the ohmically heated gels showed more than a twofold increase in shear stress and shear strain over conventionally heated gels. Degradation of structural proteins was minimal under ohmic heating, resulting in a continuous network structure of the fish surimi. Non-fish protein additives exerted better influence on the gel properties when subjected to ohmic heating (Yongsawatdigul *et al.*, 1995; Cha and Park, 2007).

Near infrared (NIR) spectroscopy has been used to assess the end point temperature (EPT) of heated fish and shellfish meats. Blue marlin *(Makaira mazara*), skipjack (*Katsuwonus pelamis*), red sea bream (*Pagrus major*), kuruma prawn (*Penaeus japonicus*) and scallop (*Patinopecten yessoensis*) meats were heat treated at different temperatures (5 °C intervals between 60 °C and 100 °C). NIR spectra were measured at 2nm intervals between 1100 and 2500nm. Changes in NIR reflectance spectra at appropriate wavelengths upon heat treatment at 60–100 °C were related to the heating temperature (Uddin *et al.*, 2002).

ADVANTAGES AND DISADVANTAGES OF THERMAL PROCESSING

Cooking, in general, enhances the digestibility of fish proteins. Cooking may result in some loss of nutrients depending on the temperature, duration of cooking and the composition of the seafood. Boiling has little effect in the composition of shellfish. Of the fish cured by different methods, smoked fish has good acceptability, while others (air dried, salted, etc.) attract limited consumer interest and may pose safety hazards. A combination of heat, light and oxygen has a higher damaging effect on nutrients, including vitamin B_6 and folic acid. Smoking Alaska salmon prior to oil extraction did not result in destruction of its rich polyunsaturated fatty acids (PUFA) (Bower *et al.*, 2009). Mild cooking causes little loss of protein with only a slight loss in available lysine, whereas drastic heating can significantly reduce the protein quality. Sulphides, including hydrogen sulphide, were generated from thermal degradation of cysteine and methionine residues of fish proteins. In addition trimethylamine (TMA) and dimethylamine (DMA) increased with a rise in temperature above 100 °C (Yamazawa, 1991). The changes that take place in fats during heat processing greatly depend on the fatty acid composition. In the presence of oxygen, unsaturated fatty acids may become oxidized to highly reactive peroxides, which decompose to a wide range of compounds. These compounds, which include aldehydes, ketones, alcohols, small carboxylic acids and alkanes, give rise to a very broad odour spectrum and also a yellowish discoloration to the product. At normal frying temperatures, these substances are formed slowly in pure fats, but their formation is catalyzed by traces of metals such as iron and copper present in the fish. In addition, overheating or repeated heating of fats results in an accumulation of the oxidation products, making the fat potentially toxic. In a recent study, slices of cultured sturgeon having a total lipid content of 3.1 percent (consisting of 29.1, 42.6 and 28.1g saturated (SFAs), monounsaturated (MUFAs) and polyunsaturated fatty acids (PUFAs) per 100 g fat) were fried, chilled, and then reheated. In fried samples the levels of C18 fatty acid groups, namely MUFAs and PUFAs as well as the n6/n3 ratio increased while SFAs, eicosa pentaenoic and decosa hexaenoic acids decreased. Free fatty acid (FFA) content decreased after frying, but peroxide value increased with a subsequent decrease in chilled conditions (Nikoo *et al.*, 2010). Canning of fish and shellfish has little impact on proximate composition. However, canned fish, frequently packed in vegetable oil, not only increases calorie content but also may nullify the beneficial effects of n-3 PUFA (Kinsella *et al.*, 1990; Pigott and Tucker, 1990). Because thermal treatment is less severe in retort pouch packaged fishery products, the treatment results in reduced increases in the volatile compounds and oxidation products as well as a reduced loss of nutrients, as compared with canned counterparts. (Mohan *et al.*, 2008). Culinary processes like boiling, grilling and frying, whether done conventionally or with a microwave oven, generally do not lead to significant oxidation of fat or reduction in the n-3 polyunsaturated fatty acids in herring fillets (Regulska and Ilow, 2002). The influence of thermal processing such as boiling, drying, roasting, baking, grilling and frying on the taste, aroma and texture can be attributed to generation of volatile compounds as well as Maillard reaction products. N-nitrosodimethylamine (NDMA) was detected as the main component of N-nitrosamines in dried seafood products when subjected to cooking by different methods. While the contents of NDMA in uncooked products ranged from 1.0 to 46.9µg/kg, cooking resulted in increased NDMA ranging from 1.1 to 630.5µg/kg, regardless of the cooking method. Indirect heating such as use of a steam cooker and a microwave oven, as compared with direct heating such as a gas range and a briquette fire, caused less increase in NDMA (Lee *et al.*, 2003).

Combination of thermal processing with other conventional methods or novel technologies ensures a better product in terms of nutritive value and storage stability and also helps in saving of energy. The synergistic effect resulting from combining high pressure treatment and gentle heating can effectively kill microorganisms or inactivate enzymes while desirable compounds, such as vitamins, colorants and flavourings, remain largely unaffected. The application of novel technological treatment and processing methods, in general, presupposes that the treatment does not lead to any additional microbial, toxicological or allergenic risks. The National Advisory Committee on Microbiological Criteria for Foods (NACMCF) on behalf of the U.S. Food and Drug Administration (FDA) and the National Marine Fisheries Service (NMFS) has provided advice to consumers on the microbiological safety of heat treated fishery products. Seafood products are consumed in a variety of forms that include raw, lightly cooked, marinated, partially or thoroughly cooked. The microbiological safety of these products is greatly enhanced when they are properly handled, cooked, served, or stored. Nevertheless, available epidemiological data are inadequate to determine the relative contributions of raw, undercooked, or properly cooked and then recontaminated seafood to the burden of food-borne diseases. The fragile nature of muscle tissues in fishery products results in a delicate balance between proper cooking to inactivate the pathogenic microorganisms and overcooking which may affect the optimal eating quality of fishery products. It was suggested that food safety should take precedence over eating quality whenever possible. Although cooking recommendations are widely available, there is no easy, practical measurement or indicator for the consumer to objectively determine if sufficient cooking to ensure safety of the treated fishery products has been undertaken. Non traditional novel preparation procedures cannot be relied upon to assure the microbiological safety of seafood products. Microwave heating is often less effective than conventional heating because of non-uniform heat distribution. There is a lack of thermal inactivation data for relevant pathogens in appropriate seafood because of the diversity of products available and the various methods of cooking that are applied to these products (Anonymous, 2008). Potential health benefits and risks of thermal processing of food including seafood have also been highlighted in a recent symposium (SKLM, 2007). Table 4 summarizes the advantages and disadvantages of thermal processing of seafood.

TABLE 4
Advantages and disadvantages of thermal processing of seafood

Advantages	
Nutritional and health benefits	Enhanced bioavailability of nutritional constituents
	Enhances palatability by improving flavour
	Ensures a sustainable and balanced diet.
	Positive influence on acceptability
	Intelligent selection of process variables contributes to positive health effects or to reduce negative ones.
Microbiological	Improves shelf-life by eliminating spoilage causing microorganisms
	Enhances safety by inactivation of pathogenic organisms
	Heat induced inactivation of toxins
	Possible production of antimicrobial substances or enzyme inhibitors
Disadvantages	
Nutritional	Temperature-dependent loss of nutrients such as vitamins, essential amino acids and unsaturated fatty acids.
	Drying at 60 °C or above causes appreciable damages to proteins, decrease in sulphydryl group contents
	Combination of heat, light and oxygen has higher damaging effect on nutrients, including vitamin B6, vitamin E and folic acid
	Leaching of nutrients occurs during blanching prior to canning
	Frying may cause oxidative loses and isomerization of fatty acids with significant loss in biological activities.
Safety	Non-sterilizing temperatures jeopardizes microbial safety
	Possible formation of carcinogenic acrylamides and heterocyclic amines, furan etc. at high temperatures
	Smoking may lead to formation of benzopyrene and other carcinogenic compounds

Adapted from SKLM (2007).

It may be pointed out that the merits of thermal treatments of foods including fishery products are not still completely understood. Future research needs to concentrate on areas which include bioavailability of nutritional constituents, evaluation of the formation of substances with antioxidant or other chemopreventive activities and development of sensitive biomarkers for heat exposure and its effects.

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Processing molluscs, shellfish and cephalopods

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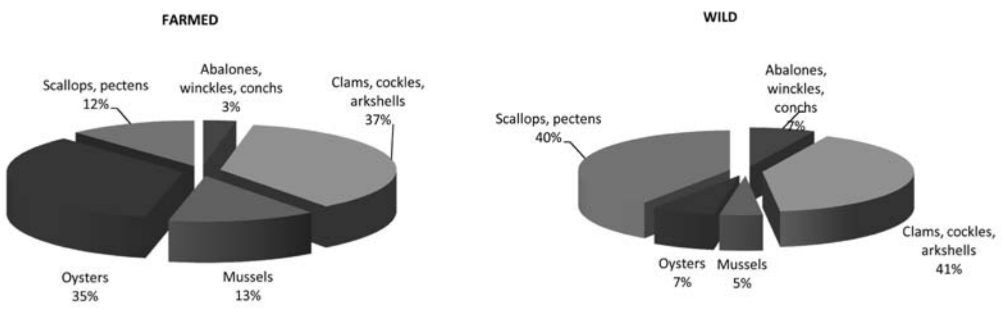
BIVALVE MOLLUSCS PROCESSING

The consumption of bivalve molluscs by humans dates back to the Late Archaic or Late Mesolithic periods. This is well documented by the shell middens found in many locations around the world. Bivalves continue to represent an important food item mainly for the population living near the rivers and seashore. In 1950, their production attained 1 034 000 tonnes (FAO, 2010) and in 2008 the total production (wild and farmed) was 13 841 000 tonnes (Figure 1). It is noteworthy that bivalves from aquaculture production represented about six times that caught in the wild.

FIGURE 1
Production of bivalve molluscs (farmed and wild) in 2008



Source: FAO, 2010.

Bivalve molluscs are usually marketed fresh as raw, unshelled or shucked refrigerated. They are also sold frozen, dried, canned, salted or in brine and marinated.

The shelf-life of bivalve molluscs is limited to the time they survive out of water. This has led to different approaches to prolong their shelf-life such as reported for instance in the US Patent 5 165 361 (1992). In this patent a method is described to preserve bivalves in the live state in a closed container partially filled with water and replacing the air contained in the space with oxygen. The effectiveness of modified atmosphere packaging (MAP) for the preservation of fish and fish products has been recognized but only a few works were published on its application to bivalve molluscs. Pastoriza *et al.* (2004) studied the stability of live mussels (*Mytilus galloprovincialis*) packaged under modified atmospheres. They obtained the highest survival in an atmosphere with high oxygen concentration (75% O_2/ 2% N_2), which allowed a shelf-life of 6 days when held at 2–3 °C. The shelf–life of control molluscs packaged in air did not exceed 3–4 days when stored under the same conditions. The application of MAP to preserve live clams (*Ruditapes decussates*) was also studied by

Gonçalves *et al.* (2009). Live clams stored both in air and packed in 70% O_2/30% N_2 for 6 days at 6 °C presented similar physiological conditions and health status. However, a significant benefit of MAP storage was observed in the preservation of the characteristic sweet taste of clams.

The shelf-life of post-mortem bivalves is very short because of the high water activity, neutral pH, high amino acid content and also the presence of psychrotolerant spoilage bacteria. On the other hand, the spoilage mechanism associated with bivalves is different from that of crustaceans and finfish because of the presence of significant levels of carbohydrate, which leads to saccharolytic activities and the accumulation of organic acids. Bivalve molluscs as water-filtering organisms accumulate microorganisms, which are closely related to the environmental conditions, microbiological quality of the water where they live and other physicochemical characteristics of the habitats. Pathogen rich microflora may be also present in bivalves, particularly on those inhabiting estuaries, which makes them more susceptible to the faecal contamination and environmental pollution of the surrounding waters. In fact bivalves are highly featured in statistics of food-borne diseases.

The effect of ozonation in aqueous solution on the shelf-life of shucked, vacuum packaged mussels, stored under refrigeration was studied by Manousaridis *et al.* (2005). Ozonation reduced bacterial populations and on the basis of sensory analyses, a shelf-life of 12 days was obtained for vacuum packaged mussels ozonated for 90 min as compared with a shelf-life of 9 days for non-ozonated vacuum packaged mussels.

In order to increase the shelf-life of mussels a combination of MAP technology and refrigeration was reported by Goulas (2008). The best results were achieved with the mixture 60% CO_2/20% N_2/20% O_2, which kept the mussels acceptable up to ca. 10–11 days based on the odour scores. In a similar study, Caglak *et al.* (2008) studied the microbiological, chemical and sensory changes occurring in mussels stored aerobically, under vacuum and three modified atmospheres (50% CO_2/50% N_2, 80% CO_2/20% N_2, 65% CO_2/35% N_2). According to these authors the gas mixture richest in CO_2 was the most effective for mussel preservation, which were acceptable for 8 days of storage.

Scallops are also valuable bivalve molluscs where MAP has been applied to increase their shelf-life. This technology was used by Kimura *et al.* (2000) to preserve the scallop adductor muscle stored at 5 °C in an atmosphere of 100% O_2, 80% O_2/20%CO_2, 60% O_2/40% CO_2, and air. The best results were obtained with 100% O_2 atmosphere, which allowed a prolongation for nearly two days in shelf-life of the scallop adductor muscle. Simpson *et al.* (2007) studied the optimal conditions for packaging scallops (*Argopecten purpuratus*) in modified atmosphere system. According to the mathematical model developed in this study the optimal conditions for scallop storage were a 60% CO_2/10% O_2/30% N_2 gas mixture and a headspace:food ratio of 2:1. With these conditions, a simulated shelf-life of 21 days was obtained.

The demand for safe foods, additive free, fresh tasting and with extended shelf-life has led also to the utilization of high pressure (HP) treatment of bivalves, particularly oysters. This treatment has the potential to improve microbial quality without compromising sensory and nutritional quality (Farkas and Hoover, 2000). Furthermore, the application of HP kills the oyster and facilitates the opening by hand or may even be used to induce shucking. As reported by Lopez-Caballero *et al.* (2000) HP treated oysters preserved their raw appearance, were slightly more voluminous and juicier and the flavour was virtually unchanged. HP treatment of oysters (200–400 MPa/7 °C/10 min) reduced the number of all targeted microorganisms. The appearance of the oyster meat was better when pressurization (400 MPa) was carried out under chilled conditions (7 °C) rather than at higher temperatures (20 °C and 37 °C). Calik *et al.* (2002) showed that *Vibrio parahaemolyticus* (Vp) numbers were reduced by HP treatment in both pure culture and whole Pacific oysters. Optimum conditions for reducing Vp in pure culture and whole oyster to non-detectable levels were achieved at 345 MPa for 30 and 90 s, respectively.

In a previous work He *et al.* (2002) also observed a reduction of the initial microbial load by 2 to 3 logs in HP treated Pacific oysters. The reduced bacterial counts remained low through the storage period at < 4 °C. The pH of HP treated oysters decreased slightly from 6.3 to 5.8 during storage while the hand shucked oysters (control) dropped to 4.1, this sharp decrease being a clear indicator of bivalve spoilage (Jay, 1996). HP treated oysters received higher quality scores than controls during the storage trial.

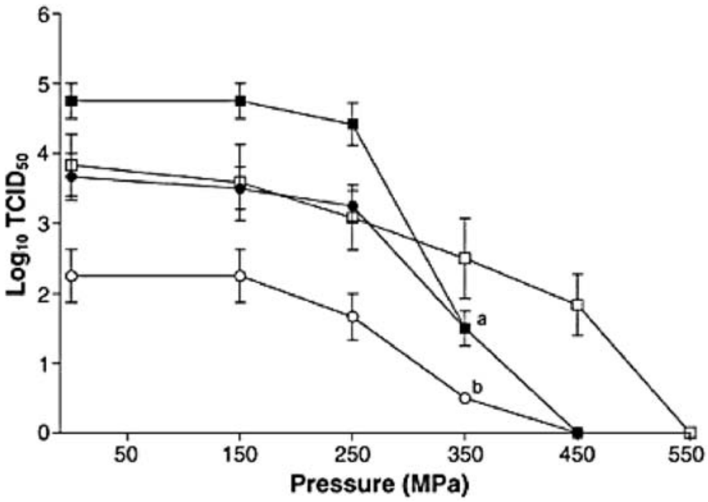
In the study by Linton *et al.* (2003) it is concluded that pressure treatment of mussels, scallops and oysters at 300, 400, 500 and 600 MPa for 2 min at 20 °C readily inactivated psychrotrophic bacteria, coliforms and Pseudomonads. The range of bacteria present in the products decreased after pressure treatment mainly because of inactivation of Gram negative bacteria. This led to an increase of proportion of Gram positive species (*Bacillus*, *Acinetobacter/Moraxella* and lactic acid bacteria).

Cruz-Romero *et al.* (2008a) studied the changes in microbiological and physicochemical quality of oysters HP treated at 260 – 600 MPa for 5 min and stored at 2 °C on ice for 31 days. This study confirmed that the HP processing of oysters can inactivate microorganisms and delay microbial growth in chilled storage, but also showed that it affects their quality attributes. In another study Cruz-Romero *et al.* (2008b) followed the microbiological and biochemical changes in high pressure treated oysters stored aerobically on ice, in vacuum packaging and under MAP (40% CO_2/60% N_2). The use of MAP was shown to be effective in extending the shelf-life of HP treated oysters and according to the authors has great potential for preserving HP treated oysters.

The potential of HP processing to reduce viral contamination in mussels and oysters was also demonstrated by Murchie *et al.* (2007). Bovine enterovirus, structurally similar to hepatitis A virus, was more pressure resistant than feline calicivirus, a surrogate for norovirus. Both viruses were more pressure resistant when treated in "naturally" contaminated mussels and oysters, compared with seawater and culture medium. The results obtained suggested that relatively mild HP treatments (approximately 260 MPa) currently used for commercial processing of oysters, may be insufficient to ensure the safety of shellfish for human consumption, particularly in relation to human pathogenic viruses (Figure 2). In the work by Kingsley *et al.* (2007) it is demonstrated that a marine norovirus (strain MNV-1) can be inactivated by high pressure. A 5 min, 450 MPa treatment was sufficient to inactivate 6.85 log PFU of MNV-1 in virus stock in Dulbecco's modified Eagle medium. The inactivation of MNV-1 directly within oyster tissue was also achieved, a 5 min 400 MPa treatment at 5 °C to inactivate 4.05 log PFU was sufficient. Taking into account that cooking may not be enough to avoid shellfish borne virus transmission (McDonnel *et al.*, 1997) HP treatment may therefore be useful for reducing infectious virus in bivalves prior to cooking.

Oyster shucking by HP processing is at present and for the last five years a well known process with commercial success by several North American and European companies (Raghubeer, 2007). Using HP patented technology, no-shell shucked oyster and a fully detached and ready-to-serve frozen half shell oyster are awarded products from Gold Band Oysters® and good examples of the exploitation of this process and of the technological advances in this field. For this specific purpose, shucking, one considerable downside of HP processing is the capital investment. An affordable cost may however be offered by other technologies under investigation. For example, with the joint utilization of oyster positioning and imaging technologies (So and Wheaton, 2002) the precise application of a laser to the shell immediately above the adductor muscle is a promising technology. According to Martin and Hall (2006), the exact application of heat precisely above the muscle scar results on a very clean release of the adductor muscle while keeping the oyster raw.

FIGURE 2
Effect of high pressure treatments on the infectivity of bovine enterovirus in culture medium

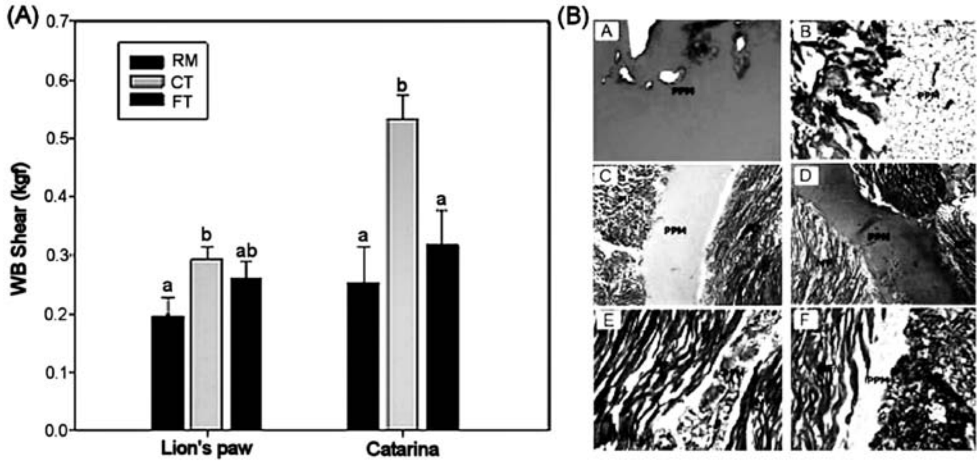


Note: Effect of HP treatments (150-550 MPa for 5 min at 20 °C) on the infectivity of bovine enterovirus (BEV) in culture medium (■), seawater (●), mussels (□) and oysters (○). Average tissue culture infectious dose for 50% ($TCID_{50}$) obtained from three independent trials. Error bars are standard error of the mean. [a]BEV was detected in two out of three trials (value shown calculated from results of two trials). [b]BEV was detected in one out of three trials ($TCID_{50} \leq 1.0$) (Murchie *et al.*, 2007; reproduced with permission of Elsevier Limited).

High pressure processing was also applied to thawing scallops (*Pecten irradians*). Optimal results were obtained at 150 MPa, and achieved a significantly reduced drip loss (31 percent) when compared with thawing under atmospheric pressure (Flick Jr., 2003). The effect of HP processing on the quality of scallop (*Aequipecten irradians*) adductor muscle was also studied by Pérez-Won *et al.* (2005). This work has shown that HP processing induced a size reduction of the honeycomb structure of myofibres giving a more compact appearance to the structure. This HP treatment also reduced initial load in total plate count of microorganisms to 10 cfu/g. The colour and compressibility of HP treated scallops were enhanced but loss of hardness was observed.

The restructuring process at low temperatures is a technological alternative for the upgrading of underutilized resources, which have an unappealing aspect or small size. This process was applied by Suklim (1998) to upgrade calico scallops (*Argopecten gibbys*) by using alginate and MTGase (Microbial Transglutaminase) at 1 percent level as cold-set binders with different setting times. At the setting temperature of 5 °C, restructured scallops bound with alginate presented the greatest binding strength at 2 hrs setting, while those bound with MTGase required 24 hours to reach the maximum binding strength. However, the products obtained with alginate had lower binding strength values, which may result in a decrease in consumer acceptability. Beltrán-Lugo *et al.* (2005) also made the restructuring of small or broken pieces of the adductor muscle of the lions-paw scallop (*Nodipecten subnodosus*) and the catarina scallop (*Argopecten ventricosus*) to obtain uniform and commercial size scallop meat. Two cold-set binding systems – caseinate-transglutaminase (CT) and fibrinogen-thrombin (FT) –were used. The results obtained led to concluding that lions-paw and catarina scallops can be successfully restructured by CT and FT systems (Figure 3). They also indicated that, not only the restructuring system, but the species have influence on characteristics of restructured scallop meat. The end colour of the FT system was noticeable in the adductor muscle from lions-paw scallops. A larger increase in most texture parameters was produced by the CT system than was produced by the FT system.

FIGURE 3
Shear tests and light microscopy of scallop meats



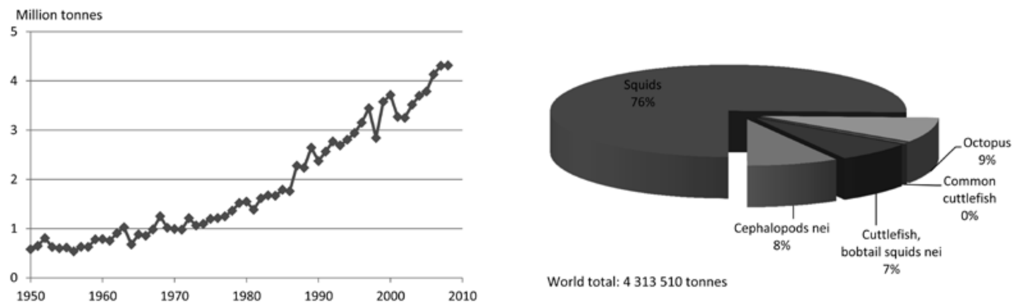
Note: (A) Warner-Bratzler shear test values of raw materials and restructured meats of lions-paw scallops and catarina scallops using two cold-set binding systems. Different letters within species indicate significant differences ($P<0.05$) between treatments. Bars represent standard deviation (n = 10). (B) Light microscopy images (40x) contrasted with Masson's trichrome stain of polymerized matrices and restructured meats of the two scallop species using CT and FT systems. A = CT matrix; B = FT matrix; binder-adductor muscle interface for lion-paw scallop meats restructured wit CT (= C) and FT (= E). Binder-adductor muscle interface for catarina scallop meats restructured wit CT (= D) and FT (= F). Muscle fibers (MF) and polymerized proteins of matrices (PPM) appear as pink to red colour. Interstitial materials appear white. CT = restructured with casein-transglutaminase; FT = restructured with fibrinogen-thrombin; RM = raw material. (Beltrán-Lugo *et al.,* 2005; reproduced with permission of John Wiley and Sons).

CEPHALOPOD PROCESSING

Cephalopods landings increased from around 600 thousand tonnes in 1950 to more than 4.3 million tonnes in 2008 (FAO, 2010). This enormous increase of cephalopod landings was previously foreseen by Caddy and Rodhouse (1998) who considered that "cephalopod fisheries are among the few still with some local potential for expansion". Figure 4 shows the evolution of cephalopod landings and the percentage of different groups of commercialized cephalopods.

Cephalopods are fishery products very much appreciated in the Mediterranean and Asia. They deteriorate more rapidly than fish and under refrigeration have a relatively short shelf-life. Autolysis of the cephalopod muscle is particularly intense because of the high level of proteolytic activity produced by their highly active metabolism. As a consequence, the products resulting from the autolytic activity favour rapid microbial growth. Thus, alternative technologies to refrigeration on ice have been tried to extend the shelf-life of cephalopods. The application of modified atmospheres is one of those technologies, having been used by Ruiz-Capillas *et al.* (2002) to preserve pota (*Todaropsis eblanae*) and white octopus (*Eledone cirrhosa*). The results reported by these authors indicated that a controlled atmosphere with 60% CO_2/15% O_2/25% N_2 together with refrigeration at 1 °C increased the shelf-life of both species by at least 54 percent.

FIGURE 4
Cephalopod production data



Note: (A) Total catches of cephalopods from 1950 – 2009; (B) Breakdown of production by groups of species in 2008
Source: FAO, 2010.

A combination of vacuum-packaging and oregano essential oil (0.4% v/v) was also applied to preserve octopus (*Octopus vulgaris*) during storage at 4 °C (Atrea *et al.*, 2009). Based primarily on sensory evaluation (odour), the use of those conditions allowed extending the shelf-life of fresh octopus by approximately 20 days.

An important characteristic of octopus is its toughness, which makes it nearly inedible if it is cooked without previous tenderization. This property of octopus muscle led Katsanidis (2004) to study the effects of tumbling time, NaCl concentration, boiling time, and acetic acid levels on the tenderness of fresh octopus (*Eledone moschata*). The author concluded that prolonged tumbling and heating of octopus muscle resulted in decreased toughness. Addition of NaCl during tumbling did not affect toughness consistently. On the other hand, acetic acid at levels of 0.1 percent and 0.2 percent significantly reduced toughness of octopus muscle. In a similar study, Katsanidis and Agrafioti (2009) evaluated the effect of using acetic, lactic and citric acids on the tenderization of octopus (*Octopus vulgaris*). The addition of these acids at 0.05 and 0.1M levels resulted in significant tenderization compared with the untreated control. Although no differences in the tenderizing effect within acids was observed, their use shortened the heat processing time of octopus almost by half.

Other approaches have been tried to softening cephalopods, mainly dried squid. This is a popular seafood product in several Far East countries, which can be cooked directly with or without prior softening. This process may be performed by various rehydration processes but immersion of dried squid in alkaline solution has become a widely used method. Kugino *et al.* (1993) studied the differences between raw squid and softened dried squid under various conditions. Electron microscopy showed water permeation throughout the muscle fibrils and fibres, while there was almost no permeation of water inside the individual fibrils. In order to investigate the effect of some processing parameters of alkaline treatments on the physicochemical properties of dried squid Benjakul *et al.* (2000) used different NaOH or Na_2CO_3 solutions for soaking. They concluded that dried squid soaked in 0.15 $mol.kg^{-1}$ $NaCO_3$ with a squid/alkaline solution ratio of 1:10 (w/v) for 20 h was the most acceptable in terms of both appearance and textural properties. In another study on softening dried squid prepared at 4 and 40 °C performed by Konishi *et al.* (2003) it was concluded that a significantly higher wet weight was observed when processing was done at 4 °C. The protein pattern obtained by SDS-PAGE of the 4 °C dried squid was almost the same as that of raw squid.

High pressure treatment is another interesting alternative for preserving cephalopods. In one of the first works (Matser *et al.*, 2000) on the application of HP to octopus (*Octopus vulgaris*) at 0 °C and 5 min pressure holding time, it was concluded that octopus retained a raw appearance till 400–800 MPa. In the work by Hurtado *et al.* (2001) the application of HP (400 MPa) continuously or in pulsed form at 7 and 40 °C to octopus is reported. A reduction of microbial flora (total viable count and lactic bacteria) after pressurization and during chilling storage was recorded. This reduction was more significant in the lot pressurized by step-pulse. A lower level of nitrogenous compounds and a decrease of the autolytic activity were obtained in the pressurized octopus in comparison with control samples. The shelf-life of the pressurized octopus was 43 days longer than unpressurized.

The application of HP treatment to squid (*Todaropsis eblanae*) mantles was studied by Paarup *et al.* (2002). These authors evaluated the changes occurring in vacuum packed pressurised squid mantle during refrigerated storage (4 °C). Squid mantles were pressurised in the range between 150 to 400 MPa for 15 min at ambient temperature. The sensory analysis showed that the higher the pressurisation the longer the shelf-life. Microbial counts conducted after one day of storage showed a reduction of bacterial loads in all pressurised lots, reaching levels below the detection limit in the lots treated with 200–400 MPa.

In a recent paper (Gou *et al.*, 2010) the effect of HP processing on the quality of squid (*Todarodes pacificus*) during refrigerated storage is described. This work is particularly focused on the effect of HP on the reduction of unpleasant off odours. Thus, the influence of HP treatment on the inhibition of trimethylamine-N-oxide demethylase (TMAOase) activity and microbial growth in squid treated at 300 MPa for 20 min was investigated. TMAOase activity and the production of dimethylamine in raw squid were significantly reduced after HP treatment. Similarly, the number of total aerobic bacteria was also reduced by 1.26 log units and HP treated squid products presented a lower production of trimethylamine.

Concerning changes during cooking, early studies on texture changes in cooked squid muscle using scanning electron microscopy date back to the 1970s (Otwell and Hamann, 1979). Thermal alterations of muscle fibres appeared as a loss of myofibril distinction first evident at 50 °C. Increasing temperature of muscle fibres caused, in order, coagulation of sarcoplasmic proteins, disintegration of the sarcoplasm, and continuous fibre shrinkage and dehydration. Later on Otwell and Giddings (1980) reported that squid muscle heated at 100 °C showed gross distortions of all mantle tissues. Mieko *et al.* (2000) also studied the textural changes occurring in three cooked squid species (oval squid, Japanese common squid and arrow squid). These authors concluded that the speed of squid muscle becoming tough and then tender depended on the squid species. The fastest tenderization was observed in arrow squid followed by the Japanese common squid and the slowest softening was recorded in the oval squid. In a later study (Mieko *et al.*, 2006) on the texture changes of boiled squid muscle, different cooking solutions (water (WA), 18 percent salt solution (SA) and 100 percent soy sauce (SO)) were used. The squid cooked in SO had the highest hardness, followed by SA and then by WA. Longer boiling in WA made the meat softer but no such effect was observed on squid boiled in SA and SO. Boiling in SO for a short time made the skin tough, seeming that some components in SO other than sodium chloride influenced the physical properties of the muscle and skin of the squid.

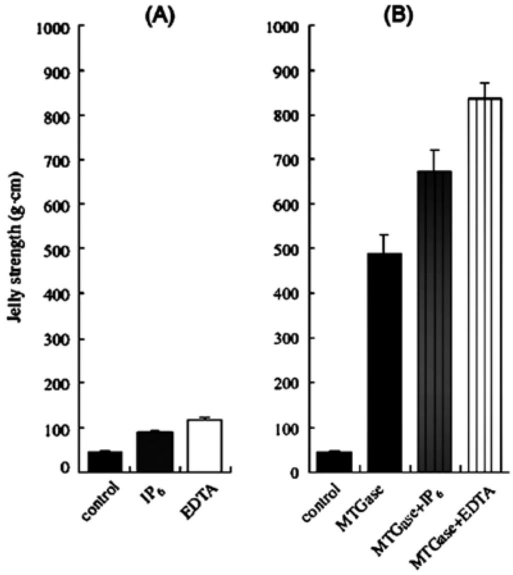
The effect of fast freezing at -40 °C and vapour cooking at 100 °C on the connective tissue extract (CTE) from giant squid (*Dosidicus gigas*) was also studied by Valencia-Pérez *et al.* (2008). Light microscopic observations of CTE after 12 minutes of freezing showed rupture of fibres but the agglutination of fibres during the cooking time was observed. The electrophoresis analysis suggested that during freezing and cooking processes molecular bond modifications that hold the integrity of the connective tissue structure had occurred.

Vacuum cooking involves heating of the raw materials vacuum packed in a plastic film bag at a relatively low temperature. Raw products processed with vacuum cooking at around 60 °C for a long time have a softer texture than products cooked by methods involving higher temperatures. This method was used by Naito *et al.* (1996) to cook squid muscle. The firmness of squid muscle cooked at 60 °C was the lowest. On the other hand, the cooking loss of squid in vacuum cooking was larger than in normal cooking but remained nearly the same over prolonged cooking time. The softening mechanism was not completely explained but later Okiani *et al.* (2008) demonstrated that much actin is liberated from myofibrils by heating at 60 °C. This reaction was proposed as one of the main reasons for the softening of squid muscle during vacuum cooking (Okitani *et al.*, 2009).

Fried battered squid rings are one of the main food items prepared from squid. They are currently one of the products most in demand by Spanish consumers. Llorca *et al.* (2001) studied the microstructural changes occurring on frozen battered squid rings during frying. It was observed that the fibres of battered and fried squid are still visible after frying but altered by coagulation of sarcoplasmic proteins. The water evaporation during frying led also to a closer packing of the muscle tissue fibres. The absorption of frying oil in the food substrate also takes place and this oil draws other components of the batter, such as starch, to the denaturated squid surface. In another work the effect of corn flour, salt and leavening agent ($Na_2H_2P_2O_7/NaHCO_3$) on the texture of fried, battered squid rings was studied by Salvador *et al.* (2002). It was concluded that the leavening agent had the greatest effect on the final texture of the fried product. The value of the force of penetration of battered squid rings with the leavening agent was significantly lower than the values of the other products. The penetrometry profile was also different and corresponded to a crispy product. In a latter study Llorca *et al.* (2007) observed at a microstructural level the formation of big voids during freezing of squid rings as a consequence of the packing of the fibres. However, the size of these voids decreased after final frying and the central sarcoplasm was still visible but altered by coagulation of the sarcoplasmic proteins and the sarcolemma separated from the myofibrillar package.

Cephalopods have been also used for the production of jellified products reported in several works. However, these studies have generally shown that products with satisfactory gel elasticity cannot be obtained when Teuthida are used as ingredients. This is the case of the gels prepared with the proteins from the squid *Loligo vulgaris*, which were weak and brittle, with low gel strength (Gómez-Guillén *et al.*, 2002a). However, the addition of different protease inhibitors increased the elastic modulus in the thermal gelation profile of squid proteins. In another work (Pérez-Mateos *et al.*, 2002) it was shown that the incorporation of protease inhibitors in addition to microbial transglutaminase (MTGase) considerably improved gel elasticity of squid (*L. vulgaris*) proteins. Park *et al.* (2003) concluded that the degradation of myosin of the Japanese common squid (*Todarodes pacificus*) was presumably because of the presence of metalloproteases. They also showed that the addition of Ca^{2+} and the calpain inhibitor E64 significantly improved the breaking strength and the strain of thermal gels preincubated at 40 °C. The results obtained by Tsujioka *et al.* (2005) working with Japanese common squid are also in agreement with those reported by Peréz-Mateos *et al.* (2002). They concluded that it is essential to inhibit myosin heavy chain degradation by adding an astatin-like squid metalloprotease inhibitor (such as EDTA) and then to add MTGase to prepare a gel with high jelly strength from Japanese common squid (Figure 5).

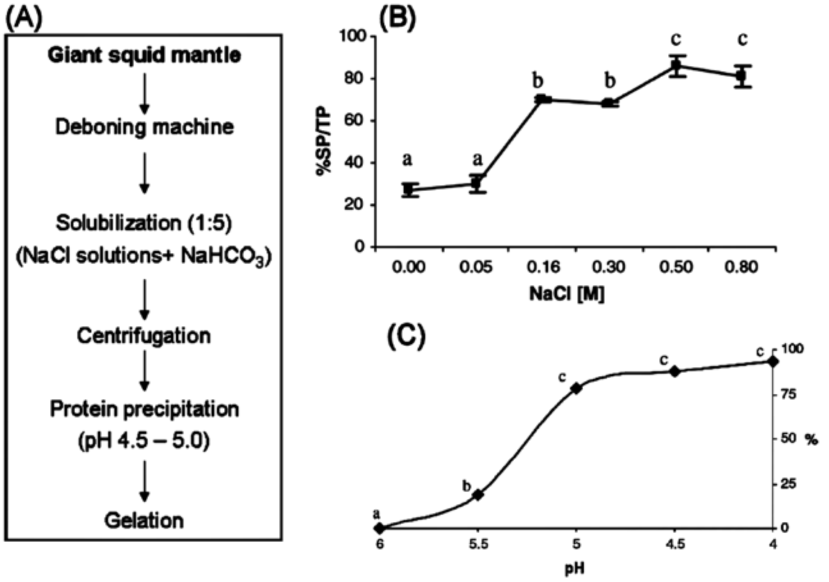
FIGURE 5
Gel strength of gels prepared from squid natural actomyosin



Note: Comparison of jelly strength of gels prepared from Japanese common squid natural actomyosin with: (A) additives (EDTA and inositol 6-phosphate (IP_6)) and (B) with additives + MTGase. Control, no additives. (Tsujioka *et al*., 2005; with kind permission of Springer Science and Business Media).

Among cephalopods giant squid (*Dosidicus gigas*) is an abundant squid species found in the eastern Pacific from Chile up to Oregon, which has deserved much interest. However, the acid or bitter taste of this species is due to the presence of some peptides and free amino acids in the muscle (Sanchez-Brambila *et al.*, 2004) and the intense ammonia odour produced by high concentration of non protein nitrogen compounds discourage direct consumption of giant squid. Several studies have also suggested that giant squid is not suitable for production of a gel type product because of the intensive proteolysis developed immediately after catch, which affects its gel forming capacity (Gómez-Guillén *et al.*, 1997; Gómez-Guillén *et al.*, 1998). As an alternative to the conventional surimi washing process a new procedure was devised (Sanchez-Alonso *et al.*, 2007) for processing the functional protein concentrate from giant squid (*D. gigas*) muscle. It is based on the solubilization of the mantle at very low ionic strength and neutral pH (0.16M NaCl and 0.1% $NaHCO_3$) with 250 ppm of EDTA and further acid precipitation (pH 4.7–4.9) of much of the muscle protein (Figure 6). Gelation should be achievable in only one stage, at 90 °C, after adding 0.2% $Ca(OH)_2$. Gels of about 400 g.cm of gel strength were obtained. Palafox *et al.* (2009) also prepared protein isolates from giant squid by the pH shift processing described by Hultin and Kelleher (1999). The former authors reported that about 85 percent of the initial muscle protein was solubilized at pH 3 and 11. About 90 percent of the protein was obtained after precipitation at pH 5.5 and the total yield from both alkaline and acid solubilization was 75 percent. The authors also concluded that most proteins from giant squid muscle may be obtained by acid and alkaline extraction, either from fresh or frozen squid muscle. The protein solubility at several ionic strengths (0 to 0.1 M), pH (2 to 13) and gelling capacity of giant squid muscle proteins were evaluated (De la Fuente-Betancourt *et al.*, 2009). Strength was higher for thermal gels prepared from the mantle. As mentioned by the authors, the solubility and gel forming capacity of the proteins from mantle and fin of giant squid suggest that these properties can provide additional value to this squid species.

FIGURE 6
Proteins in giant squid



Note: (A) Flow diagram of protein recovery from giant squid; (B) Percentage of muscular protein solubility expressed as soluble protein (SP) in relation to total protein (TP), depending on different NaCl concentrations in the solvent. Different letters indicate significant differences (P<0.05) between samples at different concentrations; (C) Protein precipitation (%) from muscle solutions in relation to total protein at different pH values of the solution. Different letters indicate differences between samples (Sánchez-Alonso *et al.*, 2007; reproduced with permission of Elsevier Ltd).

In order to avoid the problems of poor gelling properties of giant squid Félix-Armenta *et al.* (2009) described the formulation and the establishment of the technological parameters for processing a frankfurter type product from this raw material. The prepared products were vacuum–packed and stored at 2–4 °C for up to 27 days and the physicochemical characteristics, the microbial changes and the sensory quality were analysed at regular intervals during storage. According to the authors, the results suggest that a stable gelled–emulsified type product can be developed from giant squid mantle muscle.

Suklim *et al.* (2003), working with the underutilized North Atlantic short–finned squid (*Illex illecebrosus*), reported the preparation of restructured squid patties with selected heat–set binders (starch and egg white albumin). When the level of starch was increased from 2 to 10 percent, a decrease in hardness, cohesiveness and springiness was observed. However, 2 percent egg white albumin increased the hardness and cohesiveness. Starch had no ability to improve cohesiveness when combined with egg white albumin. However, starch–combinations reduced the cooking losses of restructured squid when compared with the products obtained from starch and egg white albumin separately.

Squids have been used as a raw material for collagen and gelatin extraction. In comparison with fish species, squid collagen presents a high degree of cross–linking because of the high amount of hydroxyl lysine together with high content of hydroxyproline. Thus, the squid (*Illex argentinus*) skin was used as raw material to study the parameters affecting the isolation of collagen (Kołodziejska *et al.,* 1999). The solubility of the collagen extracted in salt solutions and the efficiency of removal of skin chromatophores were determined. Collagen, soluble in dilute acid solutions, was isolated from squid skin by 24 h soaking in 10% NaCl solution at room temperature, followed by washing with water and 24 h bleaching in 1% H_2O_2 in 0.01M NaOH. The yield of collagen was 53 percent. Gómez–Guillén *et al.* (2002b) extracted squid gelatin from giant squid (*D. gigas*) using a mild–acid procedure (0.05 M acetic acid) and overnight extraction at 80 °C. However, under these conditions a low gelatin and α-chain yields were obtained and, as a consequence, poor gelling ability. A high gelatin yield (10.9%) from jumbo flying squid skin (*Dosidicus eschrichitii*) was achieved by using 0.02% H_2SO_4 for swelling and overnight extraction at 45 °C (Lin and Li, 2006). Petersen and Yates (1977) recommended an appropriate digestion of the raw collagen with proteases to improve the gelatin yield of highly cross linked collagen as squid collagen. Giménez *et al.* (2009) described a method of preparation of two different quality grade gelatins from giant squid (*D. gigas*), which has a collagen concentration of 18.33 percent (Torres-Arreola *et al.*, 2008). The former authors used the outer and inner tunics of the mantle, which were previously subjected to hydrolysis with pepsin (1/800 w/w ratio in 0.5 M acetic acid at 2 °C for 72 h) followed by a first gelatin extraction (G1) with distilled water (60 °C/18 h). The collagenous residues were swollen again in 0.5 M acetic acid for 24 h and a second gelatin extraction (G2) was carried out at 60 °C/18 h. Pre–treatment of squids with pepsin allowed collagen solubilization and the extraction yield to increase by extracting mainly α-chains. The second gelatin extraction increased the total yield. The gelatin G1 exhibited good gel forming ability but gelatin G2 showed poor viscoelastic behaviour and low gel strength. Both gelatins showed good filmogenic ability and similar physical properties were found. However, films made from gelatin G1 had higher puncture force than films made from gelatin G2.

Aewsiri *et al.* (2009) used cuttlefish (*Sepia pharaonis*) skin for the extraction of gelatin. The highest yield of gelatin (49.65 percent and 72.88 percent for dorsal and ventral skin, respectively) was obtained from skin bleached with 5% H_2O_2 for 48 h. As reported, bleaching improved the colour and enhanced the bloom strength, and the emulsifying and foaming properties of the gelatin extracted.

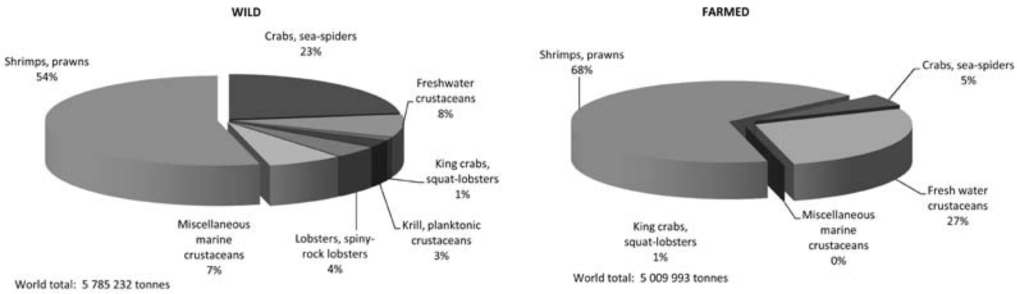
In a recent work (Uriarte–Montoya *et al.*, 2010) the extraction of collagen from the giant squid and its potential application in the preparation of chitosan–collagen biofilms is studied. Acid soluble collagen (ASC) was extracted with an average yield of 15 percent from the total muscle protein. A positive plasticizer effect of squid collagen over a chitosan film was detected. The FT–IR spectrum showed that chitosan and ASC remain linked into the films mainly because of hydrogen bonding. As reported by the authors, the blending of ASC from squid mantle and chitosan gives the possibility of producing new materials with potential applications in the food or biomedical industries.

CRUSTACEAN PROCESSING

The world's production of crustacean, wild and farmed, is shown in Figure 7. Shrimps and prawns represent the majority of the production in both cases and about 60 percent of total production is traded internationally (FAO, 2010). The aquaculture shrimp production has expanded rapidly since 1997, with an increase of 165 percent during the period of 1997–2004 and its production in 2008 attained more than 3.4 million tonnes. Shrimp is the most important internationally–traded commodity by value, accounting for about 19 percent of the total value.

Like bivalve molluscs and cephalopods MAP has also been extensively studied in crustaceans as a processing technology to enhance the shelf–life of raw or processed products. The use of MAP is, however, not devoid of limitations, and potential growth of pathogenic bacteria, such as *Listeria monocytogenes* and *Clostridium botulinum* type E, may be present in chilled cooked MAP products.

FIGURE 7
Production of crustaceans in 2008



Source: FAO, 2010

The effect of modified atmospheres on the preservation of packed deepwater pink shrimp (*Parapenaeus longirostris*) was studied by López–Caballero *et al.* (2002). A delay of microbial growth was observed in shrimps packed in MAP (40–45% CO_2/30–35% O_2) when compared with air–packed or iced stored shrimp. Trimethylamine and total volatile nitrogen production was reduced as well. However, the production of some biogenic amines seemed to be enhanced during the storage of MAP–shrimp. Another study with the same shrimp species packed in two modified atmospheres (40% CO_2/30% O_2/30% N_2 and 45% CO_2/5% O_2/50% N_2) combined with sulphites–based treatment was performed (Gonçalves *et al.,* 2003). Generally, both atmospheres preserved the shrimp quality up to 9 days compared with 4 to 7 days of ice storage, although the gas mixture richest in CO_2 seemed to be more effective. Martínez–Alvarez *et al.* (2005) also studied the joint effect of melanosis inhibitors (metabisulfite and 4–hexylresorcinol) and a controlled atmosphere (48% CO_2, 7% O_2 and 45% N_2) on the quality of deepwater pink shrimp. It was observed that the combination of CO_2–enriched atmosphere with 0.25% 4–hexylresorcinol resulted in nearly complete prevention of melanosis over 9 days of storage. Controlled atmosphere limited total viable counts, and enterobacterial growth was lower. The use of MAP was also reported by Thepnuan *et al.* (2008) to preserve Pacific white shrimp (*Litopenaeus vannamei*). Shrimp was pre–treated with 2% pyrophosphate and 0.25% 4–hexylresorcinol and stored under refrigerated MAP (80% CO_2, 10% O_2, 10% N_2 or 80% CO_2, 20% CO_2, 20% N_2). Under these storage conditions, a delay of microbial growth and lower trimethylamine and volatile base nitrogen production was observed in shrimps. The pre–treatment with 4–hexylresorcinol was also effective in the prevention of shrimp melanosis.

Shrimps are also frequently commercialized in their cooked form because they are highly perishable. However, the industrial cooking conditions may negatively affect shrimp quality. It can be affected by overcooking, which is associated with weight loss and toughening of the meat. A poor appearance, because of cooking conditions, may also occur as a result of melanosis. Several studies have reported the effect of cooking on sensory and chemical changes of shrimp. More recently Erdogdu *et al.* (2004) evaluated the effects of shrimp size and internal temperature distribution during cooking of Pacific white shrimp previously treated with sodium tri–polyphosphate (STP) solutions. The results obtained indicated that dipping shrimp in STP solutions can be used to prevent the large cooking–related yield losses of different sizes of shrimp. The moisture retaining effect of STP was greater in smaller shrimp. Similarly Benjakul *et al.* (2008) studied the effect of heating on cooking loss, physical properties and microstructure of black tiger shrimp (*Penaeus monodon*) and Pacific white shrimp meats. It was observed that an increased cooking loss occurred when shrimp samples were heated for longer time, particularly more than one minute. The higher cooking losses were recorded in the tail part. Both shear force and colour parameters values also increased when heating time increased. Cooked meat of both species had more compact fibre arrangements with the shrinkage of sarcomeres, compared with raw samples.

The changes in functional properties and quality occurring in three shrimp species (*Parapenaeus longirostris*, *Crangon crangon* and *Pandalus borealis*) cooked in the temperature range between 30 and 85 °C was also studied by Schubring (2009). In this work it was concluded that lightness, redness and yellowness values increased with increasing heating temperature. Changes in texture (hardening or softening) because of heating did not show clear tendencies. However, differential scanning calorimetry curves of differently heated shrimp species differed markedly. Some peaks corresponding to transition temperatures disappeared with increasing temperature and the enthalpy of denaturation also significantly decreased with temperature increase.

Martínez–Alvarez *et al.* (2009) evaluated the vacuum–cooking and steaming cooking of deepwater pink shrimp as alternative cooking treatments. Neither the melanosis–inhibiting blends (with a commercial sulphite– or 4–hexylresorcinol–based formula) nor the cooking methods used significantly affected the water–holding capacity, firmness or moisture content of the cooked shrimps. It was also concluded that a combination of prior spraying with 4–hexylresorcinol–based formula followed by vacuum–cooking proved to be the best method for obtaining shrimp with good appearance and high microbial quality.

The effect of protein hydrolysate prepared from salted duck egg white (PHSEW) was checked in Pacific white shrimp as a substitute for phosphate (Kaewmanee *et al.*, 2009). Shrimp soaked in 4% NaCl containing 7% PHSEW and 2% mixed phosphates had the highest cooking yield compared with shrimps with other treatments. The muscle fibres of cooked shrimp treated with the above mixture or with 4% NaCl containing 3.5% of mixed phosphate had swollen fibrils and gaps, while the control had a swollen compact structure. The authors concluded that PHSEW could reduce phosphate residue in shrimps without an adverse effect on sensory properties.

Salt–boiled shrimp is one of the shrimp products generally consumed in Turkey. Thus, the effect of different cooking brine solutions on the protein losses of shrimp (*Penaeus semisulcatus*) was studied by Ünlüsayın *et al.* (2010). The results obtained by these authors indicated that the best method for salt–boiling shrimp was with whole shrimp boiled for 8 minutes at 10% NaCl concentration.

Another shrimp commodity highly–valued in Far–East countries is dried shrimp. Its processing involves a cooking step in a salt solution aimed at reducing the number of microorganisms in shrimp to a safe level and to improve the flavour. Various works have been published to optimize the boiling conditions in salt solutions. Among the most recent works are the papers by Niamnuy *et al.* (2007, 2008). These authors investigated the effect of various parameters (salt solution concentration, mass ratio of shrimp to salt solution, boiling time and shrimp size) on the quality of cooked shrimp (*Penaeus indicus*). It was found that higher concentration of salt solution, longer boiling time and lower mass ratio of shrimp to salt solution led to higher salt content of shrimp. On the other hand, under those conditions lower levels of moisture and proteins and, as a consequence, higher values of hardness, toughness shrinkage and colour changes were observed. Finally, it was concluded that a minimum boiling time of 3 min was enough to reduce the number of microorganisms to a safe level and inactivate enzymes responsible for melanosis. In another study Niamnuy *et al.* (2008) reported the effect of boiling time and concentration of salt solution on the protein fractions, microstructural and physical changes of boiled shrimp. It was concluded that an increase in boiling time and concentration of salt solution led to a decrease in the contents of myofibrillar, sarcoplasmic and stroma protein together with an increase in alkali–soluble and protein loss during boiling as well as to a raise in cooking loss, hardness and fractal dimension values. The muscle protein denaturation was also an important factor influencing the microstructural and physical changes in shrimp during boiling in salt solution.

The drying step in the production of dried shrimp requires an adequate control to obtain a product with desired and uniform quality. The effects of shrimp (*Penaeus* spp.) size and level and pattern of inlet drying air temperature on the drying kinetics and quality attributes of shrimp dried in a jet–spouted bed dryer was studied by Tapaneyasin *et al.* (2005). In this study it was concluded that the use of a constant inlet air temperature of 100 °C yielded dried shrimp with the best quality (low percentage of shrinkage, high percentage of rehydration, low maximum shear force, and high value of redness). Similarly Niamnuy *et al.* (2007) investigated the effects of boiling parameters (salt concentration and boiling time) and drying conditions (air temperature) as well as size shrimp (*Penaeus indicus*) on the kinetics of drying and various quality attributes of dried shrimp. The conditions that gave the highest hedonic scores of sensory evaluation for small dried shrimp were a salt solution of 2% (w/v), boiling time of 7 min, and drying air temperature of 120 °C. For large shrimp the best hedonic scores were achieved with a salt solution of 4% (w/v), boiling time of 7 min, and drying air temperature of 100 °C.

MAP has been also used in the preservation of pre–cooked shrimp. Pastoriza *et al.* (2002) reported the utilization of MAP (50% CO_2, 50% N_2) in combination with lauric acid to preserve pre–cooked shrimp tails (*Parapenaeus longirostris*) in the refrigerated state. Sensory properties of shrimp tails subjected to this combined effect received the highest scores and were commercially acceptable after one month of storage at 7±1 °C.

In order to evaluate the shelf–life and the safety aspects of chilled cooked and peeled shrimps (*Pandalus borealis*) in MAP, Mejlholm *et al.* (2005) carried out storage trials with naturally contaminated shrimps at 2.5 and 8 °C. Challenge tests at the same conditions were also performed after inoculation with *L. monocytogenes*, *Brochothrix thermosphacta* and *Carnobacterium maltaromaticum*, which are responsible for sensory spoilage of those MAP products. It was concluded that to prevent *L. monocytogenes* from becoming a safety problem cooked and peeled MAP (50% CO_2/30% N_2/20% O_2) shrimps should be distributed at 2 °C and with a maximum shelf–life of 20–21 days. Mejlholm *et al.* (2008) studied the microbial changes and growth of *L. monocytogenes* during chilled storage of shrimp in brine and brined shrimp (*P. borealis*). The results obtained in this study allowed the conclusion that concentrations of microorganisms of brined shrimp from an industrial processing line were 1.0–2.3 log ($CFUg^{-1}$) higher than in manually processed samples. As a result industrially processed brined shrimp had a substantially shorter shelf–life and a more diverse spoilage microflora. The shelf–life of brined shrimp was affected by the type and concentration of organic acids used (benzoic, citric, sorbic acetic and lactic acids) and by the storage temperature (7–8 °C or 12 °C). Shrimp in brine with benzoic, citric and sorbic acids prevented growth of *L. monocytogenes* during more than 40 days at 7 °C when the preserving parameters resembled those of commercial products. A new extensive growth and growth boundary–model for *L. monocytogenes* in lightly preserved and ready–to–eat shrimp was developed by Mejlholm and Dalgaard (2009). This model includes a total of 12 environmental parameters and their interactive effects. It allowed to predicting growth rates of *L. monocytogenes* in brined shrimp with benzoic, citric and sorbic acids or with acetic and lactic acids.

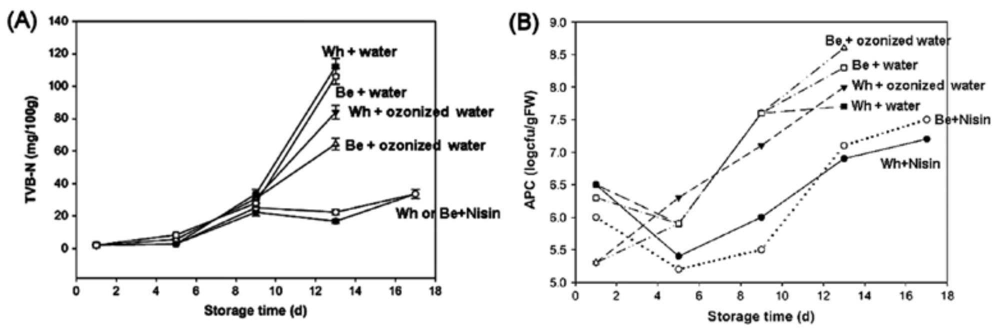
Sivertsvik and Birkeland (2006) studied the effects of storage time, modified atmospheres (30 or 60% CO_2), soluble gas stabilisation (SGS), i.e. application of 100% CO_2 saturated atmosphere at 3 bar, and gas to product volume ratio on the microbiological and sensory characteristics of cooked, peeled and brined ready–to–eat shrimp (*P. borealis*). SGS treatment prior to packaging (2 h) reduced the aerobic plate count and psychrotrophic count. The increase of CO_2 levels during

MAP and the application of SGS significantly enhanced the sensory quality of the shrimps. It is generally concluded that SGS treatment in combination with MAP can be successfully used on ready–to–eat shrimps to reduce the package volume and to improve the microbiological and sensory characteristics.

In another study Rutherford *et al.* (2007) studied the combined effect of MAP and storage temperature on growth of *L. monocytogenes* on ready–to–eat shrimp. Cooked, peeled and deveined shrimp were inoculated with this pathogenic bacteria, packed in air, vacuum and a 100% CO_2 atmosphere, and stored at 3, 7 and 12 °C. Results demonstrated that shrimps packed in CO_2 and stored at 3 °C did not permit growth of *L. monocytogenes* during the 15 day storage period. The other packaging/temperature combinations allowed for multiplication of the bacterium. However, the authors also concluded that when strict temperature control is difficult, additional antimicrobial hurdles may be necessary to ensure safety.

The combined effect of bactericides and MAP on the shelf–life of Chinese shrimp (*Fenneropenaeus chinensis*) were evaluated by Lu (2009). The aerobic plate counts, total volatile base nitrogen and organoleptic evaluation of overall acceptable score were followed during cold storage of whole or beheaded shrimp. It was concluded that, taking into consideration all the parameters analysed, the shelf–life of Chinese shrimp stored at 2±1 °C treated with MAP (40% CO_2/30% O_2/30% N_2) and 100% CO_2 after soaking with a bactericide compound (nisin) were 13 and 17 days, respectively (Figure 8).

FIGURE 8
Effect of bactericides on shrimp storage



Note: Effect of bactericides on total volatile base-nitrogen (TVB-N) values (A) and aerobic plate count (APC) values (B)in MAP (40 % CO_2/ 30 % O_2/ 30 % N_2) whole and beheaded shrimps during storage at 2±1 °C: (●) Wh+B; (○) Be+B; (▼) Wh+O; (△) Be+O; (■) Wh+W; (□) Be+W. Wh = whole shrimp; Be = beheaded shrimp; B = compound bactericide; O = ozonized water; W = water. (Lu, 2009; reproduced with permission of Elsevier Limited).

Crustaceans are commercially HP processed in several countries both to inactivate micro organisms and to automatically "shuck" the meat from the shell. The application of HP processing to crabs led to obtaining brown meat yields of 23 percent, compared with 18 percent in the control (SEAFISH Authority, 2009). Similarly, white meat yield was 12.9 percent compared with 8.3 percent in the control. However, poor quality product was obtained because of the excessive water uptake. Nevertheless, it was also concluded that a careful control of the processing parameters may "firm up" head and claw meat to enable this meat to be extracted whole. Yield on lobster claws was up to 23 percent higher than on cooked controls. For Norway lobster (*Nephrops norvegicus*), cold water and warm water prawns, yields increases of up to 3, 2 and 7 percent were obtained respectively.

In another report (Raghubeer, 2007), it is mentioned that the average total weight percentage recovered in HP processed Maine lobster at 250–500 MPa was 43 percent compared with an average of 25 percent in the traditional cooked product. A more significant increase in yield was achieved in soft shelled animals with a 45 percent recovery compared with 22 percent from cooking. Similarly, for crabs (Blue, Dungeness, Alaskan King, and Golden) the HP processing increased the yield to an average of 35 percent of total body weight whereas the mean recovered weight was 19 percent by traditional cooking method.

The possibility of using HP processing to extend the shelf–life of whole Norway lobster was studied by Albalat *et al.* (2008). Whole animals were pressurised at 150, 300 and 500 MPa for 3 min at ambient temperature and subsequently stored at 0–2 °C for up 21 days. The results showed that the bacterial load was reduced in a pressure–dependent manner until 21 days. However, microbial growth was resumed in all lots after a delay, which was also pressure–dependent.

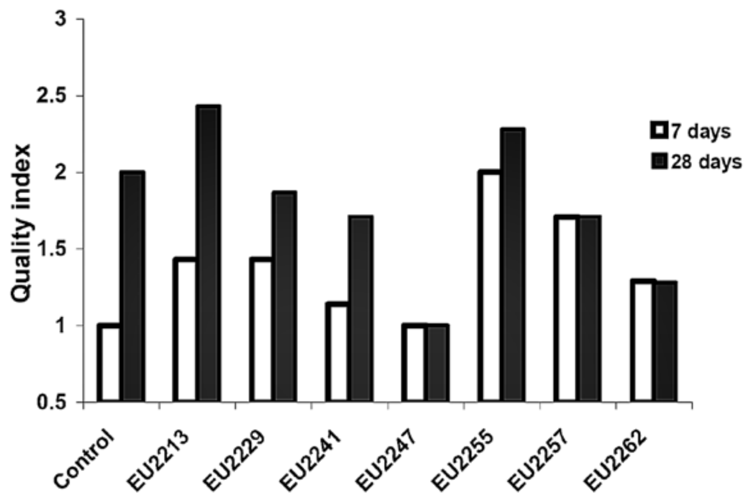
Lactic acid bacteria (LAB) have been used for centuries to preserve a wide variety of foods. Among these foods are included fish and fish products used to prepare fermented products, such as fish sauces and pastes of South East Asia. These fermented products are completely different from the raw materials exhibiting their own flavour characteristics.

LAB are not of much concern in seafood either aerobically stored or vacuum packed (VP) and in MAP because of the biochemical characteristics of fish products and their dominant microflora. However, they may present great relevance in lightly preserved fish products (LPFP), including VP and MAP. LPFP are uncooked or mildly cooked products such as peeled shrimp stored in MAP or in brine. The addition of NaCl at a concentration of about 5.5–6.5 percent has an inhibitory effect on Gram–negative bacteria but allows the growth of other micro–organisms like LAB. These bacteria can reach high levels (10^{7-8} CFU/g) in lightly–preserved shrimps such as reported for cooked or brined peeled shrimps (*P. borealis*) by Dalgaard *et al.* (2003) and Mejlholm *et al.* (2005) and for tropical cooked, peeled and brined shrimps (*P. vannamei*) stored in MAP (Jaffrès *et al.*, 2009). The LAB isolated from LPFP are mainly *Lactobacillus sakei* and *L. curvatus* and *Carnobacterium*, mainly *maltaromaticum* and *divergens*. It has been thought that LAB play a minor role in the spoilage of marine products. However, Dalgaard *et al.* (2003) anticipated that carnobacteria are involved in the spoilage of cooked shrimp stored in MAP. Later, the importance of carnobacteria as spoilage microorganisms in cooked and peeled MAP shrimps stored at 5 °C was confirmed by Laursen *et al.* (2006). *Carnobacterium divergens* and *C. maltaromaticum* caused sensory spoilage of shrimps and generated ammonia, tyramine and various alcohols, aldehydes and ketones. These authors also showed that the unpleasant odour generated by *Carnobacterium* spp. and *Brochothrix thermosphacta* were different from those produced by these bacteria in pure culture.

LPFP may represent, however, a health risk for consumers because they are processed by treatments not sufficient to destroy pathogens. Several of these products are eaten raw and thus it is necessary to minimise the presence and to prevent the growth of those pathogens for food safety. Other microorganisms responsible for the organoleptic damage to foods may be also present and the growth of those spoilage organisms should be also prevented. Biopreservation has been used as an adequate technology to extend the shelf–life and /or control the growth of pathogens in LPFP by inoculating selected bacteria to inhibit undesirable bacteria. LAB are usually chosen as they produce a wide range of inhibitory compounds (organic acids, hydrogen peroxide, diacetyl and bacteriocins). However, as mentioned by Leroi (2010), the selected LAB strain should not modify the organoleptic and nutritional quality of the products.

One of the first studies on the use of bacteriocins from LAB to increase the shelf–life of brined shrimp (*P. borealis*) was reported by Einarsson and Lauzon (1995). In this study the effects of three different LAB bacteriocins on bacterial growth and shelf–life were compared with those of a benzoate–sorbate solution and a control with no preservatives. Nisin Z was the bacteriocin which allowed a longer shelf–life of brined shrimps (31 days). At the end of the storage period the Gram–negative flora was more pronounced in the nisin Z treated shrimp.

FIGURE 9
Effect of lactic acid bacteria on the quality index in shrimp



Note: Evolution of the Quality Index of cooked peeled shrimps inoculated with seven different strains of bioprotective lactic acid bacteria (10^5 UFC/g, after 7 days and 28 days of storage under vacuum at 8 °C. Control: non inoculated sample. EU2213, 2247, 2262: *Leuconostoc gelidium*; EU 2229, 2241: *Lactococcus piscium*; EU2257: *Carnobacterium alterfunditum*; EU2255: *Lactobacillus fuchuensis*. (Improving seafood products for the consumer, ISBN 978-1-84569-019-9. Leroi *et al*., 2006; reproduced with permission of Woodhead Publishing Limited, UK).

Leroi *et al.* (2006) reviewed the main works published on the application of hurdle technology to preserve seafood products, where particular attention was given to biopreservation with LAB. The results obtained on the preservation of cooked tropical wild and farmed shrimps with seven groups of LAB strains isolated from various marine products are also described. The cooked shrimps were inoculated by each LAB strain at a level of 10^5 CFUg^{-1} and stored at 8 °C for 28 days of storage under vacuum packaging. The samples were analysed for sensory and microbiological quality after 7 and 28 days of storage. After 28 days, the samples inoculated with *Leuconostoc gelidum* EU2247 and EU2262 kept their fresh initial sensory quality showing that these two strains were able to greatly extend the shelf–life of wild and farmed cooked shrimps (Figure 9). Matamoros *et al.* (2009) also observed that two *L. gelidum* strains greatly extended the shelf–life of cooked peeled shrimp. The inhibiting capacities of *L. gelidum* and *L. piscium* were tested against three pathogenic bacteria (*Vibrio cholerae*, *L. monocytogenes* and *Staphylococcus aureus*) by challenge tests in shrimp. *L. piscium* strain EU2241 was able to reduce significantly the number of *L. monocytogenes* and *S. aureus* in the product by 2 log throughout the study for *L. monocytogenes* and up to 4 weeks for *S. aureus*.

In a more recent work, it was demonstrated that *L. piscium* CNCM I–4031 inhibited *B. thermosphacta* in tropical cooked shrimp (*P. vannamei*) and significantly prolonged sensory shelf–life (Fall *et al.*, 2010a). The inhibitory effect of this bacterial strain on *L. monocytogenes* inoculated in tropical cooked peeled shrimp (*P. vannamei*) stored at 8 °C in MAP (50% N_2 – 50% CO_2) was also demonstrated (Fall *et al.*, 2010b).

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Sashimi and sushi products

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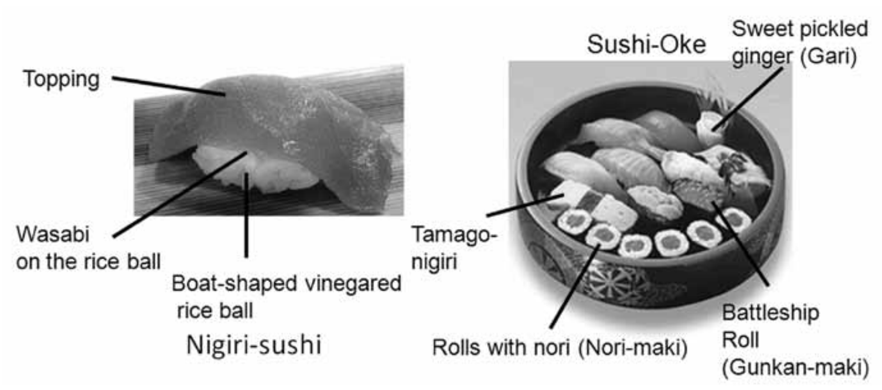
SUMMARY
Sashimi and the toppings for sushi are mainly made of raw, uncooked materials. The taste of fish and shellfish are contributed by amino acids (AA), organic acids (OA) and nucleotides (Nu). AA components differ largely among species, giving each fish and shellfish species their unique taste. As for OA, fish muscle, the main edible part of fish, contains mainly lactic acid, while the edible part of some of the shellfish species mainly contains succinic acid. These components vary with the condition of the catch and its treatment, and affect the taste. Nu, especially adenosine-5'-triphosphate (ATP) and its related compounds in fish muscle dramatically change after death. ATP is degraded into adenosine-5'-diphosphate (ADP), adenosine-5'-monophosphate (AMP), and inosine-5'-monophosphate (IMP) rapidly after death. IMP content is negligible just after death and accumulates according to degradation of ATP. IMP contributes to the umami taste of fish muscle. Up to 6 to 10hr after death, most of ATP is changed into IMP and the umami taste of fish muscle is enriched. Therefore the best time to eat raw fish is not just after harvest, but 6 to 10hr after harvest. On the other hand, most raw shellfish are optimal for eating immediately after catch, because they spoil quickly after death.

INTRODUCTION
Sashimi and sushi products are traditional and popular Japanese seafoods. They are widely recognized as a low calorie healthy food. More recently, sashimi and sushi have become popular around the world. This chapter focuses on the history of sashimi and sushi, toppings of sushi, taste of fish and shellfish and, lastly, provides tips to enjoy sashimi and sushi. The most common type of sushi is called nigiri-sushi. Figure 1 shows nigiri-sushi and a typical nigiri-sushi box.

FIGURE 1
Nigiri-sushi and a typical nigiri-sushi box



HISTORY OF SASHIMI

In the Muromachi Period (1336–1573), the word "sashimi" was found in an article in "Suzukakeki". The word sashimi means "pierced body", i.e. sashimi = sashi (to pierce or to stick) and mi (body, meat) (Figure 2). The word "sashimi" is thought to have been derived two ways:

1. It was used instead of "cut fish meat" because "cut" was an inauspicious word for the Samurai.
2. Derivation from the culinary practice of sticking the fish's tail and fin to the slices to allow identification of the fish that is being eaten.

FIGURE 2
Sashimi

Note: The word shashimi means "pierced body".

In the Edo period (1603–1867), the sashimi culture, especially related to sashimi cuisine, expanded. Skipjack sashimi was particularly popular in the city of Edo (now known as Tokyo). Figure 3 is a picture of a skipjack seller in this period.

By the middle of the 20th Century, with the invention of the refrigerator, there was a further popularization of sashimi. In recent years, high performance refrigerators, freezers and cold-chain systems have been developed. Also distribution systems for live fish have been developed. Accordingly, the quality of the sashimi has become higher.

HISTORY OF SUSHI

The most common type of sushi in the modern sushi restaurant is called nigiri-sushi. However, the original type of sushi was nare-sushi and this is different from nigiri-sushi. Nare-sushi was first produced in the 9th Century. Fish were salted and wrapped in fermented rice for preservation. The rice was removed before eating. Figure 4 shows a picture of "funazushi". It is one of the specialties of the Siga prefecture and is the same as the original nare-sushi.

FIGURE 3
Skipjack seller in the Edo period (1603-1867)

Note: From "Morisadamankou".

In the Muromachi Period, oshizushi was produced. The fermentation process was skipped and vinegar was used. The rice used in the process began to be eaten along with the fish. In this period, oshizushi was mainly made and eaten in Osaka. Figure 5 shows a picture of "oshizushi".

In the middle of the 18th century, oshizushi was brought to Edo. In the early 19th Century (the latter part of the Edo Period), nigiri-sushi was invented by the townspeople of Edo, based on oshizushi. At first, nigiri-sushi was sold mainly at sushi stands ("sushi-yatai" in Japanese) (Figure 6).

FIGURE 4
Nare-sushi

TOPPINGS FOR NIGIRI–SUSHI

Toppings for nigiri-sushi ("sushi-neta", or "sushi-dane" in Japanese) are mainly raw fish and shellfish. These are also used for sashimi.

With the development of refrigeration technology, frozen fish and shellfish were also used for toppings of sushi and sashimi – not only wild caught fish, but also farmed fish. The following is a list of popular fish used for sashimi and sushi:

1. Tuna – Five species of tuna are used. Blue fin tuna is the most popular and expensive. Many frozen tunas are also used. With the development of tuna aquaculture technology, farmed tuna are being introduced into the market. Skipjack tuna has been popular since the Edo period and it is only caught wild. Both wild and farmed yellowtail tuna are also used. Recently, farmed yellowtail tuna has become popular both within and outside of Japan.
2. Sea bream – Both wild and farmed fish are used.
3. Flounders – Again, both wild and farmed fish are used.

FIGURE 5
Oshizushi

PRE-COOKING FOR SASHIMI AND SUSHI

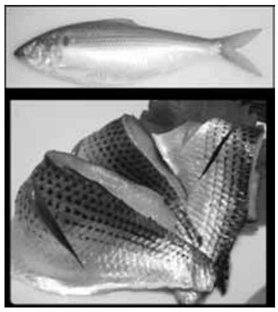
Some of the toppings for sushi are made from pre-cooked fish, and are marinated, broiled or once-frozen to circumvent rapid loss of freshness, toxins and parasites, respectively. Examples for the cases of mackerel and gizzard shad, eel, and salmon are cited as follows.

FIGURE 6
Sushi Yatai

Note: From "Gyoshokubunnka no keifu"".

Marinating (su-shime) is a method by which fish are sprinkled with salt and then soaked in vinegar in order to preserve and to kill parasites, for example, mackerel, gizzard shad (Figure 7).

FIGURE 7
Gizzard shad



Eel serum contains ichthyotoxin and raw eels should not be eaten. To inactivate the toxin, fish are broiled. Broiled eels and broiled Japanese conger eel are used not only for toppings of sushi but also una-jyu and anago-don. These are traditional items in Japanese cuisine. The eels are placed on rice with the salty-sweet Nitsume sauce. Figure 8 shoes a picture of una-jyu.

FIGURE 8
Una-jyu

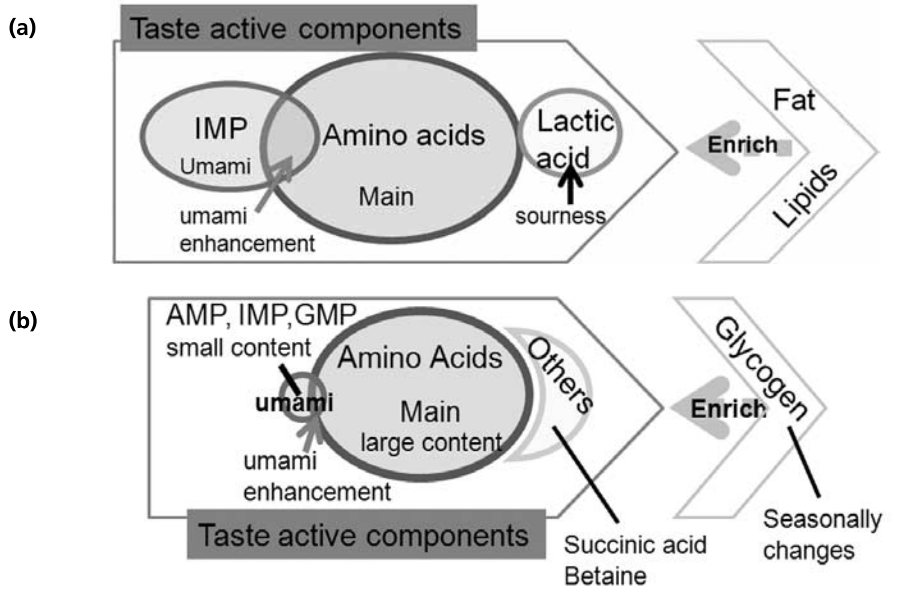
The process of freezing is sometimes used to kill parasites. For example, in salmon, tapeworm and anisakis are possible parasites, thus in order to eat salmon as sashimi or as toppings for sushi, frozen salmon is used. "Ruibe" is one of the traditional Ainu people's foods and is simply frozen salmon sashimi.

TASTE OF FISH AND SHELLFISH

Figure 9 shows the main compounds that contribute to the taste of fish and shellfish respectively. Amino acids, nucleotides and organic acids are the main compounds involved in the taste of fish and shellfish.

Amino acids (AA) contribute to the main taste of fish and shellfish. Nucleotides (Nu), AMP (adenosine-5'-monophosphate), IMP (inosine-5'-monophosphate) and GMP (guanosine-5'- monophosphate) contribute the umami taste. IMP enhances the umami taste of monosodium glutamate (Yamaguchi, 1967) and some amino acids (Kawai *et al.*, 2002). Yoshii (1987) reported that the response of the chorda tympani nerve to some amino acids was enhanced by addition of AMP or GMP. This suggests that AMP and GMP would affect the taste quality of some amino acids. Organic acids (OA) are responsible for sourness, for example, lactic acid contributes a sour taste to fish muscle. Succinic acid may contribute an umami taste to the edible parts of clams. Levels of lactic acid and succinic acid vary with the condition of the catch and treatment.

FIGURE 9
Chemical compounds that contribute to the taste of (a) fish and (b) shellfish



Fatty fish are thought to be "delicious" while fat (lipid) was thought to be tasteless for a long time. However, candidate fat taste receptors have been discovered and are thought to directly contribute to the taste (deliciousness) of foods (Gilbertson *et al.*, 1997). Also, a more recent study has shown that eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) had bitter inhibitory effects (Yasumatsu *et al.*, 2005). Glycogen does not directly contribute to but enriches the taste of shellfish (Watanabe *et al.*, 1990).

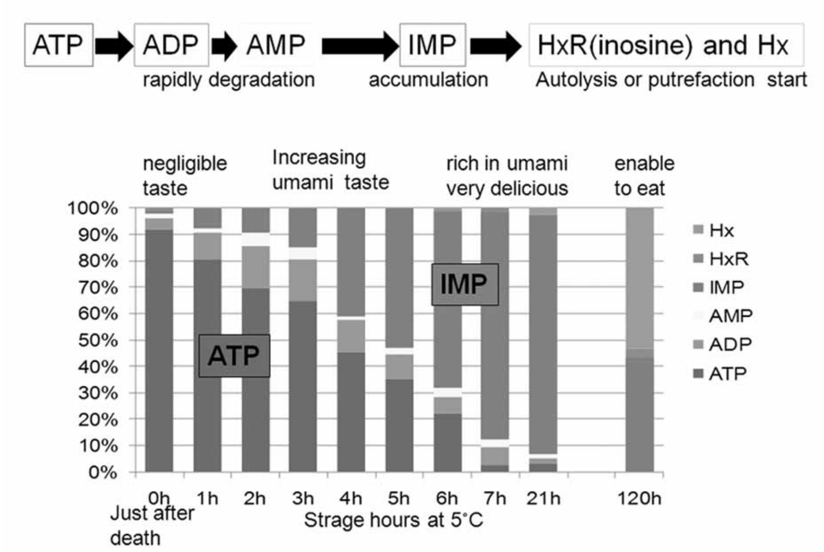
HOW AND WHY RAW FISH IS DELICIOUS?

Amino acid components are different among species and this leads to the unique taste of each fish species. Accumulation of IMP starts after death and it affects the taste. The quantity of lactic acid varies with the fishing conditions, for example, when a fish struggles at the time of catch, the quantity of lactic acid of the muscles increases. The content of fat and lipids changes seasonally and it affects the taste of fish. Generally, fish in which the fat content is at a high level are thought to be more delicious in Japanese cuisine.

THE BEST TIME TO EAT RAW FISH

Adenosine-5'-triphosphate (ATP) and its related compounds, that is, adenosine-5'-diphosphate (ADP), AMP, IMP, inosine (HxR) and hypoxanthine (Hx) are the main nucleotides in fish muscle. The components of nucleotide related compounds (Nu-ATP) in fish muscle dramatically change after death. Figure 10 shows the changes of the components of Nu-ATP in horse mackerel muscle during storage at 5 °C after catch.

FIGURE 10
The changes of the components of Nu-ATP in horse mackerel muscle during storage at 5 °C after catch



In live fish muscle, most of Nu-ATP is ATP and high levels of ATP are present. Just after death, more than 90 percent of Nu-ATP in the muscle is ATP. Because ATP is tasteless, the taste, especially the umami taste, of the fish muscle is negligible. After death, the ATP is rapidly degraded into ADP, AMP, and to IMP. The IMP content is negligible just after death and accumulates depending on the degradation of ATP. IMP contributes to the umami taste. Thus, with the accumulation of IMP, the umami taste of fish muscle increases. Up to 7~10 hours after death, more than 80 percent of Nu-ATP is IMP, and the umami taste of fish muscle is heightened. These results suggest that the best time to eat fish is about 7~10 hours after death. High levels of IMP remain for several days, but the length of time that these high levels remain in the fish muscle varies among different fish species. At a point in time, normally several days after death, the IMP is degraded into HxR and Hx and the IMP content decreases. At this time, fish should not be eaten as raw fish (sashimi) and at this point putrefaction starts.

HOW AND WHY IS RAW SHELLFISH DELICIOUS?

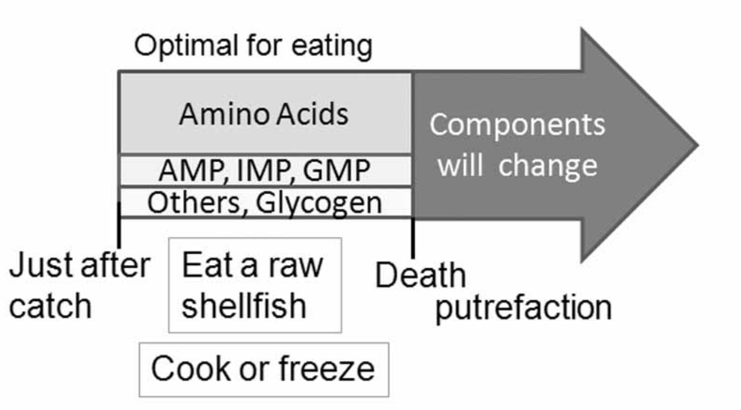
Most raw shellfish are at an optimal state for eating immediately after capture because of their rapid degradation. Just after harvesting, components similar to those found in fish species contribute to the taste of shellfish (Figure 11).

The active components of shellfish vary among the different species:

Clams:	Taurine (Tau), glutamic acid (Glu), glycine (Gly), arginine (Arg), AMP and succinic acid mainly contribute to the taste (Fuke and Konosu, 1989). They are not used as raw clams but used after being boiled and broiled.
Sea urchins:	Glu, Gly, alanine (Ala), methionine (Met), valine (Val), IMP and GMP mainly contribute to the taste (Komata, 1964). Mainly raw urchins are used for sashimi and sushi.
Prawns and Lobsters:	Glu, Gly, Ala, Arg, Proline (Pro), AMP, IMP and betaine mainly contribute to the taste (Shirai *et al.*, 1996). Raw prawns/lobsters and sometimes frozen and/or boiled products are used for sashimi and sushi.

Crabs:	Glu, Gly, Ala, Arg, AMP, GMP and betaine mainly contribute the taste (Hayashi *et al.,* 1978, 1979, 1981; Konosu *et al.,* 1978). Raw, frozen and boiled crabs are used for sashimi and sushi.
Squids:	Glu, Gly, Ala, Arg, Pro, AMP, betaine and TMAO (trimethylamine oxide) mainly contribute to the taste (Kani *et al.*, 2008). In Japan, raw squid are sometimes used for sashimi. However care is necessary because of parasites, and for this reason, squid are often frozen to kill the parasites.

FIGURE 11
Optimal stage for eating shellfish



TIPS FOR ENJOYING SASHIMI AND SUSHI

The following are some tips to maximise the enjoyment of eating sashimi and sushi:

1. Keep clean. Hands, cooking utensils and equipment must be kept clean.
2. Use fresh materials.
3. Keep materials and dishes in a cool/cold area. Do not leave them in warm areas (i.e. at room temperature) for a long time.
4. Do not eat raw freshwater fish. Often, parasitic worms are present in these species.
5. If you are inexperienced at preparing sashimi or sushi using fish and shellfish, obtain the correct information and check about parasites, toxins, and matters related to food safety.

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Minimising antimicrobial use in aquaculture and improving food safety

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SUMMARY
Aquaculture is contributing to about 50 percent of global fish production and in most parts of the world fish capture production has stagnated for over a decade because maximum sustainable yields have been reached. Therefore the increasing demand for fish has to be met by increasing fish production by aquaculture. This has been a challenge because disease outbreaks have been causing serious losses in both finfish as well as shellfish aquaculture. Detection of residues, in some countries, of certain banned antibiotics in aquaculture products has led to consumer concerns about the safety of these products. There is also growing concern about the emergence and spread of bacteria resistant to antimicrobial agents and transfer of resistance determinants to human pathogens that may be associated with the aquatic environment. In this context, there is a need to look for alternatives to antimicrobial agents for health management in aquaculture.

Most often, disease problems in aquaculture are because of a shift in the delicate balance between the host, the pathogen and the environment. Therefore, disease problems can be significantly reduced by adopting good management practices. In the aquaculture of salmonids, the use of antimicrobials could be minimised substantially by vaccinating fish against some of the common bacterial and viral diseases. However, currently, no vaccines are available for parasitic diseases. Further, global aquaculture is dominated by Asian cyprinids and currently, there are no commercial vaccines available for these species. Crustaceans have a poorly developed immune system and there are no commercial vaccines for this sector of aquaculture. However, the innate immune response of fish and crustaceans can be stimulated by certain microbial molecules like glucans that can act as immunostimulants. Currently, immunostimulants are widely used for health management both in finfish as well as crustacean aquaculture.

Probiotics have become useful tools for health management and the term "probiotics" has been more broadly used in aquaculture to refer to microbial agents that have beneficial effects on cultured animals in a number of ways. Most of the aquaculture probiotics are thought to act by modifying the microbial community around the animals in favour of beneficial microorganisms that may improve the water or sediment quality, suppress pathogenic bacteria, stimulate the immune system of the host or improve host digestion. The technology of bacteriophage therapy is attracting the attention of medical professionals because of the increasing incidence of human infections with multi-drug resistant bacteria. Scientific studies show that even in bacterial diseases of fish and shrimp, bacteriophage therapy could be effective. Commercial products based on bacteriophages for pathogen control in agriculture, aquaculture and food processing are available in some countries. Thus, there are

number of alternative technologies for health management in aquaculture and these have potential to contribute to minimising antimicrobial use in this sector.

PUBLIC HEALTH AND TRADE IMPACT OF THE USE OF ANTIMICROBIALS IN AQUACULTURE

The contribution of aquaculture to world fish production is increasing rapidly. In 2006, 47 percent of the 110 million tonnes of world food fish supply came from aquaculture (FAO, 2009). The annual growth rate in world aquaculture production during 2004 to 2006 was 6.1 percent in volume terms and 11 percent in value terms. The Asia Pacific Region accounts for 89 percent of production in terms of quantity and 77 percent in terms of value. As increasing quantities of aquaculture product are reaching markets, there is also considerable concern on safety issues and the detection of residues of antibiotics has been one the major issues. It is very difficult to obtain data on the usage of antimicrobials in aquaculture. The World Organisation for Animal Health (OIE) prepared a list of antimicrobials of veterinary importance (Table 1). This follows the recommendation of the FAO/OIE/WHO Expert Workshop on non-human antimicrobial usage and antimicrobial resistance that OIE and WHO should develop a list of critically important antimicrobials in veterinary medicine and human medicine respectively (FAO/OIE/WHO, 2003).

The OIE list was prepared based on response to a questionnaire sent to member countries. Two criteria were used to assess the importance of antimicrobials in veterinary medicine:

a) Response rate to the questionnaire regarding veterinary critically important antimicrobials. This criterion was met when more than 50 percent of the respondents identified the importance of the antimicrobial.
b) Treatment of serious animal disease and availability of alternative antimicrobials.

Antimicrobials meeting both criteria were designated “veterinary critically important antimicrobials”. Those meeting one of the criteria were designated “veterinary highly important antimicrobials”. Those meeting none of the criteria were designated “veterinary important antimicrobials”. Table 1 shows all antimicrobials used in aquaculture appearing in the OIE list and antimicrobials licensed for use in aquaculture in the United States of America and in the European Union.

There is no reliable data on licensing or national usage from the Asia Pacific region, but available evidence suggests that considerable quantities are used in some countries, often without professional consultation or supervision. Insufficient regulations and limited enforcement in many countries where aquaculture is an important industry are major problems that need to be addressed.

At the international level, it is being recognized that while antimicrobial agents are important for animal health protection, the negative impacts of their use in food producing animals should be minimized. The Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO) and the World Organisation for Animal Health (OIE) have organized several expert consultations and technical meetings to review the global situation and develop recommendations.

TABLE 1
Antimicrobials licensed/used in aquaculture

Antimicrobials appearing in OIE list[1]	Antimicrobials approved by US FDA[2]	Antimicrobials approved in EU[3]
Spectinomycin	Oxytetracycline	Amoxycillin
Streptomycin	Florfenicol	Florfenicol
Kanamycin	Sulfadimethoxine/ ormetoprim	Oxolonic acid
Bicozamycin		Oxytetracycline
Fosfomycin		Flumequine
Lincomycin		Sarafloxacin
Erythromycin		Sulphadiazine + trimethoprim
Josamycin		
Spiramycin		
Novobiocin		
Amoxycillin		
Ampicillin		
Tobicillin		
Florphenicol		
Thiamphenicol		
Flumequin		
Miloxacin		
Oxalonic acid		
Enrofloxacin		
Sulphadimethoxine		
Sulphafurazole		
Sulphamethoxine		
Sulphamonomethoxine		
Trimethoprim + sulphonamide		
Doxycycline, Oxytetracycline, Tetracycline		

[1] www.oie.int/downld/Antimicrobials/OIE_list_antimicrobials.pdf.
[2] www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/Aquaculture/ucm132954.htm.
[3] Rodgers and Furones, 2009 accessed at ressources.ciheam.org/om/pdf/a86/00801061.pdf.

The public health hazards related to antimicrobial use in aquaculture include the development and spread of antimicrobial resistant bacteria and resistance genes and the occurrence of antimicrobial residues in products of aquaculture (FAO/OIE/WHO, 2006). Bacterial resistance to antimicrobial agents is a significant public health concern. The widespread use of antibiotics in different sectors such as animal husbandry, agriculture and human medicine has contributed to selection and spread of antibiotic-resistant bacteria in the environment. Antibiotic resistance genes can spread among unrelated bacteria without any phylogenetic, ecological or geographical barriers. The Joint FAO/OIE/WHO Expert Consultation on Antimicrobial Use in Aquaculture and Antimicrobial Resistance held in 2006 identified two types of hazards with respect of antimicrobial resistance:

1. Development of acquired resistance in bacteria in aquatic environments that can infect humans. This can be regarded as a direct spread of resistance from aquatic environments to humans; and
2. Development of acquired resistance in bacteria in aquatic environments whereby such resistant bacteria can act as a reservoir of resistance genes from which the genes can be further disseminated and ultimately end up in human pathogens. This can be viewed as an indirect spread of resistance from aquatic environments to humans caused by horizontal gene transfer.

The consequences of antimicrobial resistance in bacteria causing human infections could include increased severity of infection and increased frequency of treatment failures (FAO/OIE/WHO, 2006). However, there are no recorded cases of human infections caused by antibiotic-resistant bacteria from aquaculture products.

While the issue of selection and spread of antibiotic-resistant bacteria in aquaculture has been deliberated upon for quite some time, the issue of antimicrobial residues in aquaculture products came to the fore in 2001 following marked improvements in laboratory methods to detect residues. This was followed by disruptions of trade in aquaculture products. According to the World Trade Organization's (WTO) Sanitary and Phytosanitary (SPS) Agreement, countries have the right to establish measures to protect the life and health of their population and also to determine the level of protection that is appropriate for the country; however, available scientific evidence should be used when establishing control measures, and these measures should not be taken only to favour the domestic industry. Measures adopted by countries with respect to antibiotic residues and antibiotic-resistant bacteria would be within the framework of the SPS agreement.

At the international level, the responsibility of providing advice on risk management concerning veterinary drug residues lies with the Codex Alimentarius Commission (CAC) and its subsidiary body, the Codex Committee on Residues of Veterinary Drugs in Foods (CCRVDF). The primary responsibility for risk assessment lies with the Joint FAO/WHO Expert Committee on Food Additives (JECFA). CCRVDF determines the priorities for consideration of residues of veterinary drugs and JECFA provides independent scientific advice by evaluating the available data on veterinary drugs prioritized by CCRVDF. The Risk Assessment Policy for Setting of MRLs in Food established by the CAC defines the responsibilities of CCRVDF and JECFA and their interactions. For the establishment of a priority list, CCRVDF identifies, with the assistance of Members, the veterinary drugs that may pose a consumer safety problem and/or have a potential adverse impact on international trade. Veterinary drugs meeting some or all of the following criteria could appear on the priority list:

- A Member has proposed the compound for evaluation;
- A Member has established good veterinary practices with regard to the compound;
- The compound has the potential to cause public health and/or trade problems;
- It is available as a commercial product; and
- There is commitment that a dossier will be made available (CAC, 2010).

JECFA uses a risk assessment process to establish acceptable daily intake (ADI) and maximum residue limits (MRLs). Veterinary drugs that are toxic or have carcinogenic potential are not evaluated by JECFA and therefore no ADI or MRL is established. Chloramphenicol and nitrofurans, the main compounds that caused disruptions in trade in aquaculture products, belong to this category and are banned for use in food-producing animals in most countries. Presently, there is a Codex MRL only for chlortetracycline/oxytetracycline/tetracycline in fish and shrimp (CAC, 2009). However, there are national/regional MRLs for several other antimicrobial agents. In the European Union (EU), Commission Regulation (EC) No. 1181/2002 establishes MRLs for veterinary drugs in foods of animal origin, including aquaculture products. A lack of Codex MRLs for veterinary drugs could be a problem for many developing countries that adopt Codex MRLs as national MRLs. This situation led FAO/WHO (2004) to recommend that for veterinary drugs that have been evaluated by national governments and are legally used in many countries, a comprehensive approach needs to be adopted to expedite harmonization. A JECFA evaluation of substances may be constrained by a lack of sponsors. FAO/WHO (2004) recommended that with the assistance of JECFA and based on national/regional MRLs, an initial list of temporary/operative MRLs could be adopted by CCRVDF. This list could be made permanent by CAC, if the national/regional risk assessments are not questioned or if JECFA could establish an ADI using the data used by the country/region to propose an MRL. Substances that do not fulfil these requirements could then be moved to the list of compounds not to be used in food animals.

For veterinary drugs without an ADI or MRL, regulatory authorities generally adopt a zero tolerance approach. In this situation, as the analytical capability improves, levels that were not detectable by earlier technologies become detectable and hence reportable. Therefore, independent of any toxicological risk posed by the food product, the residues would attract regulatory action. The countries taking a zero tolerance approach argue that the products are not acceptable because they have evidence of the use of a banned drug in animal production and therefore it represents a violation of regulations.

Table 2 shows the rapid alerts that appeared in the European Union market resulting from residues of antimicrobials being found in fish and fishery products. The major veterinary drugs involved are chloramphenicol, nitrofuran metabolites and malachite green.

TABLE 2
Rapid alerts from detection of residues of veterinary drugs in the European Union

Veterinary drug	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Chloramphenicol	44	102	9	8	1	1	4	2	3	4	178
Malachite green	0	2	11	18	50	17	9	2	5	4	118
Nitrofuran (including all metabolites)	0	89	51	27	30	41	31	48	89	10	416

Following the trade disruptions caused by the detection of residues, a Joint FAO/WHO Technical Workshop on Residues of Veterinary Drugs without ADI/MRL was held in 2004. This technical meeting recommended that for residues of drugs without an ADI/MRL, CCRVDF should request JECFA to perform and report, if possible, an estimate of the risks associated with the exposure to residues, because such risk estimates would be useful in risk management and that CAC should include consideration of cost–benefit and risk comparisons in their risk analysis process (FAO, 2004). Use of alternate risk management approaches that reflect the toxicological risk of the residue for regulatory analytical methods such as Recommended Performance Level (RPL) or a control strategy chosen by the competent authority were also recommended (FAO/WHO, 2004). They further emphasized that the illegal use of veterinary drugs cannot be condoned. The current lack of epidemiological data on the perceived public health risks and the cost of implementing regulatory measures based on analytical capability emphasize the need for more innovative approaches to manage this problem.

ALTERNATIVES TO ANTIMICROBIALS IN HEALTH MANAGEMENT IN AQUACULTURE

One of the major constraints faced by aquaculture is the serious loss because of disease outbreaks. Some examples are indicated in Table 3. Both shrimp and finfish farmers have lost millions of dollars because of outbreaks of diseases. Therefore, a health management strategy is very important for the success of commercial aquaculture. Most often, pathogens causing diseases are present in the environment in which fish are grown but disease outbreaks occur when the conditions are unfavourable for the fish e.g. overcrowding, environmental stress like drops in temperature, salinity. In the case of shrimp, for example, the presence of multiple viruses has been detected by sensitive diagnostic tests, like polymerase chain reaction, in shrimp farms showing normal growth (Umesha *et al.*, 2006). This suggests that for an infection (presence of a pathogen in a host system) to lead to a disease (alteration of the normal physiology of the animal), environmental factors are very important. Thus effective health management strategies should consider the interaction between the host, the pathogen and the environment. The goal of the strategies should be to prevent disease outbreaks occurring, thus minimizing the need for use of any antimicrobials.

TABLE 3
Some examples of economic losses because of diseases in aquaculture

Disease	Country	Economic impact	Reference
White spot disease of shrimp	Bangladesh	US$80.14 million during late 1990's	Alam *et al.*, 2007
White spot disease of shrimp	India	US$120 million during late 1990's	Karunasagar and Karunasagar, 1999
Yellow head disease and white spot disease of shrimp	Thailand	US$650 million in 1994	Chanratchakool *et al.*, 2001.
Shrimp viral diseases	Viet Nam	US$100 million in 1993	Khoa *et al.*, 2001
White spot disease of shrimp	Ecuador	US$280 million in 1999	Alday de Graindorge and Griffith, 2001
Bacterial diseases of finfish	China	Over US$120 million annually during 1990–1992	Wei, 2002
Infectious salmon anaemia (ISA) virus disease	United States of America United Kingdom	US$20 million in 2001 US$32 million in 1998–1999	Valderhaug, 2008

However, it should be pointed out that global aquaculture systems encompass diverse fish species and varied pond conditions. For example, carps in Asia are cultured in earthen ponds with fairly high organic matter content, while salmonids are cultured in rather clean waters in temperate environments. Aquaculture involves not only the vertebrate finfish, but also includes invertebrates like crustaceans and molluscs, which are at different evolutionary scales and have diverse physiological systems. A good understanding of the animal physiology, nutrition and immunological system would be essential to develop appropriate health management strategies. Some of the health management tools that have been successfully used in various aquaculture systems are detailed below.

Good aquaculture practices

Epidemiological studies have indicated that outbreaks of diseases in aquaculture systems are related to certain risk factors such as high stocking density, inadequate management of feed, fertilizers, water and sediment quality, the use of infected seeds, sudden changes in environmental conditions, such as temperature, salinity, dissolved oxygen, etc. Studies conducted in Asia in shrimp aquaculture have shown that, in some ponds, one can find animals infected with two or three viruses but growing normally (Umesha *et al.*, 2006). This shows that often pathogens are present in the environment (e.g. in water/sediment in the case of bacteria or in carrier animals in the case of viruses), but may not result in disease unless there are additional environmental factors affecting the host. Thus, for disease management, it is important to consider developing and implementing good aquaculture practices (GAPs). The general aspects to be looked into, such as site selection, water quality, source of fry and fingerlings, identification of hazards and defects, and production operations including feed and use of veterinary drugs, have been elaborated in the Codex Code of Practice for Fish and Fishery Products (CAC/RCP 52-2003). Depending on the species cultured and the surrounding environmental conditions, site-specific GAPs need to be worked out. One of the well known success stories is that of shrimp aquaculture in India. Following the outbreak of disease from whitespot syndrome in India, there were massive crop losses. The Marine Products Export Development Authority (MPEDA) of India, in collaboration with the Network of Aquaculture Centers in Asia and Pacific (NACA), initiated a programme to develop "Better Management Practices" (BMPs) in the State of Andhra Pradesh. The BMPs developed included a comprehensive set of measures such as good pond preparation, water quality management, pond bottom management, biosecurity and avoidance of animals carrying White Spot Syndrome Virus, good quality seed selection, feed management and waste management (Umesh *et al.*, 2010). Because most shrimp farmers in India operate small farms, often with a single pond, a cluster approach was used, so that farmers in an area joined together and followed the same practices. Over a period of 4 years, this approach led to a 31 percent reduction in disease prevalence compared with non-BMP ponds (Umesh *et al.*, 2010). This example illustrates that it is possible to achieve marked gains in production by following BMPs.

Vaccination

Vaccination has been successfully used for prevention of disease outbreaks in animal husbandry and some diseases have even been eradicated e.g. Bovine riderpest viral disease. Even in the aquaculture sector, there are success stories like the minimization of antimicrobial use in salmon culture in Norway. Bacterial vaccines were commercially used in aquaculture for the first time in the United States of America during the late 1970s against enteric red mouth disease (yersiniosis) and vibriosis (Evelyn, 1997). These early vaccines were based on inactivated whole bacterial cells administered by immersion. Application of industrially produced vaccines in aquaculture perhaps began in Norway, the major driving force being the huge losses to the salmon aquaculture industry because of vibriosis in the 1980s. In 1987, nearly 50 000 kg of antibiotics were used for production of about 5 000 tonnes of salmon, but the usage dropped following development of vaccines (Sommerset *et al.*, 2005). The antibiotics used in Norwegian salmon industry in 2003 were only 805 kg active ingredient for over 500 000 tonnes fish production (Burridge *et al.*, 2008). However, the use of antibiotics in salmon aquaculture varies depending upon the country. In Chile during 2003, 133 800 kg antibiotics were used for the production of 280 481 tonnes of salmon and in Canada, 30 373 kg antibiotics were used for production of 111 178 tonnes of salmon. This trend seems to be continuing with the salmon aquaculture industry in Chile using 385 600 kg antibiotics in 2007 and 325 600 kg antibiotics in 2008 to produce between 300 000 to 400 000 MT salmon (Burridge *et al.*, 2010). Thus, apart from availability of commercial vaccines, there are other factors like regulatory pressure that influence antimicrobial use in the aquaculture industry. Presently, vaccines are available for a large number of bacterial diseases and a few viral diseases (Tables 4 and 5). However, most of the vaccines available are for salmonids and there are very few vaccines for use in tropical aquaculture, one example being the streptococcosis vaccine for tilapia. According to FAO statistics (FAO, 2007), global aquaculture production in 2004 was dominated by carps and cyprinids (18.3 million tonnes) and shrimps and prawns (2.76 million tonnes) while salmon and trout production was only about 1.9 million tonnes. Thus, there are no commercial vaccines available for some of the major commercial fish species.

TABLE 4
Examples of multivalent/bivalent vaccines available for aquaculture in different regions

Diseases/Type of vaccines	Pathogen	Fish	Countries/Regions			
			North America	Europe	Chile	Japan/ Asia
Bivalent/Multivalent vaccines						
Furunculosis, Vibriosis	*Aeromonas salmonicida, Vibrio anguillarum, V. ordalli*	Salmonids	+	+		
Vibriosis, Yersiniosis	*Vibrio anguillarum, Yersinia ruckeri, V. ordalli*	Salmonids, cod	+	+		
Furunculosis, Vibriosis Coldwater vibriosis, Winter sore, Pancreas disease	*Aeromonas salmonicida, Vibrio anguillarum, V. salmonicida, Moritella viscosa,* Infectious pancreatic necrosis virus	Salmonids		+		
Furunculosis, Vibriosis, Infectious pancreatic necrosis, Salmonid Ricketsial Septicaemia (SRS), Infectious salmon anaemia (ISA)	*Aeromonas salmonicida, Vibrio anguillarum, Piscirickettsia salmonis*, Infectious pancreatic necrosis virus, ISA virus	Salmonids			+	
Furunculosis, Vibriosis, Infectious pancreatic necrosis, Salmonid Ricketsial Septicaemia (SRS)	*Aeromonas salmonicida, Vibrio anguillarum, Piscirickettsia salmonis,* Infectious pancreatic necrosis virus	Salmonids			+	
Infectious pancreatic necrosis, Salmonid Ricketsial Septicaemia (SRS)	*Piscirickettsia salmonis,* Infectious pancreatic necrosis virus	Salmonids			+	
Vibriosis, Infectious pancreatic necrosis	*Vibrio anguillarum*, Infectious pancreatic necrosis virus	Salmonids	+	+		
Furunculosis, Vibriosis, Infectious pancreatic necrosis	*Aeromonas salmonicida, Vibrio anguillarum,* Infectious pancreatic necrosis virus	Salmonids			+	
Vibriosis, Infectious pancreatic necrosis, Ricketsial Septicaemia (SRS)	*Vibrio anguillarum* Infectious pancreatic necrosis virus, *Piscirickettsia salmonis*	Salmonids			+	
Pasteurellosis, Vibriosis	*Photobacterium damselae, Vibrio anguillarum*	Salmonids		+		
Furunculosis, Infectious pancreatic necrosis (IPN)	*Aeromonas salmonicida,* Infectious pancreatic necrosis virus	Salmonids		+		
Pasteurellosis and Streptococcosis	*Photobacterium damselae, Lactococcus garvieae*	Yellowtail				+
Vibriosis, cold water vibriosis	*Vibrio anguillarum, V. ordalli, V. salmonicida*	Salmonids	+			
Vibriosis	*Vibrio anguillarum,* serotype O1, O2a, O2b	Salmonids, halibut, cod, seabass, seabream, Amberjack, yellowtail	+	+	+	+

TABLE 5
Examples of monovalent vaccines available for aquaculture in different regions

Diseases/Type of vaccines	Pathogen	Fish	Countries/Region			
			North America	Europe	Chile	Japan/ Asia
Vibriosis	*Vibrio anguillarum*, serotype O1	Yellowtails				+
Furunculosis	*Aeromonas salmonicida*	Salmonids	+	+		
Infectious salmon anaemia (ISA)	ISA virus	Salmonids			+	
Infectious pancreatic necrosis	IPN virus	Salmonids			+	
Enteric septicaemia	*Edwardsiella ictaluri*	Catfish	+			
Yersiniosis	*Yersinia ruckeri*	Salmonids	+	+	+	
Columnaris disease	*Flavobacterium columnare*	Catfish				+
Streptococcosis	*Streptococcus iniae*	Tilapia, seabass, grouper, flounder, halibut		+		+
Pasteurellosis	*Photobacterium damselae* subsp *piscicida*	Seabass and seabream	+	+		+
Lactococcosis	*Lactococcus garvieae*	Trout, Amberjack/ yellowtail		+		+
Cold water vibriosis	*V. salmonicida*	Salmonids	+	+		
Flavobacteriosis	*Flavobacterium psychrophilum*	Salmonids	+		+	
Bacterial kidney disease	*Renibacterium salmoninarum*	Salmonids	+		+	

While most available bacterial vaccines are based on inactivated bacterial cells (bacterins), there are a few examples of live attenuated vaccines. The efficacy of bacterins containing *Edwardsiella ictaluri* is low but, but a live attenuated vaccine has been found to be efficacious by immersion at 7 to 10 days post hatching (Shoemaker *et al.*, 1999). A live vaccine based on cross-reactive property of *Arthrobacter* spp. has been used in a vaccine licensed in North America and Chile against the intracellular bacterium *Renibacterium salmoninarum* causing bacterial kidney disease (Sommerset *et al.*, 2005). As shown in Tables 4 and 5, there are a few viral vaccines available and most of these are based on inactivated viruses or recombinant proteins. The efficacy of inactivated viral vaccines is low unless delivered by injection at relatively high doses (Sommerset *et al.*, 2005). There are safety concerns about use of live inactivated viruses as vaccines. As such, there is a need to demonstrate that they are non-pathogenic to non-target species of aquatic animals because they are likely to reach the aquatic environment, particularly if they are used for animals reared in open waters in cages. Generating such data would involve enormous cost and effort. DNA vaccines show promising results in experimental trails, but this involves introduction of a bacterial plasmid encoding antigen of interest. There are concerns that the plasmids may reach the environment and could reach other organisms with unforeseeable consequences (Magnadottir, 2010).

There are currently no vaccines available for parasites, though this group of pathogens can cause considerable economic losses. Celiate parasites like *Trichodina*, monogeneans like *Gyrodactylus* and *Dactylogyrus* and copepod parasites like *Lernea* are serious problems in warm water aquaculture. In salmon aquaculture in the northern hemisphere, the lice (*Lepeophtheirus salmonis*) alone are responsible for US$50–100 million annual losses through mortality, growth and quality reduction and pharmaceutical costs (Sommerset *et al.*, 2005). In Chile, the copepods belonging

Caligus spp. are a major problem. Parasites have complex cellular structure and the identification of a protective antigen would be important. More research efforts are needed to develop vaccines for parasites affecting aquacultured fish.

The two common methods of vaccine delivery to fish are immersion and injection. In the former, fish are immersed in a dilute vaccine suspension and this is a cheap, convenient method for a large number of fish, usually, at the fry stage. Vaccination by immersion has been found to be effective for several bacterial vaccines. On the other hand, vaccination by injection is labour-intensive and cannot be delivered to fish at the fry stage. In salmon aquaculture, use of a multiple component vaccine is common and in such multivalent vaccines, some components require delivery by injection with an oil adjuvant. In commercial salmon aquaculture, automated vaccine machines are commonly used. Because of the problems involved in delivering vaccines, the farmers prefer vaccination only once during the culture period and this has led to the development of polyvalent vaccines. Some of the commonly used vaccines for salmon contain six antigens (Table 4).

Being vertebrates, fish have a fairly developed specific immune system that has several similarities with the mammalian system. Fish produce antibodies, predominantly of the IgM type. On the other hand, the immune system of invertebrate shrimp is poorly understood. Though it is commonly believed that they do not have an adaptive immunity comparable to vertebrates, experimental studies indicate that it is possible to induce protection in shrimp through injection/oral administration of viral proteins (Witteveldt *et al.*, 2004a; 2004b), but the mechanism of protection is not known. There are no commercially available vaccines for shrimp aquaculture.

Immunostimulants

Though vertebrate finfish have a fairly developed specific immune response, the innate immune response plays an important role in preventing attack by pathogens. In the case of invertebrates like shrimp, there is no evidence of any specific immune response and the innate immunity is very important in the defence against pathogens. Even in finfish, development and maturation components involved in a specific immune response takes a few months after hatching (Zapata *et al.*, 2006) and therefore at this early stage of life, they are dependent on an innate immune response. Even after maturation, the specific immune response in fish has several constraints, such as limited classes of antibodies (IgG, IgA and IgE have not been found in fish), limited memory and relatively slow lymphocyte proliferation (Magnadottir, 2006).

Immunostimulants are naturally occurring compounds that enhance disease resistance in the host through modulation of the immune system (Bricknell and Dalmo, 2005). Studies done with various fish species show that the innate immune system can be upregulated with the help of various immunostimulants (Sakai, 1999). Many of the immunostimulants reported are molecules derived from microbial cell walls or outer membranes with characteristic patterns such as repeating units e.g. glucans, lipopolysaccharides, peptidoglycans, chitin and chitosan, and have been termed "pathogen associated molecular patterns" (PAMP). These recognise pattern recognition receptors (PRR) or pattern recognition proteins (PRP) of the innate immune system present in host cells. Stimulation of the innate immune response is indicated by parameters such as phagocytosis, activation of reactive oxygen and microbicidal activity in granulocytes, macrophage migration, complement activation and resistance to challenge by microbial pathogens (Sakai, 1999). There are numerous studies on immunostimulants and most of them report improved resistance to challenge by various bacterial pathogens, but some studies indicate no effect (Sakai, 1999).

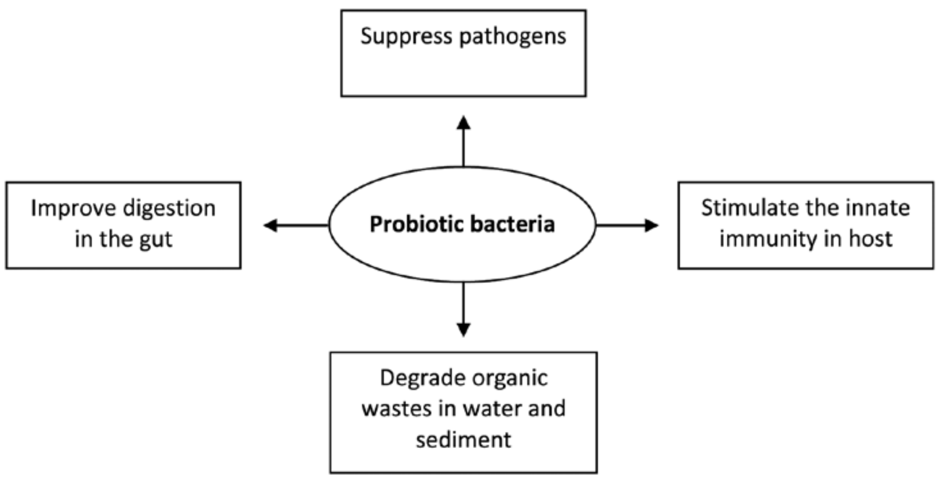
Most commercial immunostimulants are derived from yeast and seaweeds containing β 1-3 and β 1-6 glucans in the case of former and alginates and polysaccharides in the case of latter. Delivery of immunostimulants is generally by bath immersion or through feed. Pulse feeding is commonly practiced. In shrimp aquaculture in India, the intervals of feeding range from 4 to 7 days (Karunasagar and Karunasagar, 1999) and in salmonid culture, it could range from 4 to 6 weeks (Bricknell and Dalmo, 2005). In salmonid aquaculture, feeding with diet supplemented with immunostimulants has been demonstrated to reduce sea lice settlement and provide better protection against furunculosis and vibriosis (Bricknell and Dalmo, 2005). Immunostimulants are reported to be widely used in seabass and sea bream aquaculture.

Probiotics

Probiotics have been in use in human and veterinary medicine for a long time and the term has been traditionally used to refer to live microbial feed supplements that beneficially affect the host by improving the intestinal microbial balance (Fuller, 1989). A Joint FAO/WHO Working group on drafting guidelines for the evaluation of probiotics in foods recommended the following definition: "Live microorganisms which when administered in adequate amounts confer a health benefit on the host" (FAO/WHO, 2002). In the aquatic environment, the animals are in intimate contact with the environment including the microflora therein and even gut flora of aquatic animals are greatly influenced by the microflora in the surrounding environment.

Considering this interaction between environmental microflora and fish health, Verschuere *et al.* (2000) suggested the following definition for probiotics in aquaculture: "A live microbial adjunct which has a beneficial effect on the host by modifying the host associated or ambient microbial community, by ensuring improved use of feed or enhancing its nutritional value, by enhancing the host response towards disease or by improving the quality of its ambient environment". Thus, probiotic bacteria could improve the animal health either by suppressing the pathogens present in the environment, by stimulating the immune response in the host, by improving the digestion in the gut or by improving water/sediment quality by degrading accumulated wastes (Figure 1).

FIGURE 1
Potential roles of probiotic bacteria in improvement of animal health



Probiotic bacteria may modify the host associated microbial community by competitive exclusion of pathogens. The competition could be for nutrients, iron or for adhesion sites and some are known to produce compounds inhibitory to the pathogens. In fact, a common technique used by several investigators looking for potential probiotic bacteria is to screen the cultures for the ability to suppress potential fish/shrimp pathogens (Vershuere *et al.*, 2000). Lactic acid bacteria, commonly used as probiotics in mammalian systems, are known to produce bacteriocins that inhibit, predominantly, gram positive bacteria. Most fish/shrimp pathogenic bacteria are gram negative and bacteria such as *Bacillus* spp. have been shown to produce inhibitory compounds against gram negative bacteria (Karunasagar *et al.*, 2005) and have been used as probiotics in shrimp aquaculture. When added to shrimp larval rearing water or when administered through diets, *Bacillus* spp. have been shown to improve survival and weight of larvae (Rengpipat *et al.*, 1998; Moriarty, 1998). There are also reports of *Bacillus*, *Carnobacterium* and *Vibrio* spp. that enhance survival of fish eggs, larvae, juveniles or adults when challenged with pathogens (Vershuere *et al.*, 2000). Though production of inhibitory compounds by probiotic bacteria that suppress pathogens has been demonstrated *in vitro*, this has not been demonstrated under *in vivo* conditions. However, enhanced survival, moulting rate and growth of black tiger shrimp, *P. monodon*, has been reported under farm conditions (Rengpipat *et al.*,1998). Addition of probiotic bacteria such as *Lactobacillus*, *Bacillus*, *Carnobacterium* or *Roseobacter* to larval rearing water has been found to improve survival of turbot larvae, salmonid fingerlings and channel catfish (Balcazar *et al.*, 2006). Feed supplementation has been preferred in grow-out ponds and has been found to be more effective than direct addition to rearing water (Hai *et al.*, 2009).

Improvement of water/sediment quality by improving oxidation of ammonia or by oxidizing sulphides by a consortium of probiotic bacteria that included *Bacillus* spp., *Nitrosomans* and *Nitobacter* has been demonstrated under laboratory conditions in microcosms simulating shrimp pond conditions (Karunasagar, 2011). However, some studies were unable to find this effect (Vershuere *et al.*, 2000). Photosynthetic purple non-sulphur bacteria are widely used as probiotics in shrimp farms in South East Asia and in fish and shrimp farms in China (Qi *et al.*, 2009). These bacteria are reported to be efficient degraders of organic wastes in aquaculture ponds.

It has been proposed that in the case of filter feeders or larval stages of crustaceans, probiotic bacteria may serve as a complementary food source and enhance digestion (Vershuere *et al.*, 2000). Protease producing bacteria such as *Bacillus* spp. have been shown to improve growth performance in shrimp, *Litopenaeus vannamei* (Liu *et al.*, 2009).

The immunomodulating activity of probiotics in various fish species has been reported in the literature (Nayak, 2010). Stimulation of both innate immune response as well as increase in immunoglobulin levels has been demonstrated in fish. Probiotic bacteria such as *Lactobacillus* spp., *Bacillus* spp., *Carnobacterium* spp., *Clostridium butyricum*, have been demonstrated to stimulate the immune system of several fish species like tilapia, seabream and trout. But some investigators reported variable results. The high degree of variability observed by some investigators may be related to the bacterial species used as a probiotic and their source. It is now common to use multi-species probiotics. Organisms belonging to different families like *Lactobacillus* and *Bacillus* spp. have been found to act synergistically in immunomodulation (Salinas *et al.*, 2005).

In China, the biggest aquaculture producer in the world, it has been reported that over one hundred companies are involved in producing about 50 000 tonnes of probiotics with a market value of 50 million Euros. Though probiotics for aquaculture had a booming market in 2008, there was about a 50 percent decline in the market because of a lack of confidence by farmers and an issue with quality control of the commercial products (Qi *et al.*, 2009). This seems to be the experience in many countries. Regulatory approval for the use of probiotics as feed supplements has been documented in some regions. European Union regulation EC/710/2009 permits the use of authorized probiotics for disease control in organic aquaculture.

Biocontrol agents

The use of microorganisms as biological control agents for insect pests has been practiced in various forms. Bacteriophages (bacteria eaters) are viruses that replicate by using bacteria as hosts. Recently, there has been a surge of interest in using bacteriophages as therapeutic agents, particularly in the context of widespread occurrence of antibiotic resistance in several pathogenic bacteria. Bacteriophages are abundant in nature and have been found in both terrestrial and aquatic environments and in association with plants and animals. In non-polluted waters, 2 x 10^8 bacteriophages per ml have been found (Bergh *et al.*, 1989). The life cycle of a bacteriophage may include a lytic stage and some bacteriophages have their genome inserted into the host chromosome and enter a lysogenic stage. Lysogenic bacteriophages are involved in gene transfer in bacteria and some of the virulence factors found in bacteria (e.g. the ability to produce cholera toxin by *Vibrio cholerae* O1) have been associated with bacteriophages inserted into the bacterial genome.

Soon after the discovery of bacteriophages in 1917, the potential to use them against bacteria was realized. However, the interest in bacteriophages declined after the discovery of antibiotics, the subsequent scaling up of antibiotic production to industrial levels and their effectiveness in treating infections in soldiers during the World War II. But the treatment failures because bacteria show resistance to multiple antibiotics has led to a renewed interest in bacteriophage therapy. Bacteriophages are host specific, hence they lyse only the target bacteria, unlike antibiotics that suppress most of the bacterial groups. Thus bacteriophage therapy would not suppress useful commensal flora that are required for the health of the animals. This would be a great advantage in aquaculture.

The application of bacteriophages to combat fish pathogens was investigated by Nakai and coworkers (Nakai *et al.*, 1999; Park *et al.,* 2000; Nakai and Park, 2002). They used bacteriophages belonging to Siphoviridae family isolated from the aquaculture environment. Oral administration of bacteriophages against *Lactococcus garvieae* to young yellowtails (*Seliora quinqueradiata*) resulted in 100 percent survival following intraperitoneal challenge with the pathogen compared with 10 percent survival in control groups (Nakai *et al.*, 1999). Oral administration of phage impregnated feed (mixture of two bacteriophages, one belonging to Myoviridae and another belonging to Podoviridae family) to ayu (*Plecoglossus altivelis*) brought down cumulative mortality to 22.5 percent compared with 65 percent in controls, following an oral challenge with *Pseudomonas plecoglossicida* (Park, 2000). In both studies, the authors used oral administration and this would be very convenient in aquaculture. Fish digestive tracts have a relatively high pH and therefore the acid sensitivity of phages would not be an issue in aquaculture (Nakai and Park, 2002). Examples of reported efficacy of bacteriophages in improving survival of fish/shrimp when challenged with pathogens are indicated in Table 6.

Imbeault *et al.* (2006) studied the application of bacteriophages in preventing furunculosis caused by *A. salmonicida* in farmed brook trout (*Salvelinus fontinalis*). In aquarium tanks, application of bacteriophages resulted in a 6 log reduction in the number of *A. salmonicida* and reduced the mortality from 100 percent to 10 percent. Phage resistant mutants were isolated, but they were susceptible to other phages and the investigators suggested the use of bacteriophage combinations to overcome the problem. Park and Nakai (2003) also noted that a combination of two bacteriophages gave a significantly higher protection to ayu (*Plecoglossus altivelis*) infected with *Pseudomonas plecoglossicida* compared with treatment with a single bacteriophage.

TABLE 6
Reported examples of bacteriophage therapy in fish and shrimp

Pathogen	Fish/Shrimp species	Route of administration	Observed effect	Reference
Lactococcus garvieae	Yellowtail (*Seliora quinqueradiata*)	Oral administration	Improved survival on challenge	Nakai *et al.*, 1999
Pseudomonas plecoglossicida	Ayu (*Plecoglossus altivelis*)	Oral administration	Improved survival on challenge	Park *et al.*, 2000
Aeromonas salmonicida	Brook trout (*Salvelinus fontinalis)*	Addition to tank water	Reduction in *A. salmonicida* in water, improved survival of fish	Imbeault *et al.*, 2006
Vibrio harveyi	Black Tiger shrimp (*Penaeus monodon*)	Addition to larval rearing tank water	Improved survival of post-larvae during a natural outbreak	Vinod *et al.*, 2006
Vibrio harveyi biofilm	Black Tiger shrimp (*Penaeus monodon*)	Addition to water	Reduction in bacterial density in biofilm, improved survival of post-larvae	Karunasagar *et al.*, 2007

One of the concerns regarding the use of bacteriophage therapy has been the possibility that certain phages may go into a lysogenic state and may be involved in gene transfer. Virulence genes have been associated with lysogenic bacteriophages. Bacteriophages against the shrimp pathogen *V. harveyi* may belong to the family Siphoviridae or Myoviridae (Oakey and Owens, 2000, Shivu *et al.*, 2007; Crothers-Stomps *et al.*, 2010). Generally members of Siphoviridae have been reported to be lytic phages (Vinod *et al.*, 2006; Shivu *et al.*, 2007; Karunasagar *et al.*, 2007; Crothers-Stomps *et al.*, 2010). A *V. harveyi* myovirus like phage (VHML) has been reported to be temperate and confer virulence to the host strains (Pasarawipas *et al.*, 2005). Shivu *et al.* (2007) tested the host range of a collection of *V. harveyi* phages against 180 isolates from different geographical regions. Three strains of siphoviridae family were able to lyse 65–70 percent of the strains, indicating a broad host range. Vinod *et al.* (2006) tested bacteriophage therapy of shrimp (*P. monodon*) larvae and post-larvae in both laboratory microcosms as well as in hatcheries during a natural outbreak of luminous bacteria disease. The bacteriophages were added to larval tanks. In microcosms, larval survival was 25 percent in the control and 85 percent with treatment. In hatchery trials, the survival was 86 percent with bacteriophages, 40 percent with antibiotics and 17 percent in controls (Vinod *et al.*, 2006). Bacteriophage treatment brought down counts of luminous bacteria in the tanks. In another hatchery trial during a natural outbreak of luminous bacteria disease, 86–88 percent survival was obtained with bacteriophage treatment compared with 65–68 percent with antibiotics (Karunasagar *et al.*, 2007). These studies show the potential for bacteriophages to be effective alternatives to antibiotics in shrimp larval health management. Bacteriophages used by Vinod *et al.* (2006) and Karunasagar *et al.* (2007) lacked the putative virulence gene carried by VHML and hence the concern regarding carriage of virulence gene would be minimal.

One of the problems in shrimp larval health management is the persistence of *V. harveyi* in the hatchery environment, by forming a biofilm that is resistant to antibiotic and sanitizer treatment (Karunasagar *et al.,* 1996). The ability of bacteriophages to bring about a 3 log reduction in biofilm cells of *V. harveyi* on high density polyethylene (HDPE) surfaces was demonstrated by Karunasagar *et al.,* (2007). This provides an additional advantage for bacteriophages in shrimp larval health management. However, considering that the host range for selected phages was 65–70 percent, and also considering the possibility that bacterial strains may develop resistance to bacteriophages, phage therapy with a consortium of phages would be necessary to ensure effectiveness with unknown strains causing disease outbreaks.

Biocontrol of pathogens using bacteriophages has already been commercialized in agriculture, aquaculture and in the food industry. Agriphage is a commercial product from OmniLytics Inc. to combat *Xanthomonas campestris* pv. *vesicatoria*, which causes bacterial spot disease in peppers and tomatoes, and *Pseudomonas syringae* pv. *tomato*, which causes bacterial speck disease in tomatoes. It has been registered by the United States Environmental Protection Agency in 2005 (US Environmental Protection Agency, 2010). OmnilLytics Inc. has also received US FDA approval for use of bacteriophages against *Escherichia coli* and *Salmonella* in live animals before slaughtering (Garcia *et al.*, 2010). In 2007, the US FDA approved Listex P100 from EBI Biosafety as GRAS (Generally Recognised As Safe) for use in all foods in which *Listeria* could be a risk (EBI Food Safety, 2010). ListShield from Intralytix has received US FDA and US EPA approval for use in ready-to-eat foods for control of *L. monocytogenes* (Intralytix, 2010). In India, Mangalore Biotech Laboratory (2010) has a commercial product for control of luminous bacteria in shrimp hatcheries.

CONCLUSIONS

Microbial diseases have been causing serious economic losses for the aquaculture industry, but there is a need to minimize the use of antimicrobials in aquaculture to avoid problems of residues and antibiotic resistance in food-associated bacteria. A number of alternatives are available for managing the health of animals in aquaculture systems. Implementation of good aquaculture practices would to a large extent reduce the health risk for animals in aquaculture systems. Tools like vaccines, immunostimulants and probiotics could be used for prevention of diseases depending on aquaculture systems and the risks involved. Biocontrol agents like bacteriophages could be used for both prevention as well as control in case of outbreaks. It could be recommended that the farmers use a risk based approach and decide on appropriate preventive or control strategies.

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Market based standards and certification schemes in the international seafood industry

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A ROUGH GUIDE TO STANDARDS DEVELOPMENT

The business of Assurance and the desire to produce Standards is nothing new, but the concept as we recognize it, as it relates to seafood in the current market, could be traced back to the development of the Blue Angel logo in Germany in the early 1970s. The Blue Angel logo was a collaborative response, including the United Nations Environment Programme, to the desire to note best environmental practice on a range of goods and services (not foods).

Elsewhere in the world standards began to develop through different processes and with different objectives and for specific markets and goods. The one common objective may have been to assure customers of a certain set of criteria, and thus to respond to market requirements. This allowed product differentiation, promotion of character and credentials, and the building of brands promoting different customer experiences. The development of standards eventually led to the need for Standards for Standards – how could we know what is credible and what is not – how can we have processes of Standards development through which stakeholders could engage or challenge?

In the environmental and social standards arena the International Social and Environmental Accreditation and Labelling (ISEAL) Alliance stepped to the fore.

The ISEAL Alliance is the global association for social and environmental standards systems. ISEAL members are leaders in the field, committed to creating solid and credible standards systems. Working with established and emerging voluntary standards initiatives, ISEAL develops guidance and facilitates coordinated efforts to ensure their effectiveness and credibility and scale up their impacts. ISEAL's Codes of Good Practice are international reference documents for credible social and environmental standards. Compliance is a membership condition.

Within the seafood sector the Marine Stewardship Council (MSC) is a member of ISEAL, and the WWF Aquaculture Dialogues are Associate members, following the Code of Conduct for their Dialogues. The Code is strong on stakeholder engagement, comment processes and management of objections which, while being arguably appropriate, has led to some criticism around its tendency to create a lengthy process that is less able to nimbly respond to market needs.

The Food and Agriculture Organisation of the United Nations (FAO) responded to member requests to develop guidelines on what credible and appropriate standards should look like and produced the FAO Guidelines for the Ecolabelling of Fish and Fishery Products. The FAO Guidelines for the Certification of Aquaculture is nearing completion. These complement the Guidelines for the Responsible Management of Fisheries and likewise Shrimp Farming.

One of the problems of the FAO Guidelines is that people like the 'brand' of FAO and use it to buy themselves credibility. Additionally the guidelines are not themselves standards, but are often communicated as such, and also while claims are made that standards conform to FAO guidelines there is no audit process, so it is open to abuse. These challenges are not the fault of FAO or the guidelines, but something that needs to be addressed by the sector. It may be that all claims are valid, but some process of validation seems appropriate.

Increasingly we are seeing the non-governmental organization (NGO) sector 'judge' what they deem to be appropriate, or not, in the business of assurance and standards. This can be very effective in terms of being heard as this group has great agency in the press, and often with consumers. Retailers themselves are creating their own sets of standards, beyond their procurement policies. This is often to provide them with a personal proposition or to fill a need in the market place for a standard not yet developed. In many cases the retailers will engage with a respected NGO to develop their standards.

BRAND AND LABELS

A subject that is often overlooked is that of the brand and proposition of the standard setter's organisation. This may be less important in Business to Business operations, but in Business to Consumer, i.e. where the label is likely to be put on a pack, then selecting the standard/label can be a significant corporate decision.

- Is the proposition of the standard/label the same as our own?
- Is the label owner going to protect its brand and reputation, or potentially damage mine?
- Is it 'safe' for me to partner with this brand?
- What will this brand say about me?

NGO endorsement can be a part of this brand positioning, but it is worth remembering, for each party, that partnering brands can bring strength and demonstration of behaviour, but it always carries risk.

At this juncture it is useful to clarify something that may well be very obvious but causes much confusion through miscommunication: **Standards and Certification are not the same thing.**

Most of the discussion is centred on the business of standards and standard setting, while certification is the process of auditing to those standards. It is strongly believed that the two bodies should not be housed under the same roof. There are, of course, standards for the process of certification itself. The International Standards Organisation (ISO) provide ISO 65. Additionally, most standard setters are non-profit making organisations. The certification bodies are the organisations who are making money from the process. Making money in itself is a necessity of the Western economic model. However, it can be a barrier to poorer countries being able to participate in audits. Further, it can drive better or worse standards of audit and these aspects of the business of assurance need careful attention.

THE MAIN INTERNATIONAL SEAFOOD STANDARDS BODIES TODAY

Table 1 lays out those standard setting bodies that are active in the international markets associated with European and US supply at the current time. It is interesting to note that they do not all work to the same codes of standard setting or governance.

TABLE 1
Standard setting organisations in farmed and capture fisheries sectors

Farmed Fish	Organic Farmed Fish	Wild Caught Fish
Aquaculture Stewardship Council / WWF Dialogues	Soil Association	Marine Stewardship Council
Global Aquaculture Alliance	Naturland	International Fishmeal and Fish Oil Organisation
Global Gap	Global Gap	Global Gap
Friends of the Sea	Friends of the Sea	Friends of the Sea
	Agriculture Biologique	

In farmed standards, salmon and shrimp are probably the two most "needed' standards by the retail sector, with tilapia and striped catfish (Pangasius) being the next most important. The need is being driven by consumption and markets. However, the biggest controversy comes around the business of feedstuffs. There is no complete answer at the current time. The International Fishmeal and Fish Oil Organisation (IFFO) has developed a code for Responsible Fish Meal and Oil, while Friends of the Sea have certified a number of forage fisheries. The world's biggest fishery, Peruvian anchoveta, is currently under assessment for certification to Marine Stewardship Council (MSC) standards. However, there remain a number of ethical issues around forage fisheries; should fish be fed to farmed species to create a higher value product, mostly destined for Western markets? Or should that fish be sold locally for human consumption? And should there be fishing from the bottom of the food chain in simple ecosystems, such as, Antarctic krill? It is unlikely that such questions will be answered to everyone's satisfaction, but it is interesting to consider some different views to those frequently heard, for example:

- Selling forage fisheries overseas; what are the positive effects on the economy of a significant forage fisheries versus selling that fish in to domestic markets – or whether it is a consumer issue, rather than a fisheries issue, to supply a wealthy domestic market with nutritional supplements?
- Fishing of krill for rich Western markets; should those who oppose such activity focus on the fishery or the market as a route to change?
- Whose responsibility is it to decide whether a fishery should have access to certification?

THE BIG PICTURE

Already we have a sense of the complexity of the landscape of standards in the seafood sector, but here's the reality – people in the seafood sector see and hear all the noise around these standards every day, because it is their business sector, but in the bigger picture the industry is just one of many.

Consumers worldwide are faced with assurance propositions in every direction – standards and claims around different products. This is particularly true in Europe and North America, but increasingly elsewhere including in Asia's growing consumer market.

In the EU alone there are around 260 consumer-facing retail ecolabels covering timber, eggs, meat, fruit, vegetables, organic produce, fair trade products, coffee, tea, local and regional products, safe, healthy, brand propositions that look like labels and labels that make propositions.

The retail food shelves are a complex mass of information and as consumers we have to make some very quick calculations on what to purchase.

Value, quality, pack size, there are many contributing factors in making that quick decision. If consumers are concerned with the provenance and ethics of their product choice they may consider the pack claims or the labels, or they may 'hand over' responsibility to the retailer, or chef. Alternatively, when faced with many labels, consumers may decide that any label will do; suggesting that an indication of intention is good enough for now. So for the retailer or chef there is an opportunity to ensure that their proposition persuades those who want to handover responsibility to trust in their choices. For those who manage labels, there is an opportunity to create a brand and proposition for the label that is easily recognizable and generally understood. So, if there is concern about the credibility of those labels, if reassurance is needed that the quality and depth of that proposition is meaningful, then the question is how to ensure there is a framework for the creation of credible standards that lead to the label?

COMMODITY, PROCESS OR ISSUE LABELS

There is another layer of complexity that is often overlooked. This generic term, ecolabels, covers a wide range of issues and concerns. Some labels address issues such as social or animal welfare (RSPCA[1], Freedom Food, Free Range produce), while others may address production processes such as organic, or guaranteeing quality or safety. Also, some labels, such as the Fairtrade label, may apply to a wide range of products, which helps to raise recognition because of the frequency and range of use of the label, while other labels address only one commodity, making recognition and understanding harder to embed.

The MSC is the only assurance scheme seeking to set environmental standards for a wild harvested food commodity i.e. for a management process and ecosystem impact rather than a production process and environmental management.

If might be considered that, given the apparent complexity and breadth of the assurance business, there is a need to keep the seafood propositions as simple and consistent as possible to make it a clear, easily recognizable and understood option to buy responsibly produced seafood.

THE NEXT GENERATION OF ASSURANCE?

Layer and layer of complexity is added to this weighty landscape as new standards are invented when people feel that what's on offer doesn't quite do what they want to say. At the same time producers are facing increasing numbers of audits as buyers seek a portfolio of assurances to meet different consumer concerns or to protect their own reputation and positioning.

It is estimated to cost around US$20 million per year to run a robust international standards operation (not including audit fees), so each time standards are developed or redeveloped there is overlap that adds extra costs being added to the value chain.

Dr Alan Knight[2], a global thought leader on the business of Standards remarks "we have over 250 ecolabels and over 50 product stewardship bodies, the question is, is this too many? If yes, how many do we need and what makes them all different and needed? If no, how many more before there are too many? There needs to be a new look at product stewardship".

As such new conversations are considering what the future for assurance might look like, and these conversations include challenging the scope of industry responsibility – what should be included and how – carbon, water, energy?

Knight also suggests "As well as building schemes around specific product sectors and issues, we should take a toolbox approach, assessing the issues where product stewardship is part of the solution and designing the optimum portfolio of schemes without unnecessary duplication or gaps. In other words, a tool box approach. I suggest that there needs to be around 30 tools".

For example, if we look at a region of ocean, we might be able to have some collective assurance process that says "yes" the area is appropriately managed and

[1] Royal Society for the Prevention of Cruelty to Animals.

[2] www.dralanknight.com/my-papers

all boats reach minimum levels of health, safety, legality, etc. thus all fisheries in this area reach level A. Individual fisheries might then elect to reach level B, they might wish to differentiate and add value to their product and so on. Ways of adding value might be around the (currently) less regulated areas such as energy or water usage or Animal welfare. These ideas might start to build a cross product way of demonstrating assurance that builds on areas of common audit and equivalence across different commodity or propositional sectors, sharing costs and data, without using different consumer facing labels.

In conversations on standards a common question is what do we mean by ”good” – what is good enough? Should the market decide that, or should NGOs decide that, or should producers, or scientists, or consumers … that’s where the stakeholder engagement and public consultation comes in, and likely there will need to be a compromise; but as a starting point 3 tiers may be appropriate:

Good	The Law – Legislation and Government – not Bad;
Better	More than the Law and required governance; Adding value through additional propositions; Suits ‘choice editing’;
Best	High end, niche markets, informed consumers, reinforcing specific brand and reputational propositions.

Noticing and pulling together on touch points across the ‘tool box’ and across the Good/Better/Best could be a useful and cost saving exercise; working on areas of equivalence, collaborative problem solving, sharing science, might all be smart ways forward for global standard setters – and it should be remembered that this isn’t just fish, this is across the portfolio.

Building on “good”, it is interesting to notice how this often become an internality – good becomes the norm. Twenty years ago many people might not have believed the level of nutritional information there is on a pack today, but it is there, so why not also expect the same level of information for other issues such as sustainability i.e. good becoming the norm?

The next tiers start to offer the differentiation. It may be worth asking at this point if standard setters, B2B or B2C, are service providers, and not product producers in their own right? This positioning and distinction between service providers, product producer (label), NGO and position taker – may be very important to the bigger strategic proposition.

Service Provider; provides a service that allows the investors in that value chain to demonstrate their values and practices.

Product owner; may sit with the Service Provider role in offering a product which has a brand value of its own which enhances that of the ‘purchasing’ organisation. Organic labels might, for example, enhance the value proposition of the farmer or retailer investing in them. In this case it will be important for the product owner, which is likely to be a label, to manage the brand, reputation and awareness of its product.

NGO and position taker; potentially a question that needs debating. Can a standard setter, who manages and provides that set of standards, be an active NGO and position taker in the community? How does that affect their role as a product owner? How do they then find their scope of responsibility around their offering?

Something that feels important is to reposition the business of assurance and labels as a positive. All too often they are talked about, certainly in the seafood industry, in an apologetic way and used to defend production. It would be more productive to find ways in which “good” is the norm, the governance level, while “better” standards are positioned more positively and celebrate the achievements of the production investment. Standards would no longer be used to defend, but to protect and demonstrate.

PRIVATE STANDARDS OR GOVERNMENT LEGISLATION?

An often contested subject is whether private standards or government legislation work best in ensuring a responsible industry?

It could be argued that all governments have a responsibility to ensure good practice with minimum negative environmental impact in the seafood sector, be that fisheries or farms. If a government is brave enough, and has time, to create robust legislation pertaining to management of fisheries and aquaculture it may be seen as the beginning of norming the process. An example outside of seafood standards could be European safety standards. Government regulation tends to opt for ensuring safe and appropriate – the 'not bad' level and a danger is that it may be weakened to ensure that the less capable parts of the industry are not economically marginalized. Further the process may be clouded or stalled by other, non-related policies, economies or elections, possibly even traded for other legislative matters.

Independent standard setters can have the advantage of being able to respond more nimbly to markets, industry needs and changing landscapes. Further they might have better prospects of longevity. Independent standard setters can also position their offering related to the "good", "better", "best" propositions, and strategically and positively work on reputational issues. However, all these positive opportunities are likely to be quickly overshadowed if the standard setter's governance or conduct is in question.

WHERE DO WE GO FROM HERE?

There are a number of conversations regarding the future for the business of assurance in progress at the current time. Are standards driving positive change? What are our expectations of the suite of standards available? Within the world of seafood in particular there are challenges from science, and NGOs in particular, regarding how to address these questions and what is an appropriate framework for the future? Can the standard setters be seen as brand partners?

It is important to remember that seafood standards sit amongst a much wider portfolio of consumer propositions. Whilst there is a real need to address the industry challenges, it is probably important to do so in a way that still sits cohesively in the bigger picture.

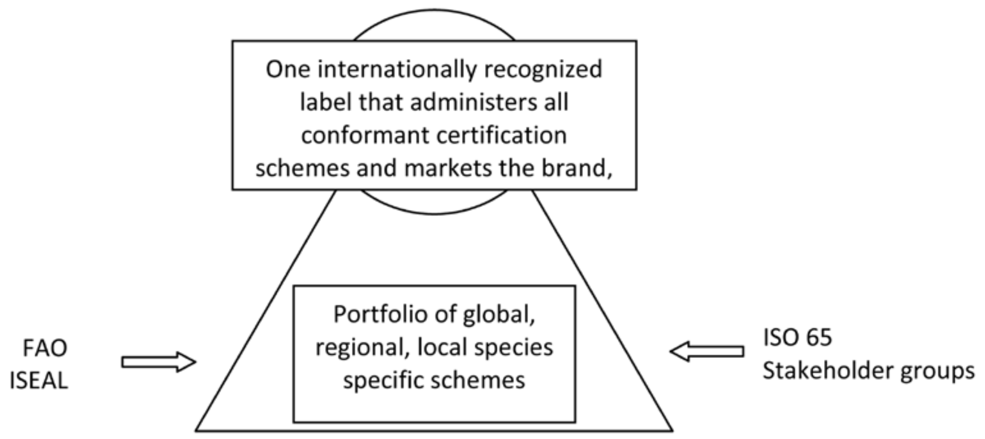
Perhaps it is time for the international standard setters to come together in a collaborative fashion to agree on areas of equivalence, to notice gaps in the standards offerings, to work on mutual positioning where it is appropriate and yet retain their unique qualities and create a smart forum to explore development of the sector.

Perhaps it would be helpful for the retailers and processors to create a framework that outlines their expectations of standard setters. The framework might suggest which codes the standards must adhere to, the reputational management the standards must work for and requirement that the standard setters must work together on areas of equivalence and development.

Ultimately it might be that through a set of frameworks as described above a mutual label of recognition for seafood might emerge – as per the pyramid model shown in Figure 1. There are, of course, the challenges of retaining 'market share' and identity.

This model might also enable one standard setter to offer two products, something for regional/local markets, and something for international markets, but through one process.

FIGURE 1
Where is the business of assurance heading?



There is much energy to find good, meaningful solutions that can benefit the environment, the socio economic needs, and more. It is bound to be uncomfortable sometimes, and there will not always be agreement immediately, but it is important that all sectors of the community work collaboratively for a common cause; in protection of the planet, communities, systems and good practice – and not in defence of a label.

A 2009 Ernst & Young report puts "Reputational Management" in the top ten business risks for global business; Reputational risk is related to corporate governance, business ethics and crisis management, and the time to develop plans and procedures is not when the world is knocking at the door looking for answers.

Education and training in seafood science and technology

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SUMMARY
Aquatic resources and seafood are a vital part of the economy, social life and tradition of many coastal countries and communities. Because of the projected human population increase to about 9 billion in 2050, and considering that the feed conversion ratio (FCR) of aquatic foods is much less than that of land animals, aquatic foods promise to deliver a significant portion of the future protein requirements more economically. To prepare for this future requires an integrated approach to use the existing aquatic resources optimally, and to develop new resources, mainly through aquaculture and to drive in efficiencies through optimal processing. The requirements for the advances in knowledge in this area, the needs of the industry to hire knowledgeable and trained workers in new areas and to replace existing workers lost through attrition in existing areas, and the need to provide well trained regulatory and political decision makers demands that the training and education in Seafood Science and Technology (SST) should be emphasised, developed, and coordinated.

IMPORTANCE OF AQUATIC RESOURCES IN THE WORLD
The world population is projected to grow from 6.1 billion in 2000 to 8.9 billion (medium estimate) in 2050 (Figure 1), increasing by 47 percent (United Nations, 2004). The high estimate is 10.6 billion by 2050. The low estimate predicts a population crash that may stabilize at 2 billion in 2300 (not shown in the figure).

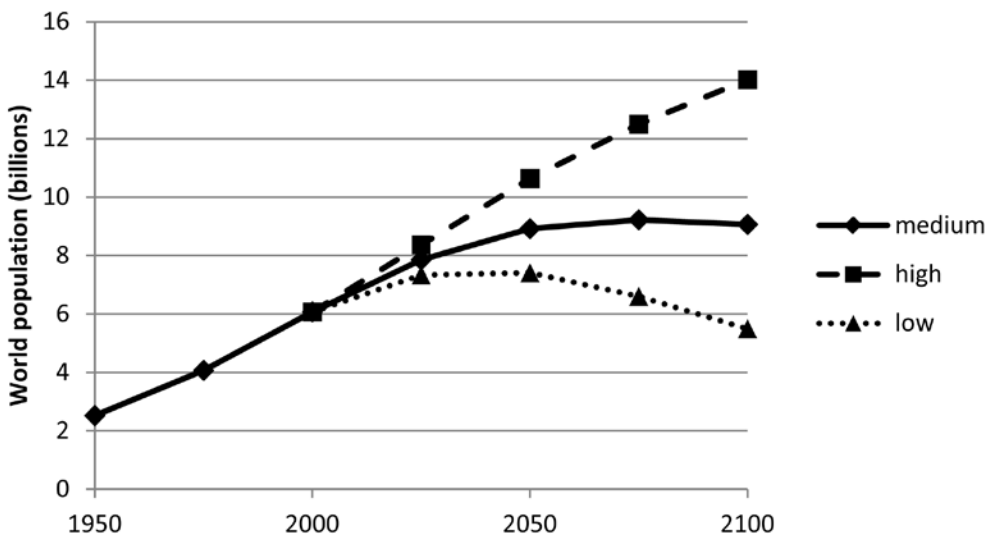
The protein requirements of the human population are also increasing dramatically. Aquatic foods constitute a significant portion of the protein supply in the world (Figure 2).

The FCR is an important consideration in animal protein production. Animals that have a low FCR are considered efficient users of feed. Sheep and cattle need more than 8 kg of feed to put on 1 kg of live weight. The US pork industry claims to have an FCR of 3.4–3.6. Poultry has a feed conversion ratio of 2 to 4. Farm raised Atlantic salmon has a very good FCR, about 1.2, and tilapia, typically, 1.6 to 1.8 (Steinfeld *et al.*, 2006). Therefore, as resources become scarce and competition for resources increases, it is more sustainable to rely on aquatic resources for animal protein requirements of the growing world population.

In the last 30 years, world seafood production from aquaculture has expanded rapidly and now supplies about half of world seafood demand (FAO, 2008) (Figure 3).

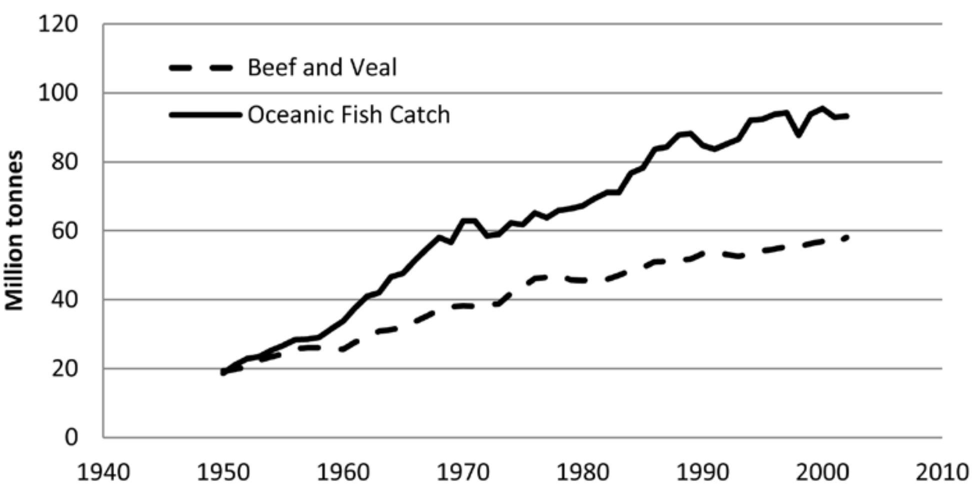
The aquaculture of tilapia alone (a freshwater, herbivorous fish) in China yielded 1 million metric tonnes in 2005. The upward trend in aquaculture production is expected to continue. The United Nations Food and Agriculture Organization (FAO) estimated that an additional 40 million tonnes of aquatic food will be required by 2030 over and above the 2005 worldwide consumption of 105.5 million tonnes (FAO, 2008). FAO projects that most of this increase will be supplied by aquaculture. Even if wild stocks are managed at sustainable levels, they will be unable to meet the increasing worldwide demand for seafood (FAO, 2008; The World Bank 2007).

FIGURE 1
Projected world population growth



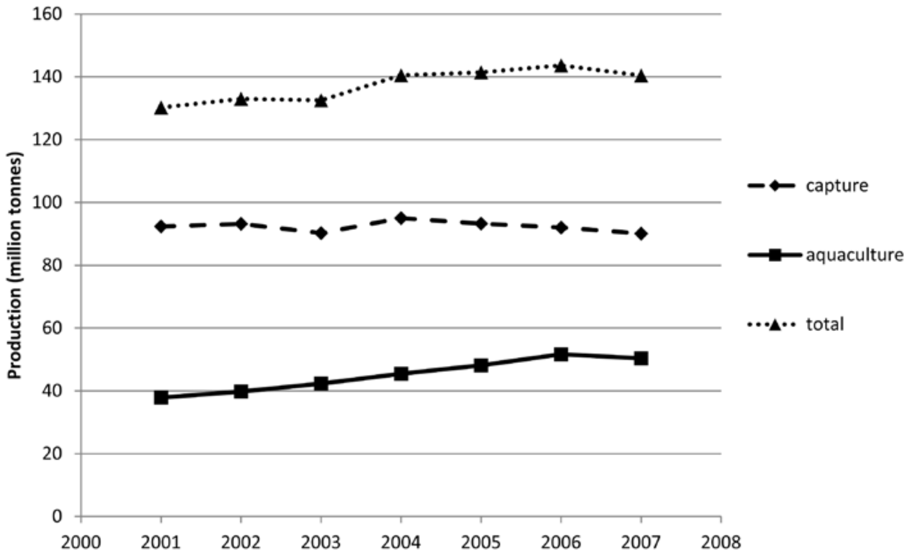
Source: United Nations, 2004.

FIGURE 2
Comparison of protein supply: aquatic foods versus beef and veal



Source: Compiled by Earth Policy Institute from FAO, 1948-1985 World Crop and Livestock Statistics. Rome, 1987; FAO, FAOSTAT Statistics Database, at apps.fao.org, updated 24 May 2004; FAO, FISHSTAT Plus, electronic database, viewed 13 August 2004.

FIGURE 3
Total fisheries production from capture fisheries and aquaculture



EDUCATION NEEDS IN SEAFOOD SCIENCE AND TECHNOLOGY

Increasingly, knowledge and know-how are becoming critical for success in any area in general, and in Seafood Science and Technology (SST) in particular.

Education, training, and continuous updating of information are the keys to provide qualified and capable workers and management for the industry as well as know-how and industrial experience, educators capable of research and generation of new knowledge and innovation in academia, and knowledgeable and forward-looking regulators and political leaders. Finally, consumers need to be knowledgeable and educated to make the proper personal and public choices. The unique properties, supply forms, demand and culture of aquatic foods requires some specialization. For other commodities, this is also the case. For example, milk and milk products require a specialization focused in the dairy area. In the United States, the per capita consumption of dairy foods is 250 kg/yr. There are several Dairy Science Departments in universities in the United States. Red meat per capita consumption is 43.8 kg/yr, and there are Meat Science/Animal Science Departments in several universities. Similarly, the per capita consumption of chickens and ducks amounts to about 50 kg/yr, and there are Poultry Science Departments. The per capita consumption of wine in the United States is about 7.7 litres/yr which amounts to about 8 kg. There are Enology Departments in various universities. Aquatic foods in the United States are consumed at about 8 kg/person/yr. However, there is no Seafood Science and Technology Department in the United States. Furthermore, the topic of SST is not covered in Fisheries and Aquaculture Departments, and in Food Science Departments there may be one of two courses offered for SST.

If aquatic foods are important now, and are to become even more important in the future, the question that needs to be answered is the following: "Where will the qualified workers, researchers and leaders in SST come from? Who will replace the current people in SST? Where is the pipeline?"

The pipeline concept is important, because in the United States, even in communities where aquatic foods contribute significantly to the economy and culture, working in this area is not considered as "glamorous" by young people, and therefore is not targeted as a career. Therefore, the continuum from middle school to PhD needs to be considered (see Appendix 1).

FIGURE 4
Requirements for education and training for seafood science and technology industry needs

The requirements for the industry regarding qualified people and educational levels are shown in Figure 4.

Typically, "research" universities concentrate on the top part of this pyramid, with the goal of producing PhDs. Generally, undergraduate education, or "skills training" is not a high priority in these universities. This type of training is expected to come from, for example, 2 year colleges (or community colleges). However, curricula targeting SST is either very scarce or non-existent in the United States at this level as well.

STAKEHOLDER SURVEYS

A flexible and multi-tier education and training system requires close interaction with stakeholders and feedback regarding the "quality and efficacy" of education. This can be achieved by conducting periodic surveys regarding educational requirements of the stakeholders (industry, academia, and regulatory agencies), follow-up interviews with graduates, alumni and their employers, and by periodic regional and international meetings to assess changing educational and training needs.

In 2009, a survey was conducted in Alaska to assess the educational needs and perspectives of the SST sector. This was done during two professional meetings by questionnaires. The summary of the results are shown in Tables 1 and 2.

TABLE 1
Industry survey regarding SST education. N=70. Question: "What level of Seafood Science and Technology education is required by your business/community? Check all that apply"

Response (%)	Education level
16	No high school diploma or GED
18	High school diploma or GED
13	One-year certificate given by community college
17	Two-years community college degree (e.g. A.A., or A.S, or A.A.S.
23	Four-years university undergraduate degree (e.g. B.A. or B.S.)
13	University graduate degree (M.Sc. or Ph.D.)

TABLE 2
Industry survey (2009): Summary of the relative importance of knowledge areas in SST and the expected institutions to deliver the education

		High	Medium	Low
Seafood Chemistry	High school	10	12	15
	Community college	16	18	5
	University	31	10	1
Seafood Microbiology	High school	11	12	15
	Community college	18	18	3
	University	31	10	2
Seafood Processing	High school	8	14	16
	Community college	17	18	3
	University	25	13	3
Inter / national Regulation	High school	4	10	22
	Community college	13	20	7
	University	26	12	2
HACCP	High school	9	12	15
	Community college	28	9	5
	University	35	4	2
Seafood Marketing	High school	4	14	21
	Community college	13	24	4
	University	24	16	4
Seafood Economics	High school	4	15	19
	Community college	12	22	5
	University	27	13	3

There are interesting results displayed in Table 1. About 47 percent of the jobs did not require a college education. This needs to be understood by academia. In fact, only about 13 percent of the jobs required an advanced degree (MSc. or PhD.). The question that emerges then is who will supply the education and training for the levels that are considered as adequate by the industry?

In Table 2, a significant number of the people surveyed were of the opinion that community colleges could deliver the level of education and training in many areas of SST, although for every area, university training received the highest response.

These types of surveys need to be performed periodically by educational institutions to adjust their training to the requirements of the “real world”. Without this interaction, the curricula become irrelevant.

CURRICULUM CONTENTS AT VARIOUS LEVELS

By its nature, SST requires many fields from various disciplines. These include biology (aquaculture), ecology (sustainability), fishing related (gear, methods), food science (safety, nutritional quality), processing and preserving (efficient resource utilization), economics (management of business, people, projects, resources), and international regulations. This makes it challenging to develop a curriculum to cover most of these subjects, yet go into some depth in them in the limited time available.

Some examples will be given from different institutions that specialize in SST education.

SST education in Turkey

Despite that the total aquatic resources are a fraction of the United States production, there are many universities in Turkey that have formal undergraduate and graduate education in the area of SST (Figure 5).

Aquaculture is an area that is rapidly increasing both in size and in capability in Turkey. Ege University in Izmir, on the Western shore of Turkey, has both undergraduate and graduate education in the area of fisheries in general, and aquatic foods processing in particular. In Appendix 2, the curriculum of a 4 year undergraduate degree is provided. During the first three years, students take common courses. In the fourth year, allowance is made for a specialization into one of three sub-topics: Marine and Freshwater Science and Technology, Fisheries and Seafood Processing Technology, and Aquaculture. It is interesting to see the diversity of the courses taken during the first three years, from basic sciences to engineering mechanics to navigation to coastal zone management. This is quite different from the traditional fisheries curricula available in the United States.

FIGURE 5
Location of universities in Turkey that have formal SST education

SST education in Taiwan

Another example of a formal tertiary level education in SST is from Taiwan. The nation has a Marine University and a Department of Seafood in this university. In Appendix 3, the curricula for both an undergraduate degree and a Master's degree are provided.

Fisheries training at the United Nations University

Finally, a 6 month course in Fisheries Training is offered by the United Nations University, and is held in Iceland. The brief contents are given in Appendix 4. It is interesting to note the breadth of the curriculum, from aquaculture to fisheries policy. This demonstrates the multi-disciplinary nature of the SST field.

EDUCATION IN THE NEW ERA

With the increasing breadth of the subjects and the multi-disciplinary nature of SST, with the increasing internationalization of the seafood trade, and with increasing pressures placed on both capture fisheries and on aquaculture, the educational needs of the near future will not be the same as that of the past.

New generation of students

How do you attract the best and the brightest students to SST? Why not medicine and law? Why should a top-tier student select SST as a career? This can be accomplished by introducing the SST area to the student as early as possible (maybe in middle school), and keep emphasizing the positive, exciting and real nature of SST throughout the student's educational life. This requires courses, materials and access to SST at many levels and throughout the year. At the same time, with increasing automation and emphasis on technology, uniform quality and safety, a typical career in SST will be elevated from the "slime line", where people cut fish all day, into one where automated machines are designed, built, maintained and operated.

The new generation of students is also "born with electronic equipment". It is natural for them to "play with" cell phones, IPods, computers, etc. They are much more tech-savvy than the last generation. This lends itself well to the concept of "student-centric education", where the mode of learning is not for a student to sit passively in class and have the material delivered to him/her, but to actively learn himself/herself at his/her own pace, at a time chosen by him/her. The new generation may therefore be more amenable to benefit from distance learning, web-based content, asynchronous education, and more reliance on technology in the delivery of information and training.

Finally, with more coordination and international cooperation, the internationalisation of the curriculum may be closer to reality. A good example of this is the European Masters in Food Engineering. Students spend a semester each in several countries, in a university with expertise in a given area, e.g. refrigeration or heat transfer. While visiting the country, they also have extensive visits to food plants and companies, and interact with the faculty and students in the host university. They then return to their home institution to perform their research, and graduate with a diploma of European Masters in Food Engineering. A similar model could be adapted to the SST education. For example, students from South and Central American countries could earn their advanced degree in SST by taking courses from several universities in different countries. The same could be done for Southeast Asian countries.

Finally, with the leadership of, for example FAO, a wiki-type content bank could be developed in many fields of SST, and made available worldwide. This may be designed as a multi-level set of courses, going from short and simple courses to semester-long and in-depth courses. The advantage of this approach would be to use the best expertise in any given area worldwide, and therefore have overall course material of a quality that cannot be achieved by one institution alone.

The advantage of this flexible approach is to be able to address the emerging issues in a timely manner. For example, traceability, allergens, energy requirements for capture, aquaculture and processing operations, and supply chain globalization can be addressed, and knowledge and content can be rapidly updated as more becomes known in a particular area.

RECOMMENDATIONS

In the United States:

- Develop a formal and comprehensive SST curriculum from K–12 to PhD. For this, a national summit needs to be convened for SST.
- Strengthen cooperation with stakeholders. With the leadership of, for example USDA, develop methods and mechanisms for easy, continuous and meaningful contact among stakeholders in the SST area.
- Develop innovative, flexible, technology-based content and materials.
- Develop international/regional linkages and cooperation for a more international curriculum.

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Appendices

Appendix 1. Proposed curricula at different levels in the education continuum

1) K–12 Courses in SST
   - The seafood we eat. An integrated view of the ecosystem approach to the aquatic resources, with human impact. The importance of seafood in the diet: proteins and omega-3 fatty acids. Safety of seafoods. International perspectives.
   - Visits to hatcheries
   - Visits to aquaculture facilities
   - Visits to fishing boats
   - Visits to seafood processing plants
   - Visits to supermarket seafood sections, and other aquatic resource areas
   - Summer internships in seafood companies
   - Development of course materials (text-based and Web-based), videos, and testing tools.
   - Elementary, middle and high school teacher education programs

2) Two Year College Courses in SST
   - Refrigeration systems
   - Marine engines
   - Economics of fishing
   - Seafood marketing
   - Aquaculture/hatchery operations
   - Preservation of seafood (canning, freezing, smoking, drying, etc.)
   - Value added seafood products (roe, by-products, fish oils, fish feed, skins, etc.)
   - HACCP and safety of seafood
   - National and International regulations

3) Undergraduate Courses in SST
   - Introduction to Aquatic Resources Utilization
   - International Seafood Marketing Systems
   - Vertical integration of production, processing and marketing systems
   - Seafood biochemistry and quality
   - Seafood Processing and Preservation 1
   - Seafood Processing and Preservation 2
   - Seafood Composition and Analysis
   - Internship, in Plants, NGOs
   - Seafood microbiology
   - National and International regulations

4) Graduate Courses in SST
   - Advanced seafood chemistry
   - Advanced by-product value-adding
   - Advanced processing technologies
   - Advanced seafood microbiology
   - Advanced international seafood economics and marketing
   - Advanced techniques of sensory and instrumental quality evaluation

5) Continuing Education/Short Courses

The list can be very extensive, spanning the range from skills improvement (e.g. refrigeration systems) to economic strengthening (e.g. direct marketing) to HACCP regulations.

6) Local Collaboration Networks

Institutions (educational, regulatory, and industrial/professional) should form networks with the purpose of communication, collaboration, and planning. There can be periodic reviews of curricula, advertisement of positions, needs assessment for the sector, and political support. Distance delivery of seafood related information, as well as workforce development can be addressed within these networks.

7) National Collaboration Network in the U.S.

Universities
Sea Grant
NOAA/NMFS
USDA/FDA
Seafood NGOs (e.g. NFI, ASMI, AFDF, Seafood Products Association, Pacific Seafood Processors Association)
Seafood Companies

8) International Collaboration Network

A successful model of international cooperation in university education is the "European Masters" program in Food Engineering. Students from the European Union visit different universities every semester, and benefit from the expertise of that institution in a particular area. They complete their research in their home institutions during the last two semesters.

In the SST curriculum, FAO, European Union, Norway, Iceland, Japan, China, Chile, Brazil, etc. can be included, in a gradual fashion, and depending on the needs for integration within a sub-category such as warm water shellfish.

- Course equivalencies
- Student exchange
- Faculty exchange
- Research cooperation
- Distance education
- Yearly teacher education meetings
- Periodic conferences

Appendix 2. Example undergraduate curriculum from Ege University, Izmir, Turkey. Curriculum for fisheries courses. The first three years are common. The fourth year allows for specialization. The seafood processing option is shown here for the 4th year.

www.erasmus.ege.edu.tr/dersListele.php?lang=en&birimKod=7

FACULTY OF FISHERIES COURSE STRUCTURE						
Code	Course Name	Total hours per Week			ECTS Credits	Type of Course
		Lecture	Practical Classes	Lab Work		
Year 1	**Semester 1**					
101	Turkish Language	2	0	0	2	Required
102	Principles of Atatürk, Recent Turkish History I	2	0	0	2	Required
106	Chemistry	2	0	2	4	Required
107	Physics	2	0	0	3	Required
108	Mathematics	2	0	0	3	Required
112	Biology (Botany)	2	0	1	3	Required
116	Technical Drawing	1	2	0	2	Required
119	Oceanography	2	0	0	3	Required
128	Introduction to Computer–I	2	2	0	3	Required
135	General Fishing Technique	2	0	0	3	Required
137	Marine Meteorology	2	0	0	2	Required
Total					30	
Year 1	**Semester 2**					
114	Mathematics II	1	0	0	2	Required
120	Biology (Zoology)	2	0	2	3	Required
122	Limnology	2	0	2	3	Required
124	Diving Techniques and First Aid	1	2	0	3	Required
125	General Economy	2	0	0	3	Required
129	Introduction to Computer–II	2	2	0	3	Required
134	Materials Science	1	2	0	3	Required
136	Basic Principles of Aquaculture	2	0	0	3	Required
138	Ecology	2	2	0	3	Required
92	Turkish Language	2	0	0	2	Required
94	Principles of Atatürk and Recent Turkish History II	2	0	0	2	Required
Total					30	
Year 2	**Semester 1**					
207	Statistics	2	0	0	4	Required
211	Genetic	2	0	0	3	Required
239	Fish Morphology and Anatomy	2	2	0	4	Required
240	General Microbiology	2	2	0	4	Required
244	Maritime Law	1	0	0	2	Required
245	Engineering Mechanics and Structural Analysis	2	2	0	4	Required
246	Measurement Science	2	0	0	3	Required
248	Aquatic Invertebrates	2	2	0	3	Required
259	Reading in Foreign Language	1	0	0	1	Required
261	Professional Technical English–I	2	0	0	2	Required
Total					30	

Year 2	**Semester 2**					
249	Navigation	2	1	0	3	Required
250	Marine Biology	2	0	0	3	Required
251	Nutritional Biochemistry	2	0	1	4	Required
253	Fishing Equipment and Gears	2	0	1	3	Required
254	Water Quality	1	0	2	3	Required
255	Fisheries Law	1	0	0	2	Required
256	Marine Fishes	2	0	1	4	Required
257	Planktonology	2	1	0	3	Required
258	Fluid Mechanics	2	0	0	3	Required
260	Professional Technical English–II	2	0	0	2	Required
Total					30	
Year 3	**Semester 1**					
301	Fishing Vessels	2	1	0	3.5	Required
303	Seafood Chemistry I	2	0	1	3.5	Required
305	Aquarium Technology	2	1	0	3.5	Required
307	Electricity and Electronics	2	0	0	3	Required
309	Business Economics	2	0	0	3	Required
311	Inland-water Fishes	2	0	1	3.5	Required
313	Seafood Processing Technology–I	2	0	1	3.5	Required
315	Freshwater Fish Culture	2	0	1	3.5	Required
317	Coastal Zone Usage and Management	2	0	0	3	Required
Total					30	
Year 3	**Semester 2**					
302	Fishing Net Making and Design Techniques	2	1	0	3	Required
304	Invertebrate Culture	2	0	1	3.5	Required
306	Plankton Culture	2	0	1	3	Required
308	Fish Feeds and Fish Feed Technology	2	0	1	3	Required
310	Marine Fish Culture	2	0	1	3.5	Required
312	Project Techniques	2	1	0	3.5	Required
314	Seafood Microbiology–I	2	0	1	3	Required
316	Fish Diseases	2	0	1	3.5	Required
318	Fish Physiology	2	0	0	3	Required
319	Practice	0	0	0	0	Required
320	Foreign Language for Occupational Life	1	0	0	1	Required
Total					30	
Year 4	**Semester 1**					
	Marine and Freshwater Sciences and Technology Programme – Autumn				30	Option
	Fisheries and Seafood Processing Technology Programme – Autumn				30	Option
	Aquaculture Programme – Autumn				30	Option
Total					30	
	Fisheries and Seafood Processing Technology Programme OPTION – AUTUMN					
03435	Fish Catching Methods	2	1	0	4	Required
03437	Seafood Processing Technology–II	2	0	1	4	Required
03439	Fishing Mechanization	2	1	0	4	Required
03441	Thesis	0	4	0	8	Required
03442	Seafood Microbiology–I	2	0	1	3	Elective
03443	Project Preparation Technique in Fisheries	2	1	0	3	Elective
03445	Fisheries Oceanography	2	1	0	3	Elective
03447	Seamanship	2	1	0	3	Elective
03449	Safety at Sea/on Board	2	1	0	3	Elective
03451	Cold Storage in Fisheries Products	2	1	0	3	Elective
03455	Processing Technology of Aquatic Plants	2	0	1	4	Elective
03459	Fisheries Economics	2	0	0	3	Elective
03463	Sports Fishing	2	1	0	3	Elective
03465	Population Dynamics in Fisheries–I	2	1	0	3	Required
03467	Modelling and Monitoring of Fishing	2	1	0	3	Elective
03461	Fishing Operations and Management	2	1	0	3	Elective

Year 4	**Semester 2**					
	Marine and Freshwater Sciences and Technology Programme – Spring				30	Option
	Fisheries and Seafood Processing Technology Programme – Spring				30	Option
	Aquaculture Programme – Spring				30	Option
Total					30	
	Fisheries and Seafood Processing Technology Programme OPTION – SPRING					
03434	Quality Control of Seafood	2	1	0	3	Required
03436	Fisheries Engineering	2	1	0	3	Required
03438	Fish Behaviour	2	0	0	3	Required
03440	Coastal Fisheries Management	2	1	0	3	Required
03444	Packaging Technique in Fisheries Products	2	0	0	3	Elective
03446	Artificial Reef Applications in Fisheries	2	1	0	3	Elective
03448	Live Fish Capture and Transportation	2	1	0	4	Elective
03450	Communication at Sea	2	1	0	3	Elective
03452	Population Dynamics in Fisheries–II	2	1	0	3	Elective
03453	Seafood Chemistry–II	2	0	1	4	Elective
03454	Storage of Cargoes	2	0	0	2	Elective
03456	Computer Usage in Fishing Gear Design	2	0	0	2	Elective
03457	Scuba Diving	2	1	0	4	Elective
03458	Population Genetics in Fisheries	2	0	0	3	Elective
03462	By Product Technology in Fisheries	2	1	0	3	Elective
03464	Tuna Fishing and Technology	2	1	0	3	Elective

Appendix 3. National Kaohsiung Marine University, Department of Seafood Science, Taiwan. Both the undergraduate and the Master's degree courses are given.

Undergraduate Course

April, 2004 revised

1st Year					
1st Semester			2nd Semester		
Required/ Optional	Subject	Credit	Required/ Optional	Subject	Credit
Required	Biology	2	Required	Organic Chemistry	2
Required	Chemistry	3	Required	The Experiment of Physics	1
Required	The Experiment of Chemistry	1	Required	Physics	3
Required	Physics	3	Required	The Experiment of Chemistry	1
Required	Calculus	1	Required		
Optional	Introduction on Fisheries	2	Optional	Basic Economics	2
Optional	The Experiment of Biology	1	Optional		
Total Credits for Required Subjects: 10			**Total Credits for Required Subjects: 7**		
2nd Year					
1st Semester			2nd Semester		
Required/ Optional	Subject	Credit	Required/ Optional	Subject	Credit
Required	Organic Chemistry	2	Required	Microbiology	3
Required	Analytical Chemistry	2	Required	The Experiment of Microbiology	1
Required	Analytical Chemistry Laboratory	1	Required	Analytical Chemistry	2
Required	Biostatistics	2	Required	Analytical Chemistry Laboratory	1
Required	Food Processing(1)	2	Required	Biochemistry	3
Required	Experiment in Food Processing(1)	1	Required	Biostatistics	2
			Required	Food Processing(2)	2
			Required	Experiment in Food Processing(2)	1
Optional	Business Administration	2	Optional	Principles and Practice of Electrical Engineering	2
Total Credits for Required Subjects: 10			**Total Credits for Required Subjects: 15**		

3rd Year					
1st Semester			2nd Semester		
Required/ Optional	Subject	Credit	Required/ Optional	Subject	Credit
Required	Microbiology	3	Required	Food chemistry	2
Required	The Experiment of Microbiology	1	Required	Nutrition	2
Required	Biochemistry	3	Required	Science of Food Refrigeration	3
Required	Biochemistry Laboratory	1	Required	Food Engineering	3
Required	Food chemistry	2	Required	Food Analysis, Inspection and Experiment	1
Required	Quality Control	2			
Required	Freeze Engineering	3			
Required	Fish Processing Technology	2			
Required	Seafood Manufacture Practice	1			
Required	Food Sanitation and Law	2			
Optional	Food Microbiology	3	Optional	Instrumental Analysis	2
			Optional	Diet Therapy	3
			Optional	Food Additives	2
			Optional	Experiments	1
			Optional	Food Microbiology Experiment	1
Total Credits for Required Subjects: 20			**Total Credits for Required Subjects: 11**		
4th Year					
1st Semester			2nd Semester		
Required/ Optional	Subject	Credit	Required/ Optional	Subject	Credit
Required	Fisheries Chemistry	3	Required	Food Sanitation and Law	2
Required	Introduction of Molecular Biology	2	Required	Seminar	2
Required	Seminar	2	Required	Factory Management	2
Optional	Nutrition of Life Cycle	2	Optional	Toxicology	2
Optional	The New Products Development	2	Optional	Introduction Life Science	2
Optional	Supermarket operation and Management	2	Optional	Nutrition Physiology	2
Optional	Meat, Dairy and Egg processing Technology	2	Optional	Introductory Immunology	2
Optional	Biotechnology		Optional	Food and Beverage Management	2
Total Credits for Required Subjects: 9			**Total Credits for Required Subjects: 6**		

(1) The required for graduation shall be at least 85 credits except the Dissertation subject.

Master Degree Course
October, 2005 revised

Required		Optional	
Subject	**Credit**	**Subject**	**Credit**
Seminar	4	Topic in Seafood Science	2
Master Thesis	6	Topic in Protein Chemistry	2
		Topic in Molecular Carbohydrate Biology	2
		Topic in Lipid Chemistry	2
		Topic in Flavour Chemistry	2
		Marine Natural Product Chemistry	2
		Topic in Nucleic Acid Chemistry	2
		Enzyme Chemistry	2
		Seafood Toxicology	2
		Topic in Seafood Biotechnology	2
		Instrumental Analysis and Experiment	2
		Topic in Science of Food Refrigeration	2
		Advanced Food Chemistry	2
		Topic in Rapid Analysis of Food Microbiology	2
		High Pressured Food	2
		Experimental Designs	2
		Cellular Biology	2
		Bioinformatics	2
		Chemical Carcinogenesis	2
		Topic in Food Processing	2
		Methodology for Food Science Research	2
Total Credits for Required Subjects: 10		**Total Credits for Required Subjects: 2**	

Appendix 4. United Nations University – Fisheries Training Programme in Iceland. Structure of 6 month training programme.

Orientation (1 week)

Introductory Course (5 weeks)

Fellows should gain a holistic view of fisheries and be able to put their own fisheries into an international and / or regional perspective

Fisheries Planning and Policy (6 weeks)	Resource Assessment (6 weeks)	Quality Management of Fish Handling and Processing (6 weeks)	Fishing Technology (6 weeks)	Sustainable Aquaculture (6 weeks)	Management of Fisheries Companies (6 weeks)
Resource economics Project planning Policy formulation Management systems	Fish biology Biological indicators Sampling strategy Survey design Environmental aspects of fisheries Assessment models Data poor situations Precautionary approach Catch rules	Fish processing HACCP Storage / shelf–life Quality indicators Sanitation Traceability Packaging Product development	Fishing methods Fish behaviour Gear design Gear material Gear selectivity Gear research Vessel structure	Aquaculture systems Aquaculture research Site selection Species selection EIA Planning and monitoring Operational aspects	Operational planning Strategic planning Business planning Human resources Raw materials Economic analysis Accounting Fleet management

Project Proposal

↓

Research Project – Final Report and Presentation (14 weeks)

Must address important issues in Fellows home country

European Union regulations governing fish and fishery products

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INTRODUCTION

Following the publication of the EC White paper on Food Safety in 2000 and the subsequent review of the European food hygiene regulations, new rules came into force in 2006 that were accompanied by Regulations on the organisation of official food controls. The approach taken in the legislation is to separate aspects of food hygiene from animal health and it aims to remove any duplication and inconsistencies that could cause difficulties both for businesses and regulatory authorities. The legislation focuses on the need to protect public health in a way that is effective, proportionate and based on risk.

A key aspect of the legislation is that all food and feed business operators, from farmers and processors to retailers and caterers, have principal responsibility for ensuring that food placed on the European Union (EU) market meets the required food safety standards. The Regulations apply at every stage in the food chain, including primary production (i.e. farming, fishing and aquaculture) in line with the "farm to fork" approach to food safety in the EU. The Regulations apply to food businesses that catch and farm fish and crustaceans, that farm and handle live bivalve molluscs and those handling and processing fish and fishery products. The responsibilities of food business operators are clearly set out in the Regulations, which also require appropriate own-checks to be carried out and include the taking of samples by industry to ensure the marketing of safe fishery products. The Regulations also include provisions for guides to good practice to be developed by industry with support from other stakeholders. The legislation applies directly to food businesses and the affect the legislation will have depends on the size and nature of the business.

The Food Hygiene Regulations constitute a complementary set of rules to harmonise EU food safety measures. They are a suite of several Regulations including Regulation EC/852/2004, which lays down the general hygiene requirements for all food business operators and Regulation EC/853/2004, which lays down additional specific requirements for food businesses dealing with foods of animal origin, including live bivalve molluscs and fishery products. Regulation EC/854/2004 lays down the official controls for foods of animal origin. The basis for the Regulations is set down by the General Food Law Regulation EC/178/2002, which provides a framework to ensure a coherent approach in the development of food legislation. The General Food Law Regulation set down definitions, principles and obligations covering all stages of food and feed production and distribution. Other related recent legislation includes the Regulation on microbiological criteria for foodstuffs, the Regulation on official feed and food controls and the Regulation on feed hygiene.

EXPORTING FISH AND FISHERY PRODUCTS TO THE EUROPEAN UNION MARKET

For all food and feed, including fish and fishery products, the general principle is that the product meets or is equivalent to EU standards. In addition, under current arrangements, in order to export products of animal origin to the EU, the country must be approved for the relevant commodity and the products must originate in an establishment that is approved to export to the EU. Lists are maintained at EU level of countries and establishments from which imports are permitted. Countries and establishments approved in this manner are commonly referred to as "listed". In order to be listed, the third country concerned must provide guarantees that exports to the EU meet, or are equivalent to, the standards prescribed in the relevant EU legislation.

All consignments of live animals and products of animal origin introduced into the territory of the EU must be presented at an EU approved border inspection post (BIP) to undergo mandatory veterinary checks and must be accompanied by a health certificate.

FOOD BUSINESS REGISTRATION AND APPROVAL

Under the current legislation, primary producers involved in fishing and aquaculture must be registered with the national competent authority as food business operators. Operators will need to register before starting at a new location and will also need to inform the competent authority of the nature of their business. Furthermore, establishments must be approved if they handle products of animal origin for which specific hygiene conditions are laid down in EU legislation. This includes those handling live bivalve molluscs and fishery products. Premises in compliance with the new regulations should be issued an approval number that must accompany all shipment documentation.

IDENTIFICATION MARKING AND LABELLING

A food business must apply its identification mark before the product leaves the establishment of production. This mark must be legible, indelible and clearly visible for inspection. It must show the name or two letter code of the country (for example IE for Ireland) and the approval number of the premises.

PRIMARY PRODUCTION

The farm-to-fork approach of EU legislation embraces primary production and the general principles of food hygiene legislation now extend to all operations engaged in the primary production of food.

'Primary production' is defined as the production, rearing or growing of primary products up to and including harvesting, hunting, fishing, milking and all stages of animal production prior to slaughter. Fish and shellfish farmers are primary producers and are required to follow good farming practices and manage their operations as set out in Annex 1 of Regulation EC/852/2004. Primary producers are not required to implement a HACCP system.

In practical terms, the requirements for primary producers amount to the application of good standards of basic hygiene. Primary producers must ensure that hazards are acceptably controlled and that they comply with existing legislation. Under the new rules, primary producers need to take steps, for example, to:

- prevent contamination arising from water, soil, feed, veterinary products, waste, etc;
- keep animals (fish) intended to be placed on the market for human consumption clean;
- take account of results from tests relevant to animal and human health;
- use medicines appropriately.

The requirements for food business operators in Annex 1 of Regulation EC/852/2004 also apply to certain associated activities that include:

- the transport, handling and storage of primary products at the place of production, where their nature has not been substantially altered;
- the transport of live animals, where this is necessary;
- transport, from the place of production to an establishment, of products of plant origin, fishery products and wild game, where their nature has not been substantially altered.

GENERAL REQUIREMENTS FOR FOOD BUSINESS OPERATORS

Food business operators, such as fish processors and manufacturers, carrying out activities other than primary production have to comply with the general hygiene provisions of Annex II of Regulation EC/852/2004. This Annex sets out the details for the hygiene requirements for:

- food premises, including outside areas and sites;
- transport conditions;
- equipment;
- food waste;
- water supply;
- personal hygiene of persons in contact with food;
- food;
- wrapping and packaging;
- heat treatment, which may be used to process certain foodstuffs;
- training of food workers.

REQUIREMENTS FOR LIVE BIVALVE MOLLUSCS AND FISHERY PRODUCTS

Food business operators making or handling products of animal origin must also comply with the provisions of Regulation EC/853/2004 and, where appropriate, certain specific rules concerning microbiological criteria for foodstuffs, temperature control and compliance with the cold chain, and sampling and analysis requirements. Foods of animal origin include live bivalve molluscs and fishery products. The provisions of Regulation EC/853/2004 apply to unprocessed and processed products of animal origin, but do not apply to composite foods i.e. foods containing both products of plant origin and processed products of animal origin.

Regulation EC/854/2004 lays down specific rules for the organisation of official controls on products of animal origin intended for human consumption. This Regulation supplements Regulation EC/852/2004 on hygiene of foodstuffs and Regulation EC/853/2004 on specific hygiene rules for foodstuffs of animal origin. This official control regulation gives details of the controls to be carried out on live bivalve molluscs and fishery products.

Details in relation to the approval of establishments and the withdrawal of approval, if serious deficiencies are identified on the part of the food business operator, are also set out in Regulation EC/854/2004. Food business operators must provide authorised officers with all assistance needed to carry out the controls, notably as regards access to premises and the presentation of documentation or records. The official controls include audits of good hygiene practices and HACCP principles, as well as specific controls that have requirements determined by sector (including live bivalve molluscs and fishery products).

Regulation EC/2074/2005 sets out implementing measures for certain provisions of the hygiene regulations that apply to fish and fishery products. This Regulation includes rules for fishery products encompassing detection of parasites, maximum levels for total volatile nitrogen for certain species as a determinant of “fitness”, testing methods for marine biotoxins and labelling with cooking instructions for specified fish.

LIVE BIVALVE MOLLUSCS

Harvested live bivalve molluscs intended for human consumption must comply with high health standards applicable at all stages of the production chain. With the exception of the provisions on purification, the rules also apply to live echinoderms, tunicates and marine gastropods. The Regulations include provisions for cooperation by food business operators in the classification system. Approved dispatch and purification centres are now required to establish a HACCP system as explained below.

Regulation EC/853/2004 specifies requirements for the following areas:

- production of live bivalve molluscs from Class A, B or C production areas;
- harvesting of molluscs and their transport to a dispatch or purification centre, relaying area or processing plant;
- relaying of molluscs in approved areas under optimal conditions of traceability and purification;
- essential equipment and hygiene conditions in dispatch and purification centres;
- health standards applicable to live bivalve molluscs: freshness and viability; microbiological criteria, evaluation of the presence of marine biotoxins and harmful substances in relation to the permissible daily intake;
- health marking, wrapping, labelling, storage and transport of live bivalve molluscs;
- rules applicable to scallops harvested outside classified areas.

Regulation EC/854/2004 specifies that new production areas require a sanitary survey and the establishment of a representative sampling programme based on the sanitary survey data.

FISHERY PRODUCTS

Specific requirements for fish and fishery products cover the following elements:

- equipment and facilities on fishing vessels, factory vessels and freezer vessels: areas for receiving products taken on board, work and storage areas, refrigeration and freezing installations, pumping of waste and disinfection;
- hygiene on board fishing vessels, factory vessels and freezer vessels: cleanliness, protection from any form of contamination, washing with water and cold treatment;
- conditions of hygiene during and after the landing of fishery products: protection against any form of contamination, equipment used, auction and wholesale markets;
- fresh and frozen products, mechanically separated fish flesh, parasites harmful to human health (visual examination), and cooked crustaceans and molluscs;
- processed fishery products;
- health standards applicable to fishery products: evaluation of the presence of substances and toxins harmful to human health;
- wrapping, packaging, storage and transport of fishery products.

RECORD KEEPING

Under current regulations, food business operators will be required to keep records relevant to food safety, including:

- the nature and origin of animal/fish feed (if used);
- any veterinary products administered and their withdrawal dates (if used);
- any occurrence of disease that may affect food safety;
- the results of any analyses carried out;
- the health status of the animals prior to slaughter.

HAZARD ANALYSIS CRITICAL CONTROL POINT (HACCP)

EU hygiene regulations legislation requires food business operators (except primary producers) to put in place, implement and maintain a permanent procedure, or procedures, based on the principles of HACCP. The requirements take a risk based approach and can be applied flexibly in all food businesses regardless of the size or nature of the business.

TRAINING

Food business operators are responsible for ensuring that food handlers have received adequate instruction and/or training in food hygiene to enable them to handle food safely. Training should be appropriate to the tasks of staff in a particular food business and be appropriate for the work to be carried out. Training can be achieved in different ways. These include in-house training, the organisation of training courses, information campaigns from professional organisations or from regulatory authorities, guides to good practice, etc. With regard to HACCP training for staff in small businesses, it must be kept in mind that such training should be proportionate to the size and the nature of the business and should relate to the way that HACCP is applied in the food business. If guides to good practice for hygiene and for the application of HACCP principles are used, training should aim to make staff familiar with the content of such guides.

MICROBIOLOGICAL CRITERIA OF FOODSTUFFS

The Microbiological Criteria for Foodstuffs Regulation (Regulation EC/2073/2005) includes limits for certain micro-organisms in specified foodstuffs and sets down limits for food safety criteria and process hygiene criteria. The Regulation sets down the *E. coli* and *Salmonella* limits for placing live bivalve molluscs and live echinoderms, tunicates and gastropods on the market for human consumption. It also sets down limits for fishery products for the following:

- *Listeria monocytogenes* for ready-to-eat food;
- *Salmonella* for cooked crustaceans and molluscan shellfish;
- Histamine for species associated with high amounts of histidine;
- *E. coli* and coagulase-positive staphylococci for shelled and shucked products of cooked crustaceans and molluscan shellfish (process criteria).

Regulation EC/2073/2005 contains detailed controls encompassing sampling and analysis requirements. It is structured so it can be applied flexibly in all food businesses, regardless of their type or size. Food business operators should apply the criteria within the framework of procedures based on HACCP principles. The criteria can be used by food business operators to validate and verify their food safety management procedures and when assessing the acceptability of foodstuffs, or their manufacturing, handling and distribution processes.

TRACEABILITY AND WITHDRAWAL OF FOOD PRODUCTS

In accordance with Regulation EC/178/2002, food business operators must set up traceability systems and procedures for ingredients, foodstuffs and, where appropriate, animals used for food production. Similarly, where a food business operator identifies that a foodstuff presents a serious risk to health, they shall immediately withdraw that foodstuff from the market and inform users and the relevant Competent Authority.

ANIMAL HEALTH RULES

Council Directive 2002/99/EC lays down the animal health rules governing the production, processing, distribution and introduction of products of animal origin for human consumption.

Council Directive 2006/88/EC covers health requirements for aquaculture animals and controls of certain fish and bivalve diseases. The main aim of the Directive is to raise standards of aquaculture health throughout the EU and to control the spread of disease while maintaining freedom for trade. While the focus of the Directive is primarily aquaculture production businesses, the Directive also contains provisions relating to stocked fisheries for angling, installations which keep fish but do not intend to market them, smaller scale farmers who produce directly for human consumption and fish kept for ornamental purposes.

ANIMAL AND FISH FEEDS

Regulation EC/183/2005 lays down the requirements for feed hygiene. It ensures that feed safety is considered at all stages of the feed chain that may have an impact on feed and food safety. The regulation requires the compulsory registration of all feed business establishments and the approval of those operators that are involved in the production of certain feed additives, pre-mixtures and compound feeding stuff. It also requires the application of good hygiene practice at all levels of feed production and the introduction of the Hazard Analysis Critical Control Point (HACCP) principles for the feed business operators other than at the level of primary production.

The regulation provides for a European Union framework for guides to good practice in feed production and such a guide has been published.

RESIDUE MONITORING PROGRAMMES

European regulations include requirements for a wide range of food monitoring for residues of veterinary drugs, pesticides and chemical contaminants. Much of the legislation in this area refers to food animal production, which would include farmed fish but does not always specifically refer to fish. Complex EU regulations exist for the approval of the use of medicines for prevention or cure of animal diseases; for setting maximum residue limits (MRLs) of permitted animal remedies and to check for compliance with these MRLs; for monitoring of levels of banned animal remedies; for monitoring levels of pesticides in farmed fish and for monitoring levels of chemical contaminants such as dioxins and heavy metals in fishery products. Methods of analyses and sampling plans for use during monitoring are also included in the regulations.

The key regulations comprise of Directive 2001/82/EC, which stipulates that veterinary medicinal products can only be authorised or used in food producing animals if pharmacologically active substances contained therein have been assessed as safe according to Regulation (EC) No 470/2009. The latter regulation establishes MRLs for these products. Directive 1996/23/EC on residues monitoring contains specific requirements for the control of pharmacologically active substances that may be used as veterinary medicinal products in food animal production. This includes primarily sampling and investigation procedures, requirements on the documentation of use, indication for sanctions in case of non-compliance, requirements for targeted investigations and for the establishment and reporting of monitoring programmes. Directive 1996/22/EC prohibits the use of certain substances in food producing animals.

Sampling frequencies for testing farmed fish for compliance with EU regulations have been published by the European Commission. For those countries where fish and fishery products from any farm are eligible to be exported to the EU, the proportion of animals sampled should be taken relative to the annual national production figures. The minimum number of samples to be collected each year for veterinary drug residue analysis must be at least 1 per 100 tonnes of annual production.

Food contaminants are substances that may be present in fish and fishery products because of environmental contamination, cultivation practices or production processes. If present above certain levels, these substances can pose a threat to human health. EU regulations ensure that food placed on the market is safe to eat and does not contain contaminants at levels which could threaten human health. Maximum levels for certain contaminants in fishery products are set in Regulation EC/1881/2006. This regulation includes MRLs for heavy metals such as lead, cadmium and mercury and for dioxins and polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbons (PAH). Methods for sampling and analysis of fish for the control of the levels of lead, cadmium, mercury and benzo-α-pyrene are included in Regulation EC/333/2007 and for dioxin and dioxin-like PCBs in Regulation EC/1883/2006.

INSPECTIONS AND AUDITING TO VERIFY COMPLIANCE

The European Commission has three main instruments at its disposal to ensure that EU legislation is properly implemented and enforced. It verifies the transposition by Member States of EU legislation into national laws and analyses reports received from Member States and third countries on the application of aspects of EU legislation, such as national residue programmes and animal feed controls. Additionally it carries out inspections in Member States and third countries to check the implementation and enforcement of EU legislation by national competent authorities.

The control function at EU level is mainly the responsibility of the Food and Veterinary Office (FVO), a directorate of DG Health and Consumers. Its main task is to carry out on-the-spot inspections to evaluate national control systems, to report on its findings and to follow up on the action taken by national competent authorities in response to its reports. The European Commission has published guidance for the importation of fish and fishery products from third countries.

CONCLUSION

The EU integrated approach to food safety aims to assure a high level of food safety, animal health, animal welfare and plant health within the European Union through coherent farm-to-table measures and adequate monitoring, while ensuring the effective functioning of the internal market. Regulations, Directives and Decisions in the food safety control area are regularly updated and published by the European Commission on their web site.

United States Food and Drug Administration. Safety requirements for seafood

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INTRODUCTION

The United States Food and Drug Administration (FDA) has tremendous responsibilities for the regulation of food (including seafood), drugs, medical devices, biologics and toxic chemicals. It is estimated that FDA regulation affects over 50 percent of the economy of the United States. In recent years there has been an exponential increase in imports because of the expansion of the globalized economy. More and more of the commodities under FDA regulation are manufactured in foreign countries. This has placed a significant burden on the agency to adequately ensure the safety of these products. Moreover, the FDA budget was significantly reduced from 2001 to 2008. Although the agency received a significant increase in resources from Congress in 2009 the effect has been to further limit their ability to respond to the challenge of ensuring the safety of all the commodities they have authority to regulate including seafood.

THE CHALLENGE FOR SEAFOOD REGULATION

Seafood safety has been controversial and high profile in the United States media for at least two decades. There is a constant barrage of questions arising about the safety of imported seafood. Federal agencies, including FDA and NOAA Fisheries have struggled to respond to them. The most recent example is concern over aquaculture drug residues from China, Vietnam and Thailand. FDA responded to this in 2007 by imposing import alert 16–131 on farm-raised products from China that produced shrimp, tilapia, dace and eels for the United States market. These products were implicated as having drug residues that included Nitrofurans (a highly effective antibiotic), Malachite Green (a substance used to control fungal infections in fish that is also a potent carcinogen), and Chloramphenicol (a mild antibiotic used to control a variety of fish diseases). An import alert effectively shifts the burden of proof for imports from FDA to the importer. Therefore, every shipment of aquacultured fish and fishery products had to be analyzed for drug residues and found to be free of them before the shipment is allowed on the United States market. Because more than 700 firms were affected, this became a significant burden to the FDA Import Operations. Moreover, at the same time melamine which is an industrial chemical that can imitate protein content in foods was found in a wide variety of food products from China including seafood. This caused further concern in the media and on the consuming public.

Food safety scares heightens the day-to-day burden of FDA who must spend precious resources answering questions from the media, Congress, consumer groups and the public at large. Besides the budget problems that FDA experienced through most of 2000s there were other factors that made the agency's job more difficult relative to seafood regulation. First, the volume of imported seafood increased significantly since the year 2000. Seafood is the world's largest traded product on the basis of value. In 2009 FDA reviewed between 900 000 and 1 000 000 entries of fish and fishery products from abroad. These shipments are manufactured in at least 13 000 and as many as 20 000 processing facilities abroad. Inspecting all of the products and facilities is a gargantuan task without considering other food (and medical) commodities. In light of the reduced resources available to the agency is has become increasingly difficult to inspect the ever-increasing volume of products and processing facilities.

Second, FDA adopted the Seafood HACCP[1] Regulation (21 CFR 123) in December 1997. This regulation required preventive control measures for food safety in addition to existing sanitation, food handling and employee hygiene requirements. This approach has proven to be largely successful in preventing food safety problems in seafood. However, the principles are complicated and the system is not easily managed. In order to be successful any regulatory HACCP control scheme needs to rely on a readily available scientific basis that creates appropriate guidance to the industry and the FDA field, and also rely on trained staff from investigators to consumer safety officers, who must continually refine their skills and apply HACCP principles to novel situations. By 2005, resource restrictions had limited FDA's ability to create guidance and perform an expert evaluation of HACCP controls because they could not replace staff lost to retirements and resignations. The quality of both investigations and reviews were affected.

Third, the legal and scientific review process that might lead to regulatory action became more complicated and burdensome in the mid 2000s. Generally, when a serious food safety violation is encountered the investigator will note it on FDA form 483 List of Observations. The investigator will write a detailed report and submit it to his or her supervisor and to a local district compliance officer. The compliance officer will determine if the evidence warrants legal action and submits the regulatory package to the Center for Food Safety and Applied Nutrition Office of Compliance and Office of Food Safety for legal and scientific review respectively. If the Office of Compliance agrees that the evidence is sound and the Office of Food Safety agrees that the science is correct then a decision is made whether the Office of General Council (OGC) in the Office of the Commissioner should be sent the case for possible enforcement action. In 2004 it was decided that all cases should be sent to OGC. This slowed the compliance process down considerably and because there was a six month deadline for completion many cases have not met the deadline.

Fourth, some new priorities have been added to FDA's burden. There are a couple of examples. There has been a recent Government Accountability Office (GAO) study that concluded that FDA should be more vigorous in enforcing firms to comply with economic fraud provisions in the Food, Drug and Cosmetic Act and regulations. GAO specifically wants economic integrity provisions to be part of the Seafood HACCP Regulation which currently only requires food safety controls. Another example is the Food Allergen Labeling and Consumer Protection Act (FALCO). This law requires clear labelling for any potential allergen that may be in a food product. For seafood FDA has decided to require this to be part of a seafood HACCP plan that increases the investigator's and reviewer's time requirement.

[1] Hazard Analysis Critical Control Point.

RESPONSE TO THE CHALLENGE

The Federal Government and the States have responded to this challenge in several ways. First, the United States Congress has proposed several legislative packages for adoption. Second, the Food Safety Enhancement Act introduced by Representative John Dingell (D-Michigan) and the Food Safety Modernization Act introduced by Senator Richard Durban (D-Illinois) have a reasonable chance for passage and consideration by President Obama. They are described below along with other significant legislation that is not likely to be adopted. FDA in 2007 published the Food Protection Plan that outlines the agency's thinking about how to address these food safety issues. Finally, other Federal agencies and the States have also responded to the potential food safety problems the United States may be experiencing.

Congressional Activity

Major Legislation Congressional Record Service Summaries

H.R. 2749 Food Safety Enhancement Act
Lead Sponsor: Representative John Dingell (D-Michigan)
Introduced: 6/8/2009
Last Action: 8/3/2009 Referred to Senate committee. Status: Received in the Senate and read twice and referred to the Committee on Health, Education, Labor, and Pensions.
House Reports: 111–234

Committee Summary of House passed bill (July 2009):

1. Creates an up-to-date registry of all food facilities serving American consumers: Requires all facilities operating within the United States or importing food to the United States to register with FDA annually.
2. Generates resources to support FDA oversight of food safety: Requires payment of an annual registration fee of US$500 per facility that would generate revenue for food safety activities at FDA.
3. Prevents food safety problems before they occur: Requires foreign and domestic food facilities to have safety plans in place to identify and mitigate hazards. Safety plans and food facility records would be subject to review by FDA inspectors and third-party certifiers.
4. Increases inspections: Sets a minimum inspection frequency for foreign and domestic facilities. Each high risk facility would be inspected at least once every six to 12 months; each low risk facility would be inspected at least once every 18 months to three years; and each warehouse would be inspected at least once every five years. Refusing, impeding or delaying an inspection is prohibited.
5. Requires food imports to demonstrate safety: Directs the Secretary to require certain foreign food to be certified as meeting all United States food safety requirements by third parties accredited by FDA.
6. Creates fast-track import process for food meeting security standards: Directs FDA to develop voluntary safety and security guidelines for imported foods. Importers meeting the guidelines would receive expedited processing.
7. Requires safety plans for fresh produce and certain other raw agricultural commodities: Directs FDA, in coordination with United States Department of Agriculture, to issue regulations for ensuring the safe production and harvesting of fruits and vegetables and other raw agricultural commodities, like mushrooms.

8. Improves traceability: Significantly expands FDA traceback capabilities in the event of a food borne illness outbreak. Directs the Secretary to issue traceback regulations that enable the Secretary to identify the history of the food in as short a timeframe as practicable, but no longer than two business days. Prior to issuing such regulations, the Secretary would be required to conduct a feasibility study, public meetings, and one or more pilot projects before issuing traceback regulations. There are exemptions for certain foods or facilities.
9. Requires country-of-origin labelling: Requires all processed food labels to indicate the country in which final processing occurred. Requires country-of-origin labelling for all produce.
10. Expands laboratory testing capacity: Requires FDA to establish a program to recognize laboratory accreditation bodies and to accept test results only from duly accredited laboratories. Requires laboratories to send certain test results directly to FDA. Provides strong, flexible enforcement tools: Provides FDA new authority to issue mandatory recalls of tainted foods. Strengthens penalties imposed on food facilities that fail to comply with safety requirements.
11. Advances the science of food safety: Directs the Secretary to enhance food borne illness surveillance systems to improve the collection, analysis, reporting, and usefulness of data on food borne illnesses. Requires the Secretary to provide greater coordination between federal, state, and local agencies.
12. Enhances transparency of GRAS program: Requires posting on FDA's Web site of documentation submitted to FDA in support of a "generally recognized as safe" (GRAS) notification.
13. Allows FDA to charge a fee to cover the cost of additional inspections of facilities that previously committed a violation of the Act related to food.
14. Infant Formula: Requires that a manufacturer of a new infant formula submit certain safety information regarding new ingredients. Grants FDA additional time to review such new ingredients.
15. Enhances FDA's ability to administratively detain tainted food products.
16. Allows the Secretary to prohibit or restrict movement of harmful food products: If the Secretary, after consultation with the Governor, determines there is credible evidence that an article of food presents an imminent threat, he or she would be able to prohibit or restrict movement of food in a state or portion of a state.
17. Creates an up-to-date registry of importers: Requires all importers of foods to register with FDA annually and pay a registration fee.
18. Requires unique identification numbers for facilities and importers: To improve the accuracy of data and the ability of FDA to more quickly identify involved parties in a crisis situation, creates unique identification numbers for all food facilities and importers.
19. Provides protection for whistleblowers that bring attention to important safety information: Prohibits entities regulated by FDA from discriminating against an employee in retaliation for assisting in any investigation regarding any conduct which the employee reasonably believes constitutes a violation of federal law.
20. Grants FDA new authority to subpoena records related to possible violations.

S.510 FDA Food Safety Modernization Act
Lead Sponsor: Senator Richard Durbin (D-Illinois)
Introduced: 3/3/2009
Last Action: 12/18/2009 Placed on Senate Legislative Calendar under General Orders. Calendar No. 247.

Official CRS Summary of Introduced version:
FDA Food Safety Modernization Act – Amends the Federal Food, Drug, and Cosmetic Act (FFDCA) to expand the authority of the Secretary of Health and Human Services (the Secretary) to regulate food, including by authorizing the Secretary to suspend the registration of a food facility.
Requires each food facility to evaluate hazards and implement preventive controls.
Directs the Secretary to assess and collect fees related to:

1. Food facility reinspection;
2. Food recalls; and
3. The voluntary qualified importer program.

Requires the Secretary and the Secretary of Agriculture to prepare the National Agriculture and Food Defense Strategy.

Requires the Secretary to:

1. Identify preventive programs and practices to promote the safety and security of food;
2. Promulgate regulations on sanitary food transportation practices;
3. Develop a policy to manage the risk of food allergy and anaphylaxis in schools and early childhood education programs;
4. Allocate inspection resources based on the risk profile of food facilities or food;
5. Recognize bodies that accredit food testing laboratories; and
6. Improve the capacity of the Secretary to track and trace raw agricultural commodities.

Requires the Secretary, acting through the Director of the Centers for Disease Control and Prevention (CDC), to enhance food borne illness surveillance systems.

Authorizes the Secretary to order an immediate cessation of distribution, or a recall, of food.

Requires the Administrator of the Environmental Protection Agency (EPA) to assist state, local, and tribal governments in preparing for, assessing, decontaminating, and recovering from an agriculture or food emergency.

Provides for:

1. Foreign supplier verification activities;
2. A voluntary qualified importer program; and
3. The inspection of foreign facilities registered to import food.

Minor legislation summarized by NOAA Legislative Affairs

Number	Name	Sponsor	Details
S92	Imported Seafood Safety Enhancement Act of 2009	Senator David Vitter (R–LA)	A bill to ensure the safety of seafood and seafood products being imported into the United States. Authorizes the FDA to refuse entry of products that do not meet United States food safety regulatory requirements and establishes marking and notification procedures in the event product is refused (so that the refused product is not re-shipped through another port of entry.)
HR875	Food Safety Modernization Act of 2009	Representative Rosa DeLauro (D CT–3)	The bill reorganizes several inspection services and agencies within the Department of Health and Human Services (HHS) Food and Drug Administration (FDA) to establish a new Food Safety Administration within HHS. Part of the "consolidation" of food safety agencies within HHS includes moving all of the personnel and assets of the NOAA Seafood Inspection Program into the newly formed Food Safety Administration.
HR1370	Commercial Seafood Consumer Protection Act	Representative Anthony Weiner (D NY–9)	To improve the protections afforded under Federal law to consumers from contaminated seafood by directing the Secretary of Commerce to establish a program, in coordination with other appropriate Federal agencies, to strengthen activities for ensuring that seafood sold or offered for sale to the public in or affecting interstate commerce is fit for human consumption.
HR4363	National Sustainable Offshore Aquaculture Act of 2009	Representative Lois Capps (D CA–23)	To establish a regulatory system and research program for sustainable offshore aquaculture in the United States EEZ, and for other purposes.
S2913	Comprehensive National Mercury Monitoring Act	Senator Susan Collins (R–ME)	The bill mandates the establishment of a monitoring program for mercury led by the EPA in order to track: (A) long-term trends in atmospheric mercury concentrations and deposition; and (B) mercury levels in watersheds, surface waters, and fish and wildlife in terrestrial, freshwater, and coastal ecosystems in response to changing mercury emissions over time (including endangered species and marine mammals). Authorizes funds for NOAA.

FDA Food Protection Plan

(www.fda.gov/Food/FoodSafety/FoodSafetyPrograms/FoodProtectionPlan2007/ucm132705.htm)

For more than 100 years, the United States Food and Drug Administration has protected the health of Americans by improving the safety of those components of the food supply the agency regulates. Today, the United States food supply is one of the safest in the world. The Food Protection Plan outlines a strategy to strengthen an already safe food system. The plan reflects recent challenges and global changes, and it builds upon advances in science and technology to safeguard the nation's food supply against unintentional and deliberate contamination. The Food Protection Plan provides a comprehensive and integrated strategy of prevention, intervention, and response.

The plan focuses FDA's efforts to prevent problems before they start. It employs risk-based interventions to ensure preventive approaches are effective. And it provides for a rapid response when contaminated food or feed are detected, or when there is harm to humans or animals.

Here are the main elements:

Prevention

Prevention is the keystone of an effective, proactive food defence and food safety plan. Preventive measures must be built in from the start of domestic and international food production processes. FDA will continue to work with industry, state, local, and foreign governments to further develop the tools and science needed to identify vulnerabilities and determine the most effective approaches.

The plan calls for:

- Increasing corporate responsibility to prevent food-borne illnesses;
- Identifying food vulnerabilities and assess risks;
- Expanding the understanding and use of effective mitigation measures.

Intervention

Targeted risk-based intervention involving domestic and imported products will provide the second layer of protection. The goal is to ensure that preventive approaches are implemented and that contaminated food is identified when preventive measures are not taken or fail. The components of intervention are:

- Focus inspections and sampling based on risk;
- Enhance risk-based surveillance;
- Improve the detection of food system "signals" that indicate contamination.

Response

The plan bolsters FDA's existing emergency response system. To shorten the period between detection and containment of a food-borne illness requires faster response activities and more effective communication to consumers, industry, and federal, state and international partners. To that end, FDA will:

- Improve immediate response;
- Improve risk communications to the public, industry and other stakeholders.

To meet the above goals, the FDA Food Protection Plan outlines specific actions and requested legislative authorities. The requested authorities and actions include:

Prevention

Action steps:

- Meet with states and consumer groups to solicit their input on implementing preventive approaches to protect the food supply;
- Develop written food protection guidelines for industry to develop food protection plans for produce and other food products, and implement other measures to promote corporate responsibility;
- Analyze food import trend data and integrate it into a risk-based approach that focuses inspection resources on those imports that pose the greatest risk.
- Improve FDA's presence overseas;
- Legislative proposals;
- Allow FDA to require preventive controls against intentional adulteration by terrorists or criminals at points of high vulnerability in the food chain;
- Authorize FDA to issue additional preventive controls for high risk foods;
- Require food facilities to renew their FDA registrations every two years, and allow FDA to modify the registration categories.

Intervention

Action Steps:

- Focus food and feed inspections and sampling based on risk;
- Train FDA and state investigators on new, technically complex and specialized food manufacturing processes, as determined by a risk-based needs assessment, and modern inspection strategies;
- Collaborate with foreign authorities to reduce potential risk of imported foods
- Use advanced screening technology at the border;
- Legislative proposals;
- Authorize FDA to accredit highly qualified third parties for voluntary food inspections;

- Require new reinspection fee from facilities that fail to meet current Good Manufacturing Practices (cGMPs);
- Empower FDA to require electronic import certificates for shipments of designated high risk products;
- Require new Food and Animal Feed Export Certification Fee to improve the ability of United States firms to export their products;
- Authorize FDA to refuse admission of imported food if FDA inspection access is delayed, limited or denied.

Response

Action Steps:

- Enhance data collection, incident reporting and emergency response capabilities
- Work with stakeholders to implement a more effective trace back process, using technologies to rapidly and precisely track the origin and destination of contaminated foods, feed and ingredients
- Work with communications and media experts to design and conduct consumer communications and behaviour response studies
- In a food related emergency, implement this communications plan, including using all relevant media and technologies available, to reach consumers, retailers, industry, public health officials and other stakeholders
- Legislative proposals
- Empower FDA to issue a Mandatory Recall if voluntary recalls are not effective
- Give FDA enhanced access to food records during emergencies

Other U.S Federal and State Agencies

United States Department of Agriculture

There was a provision in the 2008 Farm Bill that authorized the United States Department of Agriculture Food Safety Inspection Service (FSIS) to regulate catfish under the Federal Meat Inspection Act (FMIA) by making farmed catfish an "amenable" species under the Act along with meat and poultry. There have been several developments since the Farm Bill was enacted. First, FSIS developed a risk analysis that selected Salmonella as the major risk factor for food safety. Most food safety experts disagreed with this assessment citing the relevant literature that had only one anecdotal instance of a food borne illness associating both Salmonella and catfish. Second, FSIS was required to produce regulation by January 1, 2010 that would describe how the legislation would be implemented. The regulations have not been approved by the Office of Management and Budget (OMB) of the Executive Branch at this writing. Third, the FMIA requires that a Federal inspector be present during slaughter. The rationale for this is to prevent zoonotic disease transmission from the animals (cattle, hogs, chickens). Fish does not transmit diseases to humans so the requirement does not seem to be a relevant food safety measure. Fourth the legislation did not define "catfish" but left that decision to the Secretary of Agriculture. Secretary Vilsack decided that the term "catfish" included all species within the order Siluriformes. This includes all catfish species grown in China, Vietnam and Brazil. If the regulations are implemented this will mean that (FMIA) will require that all imported catfish have an equivalent system of control to the United States system. Any such system would take most foreign competent authority years to implement and gain approval. In the meantime no foreign produced catfish would be allowed onto the United States market. Because the importation of Pangasius species from Vietnam and China are major commodities, this will cause a potential major impediment to trade. OMB has granted an indefinite extension to the approval of these regulations in February, 2010 and no decision or activity has occurred since.

Seafood Inspection Program of NOAA Fisheries

The Seafood Inspection Program (SIP) of NOAA Fisheries has made it a priority to assist FDA in promoting food safety and quality in seafood products. In October 2009 the agencies signed a Memorandum of Understanding (MOU) that outlined areas of cooperation between the agencies. Moreover, both agencies have created better lines of communication and planned and provided training to the other agency. Both agencies believe that the relationship defined in the MOU should evolve into a closer working relationship. SIP has also adopted the policy that all regulatory requirements for all processes in participating establishments must be met. If the firm does not do so, they face suspension of services. SIP also provides food safety consultations and international inspection services as well as food safety training in HACCP principles and sanitation.

States

In response to the economic fraud problems discussed above and in cooperation with the National Institute of Standards and Technology, the Federal agency that sets methodologies for all industries including food, several states launched a survey of net weights in seafood products in early 2010. They found that there was significant consumer fraud in products that did not contain the stated net weights. The final impact of this event has not occurred at this writing in March 2010.

DOMESTIC REGULATION OF SEAFOOD

Presently the two Federal agencies that regulate the product and conditions of production are the Food and Drug Administration and NOAA Fisheries Seafood Inspection Program. FDA focuses their inspection effort on the conditions of production that may affect the safety of the product e.g. sanitation and preventive HACCP programs. FDA investigators will take samples of seafood on a routine basis for analysis for any possible hazard that may occur in that product. SIP will concentrate on ensuring compliance with FDA laws and regulations and will also evaluate product for safety and quality.

The two most important regulations for seafood are the Current Good Manufacturing Practices (cGMPs) 21 Code of Federal Regulation 110, and the Seafood HACCP Regulation 21 Code of Federal Regulation 123. The current Good Manufacturing Practices deal mainly in sanitation, food handling and hygiene. These requirements are applicable to all food products. These are the so-called prerequisite programs for preventive control systems that are basic tenets to any food safety system. The FDA Web site for this is here: www.cfsan.fda.gov/~dms/gmp-toc.html. The Seafood HACCP regulations are specific to seafood and require that appropriate preventive controls of likely hazards be established for the processing of all seafood products. HACCP is an acronym for Hazard Analysis Critical Control Point which is a system where all possible hazards in a food processing establishment are identified, control points are established, monitoring procedures are implemented and critical limits and corrective actions for each safety parameter are specified. A system of systems verification including records review is also required to ensure that the system is working properly. The Seafood HACCP regulation may be found at: www.cfsan.fda.gov/~comm/haccp4x8.html.

This regulation is supported by the Fish and Fishery Products Hazard Guide that gives detailed instruction about how to identify hazards, write and implement a HACCP plan and other regulatory requirements that seafood producers need to be aware.

FDA inspections are auditory in nature. They will visit a plant unannounced and evaluate its sanitation conditions and HACCP systems. These inspections will generally take one to five days to complete. When the investigator is done with his or her evaluation a so-called Form 483 will be issued that lists objectionable observations. The investigator will usually advise the firm to submit a written description of how they intend to correct the problems.

It is advisable that the firms respond immediately to the observations and submit appropriate corrections. In many cases responsiveness by the firm will convince FDA officials that further regulatory action is unnecessary. If the firm believes that the FDA investigator's observations are incorrect or not scientifically based they should inform FDA in writing, and include their reasoning. FDA has a policy related to HACCP controls that they have been called the "continuation policy" which states that the firm may petition FDA if they believe that their system of control has a sound scientific basis but does not conform to the Fish and Fishery Product Guide. See the following link: www.cfsan.fda.gov/~comm/seaguide.html. If the reasoning appears to be valid scientists at the Center for Food Safety and Applied Nutrition will evaluate the information submitted by the firm for scientific validity. If the firm's reasoning is acceptable no further regulatory actions will likely take place for that issue.

FDA also requires that all food manufacturers register under the Bioterrorism Act of 2002. The process is fairly simple and is accomplished by filling out a web based form and submitting the information to FDA. See instruction on the FDA web site at: www.cfsan.fda.gov/~furls/ffregsum.html.

The SIP has contracts with many of the larger firms in the United States and depending on the type of service will be in the plant and inspect on a continuous basis or will audit the firm four or more times per year. SIP oversees about one third of the United States consumption of seafood. In either case, the firm will undergo a rigorous systems audit for preventive controls and sanitation at least four times per year. SIP will also require that the firm submit written corrective actions to systems audit checklists. If corrections are not made the contract may be suspended or revoked and the firm will not receive certifications and grade marks that their customers require.

IMPORT REGULATION OF SEAFOOD

Imported seafood is subject to the regulatory oversight of FDA. Any consignment offered for entry into the United States is subject to inspection by FDA import officers. These officers use a digital system for selection of seafood products that is based on the relative risk of the product to the consumer. Theoretically a cooked-ready-to-eat product should be sampled and analyzed at a much higher rate than raw products with no inherent hazards. Once a consignment is targeted for inspection and analysis it may be subject to a visual examination or more rigorous analytical testing for contaminants. If the officer sees any discrepancy with the product that constitutes an "appearance of adulteration" the importer then assumes the burden of proof that the product is not adulterated and it may be tested at the expense of the importer or denied entry. In any case, the product will be placed in an expensive bonded warehouse until the matter is resolved. An appearance can be mis-labelling, inadequate packaging protecting the product or anything that seems to be non-compliant to the regulations and laws. If contaminants are found and there is a reasonable way to eliminate them e.g. cooking raw product for microbiological contamination then the importer may petition FDA to do so with specific explanations about how the processing will eliminate the hazard.

If FDA believes that product imported from a particular firm, country or region has a high probability of adulteration they may issue an import alert. An import alert will list all the affected firms, countries or regions and it will require appropriate analytical testing on each lot offered for importation into the commerce of the United States. Firms, countries or regions will have to show that the root cause of the problem that created the adulteration has been eliminated. For seafood firms that are subject to the Seafood HACCP Regulation this usually requires that FDA or a reliable third party has verified that the correction has occurred. This may cause problems if there are many affected firms as it may take FDA quite a while to verify the corrections.

Importers must give prior notice to Customs and Border Protection (CBP) that a shipment is going to be offered for entry under the food protection provisions of the Bioterrorism Act. The time limitations vary according to what conveyance the product is transported. For more information consult the FDA Web site at: www.cfsan.fda.gov/~dms/fsbtact.html#oct2003.

Importers also must comply with 21 Code of Federal Regulation 123.12, Special requirements for imported products. The purpose of this provision in the HACCP regulations is to ensure that products entering into United States commerce are in compliance with the Seafood HACCP Regulation similar to domestically produced seafood. The importer of record must buy seafood from a country with an active memorandum of understanding (MOU) with FDA or have written verification procedures that outline product food safety specifications and affirmative steps as follows:

- Obtaining from the foreign processor the HACCP and sanitation monitoring records required by this part that relate to the specific lot of fish or fishery products being offered for import;
- Obtaining either a continuing or lot-by-lot certificate from an appropriate foreign government inspection authority or competent third party certifying that the imported fish or fishery product is or was processed in accordance with the requirements of this part;
- Regularly inspecting the foreign processor's facilities to ensure that the imported fish or fishery product is being processed in accordance with the requirements of this part;
- Maintaining on file a copy, in English, of the foreign processor's HACCP plan, and a written guarantee from the foreign processor that the imported fish or fishery product is processed in accordance with the requirements of this part;
- Periodically testing the imported fish or fishery product, and maintaining on file a copy, in English, of a written guarantee from the foreign processor that the imported fish or fishery product is processed in accordance with the requirements of this part; or
- Other such verification measures as appropriate that provide an equivalent level of assurance of compliance with the requirements of this part.

An importer may hire a competent third party to assist with or perform any or all of the verification activities specified above, including writing the importer's verification procedures on the importer's behalf. See the following on the FDA Web site: www.cfsan.fda.gov/~comm/haccp4x8.html.

MONITORING AND ANALYSIS FOR SEAFOOD

FDA does not perform a large volume of analytical monitoring for domestic product. The Center for Food Safety and Applied Nutrition has an annual compliance plan that specifies, among other inspection activities, what products will be sampled and what analysis will occur. There is also a standing sampling plan called Toxic Elements where appropriate chemical analysis is performed at a specified rate.

Imported products are more likely to be monitored and analyzed than domestic product even though the overall monitoring rate is about one percent. Import officers use a digital risk assessment system to make random choices of consignment for sampling, and the appropriate analysis will be performed.

REGULATORY ACTIONS FOR SEAFOOD

FDA investigators during routine inspections of seafood manufacturing facilities may find conditions of production or lack of preventive controls that they judge to be serious or critical in nature. The investigator will note the egregious condition on their Form 483 List of Observations. If the firm does not correct the deficiency FDA will issue a Warning Letter. This is an official letter informing the firm that FDA intends to take regulatory action through the court system. If FDA finds similar conditions on a follow-up inspection, regulatory action will likely occur. This will mean that FDA will pursue a court action. However, the agency must go through an exhaustive review process before the court action can go forward. This will include a review of the sufficiency of the evidence by the district who will classify the action and send the case file to the Center for Food Safety and Applied Nutrition who will again look at the evidence development through the Office of Compliance and send it to the Office of Food Safety Division of Seafood for scientific review. If the investigator and district scientific reasoning is sound the case file goes to the Office of General Counsel (OGC) for final legal review. Once the OGC is satisfied that a sufficient case exists, the assigned attorney will refer the case to the United States Attorney (who works for the Department of Justice) near the location of the manufacturing plant, who may or may not choose to prosecute the case. If the prosecution is successful the Federal court will generally issue an injunction against the firm that is an order by the court to stop all processing until the FDA is satisfied that the egregious conditions are corrected. Because this is an elaborate process only a few regulatory actions are adjudicated in court every year.

If FDA has knowledge that much food is adulterated they may take action against the product itself and will seek a seizure of the product by Federal officials. Because FDA does not do a great deal of product inspection for domestic seafood this is generally a rare event. However, imports are routinely analyzed for appropriate hazards. If an imported consignment is found to be adulterated it can either be reprocessed to eliminate the hazard if possible, destroyed or not allowed in commerce and shipped out of the United States.

LAWS AND REGULATIONS GOVERNING SEAFOOD IN THE UNITED STATES

Food, Drug and Cosmetic Act

This law covers all food (except meat and poultry), drugs and cosmetics.

www.fda.gov/opacom/laws/fdcact/fdctoc.htm

Public Health Act

This is a compendium of laws that promote public health.

www.fda.gov/opacom/laws/phsvcact/phsvcact.htm

Agricultural Marketing Act

Provides for voluntary grading programs for all food commodities under the Agricultural Marketing Service that promoted the safety and quality of food. edocket.access.gpo.gov/cfr_2008/janqtr/pdf/7cfr53.1.pdf

Fish and Wildlife Act

This Act transferred seafood inspection from the Department of Agriculture to the Department of Interior Bureau of Commercial Fisheries (later National Oceanic and Atmospheric Administration). It also gave DOI the authority to perform food safety inspections.

www.access.gpo.gov/uscode/title16/chapter9_.html

Bioterrorism Act 2002

This Act calls for security measures for food, drugs and drinking water and national preparedness for terrorist acts.

www.fda.gov/oc/bioterrorism/PL107-188.html

Lacey Act
This Act is designed to protect wildlife from illegal exploitation. It allows any Federal or state law to be used as a basis of prosecution. It is useful to fisheries enforcement officers and food and drug FDA officers in taking legal action against illegally caught or mis-branded wild seafood.
21 Code of Federal Regulation 110
This regulation specifies Good Manufacturing Practices for Food Production.
www.cfsan.fda.gov/~dms/cgmps.html
21 Code of Federal Regulation 113
This regulation addresses low-acid canned food requirements.
ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=f7cd1d3ff180ae237d453e96096dd330&rgn=div5&view=text&node=21:2.0.1.1.12&idno=21
21 Code of Federal Regulation 123
This is the Seafood Hazard Analysis Critical Control Point requirements for all seafood produced or shipped to the United States.
vm.cfsan.fda.gov/~dms/qa2haccp.html
50 Code of Federal Regulation 260
This is regulations government processed fishery products.
www.seafood.nmfs.noaa.gov/50CFR260-261.PDF

CONCLUSION

Although there are great challenges for any governmental organization to ensure food safety to its citizens, the United States is addressing these issues. Although the responses are not well coordinated and sometimes at cross purposes there will eventually will be an improved safety system for all food consumed in the United States including seafood. This will likely come at a cost of more inspection oversight, more demands for in-plant control systems, more restrictive labelling and more traceability of products in commerce. Ideally, there will be more cooperation and resource leveraging by regulatory agencies in the future that result in more effective food regulation. This cooperative spirit coupled with a stronger, better funded FDA should help address these issues.

Basic economics of value adding for fish products

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ABSTRACT
Value adding may represent an opportunity for companies and regions to derive greater economic benefits from the fish that they produce and process. Whether value adding is profitable depends on whether the increase in value offsets the increase in costs. This paper reviews important things to understand about the economics of value adding for fish products. These include: (1) not all value adding which is technically possible is necessarily profitable; (2) location affects the economics of value adding; (3) the most profitable location for value adding is not necessarily where primary processing occurs; (4) how capture fisheries are managed may affect the economics of value adding; (5) whether fish are produced in capture fisheries or aquaculture may affect the economics of value adding; (6) tax and trade policies may affect the economics of value adding; (7) the economics of value adding may change significantly over time; (8) marketing is critical to successful value adding; (9) choices which maximize the overall profitability of a fish processing operation do not necessarily maximize the profitability of by-product processing; and (10) different groups within a region may be affected in different ways by value adding.

INTRODUCTION
The purpose in this paper is to review, as simply and clearly as possible, some of the most important things to understand about the economics of value adding for fish products.

"Value adding for fish products" may be broadly defined as "additional processing to produce higher valued products."[1] An example would be processing Alaska salmon into fillets rather than the traditional "frozen headed and gutted" product form. Other examples of "value adding" include breading, smoking, flavouring, portioning, and combining fish with other ingredients to produce consumer-ready meals. Another kind of value adding would be using fish parts which might previously have been disposed of (such as fish heads and entrails) to produce "by-products" such as fish meal, fish oil and pet food.

[1] "Value adding" is a commonly used but rarely precisely defined term in the seafood business. This simple definition is intended to convey the meaning in which the term is commonly used. A more formal definition would require defining more precisely what distinguishes a product which is "value-added" from one which is not "value-added." In common usage, "value-added" typically means "higher-priced," "more consumer-ready," "non-traditional," and "requiring more processing." Because it is a traditional product, canned salmon would generally not be considered to be a "value added" product, even though it is higher-priced, more consumer-ready, and requires more processing than frozen headed and gutted salmon.

In theory, value adding represents an opportunity for regions to derive greater economic benefits from the fish that they produce and process. But many companies do not engage in value adding to the extent that would be possible given existing production technologies. For example, Alaska salmon processors typically produce much more headed and gutted salmon than salmon fillets—even though salmon fillets command significantly higher prices.

In some cases, companies produce non value-added products in the region where the fish are caught or farmed, and "export" those products to other regions (in the same country or in foreign countries) where further value-added processing occurs. For example, a significant share of Alaska salmon production is exported as frozen headed and gutted salmon to China, where it is processed into value-added products for sale to markets in the United States and Europe.

In some cases, companies do not fully utilize fish even though technologies exist to do so. For example, many Alaska salmon processors do not utilize salmon heads or entrails, even though they could be processed into fish meal, fish oil or pet food.

The fact that seafood processing companies engage in less value adding than would be possible given existing production technologies can be both puzzling and frustrating for residents of fish producing regions, who perceive that they are not receiving the full potential benefits of their fishery resources.

However, seafood processing companies which engage in less value adding than they might are not necessarily lacking in knowledge or willingness to innovate. They may rather be making fully rational business decisions. Not all value adding that is technically possible is necessarily profitable or optimal for a company.

In almost all cases, higher value products are also higher cost products to produce. When and where value adding is profitable depends on the extent to which the increase in value offsets the increase in costs.

In this paper the basic economics of secondary processing and by-product processing are briefly reviewed first and then ten important things to understand about the economics of value adding for fish products are discussed.

For purposes of this paper, the term "primary product" refers to a non-value added product, and "secondary product" refers to a value-added product that could be made by further processing of the primary product. The term "by-product" is used to refer to products that could be made from the fish in addition to whatever primary or secondary products are produced, utilizing parts of the fish that would otherwise be discarded as waste.

BASIC ECONOMICS OF SECONDARY PROCESSING

Under what conditions would secondary processing, following primary processing, increase a fish processor's profits? Suppose first that secondary processing could be done without any additional cost. Secondary processing increases profits only if the increase in price is sufficiently great to make up for any volume loss involved in secondary processing. Put differently, the profitability of secondary processing depends not only on the relative prices of the secondary and primary products, but also on the yield from the primary product volume to secondary product volume. Mathematically, secondary processing increases value only if the following condition is met:

$$\text{(1)} \quad \text{Secondary product price} \times \text{Secondary product volume} > \text{Primary product price} \times \text{Primary product volume}$$

Equation (1) may be rearranged to give:

$$\text{(2)} \quad \text{Secondary product price} \times \text{Primary product volume} \times \text{Yield} > \text{Primary product price} \times \text{Primary product volume}$$

$$\text{(3)} \quad \text{Secondary product price} \times \text{Yield} > \text{Primary product price}$$

$$\text{(4)} \quad \frac{\text{Secondary product price}}{\text{Primary product price}} > \frac{1}{\text{Yield}}$$

Suppose next that secondary processing adds additional variable costs of labour and other inputs. Secondary processing increases profits only if the increase in price is sufficiently high to make up for both yield losses and any net increases in unit costs of labour and other inputs, such as packaging and ingredients. Mathematically, secondary processing increases profits only if the following condition is met: [2]

$$\text{(5)} \quad \frac{\text{Secondary product price} - \overbrace{\text{Wage rate} \times \text{Labor use per unit of secondary product}}^{\textit{Additional labour cost per unit}} - \overbrace{\text{Other inputs unit cost} \times \text{Other inputs use per unit of secondary product}}^{\textit{Other additional costs per unit}}}{\text{Primary product price}} > \frac{1}{\text{Yield}}$$

Suppose next that secondary processing requires additional capital investment in plants and machinery. Secondary processing will increase profits only if the increase in price is sufficiently high to also cover additional unit capital costs. Unit capital costs depend on the efficiency of utilization of capital. Secondary processing is less likely to be profitable if the scale of production is too small to fully utilize the additional plants or machinery, or if they can only be utilized some of the time.

Secondary processing may affect transportation costs in several ways. Secondary processing may reduce transportation costs by reducing the volume of product to be shipped. This potential cost advantage may be offset by additional costs of packaging or special handling requirements for secondary products.

BASIC ECONOMICS OF BY-PRODUCT PROCESSING

By definition, "by-products" are produced using parts of the fish that would otherwise be discarded as waste. By-product processing is profitable only if the additional revenue from the by-products exceeds the additional processing costs.

Processing for certain kinds of by-products, such as fish meal and fish oil, is highly capital intensive. Processing these kinds of by-products is more likely to be profitable with a larger scale of production. Put differently, it is harder for plants that process small volumes of fish to cover the high capital costs of fish meal or fish oil processing.

Note that it is unlikely that any kind of by-product processing utilizing traditional technologies to process fish parts that have traditionally been discarded as waste would

[2] To see why, think of the numerator on the left side of the previous equation at "net secondary product price", or price per unit net of increases in unit costs of wages and other inputs.

be *highly* profitable. This is simply because processors are unlikely to have ignored or overlooked highly profitable ways of using fish resources. However, if by-product prices increase or by-product processing costs decrease, formerly unprofitable types of by-product processing may become profitable. In contrast, new technologies to produce new kinds of by-products, or to produce traditional by-products in new ways, may *potentially* be highly profitable.

TEN IMPORTANT THINGS TO UNDERSTAND ABOUT THE ECONOMICS OF VALUE ADDING

Below are ten important things to understand about the economics of value adding for fish products.

1. Value adding isn't necessarily profitable.

Whether value adding increases a fish processor's profits depends on numerous factors, including (but not limited to) relative product prices, secondary processing yields, wage rates, secondary processing labour requirements, secondary processing unit costs and uses of other inputs such as packaging and ingredients, transportation costs for secondary processing inputs, and relative transportation costs for primary and secondary products. *All* of these factors matter. You can't conclude that secondary professing would necessarily increase a processor's profits simply because value added products may command a much higher price.

2. Location affects the economics of value adding.

Many of the factors that affect the economics of value adding may vary significantly between different locations. These include, in particular, labour costs, energy costs, transportation costs of secondary processing inputs such as packaging and ingredients, and relative transportation costs for primary and secondary products. Value adding that is profitable in one location may not be profitable in another location. For example, labour-intensive value adding is less likely to be profitable in places where wage rates are high.

3. The most profitable location for value adding is not necessarily where primary processing occurs.

Because primary processing must be done soon after harvesting in order to stabilize fish quality, most primary processing has to occur relatively close to where fish are harvested by capture fisheries or grown in aquaculture systems. Secondary processing does not necessarily have to be done soon after harvesting or in the same location as primary processing.

It might seem that value adding at the same location as the primary processing would convey an obvious economic advantage by saving on the cost of transporting primary product to another location. But this potential transportation cost advantage may be outweighed by many other factors which might be more favourable at a different location, such as labour costs, costs of other processing inputs such as packaging and ingredients, and transportation costs to end markets. Note in particular that if value adding occurs near end markets, there may be little or no transportation cost advantage to value adding at the same location as primary processing.

Suppose, for example, that a "local" processor has a choice of value adding "locally" where primary processing is done, or in a different "foreign" location. Assume that "foreign" wage rates and other unit processing costs are lower than "local" wage rates and other unit processing costs. "Local" value adding will be more profitable than "foreign" value adding only if the foreign savings on labour and other costs are less than the increase in transportation costs. This depends not only on relative wage rates and other unit costs, but also the labour intensity of processing and the intensity of use of other inputs.

"Local value adding" is more profitable than "foreign value adding" only if the condition in Equation (6) is met:

(6)

$$\textit{Foreign savings on labor costs per unit} + \textit{Foreign savings on other costs per unit} < \textit{Increase in transportation cost per unit}$$

Where:

$$\textit{Foreign savings on labor costs per unit} = \left[\text{Local wage rate} - \text{Foreign wage rate}\right] \times \text{Labour use per unit of secondary product}$$

$$\textit{Foreign savings on other costs per unit} = \left[\text{Local other inputs unit cost} - \text{Foreign other inputs unit cost}\right] \times \text{Other inputs use per unit of secondary product}$$

$$\textit{Increase in transportation cost per unit} = \left[\frac{\text{Transport cost per unit of primary product from ``local'' plant to ``foreign'' plant}}{\text{Yield}} + \text{Transport cost per unit of secondary product from ``foreign'' plant to end market}\right] - \text{Transport cost per unit of secondary product from ``local'' plant to end market}$$

This helps to explain why an increasing share of the fish captured or grown in American and European fisheries and aquaculture are being shipped to China, Viet Nam and other countries for secondary processing—and then shipped back to markets in America and Europe. The savings on labour and other costs outweigh the additional transportation costs.

In recent years, increasing volumes of Alaska salmon have been exported to China for value-added processing. In China, frozen headed and gutted Alaska salmon are thawed, filleted, portioned and packaged for re-export to U.S. and European markets.

4. How capture fisheries are managed may affect the economics of value adding.
Fisheries management may affect the timing of fish deliveries to processors. For example, in competitive "derby"[3] fisheries, processors may receive large daily volumes of fish during a short season, followed by long periods during which they don't receive any fish. In contrast, in fisheries with individual quota management, fishermen may deliver smaller daily volumes over a longer season.

The timing of fish deliveries affects how efficiently processors can utilize the additional investments in plants and machinery needed for fish processing. The unit cost of a packaging machine will be much lower if the machine is operated every day than if it is only operated part of the year.

Fisheries management may also affect the quality of fish delivered to processors. For example, in competitive "derby" fisheries where fishermen are trying to catch fish as fast as possible, they may not take the time to handle fish as carefully as they would in fisheries with individual quotas. This may result in more bruising, reducing the processing yield for value-added products such as fillets and portions.

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[3] Fishermen and fishery managers commonly refer to highly-competitive fisheries in which large numbers of fishermen compete for a limited available volume of fish during a short season as a "derby" fishery.

5. Whether fish are produced in capture fisheries or aquaculture may affect the economics of value adding.

Regardless of how capture fisheries are managed, they may face certain inherent competitive disadvantages relative to aquaculture with respect to the potential for efficient secondary processing. Capture fisheries tend to have greater inherent variability in fish size and other fish characteristics, making it more difficult to design secondary processing machinery and reducing processing yields. Capture fisheries are subject to greater seasonality and annual harvest variability and uncertainty, increasing the difficulty of utilizing secondary processing capacity efficiently. Wild fisheries may occur in remote locations with extremely high labour, transportation and utility costs and where aquaculture facilities would not be situated.

6. Tax and trade policies may affect the economics of value adding.

If primary and secondary products are subject to different tax policies (by domestic governments) or trade policies (by foreign governments in end-market countries) this may affect the relative profitability of primary and secondary processing.

7. The economics of value adding may change significantly over time.

Seafood industry technology, prices, costs, taxes, consumer tastes, regulations and other factors affecting the profitability of secondary processing are subject to significant and sometimes rapid change. These can create new opportunities for profitable value adding – or make formerly profitable value adding unprofitable. New labour saving technologies such as salmon pinbone-pulling machines can make secondary processing profitable in areas with high labour costs. Increasing labour costs in China could reduce the profitability of the large secondary processing industry that has developed there in recent years.

8. Marketing is critical to successful value adding.

Secondary products may command significantly higher prices than primary products. This creates an incentive for processors to increase production of these products. Unless increased production is accompanied by effective marketing to expand demand, prices may fall as production expands – particularly for niche market products. Successful value adding requires more than producing value added products cost effectively. It also requires an understanding of what kinds of products markets demand and communicating effectively about how products meet those demands.

9. Choices which maximize the overall profitability of a fish processing operations do not necessarily maximize the profitability of by-product processing.

Fish processors make choices such as the location and scale of plants based on how the choices affect total revenues, costs and profits rather than the revenues, costs and profits from by-products. In general, processors face trade-offs between having more smaller-scale operations located closer to where fish are harvested or grown (which reduces costs of fish transportation and improves product quality) or having fewer larger-scale operations (which benefit from greater economies of scale). In general, because of the relatively greater intensity of by-product processing than food product processing, the optimal fish plant scale for maximizing total profits is lower than the optimal scale for maximizing the profitability of by-product processing. In fisheries that are widely dispersed and/or highly seasonal, such as some Alaska salmon fisheries, the scale of production may be insufficient to economically justify the capital costs of utilizing the entire fish, resulting in the discarding of significant volumes of "waste" products such as fish heads and entrails.

10. Different groups within a region may be affected in different ways by value adding.

Fish processors benefit most from whatever types of processing are most profitable. In some cases, it may be most profitable for processors not to engage in value-added processing or to "export" primary products for further value-added processing outside a region.

In general, fishermen and fish farmers also benefit most from whatever types of processing are most profitable for processors – which maximize the prices processors might potentially be able to pay for their fish.

In contrast, other businesses within a region – those which sell to fish processors or to their employees – may benefit most from whatever types of processing maximize expenditures by processors within the region, or which maximize processing employment. Similarly, local and regional governments may benefit most from whatever types of processing maximize sales taxes or property taxes. Thus other businesses and local governments may advocate for relatively more value adding than processors prefer.

In some cases, local governments may provide tax incentives or subsidies as incentives for processors to undertake value adding – or they may mandate it. Mandating value-adding may be rational from a local business development perspective but is not necessarily optimal for processors or fishermen.

The future of fishmeal and fish oil

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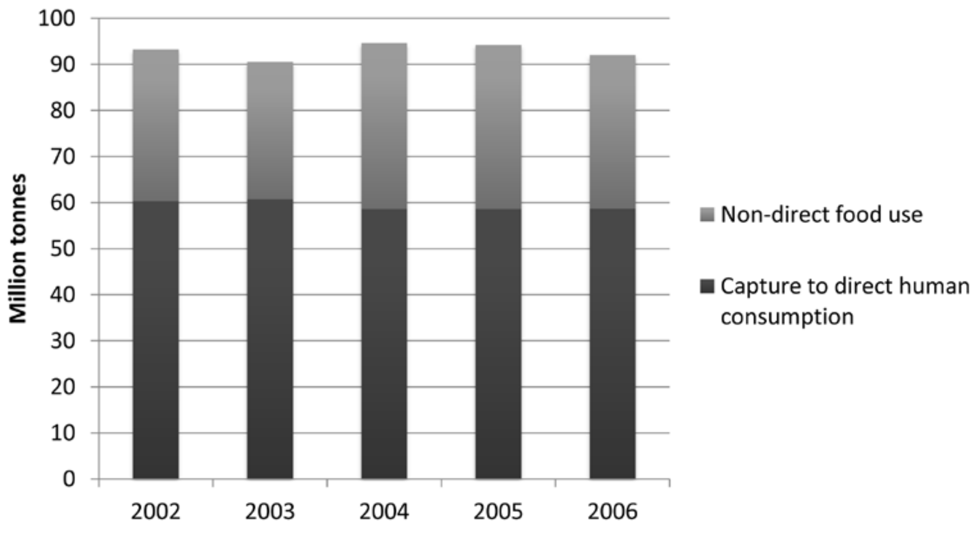
INTRODUCTION

Fishmeal is a natural feed ingredient used in diets for farmed fish and crustaceans and as a supplement in nutritionally demanding periods in the life cycle of pigs and poultry, as well as in pet food. The main nutritional benefits of fishmeal are that it is high in protein with an excellent amino acid profile as well as being highly digestible with no anti-nutritional factors.

Fish oil is the major natural source of the long chain omega-3 polyunsaturated fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Most fish oil is used in feeds for farmed fish and there is an expanding market for fish oil as a human nutritional supplement in the form of oil capsules and as a food additive.

The annual global fish catch (excluding aquaculture) of around 90 million tonnes includes approximately 30 million metric tonnes representing fish which go for non-direct food use (FAO, 2008) (Figure 1). Of this 30 million tonnes around 16.5 million tonnes goes for fishmeal and fish oil production, the remainder going for a range of uses, including direct feeding as minced wet fish to animals (particularly fish and crustaceans in Asia), as well as pet foods and fur producing animals.

FIGURE 1
Total global capture fisheries



Source: FAO, 2008.

As summarized by Jackson and Shepherd (2010), about 5 million tonnes of fishmeal and 1 million tonnes per annum of fish oil are derived from that 16.5 million tonnes of whole fish. In addition to this production from whole fish, an increasing proportion of fishmeal and fish oil is derived from trimmings as a by-product of fish processing for human consumption (approximately 5 million tonnes of by-products were converted to approx 1.25 million tonnes of fishmeal and fish oil in 2008).

Figures 2 and 3 show global production of fishmeal and fish oil respectively from the early 1960s to 2008, with fishmeal output at about 5 million tonnes and fish oil at about 1 million tonnes in recent years. The largest producer of fishmeal and fish oil from whole fish is Peru followed by Chile. Other important producing countries include United States, Iceland, Norway, Denmark and Thailand. Much of the year to year variation can be explained by the periodic El Niño events in the Pacific, for example in 1998, which displace the upwelling of cold water responsible for the exceptionally productive anchovy and other species fisheries off the Peruvian and Chilean Pacific coasts.

FIGURE 2
Fishmeal production 1962 onwards

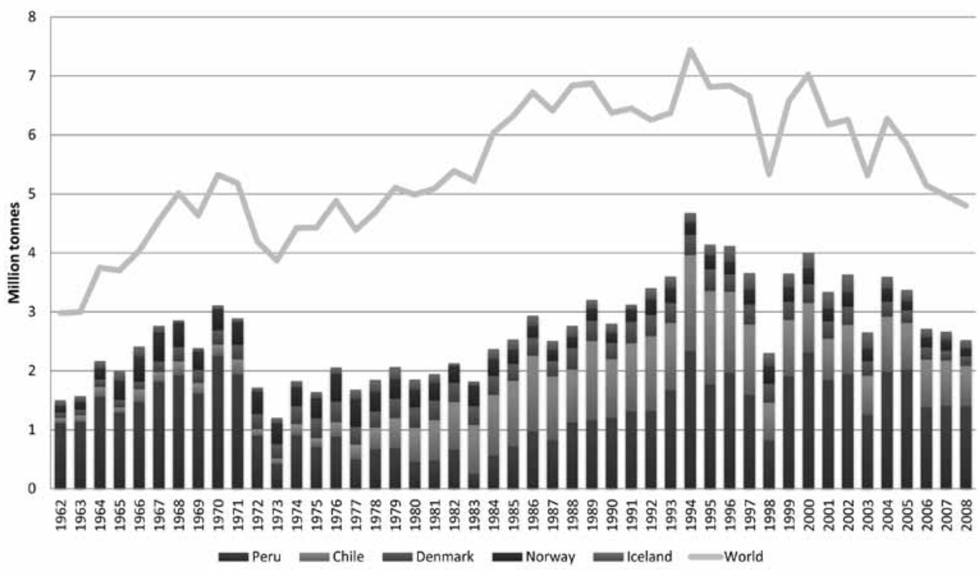
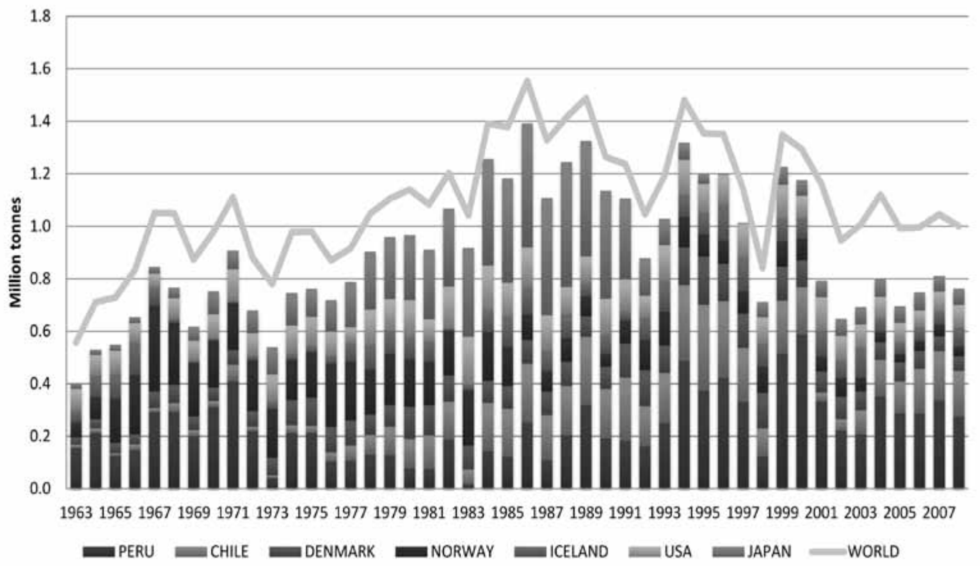


FIGURE 3
Fish oil production 1963 onwards



This chapter looks at the changing pattern of use of fishmeal and fish oil as a component of feed, mainly for farmed aquatic animals, and comments on the implications for sustainable aquaculture. When describing populations of whole, wild (normally pelagic) fish being caught for manufacture of fishmeal and fish oil, the term 'feed' fish will be used; such targeted fisheries are sometimes also referred to as industrial, reduction or forage fisheries.

AN OVERVIEW OF STOCK MANAGEMENT OF GLOBAL FEED FISHERIES, WITH SPECIAL REFERENCE TO PERU

Global feed fisheries in general

The estimate of 16.5 million tonnes of whole, wild fish used to make fishmeal and fish oil in 2008 excludes an additional 4.5 million tonnes of process trimmings derived from wild and farmed fish for human consumption. This whole fish tonnage is caught mainly by targeted fishing of pelagic species for which there is limited or no demand for human consumption. By far the largest example in volume terms is the Peruvian anchovy (*Engraulis ringens*), with an annual catch subject to El Niño fluctuations, but during the period 2000 to 2006 varying from 6 to 10 million tonnes (including approximately 1 million tonnes of Chilean landings) and thus representing 25 percent to 30 percent or more of global fishmeal production depending on the year. National production by industrial fisheries has recently been surveyed by Peron *et al.* (2010). Table 1 shows the production data for the average of the period 2001 to 2006.

TABLE 1
Average annual catches of the largest pelagic fisheries used at least in part for feed purposes

Species	Latin name	Countries	Average annual catch (tonnes)
Peruvian anchovy	*Engraulis ringens*	Peru, Chile	8,468,000
Chilean jack mackerel	*Trachurus murphyi*	Chile, Peru	1,749,000
Japanese anchovy	*Trachurus japonicus*	China, Japan	1,567,000
Chub mackerel	*Scomber japonicus*	Peru, Chile, China, Japan, Mexico	1,403,500
Blue whiting	*Micromesistius poutassou*	Norway, Faroes, Denmark, Iceland	1,398,500
Capelin	*Mallotus villosus*	Norway, Iceland, Faroes, Canada	958,500
Menhaden	*Brevoortia patronus & Brevoortia tyrannus*	USA	691,000

Source: Peron *et al.*, 2010.

Additionally there are smaller catches of a variety of other small pelagic fish species, e.g. Atlantic herring (*Clupea harengus*) and sardines (*Sardina* spp.) which are used for both fishmeal and human consumption, as well as other species e.g. sandeel (*Ammodytes* spp.) which are used only for fishmeal and fish oil. It is important to recognise, however, that species such as chub mackerel *(Scomber japonicus),* blue whiting *(Micromesistius poutassou),* and capelin *(Mallotus villosus)* are now used mainly for human consumption and this is increasingly true also for Chilean jack mackerel *(Trachurus murphyi)*. By contrast it has been estimated that 97 percent of Peruvian anchovy is used for fishmeal and fish oil and menhaden *(Brevoortia* spp.*)* is almost exclusively used for fishmeal and fish oil with a minor quantity going for bait fish.

Growing recognition of the need for responsible practice

Recent years have seen a growing trend towards improving fisheries management and adopting a more precautionary approach as laid out by the United Nations' Food and Agriculture Organization in their Code of Conduct for Responsible Fisheries (FAO, 1995). This has resulted in some fundamental changes to the way many of the world's largest feed fisheries have been managed. This is particularly true in both North and South America as well as Europe. The multi-national nature of European waters has given particular problems, but despite many serious issues, there is clear evidence that the EU Common Fisheries Policy is being reformed. Meanwhile for many of the feed fisheries, such as Norway pout *(Trisopterus esmarkii),* Blue Whiting and sand eels, there are good management measures already in place which are allowing the stocks to recover.

In Asia, where 20–25 percent of the world's fishmeal is produced, the management of the fisheries, which provide some of the raw material, presents a complicated picture. Many of the fish that are destined to be made into fishmeal do not originate from targeted pelagic species, but are fish for which there is no ready market for human consumption. As such many of them are juvenile fish or slow growing benthic fish, both of which are important for the sustainability of the ecosystem. In addition there are often few fishery controls and very limited knowledge on the state of the fishery. In addition to the fish which go for fishmeal and fish oil production, there are significant volumes of fish which are used in a fresh state for direct feeding, particularly to marine fish species. Estimates vary as to the annual quantity of fish used this way but are thought to be in the order of around 5 million tonnes. This is an area where considerable efforts are going to be needed in order to try and improve the situation.

All this is in contrast with what we can now see in South America where, following problems during the 1970s and 1980s, significant efforts have been made to improve the scientific knowledge of the major fisheries. This is particularly true of the management of the world's largest feed fishery, that for Peruvian anchovy, which is found principally in Peru but also in northern Chile. The fishery lies within the exceptionally productive Humboldt Large Marine Ecosystem (LME). The anchovy population fluctuates as a result of natural events, mainly climatic – which occur in seasonal, annual, interannual and interdecadal scales. One of the most dramatic events affecting the LME is the occurrence of El Niño.

Processing of anchovy into fishmeal and fish oil on a serious scale in Peru had begun in the 1950s. By 1964 rising demand for poultry and pig feed and improved fishing and processing technology had resulted in Peru producing 40 percent of the total global supply of fishmeal. Fish products accounted for 25–30 percent of export earnings in the 1960s, but as the decade wore on, signs of overfishing appeared and the newer larger fishing boats were forced to explore fresh untapped fishing grounds. In 1970 the FAO warned that the maximum (annual) sustainable yield of anchovy was 9.5 million tonnes, compared with an actual catch in that year of 12 million tonnes. FAO's warning was emphasised by a dramatic fall in catches in 1972 and 1973. Low catches persisted through the eighties and the industry struggled, although the biomass of other species, like sardines, increased.

It was then that the Peruvian Government, industry and the Peruvian national fisheries research institute (Instituto del Mar del Perú; IMARPE) started working together to develop the extensive policies and controls in place now. Peruvian policy has been based on five principles:

1. Protection of ecosystems
2. Implementation of clean technologies
3. Preservation of biodiversity
4. Social justice
5. Sustainable use of marine resources

Anchovies are a pelagic, fast growing and short lived species and IMARPE has stated (Soldi, 2009) that it is impossible to estimate an "optimal catch". It is therefore essential to manage this fishery in an adaptive, flexible and rapid manner. To do this the controlling authorities (government) needs quasi real-time scientific information of fisheries and the capability to make, implement and enforce decisions rapidly.

Information on stock status is provided by extended acoustic surveys three times a year, plankton surveys to estimate fish abundance based on eggs and larvae density, and plankton and oceanographic and plankton productivity by *in situ* and satellite monitoring and analysis.

The management controls imposed by the Peruvian Government include:

Biomass controls

- Statutory seasons when the fisheries are open and closed
- Annual and seasonal total catch limits
- Only artisanal boats are permitted to fish within five miles of the coast
- Rapid closure when limits are reached of more than 10 percent juveniles in catch
- Maximum Limits of Capture per Vessel (from 2009).

Bycatch controls

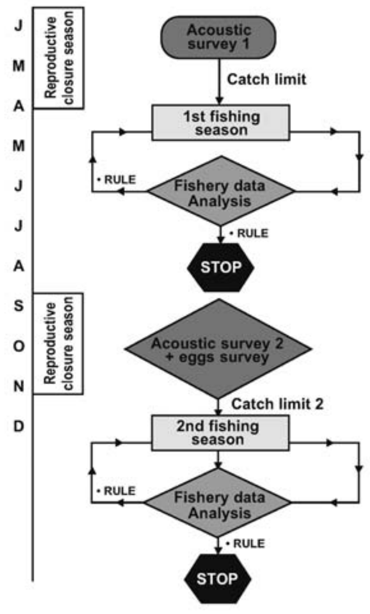
- Bycatch limit 5 percent (actual in 2007 was 3.6 percent according to IMARPE)
- Minimum mesh size of 1/2 inch (13mm)

Unloading

- Formal declaration of hold capacity
- Closed entry to new fishing boats
- Licences required to fish within the 200 mile limit and to land catch
- Security-sealed satellite tracking of all boats operating outside the 5 mile limit
- 24 hour independent recording of landings at 134 unloading points
- Fines and revoking of licences for breaches of rules

The capacity to make the rapid decisions necessary to protect the Peruvian anchovy stock is illustrated by the decision flow diagram (Figure 4). If landings exceed the catch limit set for a season, then there is an immediate and final stop to fishing. If catches of juveniles exceed 10 percent of the catch, there is provisional closure while further checks take place. Either, or both, of these decisions can be implemented within 36 hours.

FIGURE 4
Decision flow diagram



There are further controls and information systems, many imposed to protect the landings of fish for direct human consumption, for example, receiving plants are not authorised to land fish coming from vessels without valid licenses.

Assessment of Peruvian controls

The controls introduced in Peru have resulted in the sustainability of Peru's fisheries and marine ecosystem recently being ranked as the best in the world by Mondoux *et al.* (2008). Since this assessment Peru has undertaken further improvements including the introduction of Maximum Limits of Capture per Vessel (MLCV), a form of catch share, introduced in 2009 (Legislative decree 1084). This changed the system from what had been until then a competitive race among fishing vessels to each secure as much as possible of that fishing season's total permitted catch for the whole fleet.

This change has shown a considerable number of benefits. For the 2009 fishing season a Total Maximum Limit of Permissible Capture (TMLPC) of 2 million tonnes for the whole fleet was set; this was then distributed as MLCVs amongst the fishing vessels with a valid fishing permit. MLCVs were assigned to 1,147 fishing vessels. However, only 886 fishing vessels were active during this season, a reduction in 23 percent of the hold capacity and the number of fishing vessels compared with a year earlier.

The fishing effort was sustained for 87 days in 2009/2010 compared with only 19 days in 2008, 25 days in 2007, 21 days in 2006 and 50 days in 2005. In comparison to 2008, there was a significant reduction in the average number of fishing vessels active each day and also on the average number of landings of anchovy each day, down by 70 percent and 72 percent respectively (Table 2). This reduction improved the freshness of the raw material which increased the price of the anchovy, benefiting the fishermen, and also improved the quality of the final products.

TABLE 2
The impact of MLCVs on landings and fishing days

Indicator	Seasons 2008			Seasons 2009			Difference
	1st	2nd	Total	1st	2nd	Total	2008/2009
LMTCP metric tonnes	3 000 000	2 000 000	5 000 000	3 500 000	2 000 000	5 500 00	10%
Landings metric tonnes	3 147 954	2 136 205	5 284 159	3 419 379	1 961 449	5 380 828	2%
Days Fishing	33	19	52	102	87	189	263%
Av FV/day**	836	901	860	280	233	258	-70%
Av Auth Cap/day* metric tonnes	159 415	166 285	161 925	54 089	47 511	51 061	-68%
Av Landings/day metric tonnes	95 393	112 432	101 618	33 523	22 545	28 470	-72%

** Average Number of Vessels fishing per day.
* Average total of Authorised Capacity fishing per day.
Source: Peruvian Ministry of Production.

The outcome of all these improvements is that the high quality of Peruvian management of the anchovy fishery is now becoming better recognised internationally when compared using criteria from the FAO Code of Conduct for Responsible Fisheries. The FAO Code is however under some criticism for not having a full ecosystem approach. Meanwhile, Peru has launched a project called Peru Ecosystem Projection Scenarios (PEPS), which will evaluate the impact of fisheries on parts of the ecosystem. Already started are projects looking at how a warmer world may affect atmospheric forcing and oceanic circulation and productivity; how setting aside five million tonnes from spawning stock would affect the ecosystem; and sea bird and sea lion population monitoring as indicators of the interaction between anchovy stocks and numbers of higher predators. Marine Protected Areas are also to be implemented.

CURRENT SUPPLY TRENDS

Maximising the proportion of feed fish sold for human consumption

There is no definitive list of 'feed species' or fisheries – most of them are edible and provide nutrition to humans. However, many of the species used to manufacture fishmeal and fish oil are small, bony, not very palatable or unfamiliar to consumers; or the logistics of transporting them to markets in good condition and at realistic price levels have been problematic. Small pelagic fish, such as anchovy, deteriorate rapidly in unrefrigerated holds or storage. Lack of investment in processing facilities (for human consumption) has also restricted the opening up of human consumption markets. For some other species, such as herring in the North East Atlantic, that part of the catch that is not supplied into its usual human consumption market, has been diverted to produce fishmeal. Later in this chapter the efficiency of feeding wild caught fish to farmed fish is addressed, but there is an *a priori* argument that fish should go for direct human consumption wherever possible since, other things being equal, this is usually the higher value use. As regards ethical considerations, Wijkström (2009) has recently criticised the view that making fishmeal for feeding to fish is wrong if the purpose is to maximise food production, arguing that it gives no weight to the economic realities or food preferences that govern the use of fish.

Traditionally fishmeal factories have often been located alongside canning and freezing factories, to process and pack fish for human consumption. If fish could find a market for human consumption, the fish took the canning or freezing route. For the last five to ten years there has been increased effort put into finding a human consumption outlet for what were previously regarded as feed fish by means of:

- investment in processing facilities and adding value by government and industry;
- new product development (such as surimi);
- more even landings through introduction of catch share schemes, as opposed to alternating glut and shortage;
- national or international food aid schemes;
- improved handling and methods of preserving the catch in good condition.

Norway reports an increasing proportion of its catch of capelin, herring and blue whiting going for human consumption; and Denmark similarly with herring and blue whiting. In Chile there has been a large rise in the proportion of jack mackerel and chub mackerel catch going for human consumption with some processors finding human consumption outlets for more than half their output and exporting mackerel products to dozens of countries.

Recently the Peruvian government has been actively encouraging the development of a local market for the direct human consumption of anchovy. As a result there has been considerable investment in the processing and distribution of anchovy throughout the country and particularly into the poorer areas in the mountains. Sales of anchovy for human consumption in both local and export markets are expected to grow. However, in relative terms, the volumes are likely to remain fairly small and will not greatly affect the output of fishmeal and fish oil. For example, in 2009, approximately 120 000 tonnes (2 percent) of Peruvian anchovy went for human consumption (Peruvian Ministry of Production, 2009).

Increased production of fishmeal and fish oil from processing by-products (wild and farmed)

Globally in 2009 about 25 percent of fishmeal and fish oil was produced from by-products and this proportion has been rising steadily in recent years, by about 1–2 percent per annum (source: IFFO estimates).

Table 3 is a country-by-country estimate of fishmeal production from by-products (frames, offal, trimmings) for 2008 with the largest such producers being Thailand, Japan, and Chile (in that order). The factors which encourage by-product based production include reliable local availability of offals from seafood processing, local demand from fish feed factories, and favourable logistics. For example, Chilean seafood factories processing for human consumption markets are frequently integrated with fishmeal production plants; fresh offals and off-cuts, which have no commercial value for human consumption, are diverted direct to the fishmeal intake channel. On the other hand Alaskan processors of Pollock for human consumption often have difficulty manufacturing fishmeal and fish oil cost-efficiently because of problems of seasonality, lack of geographical concentration, lack of local demand etc., despite the large size of the pollock fishery. Local year round demand for fishmeal from neighbouring animal and fish feed plants has encouraged by-product utilisation and there is also an increasing use of aquaculture processing by-products as raw materials, although most countries have regulations prohibiting such material from being recycled back to the same species.

TABLE 3
Estimate of global production by-product fishmeal, 2008

Country	Total Fishmeal Production ('000 tonnes)	By-Product Coefficient (%)	By-product Fishmeal Production ('000 tonnes)
Angola	5.3	50	2.7
Argentina	50.0	55	27.5
Australia	14.0	50	7.0
Brazil	42.5	22	9.4
Cambodia	3.0	60	1.8
Canada	31.2	100	31.2
Chile	673.3	14	94.3
China	141.0	5	7.1
Denmark	161.3	20	32.3
Ecuador	48.0	14	6.7
Faroe Islands	44.4	5	2.2
Finland	3.6	70	2.5
France	13.7	100	13.7
Germany	19.0	100	19.0
Iceland	140.9	32	45.1
India	19.3	5	1.0
Indonesia	15.0	30	4.5
Iran	29.8	30	8.9
Ireland	19.3	40	7.7
Italy	4.3	100	4.3
Ivory Coast	1.0	60	0.6
Japan	202.9	90	182.6
Korea (Rep)	49.6	20	9.9
Lithuania	22.0	20	4.4
Malaysia	44.2	40	17.7
Maldives	2.0	80	1.6
Mauritius	5.0	60	3.0
Mexico	105.8	50	52.9
Morocco	78.0	15	11.7
Namibia	12.5	100	12.5
New Zealand	27.0	10	2.7
Norway	135.0	22	29.7
Pakistan	56.2	20	11.2
Panama	55.2	10	5.5
Peru	1 396.1	2	27.9
Poland	22.4	40	9.0
Russian Fed.	71.0	50	35.5

TABLE 3
Estimate of global production by-product fishmeal, 2008 (continued)

Country	Total Fishmeal Production ('000 tonnes)	By-Product Coefficient (%)	By-product Fishmeal Production ('000 tonnes)
Senegal	4.3	100	4.3
Seychelles	20.0	70	14.0
South Africa	83.8	10	8.4
Spain	20.0	100	20.0
Sweden	23.6	50	11.8
Taiwan	18.2	70	12.7
Thailand	468.0	60	280.8
U.K.	42.0	70	29.4
U.S.A.	216.2	25	54.1
Vietnam	45.9	50	23.0
Total 47	4 706.8		1 205.6
Others	111.2	20	22.2
Total world	**4 818.0**	**25%**	**1 227.9**

Increased pressure to convert trash fish to fishmeal and fish oil in South East Asia

More than five million tonnes of low value fish is used for animal feed each year in South East Asia and is reviewed by Funge-Smith *et al.* (2005). Most of this material has been fed directly to pigs, poultry and, increasingly, to farmed fish. This practice is now being discouraged because of poor storage qualities and high levels of wastage at feeding. In its place fish farmers are increasingly using pelletted feed, including varying proportions of fishmeal and fish oil.

Overview of current supply trends

IFFO expects production of fishmeal and fish oil to remain broadly static, or to decline slightly, over the next five to 10 years. Initiatives, often led by governments, to protect and preserve stocks and to maximise the quantity of feed fish being sold for direct human consumption will have a broadly negative effect on production volumes; while increased production from the by-products of wild caught and farmed seafood processing plus the replacement of 'trash fish' feed with manufactured pellets will have a balancing positive effect (Table 4). This does not take account of the likely market entry of long chain omega-3 oils derived from algal production and from genetically modified plants within the next 5 to 10 years.

TABLE 4
Forecast supply trends, 2010–2020

Forecast supply trend	Impact on production
Rigid application of stock conservation controls based on the precautionary principle	Broadly negative
Maximising the proportion of feed fish sold for human consumption	Negative
Increased production of fishmeal and fish oil from processing by-products (wild and farmed)	Positive
Replacement of direct 'trash' fish feeding in aquaculture feeds with pelletted feed (including fishmeal and fish oil)	Positive
Overall	Static or slightly declining

Source: IFFO

CURRENT DEMAND TRENDS

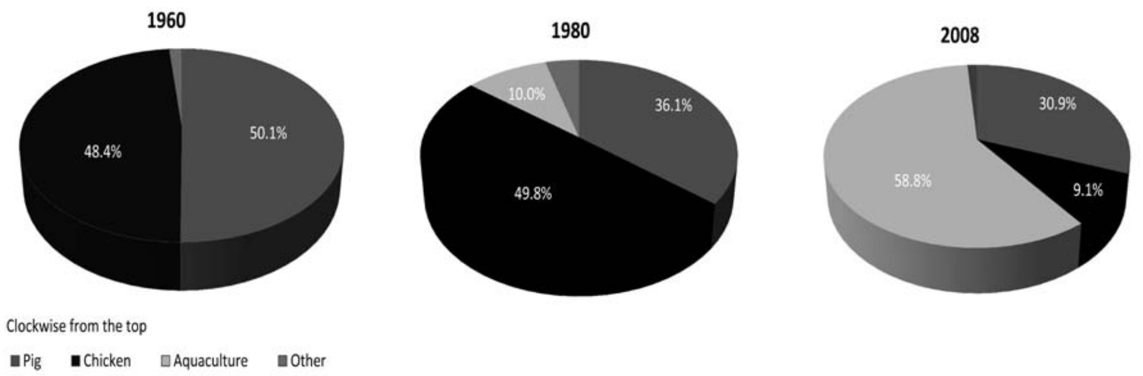
Move from 'Agri' to 'Aqua' during 1960 to 2005

Current demand issues should be considered against a background of the dramatic changes which have occurred in the pattern of global fishmeal and fish oil consumption in the last thirty to forty years, both in terms of the sectors in which they were used and geographically.

Figures 5 and 6 summarise the changes by sector according to IFFO estimates. In 1960 98.5 percent of fishmeal was used in chicken and pig feeds. By 2008, this had shrunk to 40 percent and aquaculture had taken over as the major user at 60 percent. For fish oil the switch has been from hardened edible (margarine) used at 80 percent of consumption in 1970 to 80 percent use in aquaculture by 2010. Two things happened simultaneously, one was a move from hard margarines made from hydrogenated fats to vegetable margarines, principally on the evidence of reduced heart disease, and secondly there was a rapid growth in aquaculture over this period, particularly salmon which require a high oil diet. Thus the use of hydrogenated fat was severely reduced in the United States and Europe, which happened to coincide with the rapid growth in salmonid production, providing a new outlet for fish oil. Figures 7 and 8 show detail by species on use in aquaculture.

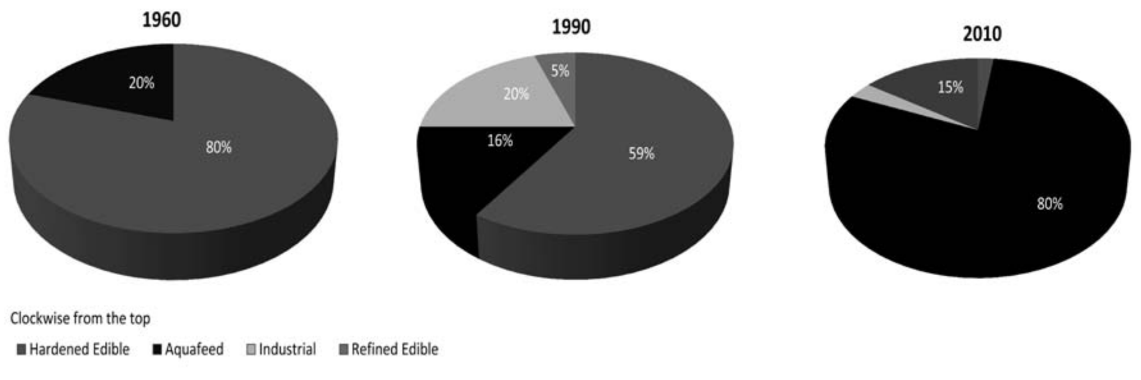
Also of note is the growth, from near zero in 1970 to an estimated 15 percent of production by 2010, in refined edible oil for human consumption, which includes fish oil supplements and additives.

FIGURE 5
Changing uses of fishmeal



Source: IFFO estimates.

FIGURE 6
Changing uses of fish oil



Source: IFFO estimates.

FIGURE 7
Use of fishmeal in aquaculture, 2008

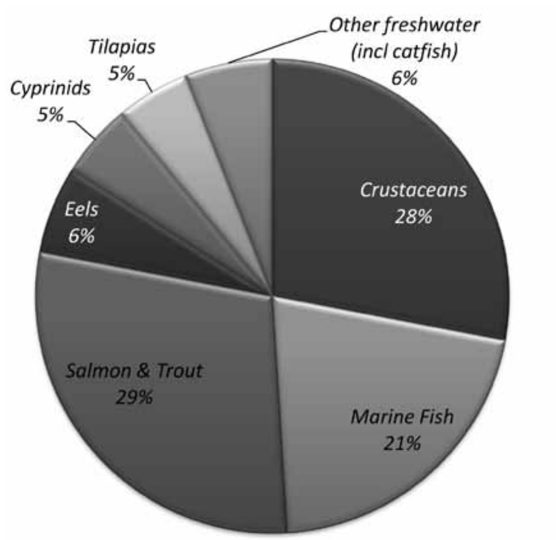
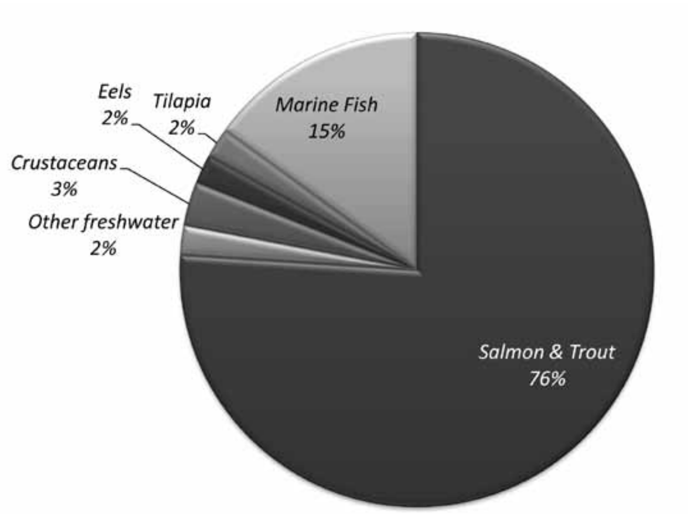


FIGURE 8
Use of fish oil in aquaculture, 2008



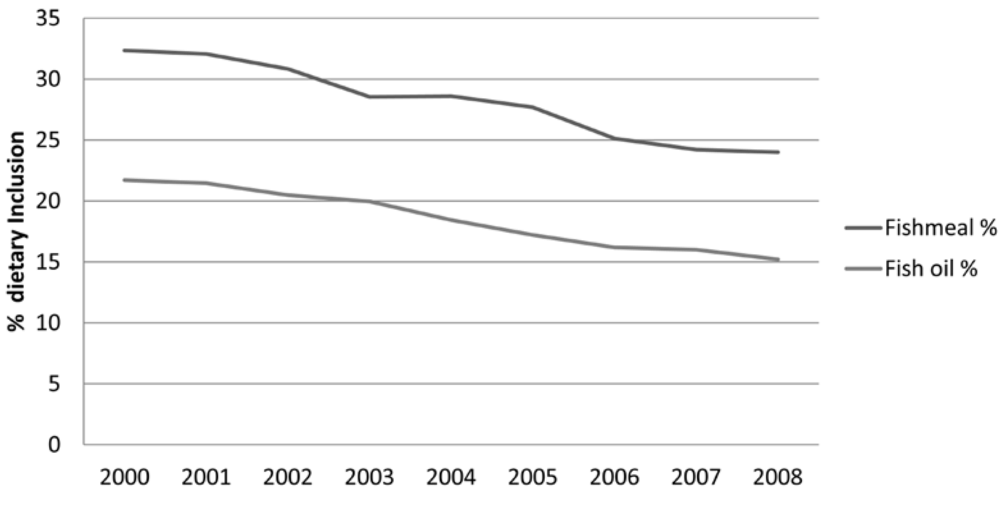
Currently then, the rapidly expanding aquaculture sector is the major user of both fishmeal and fish oil. This has led to concerns that the continued growth of aquaculture could be constrained by a shortage of fishmeal and fish oil or else lead to unsustainable fishing to meet the demand (Naylor *et al.*, 2009). These concerns are discussed further later.

Current trends in consumption – reducing dietary inclusion levels

The aquafeed industry has recognised for some time that supplies of fishmeal and fish oil were finite and now appear limited to a range of approximately 5–6 million tonnes and 1–1.5 million tonnes per annum, respectively. Extensive research has been undertaken to identify and introduce alternative sources of lipids and protein, particularly for the more intensively farmed species with a longer history of being farmed, such as salmonids and shrimp. The result is that the proportion of marine ingredients in salmonid diets has been progressively reduced by feed formulators since 2000 (Figure 9). Where technology and cost considerations have allowed, fishmeal has been increasingly substituted by soybean meal and land animal proteins, whereas fish oil has been increasingly substituted by vegetable oils, mainly rapeseed oil. This trend is likely to continue as nutritional knowledge and processing technology increases and has occurred in both chicken and pig diets. These two species, which in 1960 consumed almost 100 percent of the world's fishmeal production, have achieved phenomenal growth in production over the last 50 years but now use under 40 percent of the world's fishmeal production. It should be noted that dietary inclusion in chickens is now largely restricted to chicks in the first day or two after hatching and is largely restricted in piglets to the period during and immediately after weaning.

Judging from the pattern of substitution, it seems likely that marine ingredients will be used more and more strategically at critical stages in the life cycle of both fish and farmed land animals, where their health, welfare and nutritional properties are especially beneficial and valuable, for example in weaner feeds for young pigs and in hatchery feeds for farmed fish fry and fingerlings. Thus it is not usually nutritionally necessary or cost-effective to feed fishmeal in broiler chickens or fattening pigs. Also the growing evidence for the role played by the long-chain omega-3 fatty acids EPA and DHA, found almost exclusively in marine oils, will ensure that there is a continuing demand for including fish oil in the diets of farmed fish (particularly salmonids) to ensure health giving properties for the final consumer. The link in humans between sufficient intake of these two omega-3 fatty acids and healthy hearts and brain development is now well established and there is a growing body of evidence indicating their health benefits with respect to other conditions (Ruxton *et al.,* 2004).

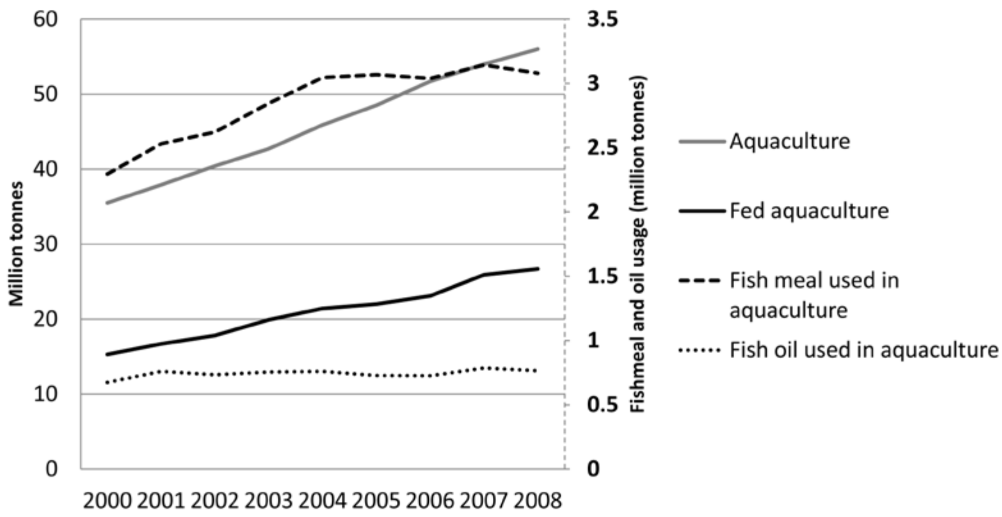
FIGURE 9
Inclusion levels of marine ingredients in salmonid diets, 2000–2008



The result of lower inclusion levels of fishmeal and fish oil in aquaculture diets has been a levelling off the total global consumption of these two products by the aquaculture sector. Figure 10 shows that while overall aquaculture production continues to grow, the use of fishmeal for aquaculture rose during the period 2000 to

2004 and then reached a plateau at about 3.1 million metric tonnes. This compares with total fishmeal supply in 2008 of approx 4.9 million metric tonnes (the balance being taken up mainly by pigs and poultry). It can be seen that the annual use of fish oil for aquaculture over the period 2000 to 2008 remained fairly constant at between 700 000 and 800 000 metric tonnes compared with a total annual supply of around 1 million metric tonnes.

FIGURE 10
Global aquaculture production with fishmeal and fish oil usage, 2000–2008

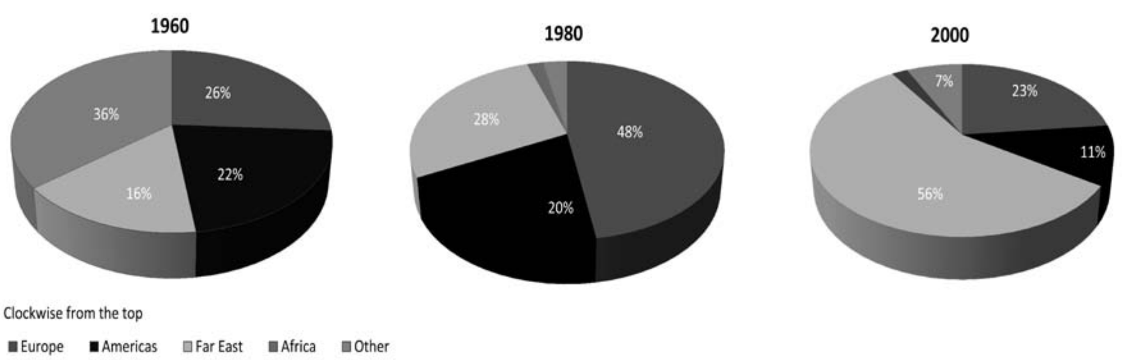


Source: Data FAO and IFFO.

Fishmeal usage moving to Asia

Equally there has been a large change in the geographical pattern of consumption as shown in Figure 11 comparing 1960, 1980 and 2000. As intensive aquaculture has grown in China and South East Asia, this area has become the dominant user of fishmeal. This trend will undoubtedly be maintained because of the rapid modernisation of intensive livestock production in order to meet the demand for animal protein by an increasingly affluent oriental population with a keen demand for pork and fish.

FIGURE 11
Changing pattern of global fishmeal consumption, 1960–2000

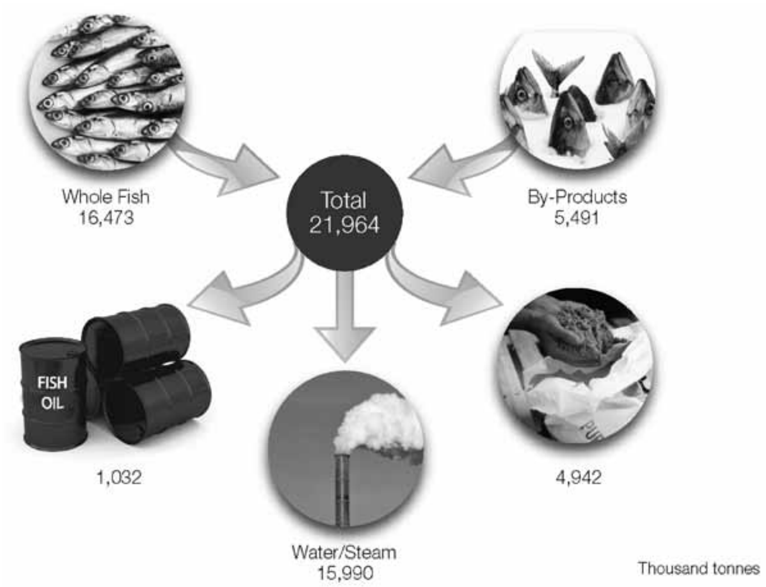


Souce: IFFO estimates.

Efficiency of transformation of wild feed fish via aquaculture into fish and other seafood for human consumption

In the wild it is generally considered that salmon consume around 10 kg of prey fish to produce 1 kg of live weight gain. Under farming conditions this ratio of 10:1 is considerably improved, but there has been considerable debate as to the best way to calculate this ratio. Tacon and Metian (2008) produced estimates that in 2006 farmed salmon required 4 or 5 kg of wild fish, in the form of fishmeal and oil in their feed, to achieve each kilogram of weight gain. Focus on this high Fish-in/Fish-out (FIFO) ratio for salmonids and other species has been cited in questioning the eco-efficiency of expanding aquaculture to increase supplies of seafood.

FIGURE 12
Mass balance for fishmeal and fish oil



Jackson and Shepherd (2010) demonstrated, by means of a mass balance model for the transformation of wild fish to fishmeal and fish oil and its subsequent use in aquaculture feeds, that the method used by Tacon and Metian gave much higher values than those calculated with this alternative method. The results of the mass balance calculations are given in Figure 12 and Tables 5, 6 and 7. The output shows that in 2008 just under 22 million tonnes of raw material, comprising 16.47 million tonnes of harvested whole fish and 5.49 million tonnes of by-products, were processed into fishmeal and fish oil. The by-products are frames, guts, skin etc from the processing of whole wild and farmed fish and other seafood for human consumption. These inputs yielded 4.94 million tonnes of fishmeal, 1.03 million tonnes of fish oil and 15.99 million tonnes of water. The water obviously remained at the site of production released as water or steam.

Table 5 and Table 6 are the result of analysing where the outputs, respectively and separately, of fishmeal and fish oil are used, and of the amount of raw material and whole fish that can be attributed to each activity. The resulting whole fish attribution is then used to calculate a Fish-in/Fish-out ratio (FIFO) for each 'fed' aquaculture activity, using the definition of fed aquaculture used by Tacon (Tacon, 2005). These two tables show clearly why looking at fishmeal and fish oil attribution separately gives a distorted view. For example, it can be seen that, according to Table 6, to produce the

120 000 metric tonnes of fish oil going for direct human use, such as capsules, required over 2 million tonnes of fish. Whilst being correct, this implies that the fish were caught only for their oil, which is not the case because nearly five times the amount of meal is extracted as oil.

TABLE 5
Fishmeal used in farmed production and the resultant whole fish FIFO[1] ratio (thousand tonnes)

	Fishmeal	Raw material	Whole Fish	Farmed production)	FIFO[1]
Chicken	440	1 957	1 468	N/A	N/A
Pig	1 263	5 613	4 210	N/A	N/A
Other Land Animals	160	711	533	N/A	N/A
Crustaceans	786	3 494	2 621	4 673	0.56
Marine Fish	738	3 281	2 461	2 337	1.05
Salmon & Trout	916	4 069	3 052	2 365	1.29
Eels	186	825	619	244	2.53
Cyprinids	130	577	433	13 037	0.03
Tilapias	143	636	477	2 737	0.17
Other Freshwater	180	800	600	2 102	0.29
Aquaculture Sub-total	3 079	13 683	10 262	27 495	0.37
Total	4 942	21 964	16 473		

[1] FIFO = Fish-in/Fish-out ratio

TABLE 6
Fish oil used in farmed production and the resultant whole fish FIFO[1] ratio (thousand tonnes)

	Fish oil	Raw material	Whole Fish	Farmed production	FIFO[1]
Human Consumption	126	2 689	2 017	N/A	N/A
Other uses	110	2 340	1 755	N/A	N/A
Crustaceans	28	589	442	4 673	0.09
Marine Fish	115	2 455	1 841	2 337	0.79
Salmon & Trout	604	12 857	9 642	2 365	4.08
Eels	15	320	240	244	0.98
Cyprinids	1	24	18	13 037	0.00
Tilapias	18	376	282	2 737	0.10
Other Freshwater	15	313	235	2 102	0.11
Aquaculture Sub-total	796	16 934	12 700	27 495	0.46
Total	1 032	21 964	16 472		

[1] FIFO = Fish-In/Fish-out ratio

Given that both fishmeal and fish oil currently yield about the same revenue per tonne (US$1 000–1 500/tonne), the fishmeal and fish oil are therefore equally valued today and equally important in determining the profitability of the enterprise. It therefore seems logical to combine the fishmeal and fish oil production and conduct a full mass balance analysis of the global system for their production. Table 7 is the result of such a mass balance analysis which accounts for all raw materials entering the system and the resulting outputs (meal, oil and water) and their attribution to each destination activity.

Taking fed aquaculture alone it can be seen that, if the inputs and outputs are compared by species, 27.49 million tonnes of fed aquaculture were produced in 2008 using feed derived from 10.68 million tonnes of whole wild fish representing a Fish-in/Fish-out ratio of 0.39:1. This is further broken down to show the corresponding ratios for species groupings, ranging from 2.26:1 for farmed eels down to 0.03:1 for carp, with salmonids at a ratio of 1.77:1. It should be noted that this mass balance approach gives FIFO ratios that are lower than those calculated by Tacon and Metian (2008) using the single ingredient approach.

TABLE 7
Mass Balance for Fish oil & Fishmeal combined including overall whole fish FIFO[1] ratio (thousand tonnes)

	Fish oil	Fishmeal	Water	Total Raw material	Whole Fish	Farmed production	FIFO[1]
Chicken	0	440	1 178	1 619	1 214	N/A	N/A
Pig	0	1 263	3 380	4 643	3 482	N/A	N/A
Other Land Animals	0	160	428	588	441	N/A	N/A
Other oil uses	110	0	294	404	303	N/A	N/A
Human Consumption	126	0	337	463	347	N/A	N/A
Crustaceans	28	786	2 178	2 992	2 244	4 673	0.48
Marine Fish	115	738	2 285	3 138	2 354	2 337	1.01
Salmon & Trout	604	916	4 069	5 588	4 191	2 365	1.77
Eels	15	186	537	738	554	244	2.26
Cyprinids	1	130	350	481	361	13 037	0.03
Tilapias	18	143	430	591	443	2 737	0.16
Other Freshwater	15	180	521	716	537	2 102	0.26
Aquaculture Sub-total	796	3 079	10 371	14 246	10 684	27 495	0.39
Total	1 032	4 942	15 990	21 964	16 473		

[1] FIFO = Fish-in/Fish-out ratio

Salmonid's FIFO ratio is not only lower than has previously been suggested, but it is steadily declining (Fig 13), from 2.5 in 2001 to 1.8 in 2008. During the same period the ratio for all aquaculture reduced from just over 0.5 to 0.39. The main reason for this trend is the substitution of fishmeal and fish oil by other ingredients, notably soybeans and rapeseed oil.

Estimates can also be made as to the amount of whole wild fish that are being used in different food production sectors (Figure 14). Here it can be seen that over recent years there has been a steady decline in the amount of whole fish which has gone for rendering, falling from around 23 million tonnes in 2000 to about 16.5 million tonnes in 2008. The biggest reduction has been in the amount of whole fish going to the pig and poultry industry while, as already discussed, volumes going to the aquaculture industry have remained fairly constant over the last five years.

FIGURE 13
FIFO 2000–2008 for farmed Salmonids, based on whole rendered fish

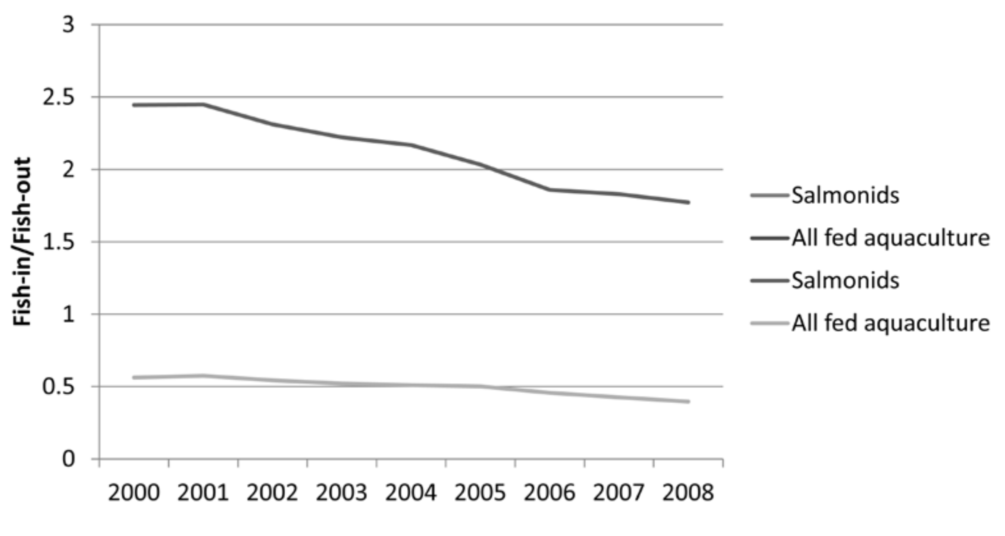
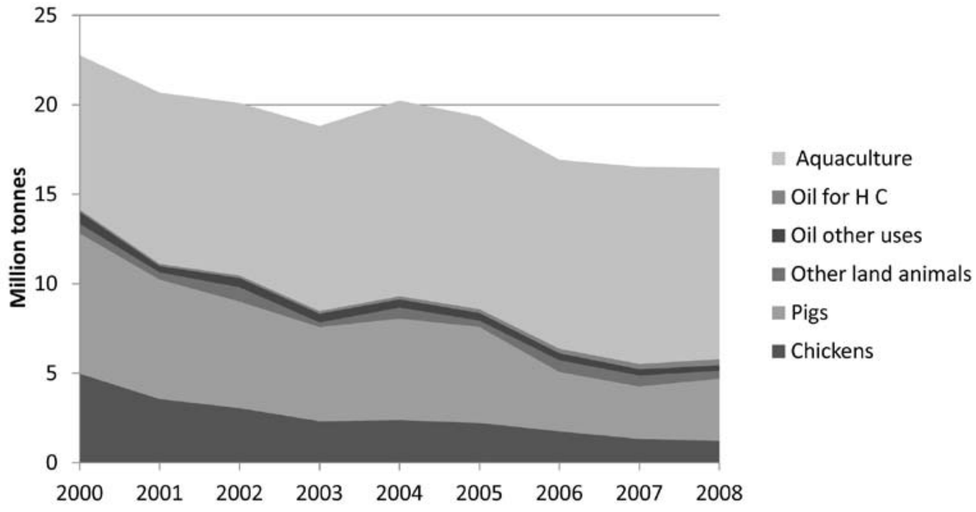


FIGURE 14
Global use of rendered whole fish



Reassuring the value chain about fisheries management

Supermarkets, processors and wholesalers wish to be able to reassure their respective customers that seafood and animal products are responsibly sourced and supplied. The FAO Code of Conduct for Responsible Fisheries is the only internationally recognised measure of good fisheries management and is therefore the commonest reference point for accreditation programmes.

There are a number of such initiatives in the fisheries and aquaculture sectors – some already operational, including those from Global Gap, Friend of the Sea, Best Aquaculture Practice (from the Global Aquaculture Alliance), and the Marine Stewardship Council – and others in the pipeline – such as the Aquaculture Stewardship Council. All of these audit to a Standard and grant certified status. Some of these are consumer ecolabels and others are focused on business-to-business reassurance of good and responsible practice.

None of these has addressed the needs of the fishmeal and fish oil producers both to be able to demonstrate responsible sourcing (from well managed fisheries) and responsible production of safe and pure products. Only small quantities of fishmeal are available so far from MSC certified fisheries. In 2009 IFFO therefore launched its own Global Standard for Responsible Supply (the IFFO RS) and associated certification programme for fishmeal and fish oil factories. In order to ensure that the Standard and programme reflected the needs of all stakeholders, they were developed by a multi-stakeholder Technical Advisory Committee, including representatives of producers and traders of fishmeal & fish oil, fish feed producers, fish farmers, fish processors, retailers and environmental NGOs. The unit audited is the factory. The programme opened to applications from October 2009 and the first factory was awarded certification in February 2010. Supplies of fishmeal and fish oil from factories, which had been independently audited and certified as complying with the IFFO RS, first came on to the market in 2010. Forty seven factories in four countries, representing approx 25 percent of world production, had been approved by 31st August 2010. This progress suggests that the IFFO RS programme will form the first link in a fully certified aquaculture supply chain.

Key features of the IFFO RS are:

- It is a business-to-business certification programme that enables a compliant factory to demonstrate that it responsibly sources its raw material from well managed fisheries and responsibly converts that into safe products free from cross contamination.
- Whole fish used must come from fisheries that have been independently scientifically assessed and meet the key principles of the FAO Code of Conduct for Responsible Fisheries – the only internationally recognised measure of good fisheries management. Illegal, unreported and unregulated (IUU) fish are excluded.
- Applicants must demonstrate that they manufacture under a recognised quality control scheme to ensure product safety and purity whilst also maintaining product traceability
- All applications are assessed through audits against the IFFO RS standard by an independent ISO 65:1996 accredited certification body
- The Certification Committee, which reviews all audit reports, comprises a retailer, a processor, an environmental NGO, and one IFFO representative
- The IFFO programme recognises other certification programmes which have demonstrable equivalency and which are accepted within the industry e.g. Marine Stewardship Council (MSC) for the fishery element.

The IFFO RS is in continuous development. During 2011 IFFO expects to add a fisheries by-product module and is also evaluating and developing an emissions and effluent module, as well as an Improvers' Programme.

The development of an Improvers' Programme relates to concern that factories in some countries will find the IFFO RS Standard difficult to achieve, yet there is a will to raise standards. IFFO does not wish to dilute the IFFO RS Standard but hopes to work with manufacturers and government as well as other international bodies, such as the FAO and World Bank, which can provide access to capital funds for investment in factories and fisheries management. The approach will be to identify areas of non-compliance, and develop a structured programme of continuous improvement with agreed milestones along a defined timeline towards a final goal of certification to the IFFO RS Standard (IFFO, 2010).

Summary and implications of future trends

To sum up, it seems likely that current global supplies of fishmeal and fish oil will not increase beyond current annual production levels in the region of 5 million tonnes and 1 million tonnes respectively and may reduce to a limited extent. Aquaculture feeds are the main use of fishmeal and fish oil and world 'fed' aquaculture production continues to rise; however, the ceiling on supply of marine ingredients and their reducing dietary inclusion levels because of substitution, has resulted in a levelling off of total annual consumption since 2004 and 2001 of fishmeal and fish oil respectively. Increased fishmeal market share for aquaculture feeds (today approximately 60 percent) versus land animal feeds (today approximately 40 percent) is likely to come about only if aquaculture is prepared to pay more than agriculture (especially for the weaner piglet feed market). The fish oil market is even more dominated by aquaculture feeds (today approximately 80 percent), especially for salmonid farming; however, the growth rate of salmonid culture is slowing and dietary inclusion levels for fish oil are reducing because of substitution with vegetable oils. This trend is expected to continue, whereas we have recently seen the emergence of a high omega-3 segment to supply the human health market; this is a higher value segment and today represents a market share of c 20 percent by volume. The likelihood is that the human health market will continue to increase market share versus aquaculture feeds in volume and value. Another important factor in this market place will be the probable introduction of algal- and GM-derived competitors to EPA and DHA which, price permitting, could be used for both feed and human nutraceutical purposes.

Overall the fishmeal and fish oil markets are expected to remain scarcity-driven with price volatility due to supply fluctuations against a background of continuing demand pressures, driven in particular by increased food production in Asia. Traditionally used as feed commodity raw materials, marine ingredients are now being increasingly fed strategically at critical stages of the life cycle in farming fish and land animals or alternatively in the manufacture of added value speciality products for the human nutritional and pharmaceutical markets.

It is clear that as finite live natural resources, fish stocks supplying fishmeal and fish oil must be managed responsibly to ensure a sustainable future for the industry. Also it is important that producers are able and willing to demonstrate responsible practice in sourcing and production; in this regard the recent trend towards seeking third party audited certification is likely to increase and is to be welcomed. Provided the industry is sustainable, the evidence presented indicates that nutritional innovation to enable (at least) partial substitution, together with increasing price, means the market will continue to reallocate marine ingredients to the highest value market, rather than creating shortages which would curb continuing expansion of aquaculture and land animal production.

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Health benefits of bio-functional marine lipids

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INTRODUCTION

The importance of marine polyunsaturated fatty acids (PUFAs) phospholipid of n-3 series specially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), in human nutrition is becoming recognized (British Nutrition Foundation, 1992). N-3 PUFAs such as EPA and DHA have many biological functions. Sphingolipids are other functional lipids that are found in all eukaryotic cells. The complex sphingolipids consist of a long chain sphingoid-base, usually sphingosine, which is acylated at the 2-amino position, forming a ceramide. In sphingomyelin (SM), a phosphatidylcholine is bound to the 1-ol position of ceramide, while a mono- or an oligosaccharide is found in this position in the glycosphingolipids. Thus, sphingolipids can be expected in minor amounts in all food products. They act as intracellular messengers, being involved in cell cycle regulation and induction of apoptosis (Hannun *et al.*, 2000; Huwiler *et al.*, 2000). Glycolipids also play certain physiological roles such as regulation of protein kinase activity and inhibit tumour cell growth (Jennemann *et al.*, 1990). Glycolipids are usually rare in terrestrial plants and animals but are present in relatively large amounts in some species of marine algae (Richmond, 1990). Monogalactosyl diacylglycerol (MGDG), Digalactosyl diacylglycerol (DGDG) and Sulfoquinovosyl diacylglycerol (SQDG) are known as important biofunctional glycolipids.

These marine lipids have been applied in a variety of fields such as biochemistry, food technology, cosmetics etc. Beside these industries, scientists identified their potential application in pharmaceutical sciences. Recently, there has been a growing interest in the ingestion of n-3 fatty acids in the treatment of cancer (Karmali, 1996). Since the 1990s, marine complex lipids are being recognized as useful complex lipids for health care purposes. In this article, the focus will be on the sources and health benefits of marine lipids.

SOURCES FOR MARINE LIPIDS

Marine Phospholipids

Marine fishes are rich in PUFAs inserted EPA and DHA. Krill oil also contains phospholipids that have a naturally high content of EPA and DHA. The oil also contains other nutrients considered essential for the human body. The sources of DHA and EPA in marine fishes are shown in Table 1.

Krill are tiny open ocean crustaceans and are found in very large quantities. They are rich in n-3 PUFAs. Other sources of marine lipids that are rich in DHA inserted phospholipids are squid skin, muscle, connective tissues, and the gonads of marine animals. A recently identified source for EPA inserted phospholipids is starfish (*Asterias amurensis*). A notable feature is that starfish is not only rich in EPA inserted phospholipids but also rich in cerebroside, an extremely useful material for cosmetics. Starfish eat scallop and fish in the sea. Set nets are also often damaged by starfish. Though starfish are a nuisance for fisherman, they are rich in useful complex lipids. For example, cerebroside content in starfish is approximately 0.1–0.2 percent and phospholipid content is 0.2–0.3 percent. The fatty acids composition of squid and starfish phosphatidylcholine is shown in Table 2 (Hossain *et al.,* 2006).

TABLE 1
Sources of EPA and DHA in different marine fishes

Fish/Seafood	Total EPA/DHA (mg/100 g)
Mackerel	2 300
Chinook salmon	1 900
Herring	1 700
Anchovy	1 400
Sardine	1 400
Coho salmon	1 200
Trout	600
Spiny lobster	500
Halibut	400
Shrimp	300
Catfish	300
Sole	200
Cod	200

Source: USDA Nutrient Database www.nal.usda.gov/fnic/foodcomp/search/

TABLE 2
Fatty acid composition of soy, squid meal and starfish phosphotidylcholine

Fatty acid	Soy PC (%)	Squid meal PC (%)	Starfish PC (%)
C 16:0 (Palmitic acid)	12.5	35.2	3.4
C 18:0 (Stearic acid)	0.2	1.3	9.5
C 18:1 (Oleic acid)	14.8	2.4	6.7
C 18:2 (Linoleic acid)	63.4	1.0	—
C 20:1 (Eicosenoic acid)		0.4	11.4
C 20:4 (Arachidonic acid)		1.0	5.6
C 20:5 (EPA)		9.2	47.3
C 22:5 (Docosapentaenoic acid)		—	1.5
C 22:6 (DHA)		42.6	8.3

Marine Sphingolipids

The physiologically active substances including glycosylceramides and some related compounds are found in a variety of sea cucumber species (Yamada, 2002; Yamada *et al.,* 2003). Dry sea cucumber contains approximately 200 mg cerebroside per 100 g dry weight (Sugawara *et al.,* 2006). Glycosylceramides used for food ingredient have been isolated from some plant sources, but their content is very low (1–40 mg/100 g dry weight, Sugawara and Miyazawa, 1999). Thus, sea cucumber might be a suitable dietary source of sphingolipids. However, the sphingoid base structures in sea cucumber are more complicated than those in mammals and there is little information about food function of these sphingoid bases, which are not found in mammals. The fatty fishes contain relatively high amounts of glycosphingolipids. Salmon contains 114 nmol glycosphingolipids/g and herring 88 nmol/g, indicating that fatty fish are among the richest sources of dietary glycosphingolipids (Hellgren, 2001). Sphingolipids were extracted and quantified from Pacific saury (*Cololabis saira*). Sphingomyelin in different tissues of *C. saira* ranged from 2.5 mg/g to 27.6 mg/g, the content in brain was the highest, followed by eyes, and ceramide monohexoside content was less than 23.0 mg/g in all tissues (Duan *et al.,* 2010).

Marine Glycolopids

Brown algae, especially *Sargassum horneri*, are a very good source of glycolipids (Hossain *et al.,* 2003). Glycoglycerolipids are glycolipids in which one or more saccharide residues are linked by a glycosyl linkage to a lipid moiety containing a glycerol residue. They constitute an important class of membrane lipids that are synthesized by both prokaryotic and eukaryotic organisms (Kates, 1990a, 1990b). Algae represent valuable sources of a wide spectrum of complex lipids with different potential applications. The lipids containing PUFAs are especially interesting in various applications. Some of these compounds are usually rare in terrestrial plants and animals but are present in relatively large amounts in some species of algae and fish (Caughey *et al.,* 1996). They have beneficial effects on heart diseases, Parkinson's disease, multiple sclerosis, inflammatory diseases, premenstrual syndrome, plasma cholesterol levels, cancer and others (Rodriguez and Guerrero, 1992). Glycolipids (MGDG, DGDG and SQDG) were 1.96 percent of dry sample of marine brown algae (*S. horneri*). The major fatty acids composition of MGDG, DGDG and SQDG are shown in Table 3 (Hossain *et al.*, 2003).

TABLE 3
Fatty acid profiles of monogalactosyldiacylglycerol (MGDG), digalactosyldiacylglycerol (DGDG) and sulfoquinovosyl diacylglycerol (SQDG) of the brown alga *Sargassum horneri*

Fatty acid	%		
	MGDG	DGDG	SQDG
C14:0	3.04	1.5	3.1
C16:0	14.79	12.0	41.6
C16:1	2.87	2.0	4.0
C16:2	–	—	1.9
C18:0	–	2.8	14.7
C18:1	6.35	4.1	—
C18:2	5.77	3.3	2.9
C18:3	4.71	4.6	5.1
C18:4	–	12.0	—
C20:1	31.25	3.5	5.2
C20:4	10.62	23.8	6.2
C20:5	20.60	23.5	4.7
Others	0.05	6.9	11.6

FUNCTIONAL BENEFITS OF MARINE LIPIDS

Benefits of Phospholipids

The n-3 fatty acids DHA and EPA are orthomolecular, conditionally essential nutrients that enhance quality of life and lower the risk of premature death. DHA is essential to pre- and postnatal brain development, whereas EPA seems more influential on behaviour and mood. Both DHA and EPA generate neuroprotective metabolites. In double blind, randomized, controlled trials, DHA and EPA combinations have been shown to benefit attention deficit/hyperactivity disorder (AD/HD), autism, dyspraxia, dyslexia, and aggression. Krill oil inserted cosmetics such as shampoo, conditioners, creams, lotion etc. are now available on the world market. Krill n-3 fatty acids are also increasingly more popular as a food additive. Krill n-3 phospholipids demonstrated anti-inflammatory activity, lowering C-reactive protein (CRP) levels. The n-3 fatty acids may play a role in certain cases of depression. Fish oil supplements are well tolerated, and have been shown to be without significant side effects over large scale, 3 year research (Logan, 2004; Marchioli *et al.*, 2002).

The DHA and EPA inserted marine phospholipids are useful for medical applications. Both phospholipids prevent over-production of arachidonic acid-derived eicosanoids which often increase risk of cancer, thrombosis, allergy and other diseases. The phospholipid form results in a higher PUFA content in plasma than the triacylglycerol form (Hosokawa and Takahashi, 2005; Wijendran *et al.*, 2002). For this reason, the phospholipid form may be more effective than the triacylglycerol form when PUFAs are administered. Not only the functionalities of PUFAs themselves, but also the phospholipid chemical structure should exert notable health benefits. A typical example for this is the prevention effect of DHA inserted phospholipid on apoplexy. Among fish oil triacylglycerol, egg yolk phospholipid, and squid phospholipid rich in sn-2 DHA inserted phospholipids, squid phospholipid was the only available chemical form to prevent apoplexy in rats (Galli *et al.,* 1992).

The DHA and EPA are reported to induce growth inhibition with sodium butyrate (NaBt) in HT-29, DLD-1, and Caco-2 colon cancer cell lines (Hofmanov´a *et al.,* 2005). It was shown that NaBt enhances growth inhibition, lipid peroxidation, and apoptosis with DHA and EPA in the form of free fatty acid and phospholipids (Hossain *et al.,* 2009). Epidemiological and experimental studies conducted over the past few decades suggest a protective role for n-3 PUFA against the development of colon cancer (Bartsch *et al.,* 1999). It was also shown that the three human colon cancer cell lines are growth inhibited by n-3 PUFA (Hossain *et al.,* 2009). DHA were found to elicit the most pronounced effect on cell growth in all of the three cell lines, whereas EPA induced growth inhibition to a lesser extent. Arachidonic acid (AA) or AA PC did not affect growth. This may be the cause for the number of double bonds, as DHA is the longest (22 C) and most unsaturated (6 C–C double bonds) fatty acid. On the other hand, EPA and AA contain 5 C–C and 4 C–C double bonds, respectively.

Several reports have shown that antioxidants like vitamin E, butylated hydroxytoluene (BHT), and butylated hydroxyanisole (BHA) block the cytotoxic effect of different PUFAs, indicating that non-enzymatic lipid peroxidation is frequently involved (Finstad *et al.*, 1998). It was found that BHT was able to reduce the growth inhibition of cells. Moreover, PUFAs induced an increased generation of thiobarbituric acid reactive substances (TBARs) in the cells. It indicated that lipid peroxidation must be in part responsible for the cytotoxicity in the cells. It was observed that the treatment of HT-29 cells with n-3 PUFAs for 48 h enhanced lipid peroxidation (Hossain *et al.*, 2009). Thus, lipid peroxidation is considered, at least in part, one of the main mechanisms of the PUFAs cytostatic and cytotoxic action on cancer cells (Das, 1991). These events are mainly consequences of structural and functional changes in cell membranes (Chapkin *et al.*, 2002). At any rate, cancer cells are known to be more susceptible to lipid peroxidation damage than normal cells, resulting in the selective cell growth suppression and apoptosis on cancer cells.

Hossain *et al.* (2009) detected that the apoptosis was increased by potentiation of caspase-3 activity. Apoptosis is controlled by mainly mitochondrial pathway (Green and Reed, 1998). Mitochondrial release of cytochrome c into the cytosol has been shown in cell-free systems to be rate limiting for the activation of caspases and endonucleases (Martinou *et al.*, 2000). Cytosolic cytochrome c activates procaspase-9 by binding to Apaf1 in the presence of dATP, leading to caspase-9 activation and subsequent activation of downstream effector caspases, including caspase-3, with triggering of apoptosis (Li *et al.*, 1997). Caspase-3 activity was increased significantly when HT-29 cells were treated with EPA or DHA in combination with NaBt. But caspase-3 was not increased significantly when it was treated with DHA- or EPA- PC and NaBt. It is anticipated that fatty acid-derived metabolites can interact with and activate the caspase cascade. Although cellular damage by chemotherapeutic agents and radiation is generally considered to cause caspase activation and apoptosis by mechanisms that involve cytochrome c release from mitochondria, death receptors are implicated in apoptosis induced by certain cytotoxic agents (Kaufman and Earnshaw, 2000). Incorporation of PUFAs into the cellular lipids of HT-29 cells was associated with an increase in caspase 3 activity. This is an important characteristic of apoptosis (Latham *et al.*, 2001).

Evidence indicates that Bcl-2 acts to stabilize mitochondrial membrane integrity by preventing cytochrome c release and subsequent caspase activation and apoptosis (Tsujimoto and Shimizu, 2000). To determine whether attenuated cytochrome c release was related to alterations in Bcl-2, Bcl-2 expression was analyzed (Hossain *et al.*, 2009). Therefore, decreased Bcl-2 may contribute to attenuated cytochrome c release and increased caspase-9 and -3 activity in the colon cancer cells. The Bcl-2 family proteins, whose members may be antiapoptotic or proapoptotic, regulate cell death by controlling the mitochondrial membrane permeability during apoptosis (Adams and Cory, 1998). However, the transfection studies have expressed that when cleaved by caspase, Bcl-2 and Bcl-xl proteins are converted into potent proapoptotic factors, and they may accelerate apoptosis by amplifying the caspase cascade (Bellows *et al.*, 2000). It was, therefore, inferred that the Bcl-2 family protein might participate in the event that controlled the change in mitochondrial membrane potential and trigger cytochrome c release during apoptosis induced by n-3 PUFAs (Hossain *et al.*, 2009). It is speculated that marine n-3 PUFAs induced apoptosis appeared to occur mainly via a mechanism that was TBARs formation and was associated with increased activity of caspase-3 and down regulation of Bcl-2.

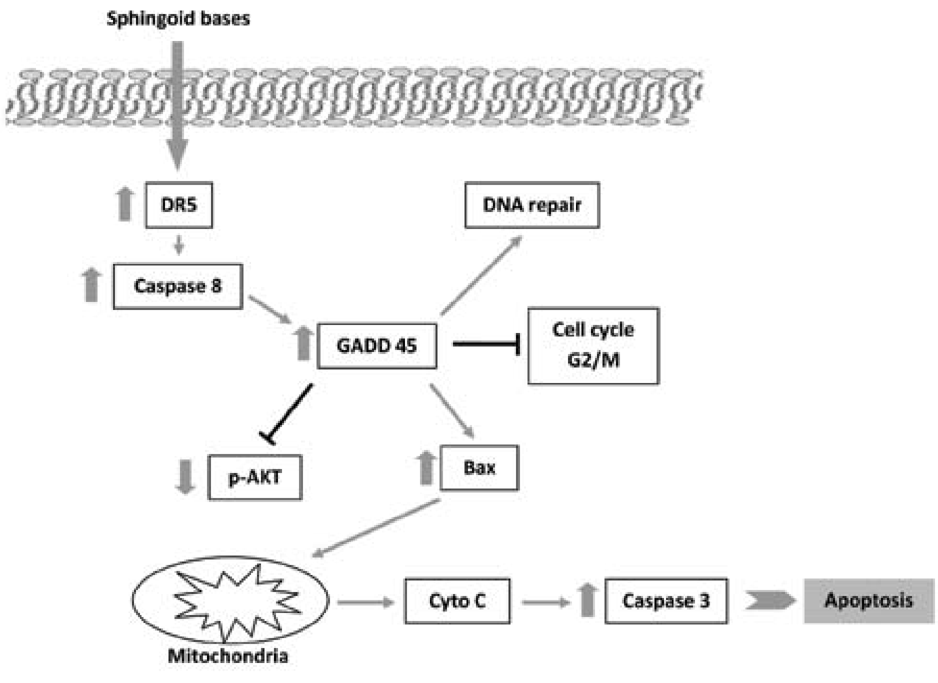
Benefits of Sphingolipids

Dietary sphingolipids have gained attention for their potential to protect the intestine from inflammation and cancers (Duan and Nilsson, 2009; Schmelz, 2004). Sphingolipids hydrolyze to bioactive ceramide and sphingoid bases (Hannun and Obeid, 2008). Sphingoid bases can induce apoptosis in colon cancer cell lines (Sugawara *et al.,* 2006). In addition, other physiological functions of sphingolipids such as improving the barrier function of skin, lowering plasma lipids and preventing melanin formation, have also been reported (Kinoshita *et al.*, 2007). The effects of the sphingoid bases, C(2)-ceramide, and C(2)-dihydroceramide on apoptosis were determined by detecting 200-bp DNA ladders or hypo-diploid areas (sub-G(0)/G(1)), indicative of apoptosis, in HCT-116 human colon cancer cells. In addition, the effects of the sphingoid bases at an apoptotic concentration for 12 hours on cell cycle distribution were determined by flow cytometry. The results indicated that the sphingoid bases and C(2)-ceramide induced apoptosis, whereas C(2)-dihydroceramide had no effects (Ahn and Schroeder, 2010). Dietary SM inhibited the tumorigenesis and increased the alkaline SMase activity in the colon by 65 percent. The increased activity was associated with increased enzyme protein and mRNA expression. No changes of acid and neutral SMase activities were found (Zhang *et al.,* 2008).

Sphingosine is also a potent signalling molecule that alters the Ca2+ homeostasis by directly interacting with voltage-gated Ca2+ channels (Titieysky *et al.*, 1998; Mathes *et al.*, 1998). Additionally, it affects the activity of several protein kinases, e.g. it inhibits the calmodulin-dependent protein kinase and the insulin receptor tyrosine kinase, while enhancing the activity of diacylglycerol kinase (Hannun *et al.*, 2001). Furthermore, within the epithelial cells, sphingosine may be phosphorylated to sphingosin-1-phosphate by the sphingosine kinase (Huwiler *et al.*, 2000). Sphingosine-1-phosphate is also a potent cell regulator, with effects that are antagonistic to ceramid. Thus, sphingosine-1-phosphate induces DNA synthesis, proliferation and inhibits the ceramide-induced apoptosis (Pyne and Pyne, 2000).

Ceramide is a very potent inducer of apoptosis, cell cycle arrest and differentiation (Huwiler *et al.*, 2000) increased cellular content of ceramide might thus alter the developmental fate of the cells. Biologically active sphingolipid metabolites formed from dietary sphingolipids may influence cell differentiation and tumour development in the gut (Merrill *et al.*, 1997). Furthermore, it has been shown that human colon carcinomas have a significantly lower activity of the alkaline SMase than non-transformed tissue and it has been suggested that the decreased SMase activity is an early event in development of colorectal cancer (Hertervig *et al.*, 1997). Ceramide, supplied from the hydrolysis of dietary sphingolipids, would then increase the ceramide levels in the transformed cells over a threshold level that triggers apoptosis and thereby inhibit the development of carcinomas (Duan, 1998). The outline of sphingoid bases-induced apoptotic signalling pathway in Figure 1 has been proposed (unpublished data). Sphingoid bases-induced DNA damage resulted in the up-regulation of GADD45, which induced cell cycle arrest in G2/M phase giving cells the chance to repair the DNA damage. On the other hand, if DNA damage could not be repaired, cells will execute apoptotic pathways. The GADD45 can up- and down-regulate Bax and p-AKT, respectively, and lead to the disruption of mitochondrial membrane, which in turn would cause cytochrome c release from the intramitochondria into the cytosol, thus activating caspase-3 and -8, which then cleaves the death substrates, leading to apoptosis. In conclusion, it has been shown that sphingoid bases induce HepG2 cell apoptosis by the GADD45 induction and activation of caspase-3, -8, and PPARγ (Figure 1).

FIGURE 1
The proposed outline of the sphingoid bases induced apoptotic signalling pathway



Benefits of Glycolipids

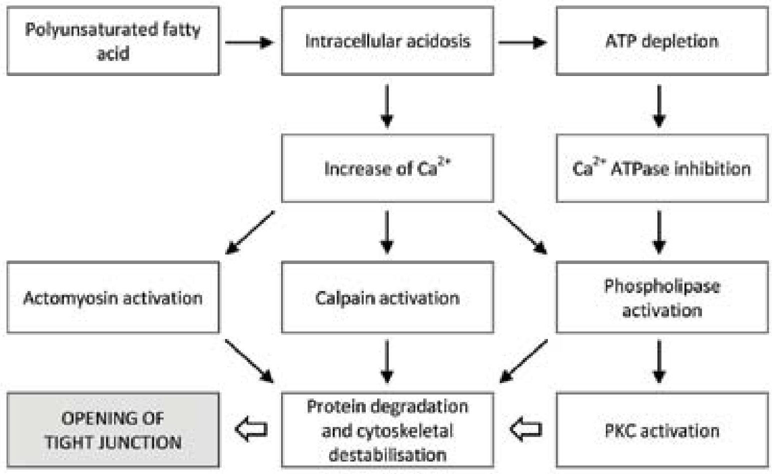
Glycolipids have shown potent anti-tumour and anti-viral activities as well as potential for the treatment of certain autoimmune disorders. Detailed mechanistic studies suggest this biological activity occurs via Natural Killer T (NKT) cell activation. Several alpha glycolipids are already in Phase I clinical trials for a variety of disease treatments that include cancer and diabetes. Because the structure of the glycolipid dictates the type as well as the extent of immunological activity, a readily accessible library of these molecules is desirous for drug discovery and development.

SQDG, a class of sulphoglycolipids, is a potent inhibitor of DNA polymerase. Because DNA polymerases are essential enzymes for DNA replication and repair and subsequent cell division, the inhibition of these enzymes will lead to the death of tumour cells, especially under conditions of active proliferation (Mizushina *et al.*, 1998). SQDG exhibits the inhibition of growth on the human colon adenocarcinoma cell DLD-1 (Ohta *et al.,* 2002) and on the human gastric cancer cell SNU-1 (Quasney *et al.*, 2001) as well as apoptosis on SNU-1 (Quasney *et al.,* 2001). DGDG is also a valuable antitumor promoter in carcinogenosis (Shirahashi *et al.*, 1993). DGDG has inhibitory activities in mouse skin papilloma as well as Epstein-Barr virus-early antigen activation test on Raji cells (Tokuda *et al.*, 1996).

MARINE LIPIDS INCREASE THE TIGHT JUNCTION PERMEABILITY

It has been shown that the trans-10, cis-12 isomer of conjugated linoleic acid (CLA) altered the transcription of zonula occludens (ZO)-1, occludin, claudin-1 and claudin-4 genes, which encode protein components of the tight-junction (TJ) complex between neighbouring intestinal cells. Exposure of Caco-2 cells to trans-10, cis-12 isomer of CLA led to a down-regulation of claudin-1 gene transcription while transcription of claudin-4, occludin and ZO-1 genes was up-regulated. The exact role of the individual claudin proteins within the functionality of the TJ has still to be fully elucidated, and thus, the physiological meaning of the differential regulation of the expression of these two claudin genes by the trans-10, cis-12 isomer of CLA is as yet unclear (Turksen and Troy, 2004). TJ represents a unique signalling membrane microdomain that influences fundamental properties of epithelial cells. The pro-inflammatory cytokines play an important role in epithelial barrier defect and in pathophysiology of Crohn`s disease (Sartor, 2003). DHA and EPA could prevent distortion of TJ morphology induced by proinflammatory cytokines. DHA and EPA have positive effect on impaired epithelial barrier function induced by IFN–γ and TNF–α (Li *et al.*, 2008). Of interest, an investigation of the role of TNF in disrupting TJ assembly in Madin-Darby canine kidney (MDCK) cells, a renal epithelial cell line, showed that TNF–α decreased claudin-1 expression, which it has been suggested may cause a relocation of ZO-1 away from the TJ and consequent increased permeability (Poritz *et al.*, 2004), similar to that observed in CLA-treated Caco-2 cells (Jewell *et al.*, 2005). There is some information on the effect of fatty acids on occludin expression. For example, Jiang *et al.* (1998) showed that gamma-linoleic acid and EPA increased the expression of occludin in human vascular endothelial cells, which was also associated with reduced paracellular permeability. In addition, less phosphorylated forms of occludin are found in the basolateral membrane and cytosol, whereas more phosphorylated forms are concentrated in TJs (Sakakibara *et al.*, 1997; Wong, 1997). Immuno-fluorescent staining has shown a preponderance of occludin (and ZO-1) in cytosol of Caco-2 cells exposed to the trans-10, cis-12 isomer of CLA (Jewell *et al.*, 2005). Roche *et al.* (2001) suggested that the inhibition of phosphorylation of occludin might arise by interference by the trans-10, cis-12 isomer of CLA with one of the signalling pathways that regulate TJ biogenesis. In a recent study, it was found that EPA- and DHA-enriched marine phospholipids increased the TJ permeability (Hossain *et al.*, 2006). The authors assumed that PUFA induces intracellular acidosis to decrease the intracellular ATP level and inhibit Ca^{+2} -ATPase. The increase in the calcium level activates the actomyosin contraction by the activation of cytoskeletal destabilization or through other processes leading to the opening of the TJ (Figure 2) (Hayashi and Tomita, 2007).

FIGURE 2
Proposed opening mechanism of tight junctions by polyunsaturated fatty acids



ATP – adenosine tri-phosphate
PKC – protein kinase C

Interestingly, the microarray data showed that transcription of the protein phosphatase 2A (PP2A) gene was up-regulated in Caco-2 cells exposed to the trans-10, cis-12 isomer of CLA. Enhanced PP2A activity induces dephosphorylation of ZO-1, occludin and claudin-1, possibly preventing TJs assembly and, consequently, is associated with increased permeability. However, other mechanisms of action may also be involved; for example, the data also suggests that other potential mediators of TJ function, such as ZONAB, Rab3B and Rab13 that are thought to have a regulatory function (Harhaj and Antonetti, 2004), were also altered. Some researchers have shown that the PUFA up-regulates the expression of occludin or occludin mRNA. In addition, levels of different claudins are related to carcinoma cell invasion and disease progression. The relative expression levels of the claudin-1, -3, and -4 genes were higher in cancer than in normal adjacent mucosa, whereas the relative expression of the claudin-7 genes was similar. Thus, reduced expression of the claudin-7 gene may be a useful predictor of liver metastasis patients with colorectal cancer (Oh-l *et al.*, 2005). It was proposed that PUFA may change the lipid composition and fatty acyl substitution of phospholipids in membrane microdomains in TJ (Hossain and Hirata, 2008). EPA changed the phospholipid composition of membrane microdomains of TJ by enriching the unsaturated fatty acyl substitution of phospholipids (Oshima *et al.*, 2008).

CONCLUSION

Fish oils are an excellent source of long-chain n-3 PUFAs, such as DHA and EPA. After consumption, n-3 PUFAs can be incorporated into cell membranes and reduce the amount of arachidonic acid available for the synthesis of pro-inflammatory eicosanoids (e.g., prostaglandins, leukotrienes). Likewise, n-3 PUFAs can also reduce the production of inflammatory cytokines, such as tumour necrosis factor alpha, interleukin-1, and interleukin-6. Considerable research has been conducted to evaluate the potential therapeutic effects of fish oils in numerous conditions, including arthritis, coronary artery disease, inflammatory bowel disease, asthma, and sepsis, all of which have inflammation as a key component of their pathology.

The stocks of wild salmon and other species that are not contaminated with mercury or other pollutants are increasingly restricted. An alternative is to take dietary supplements rich in DHA/EPA, including the n-3 phospholipid complex from krill.

While the wild salmon stocks are shrinking, concerns are being voiced about the increasing use of krill for salmon farming. Krill is thought to be the largest single biomass on the planet and is a life-sustaining food for diverse marine animals. The Antarctic stocks (*Euphausia superba*) are estimated at 50 to 500 million metric tonnes (McMichael *et al.*, 2005). Cultivated microalgae are a good source of DHA. Although high doses of ALA can increase tissue EPA levels, ALA does not have the same effect on DHA levels, rendering supplementation necessary. How does one know whether supplementation is necessary? Physical signs and symptoms of deficiency include excessive thirst, frequent urination, rough dry hair and skin, and follicular keratosis (Richardson, 2006; Stevens *et al.*, 1996). Harris (2007) developed an "omega-3 index" (RBC DHA/EPA) as a marker and perhaps also a risk factor for coronary heart disease and suggests that adequate sufficiency is likely to have been attained when DHA and EPA exceed eight percent of the total membrane fatty acids. The evidence presented in this review clearly suggests that the fundamental basis for applying DHA/EPA to human health is their presence in cell membranes. Additional investigations into the use of supplementation with fish oils in patients with neural injury, cancer, ocular diseases, and critical illness have recently been conducted. It concluded that the n-3 PUFAs have been shown to be efficacious in treating and preventing various diseases.

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Vacuum and modified atmosphere packaging of fish and seafood products

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INTRODUCTION

In trends observed over the last few years, the distribution of fish and seafood products shows a growing development in packaging options used in the marketplace and an increasing sophistication in their presentation.

Nowadays, various packaging techniques are used to address different problems faced in the distribution of fish, from the need to maintain hygiene in the value chain, through innovations in product development, to maintaining or improving profitability of the product line.

Some major facts are presented below, summarizing the market trends of fish products and packaging, followed by a reminder of the constraints relating to the use of fish as a raw material, and finally on the advantages offered by vacuum and modified atmosphere packaging.

SOME MAJOR FACTS CONCERNING FISH AND SEAFOOD MARKETS GLOBALLY

The image of fish in developed countries

In developed countries, fish has a very positive image with respect to its food value and effects on health. Because of the discovery of omega-3 fatty acids, the awareness raising about problems linked to obesity and its effects on life expectancy and the negative images conveyed by meat (BSE) and poultry (bird flu), fish consumption is increasing and will continue to do so significantly over the next ten years.

Distribution of fish in developed countries

The intensive development of supermarket stores has increased the demand for more and more processed, packaged and easy-to-use (ready-to-cook, ready-to-heat, ready-to-eat) products with a long shelf-life.

The retail consumer unit (for 1 or 2 persons) is being continually refined, whereas fresh fish stalls, where fish is displayed on ice and not packaged, are in significant decline due to two main reasons; (a) the cost – the space taken up in the shop/food hall, labour, cleaning the food hall department, logistics, loss of unsold goods, etc., and (b) the inconvenience related to the products (odours, hygiene risks, practicality, etc.).

Evolution of food practices and consumer behaviours

Over the last ten last years, purchasing habits of households have been transformed by the increase in the number of women at work, of single-parent families and of single people. Consumers increasingly want prepared products that are ready-to-cook and easy-to-prepare and that do not require a high level of cooking skills.

Purchases are made once a week in supermarkets and the fresh products must have a long shelf-life (at least 6 to 10 days). Appropriate packaging and preparation (filleting, convenience meals) remove the most frequent objections to buying fish, namely odour, preparation, viscous feel, poor shelf-life, etc.

Consumers also like to have a choice. They are used to making quick decisions and varying their purchases according to the visual stimuli (packaging and innovative products). To some extent, they are becoming fickle, even if they consider themselves loyal to the brand.

Decline in the catch resource and the development of aquaculture

The decline in wild resources and the considerable increase in demand for fish has led to an increase in prices, making it possible for processed products to support the cost of packaging.

Packaging also contributes to reduced fish wastage and increased efficiencies in product handling, while facilitating improved hygiene.

The development of aquaculture has given rise to the supply of a raw material that can maximise the advantages offered by the use of packaging techniques, such as vacuum and modified atmosphere packaging (more commonly called MAP). Total control of the date of harvest as well rapid handling and processing will mean that farmed products have a shelf-life that is particularly attractive to distributors and consumers.

An opportunity for developing countries

The increase in the demand for fish and the globalization of trade, together with the need to reduce production overheads (labour costs) and combined with the trends mentioned above, present many opportunities for developing countries to create added value in their fishery and aquaculture value chains.

Packaging and logistics are important factors in the success of outsourcing fish processing operations to lower cost countries. It is thus possible to prepare the product (gutting, filleting, pasteurization, pre-cooking, etc.) in a developing country so it can be delivered in bulk packs to factories located in developed countries for a second level of processing (convenience food, smoking, putting in salads, etc.). Because packaging facilitates good hygiene of the product, a product's organoleptic qualities are preserved for the duration of its shelf-life.

Packaging as a creative factor

The new techniques described below enable the development of new distribution systems and the appearance of new products, thereby increasing consumer choice and the upgrading of species not yet marketed.

Packaging is being increasingly integrated into the manufacturing process, thus contributing considerably to the development of the basic commodity (cooking under vacuum, pasteurization, etc.).

Packaging as a factor of differentiation

The development of products containing fish or seafood for the supermarket shelf also involves the need to make these products attractive to the consumer. This requirement has driven the development of the whole packaging sector and contributes strongly to a positive product image with the consumer (Figure 1).

Increasing the number of different products on offer leads to improved sales simply by making the product display attractive.

FIGURE 1
Some examples of the importance of packaging on a sophisticated market

SOME MAJOR FACTS ABOUT FRESHNESS AND SHELF-LIFE

Many studies have been published on fish processing, hygiene, deterioration of fish and seafood, as well as the toxicological risks related to fishery products. Some important points related to the hygiene and organoleptic qualities of packaged fish are mentioned below.

Freshness and stress

The first requirement is to work only with very fresh fish caught under the best conditions. In aquaculture, gentle killing techniques that do not cause stress are favoured, in particular stunning by immersion in ice slurries before bleeding.

Recent studies have shown that processing the fish in the pre-rigor phase significantly extends the shelf-life of the product (Table 1).

TABLE 1
Onset and duration of rigor mortis in various fish species

Species	Condition	Temperature (°C)	Time from death to onset of rigor mortis (hours)	Time from death to end of rigor mortis (hours)
Cod	Stressed	0	2–8	20–65
	Stressed	10–12	1	20–30
	Stressed	30	0.5	1–2
	Unstressed	0	14–15	72–96
Blue tilapia	Stressed	0	1	20–40
	Unstressed	0	6	40–80
Tilapia	Unstressed	0–2	2–9	26
Plaice	Stressed	0	7–11	54–55
Redfish	Stressed	0	22	120
Grenadier	Stressed	0	1	35–55

Chilling

The second requirement is the rapid chilling of fish. This is important as temperature reduction restricts microbial growth. A temperature ranging between minus two and zero degrees Celsius is considered as ideal.

Rapid and careful gutting

The third requirement relates to gutting which must be done as early as possible. Internal organs can cause contamination in the muscle tissues, in particular when the animals are stressed. Contamination crosses the intestinal barrier and enters the blood vessels. Gutting is itself an operation which involves large risks of contamination of the abdominal cavity. A gutted fish is preserved much better than a whole fish, but it is necessary to pay attention to drying the abdominal cavity in order to avoid proliferation of bacteria.

Filleting immediately before packaging

The last requirement relates to filleting (or portioning) which must take place immediately before packaging the products, so as to ensure a good shelf-life (Figure 2).

Cold chain

After packaging, strict compliance with the cold chain (at chilled or frozen temperatures) is a legal requirement to minimize microbiological hazards.

FIGURE 2
An example of hygienic working conditions in gutting and filleting operations

ADVANTAGES RELATED WITH PACKAGING

Packaging is becoming an important factor in the development of the entire fish sector, at a time when the product is enjoying a healthy image in the mind of many consumers.

The packaging of fish products and the processing techniques to be used are among the most important points to be considered in any producers' business strategy. They are the key points for real success in the marketing and development of the sector (Figure 3). They are also an effective means of adding value (Table 2).

Control of on-board handling, processing and storage during fishing, as well as temperature control, hygienic work conditions and compliance with the cold chain requirements are all factors which cannot be circumvented if you are to maintain the quality of the product.

FIGURE 3
Supermarket shelf containing attractively packaged fish products

Note: The packaging also helps with good hygiene.

TABLE 2
Advantage of packaging for producer, distributors and end user

Product Storage	**Industrial**	**Distributor**	**Consumer**
Longer period of storage: several days in vacuum or protective atmosphere*	X	X	X
Less handling of products: no direct contact with product, guaranteed cleanliness		X	X
Storage of product for optimal freshness	X	X	X
Reduced microbiological damage (hygiene)	X	X	
Protection against physical damage: the packaging avoids desiccation (drying out) of product and direct contact with ice	X	X	X
Protection against perforations (fish bones) thanks to the re-injection of gas	X	X	
No contamination possible because product is protected in airtight packaging: guarantee of healthy food	X	X	X
Protection against chemical damage: oxidation of vitamins, flavours and fats is avoided by very high elimination of oxygen	X	X	
Presentation of product	**Industrial**	**Distributor**	**Consumer**
No deformation or loss of product, an economic advantage	X	X	
Product hygiene and removal of unpleasant smells	X	X	X
Practical product: easy to open, simple to use and cook thanks to microwavable trays			X
Expansion in varieties of fish in fish world thanks to longer use-by dates		X	X
Display of product in selling shelves (differentiation through packaging: attractive, practical and "marketed" packaging)	X	X	
Communication of brand thanks to printing, possibility of informing and communicating information (recipes)	X	X	X
Logistics	**Industrial**	**Distributor**	**Consumer**
Easy to transport through use of stackable trays	X	X	
Simplified logistics thanks to longer use-by date of products	X	X	X
Eliminates effects of cross contamination	X	X	X
Traceability of product thanks to labelling on consumer industrial sale unit	X	X	X
Less labour in fish sector		X	

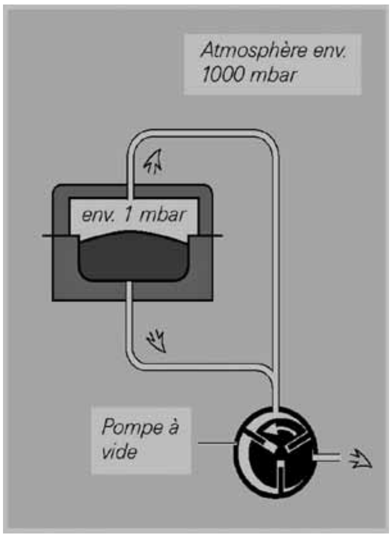
VACUUM AND MODIFIED ATMOSPHERE PACKAGING TECHNIQUES

Vacuum packaging

This process consists of removing the maximum possible amount of air from a packaged product, using a vacuum pump to achieve a vacuum state in the packaged product (Figure 4). The aim is to improve the shelf-life of the foodstuff by reducing the oxygen concentration in the packaged product to as low a level as possible (Figure 5).

The absence of oxygen in contact with the product reduces the growth of aerobic bacteria, which are a primary cause of spoilage in fish.

FIGURE 4
Air level in the pack is near 1



The higher the level of vacuum in the package, the longer the conservation of the product. For the majority of products, the residual amount of oxygen in the packaging should not exceed 0.5 percent of the volume of the package, which is equivalent to a vacuum pressure of lower than 1 millibar.

Because the pressure of the air inside the packaging is almost at zero, the external atmosphere will exert a pressure of about 1 bar on the package.

Mechanical effects must be taken into account when packaging more fragile products that could be crushed under vacuum. Such effects include large amounts of exudation in the package or the deformation of the product itself. Similarly, packaging of products that have sharp edges (e.g. lobsters) requires special consideration (Figure 6).

For presentation purposes, it is common to insert the vacuum packaged product into a cardboard box or sleeve containing a "window", thus protecting the package while allowing the product to be seen (Figure 7).

Generally, vacuum packaging techniques are used for processed fish (cured, marinated, cooked) to improve the shelf-life. For unprocessed fish, a variant of vacuum packaging is used, called modified atmosphere packaging.

FIGURE 5
Vacuum packed salmon

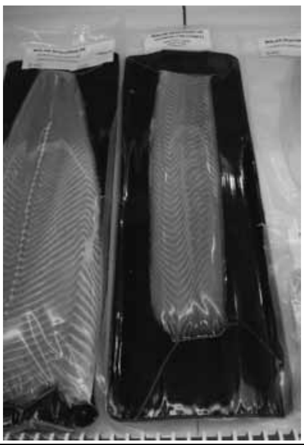


FIGURE 6
Example of atmospheric pressure on a package

FIGURE 7
Vacuum packed sliced fish with a cardboard outer pack

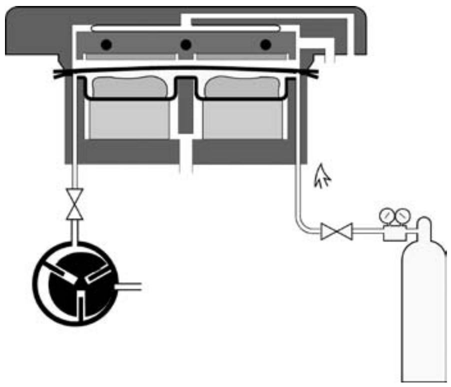
MODIFIED ATMOSPHERE PACKAGING

This technique uses vacuum packaging principles (described above) by removing the air from inside the container and then re-injecting one or several food grade gases into the package. The altered gaseous atmosphere further inhibits bacterial growth when compared with a pure vacuum (Figure 8).

Also, by re-injecting gas, or gases, into the package, the external atmospheric pressure can be prevented from crushing the contents, as can happen in vacuum packaging, as mentioned. In this way, the product will have a more attractive presentation to the consumer (Figure 9).

The gases used in modified atmosphere packaging (MAP) are only those normally contained in the air, but in a purified form and devoid of any bacteria. They are checked and certified as food grade gases.

FIGURE 8
Diagram of gas-flushing programme in a sealing die



Note: The process is: (a) Air evacuation through the vacuum pump; (b) Gas flushing from the gas bottle or container; and (c) Sealing of the top film.

FIGURE 9
Example of a raw fish with MAP packaging

Which choice? Vacuum or modified atmosphere packaging

These two techniques are the most appropriate to extend the shelf-life of some products (Figures 10 and 11). But it is important to define what kind of product is being packaged.

FIGURE 10
Vacuum packed salmon

FIGURE 11
Examples of vacuum packed or MAP fish products

Fresh fish (whole or fillets)

Vacuum packaging does not extend shelf-life more than traditional wrap packaging. One of the main reasons for this is the development of histamine and total volatile base amines (TVBA). MAP is preferred for such products. There are some exceptions with shellfish, for example, with mussels.

Processed fish

Cooked, cured, smoked or marinated fish can be vacuum packed, having a longer shelf-life than traditional packaged fish products but also longer than with MAP.

What are different gas and properties

Nitrogen forms 80 percent of the air that surrounds us. Without any taste or odour it does not have any effect on food and is known as an "inert" gas. Its function is to replace the evacuated volume of air in the package, helping to avoid physical damage to the products by atmospheric pressure.

Carbon dioxide dissolves readily in the liquids and fatty substances contained in the product. It combines with water to form carbonic acid and thus decreases the pH on the surface of the product. Because of this, the growth of microorganisms and the formation of moulds are inhibited and shelf-life is consequently extended (Table 3).

Carbon dioxide also impacts on the formation of histamine that occurs in raw scombroid species of fish, reducing the impact of this food safety hazard and extending shelf-life.

Oxygen is generally used to preserve the red colour of tuna meat. At saturation levels of 70 to 80 percent, over-oxygenation can improve the conservation for some products. A small injection also reduces the risk of botulism (10 percent of the total volume of the tray).

TABLE 3
Average shelf-life in different packaging solutions

Products	Vacuum (%)	Nitrogen (%)	Carbon dioxide (%)	Oxygen (%)	Temperature (°C)	Shelf-life (days)
Whole fish gutted	100	Not	Not	Not	2–4	7–9
Filets	100	Not	Not	Not	2–4	5–6
Whole fish gutted	100	40	60	Not	2–4	9–13
Filets	100	60	40	Not	2–4	7–10
Tuna steaks	100	Not	20	80	2–4	8–10
Live Mussels	20	Not	Not	Not	2–4	8–9
Live Oysters	20	Not	Not	Not	2–4	8–9
Live Mussels	100	Not	20	80	2–4	11–13
Live Oysters	100	Not	20	80	2–4	11–13
Shrimps	100	30	40	30	2–4	8–10
Shrimps coated with lactic acid	100	30	40	30	2–4	18–21
Marinated herrings	100	Not	Not	Not	2–4	> 30
Smoked fish sliced	100	Not	Not	Not	2–4	> 30

SKIN PACKAGING

Using the same basic technology as vacuum packaging, skin packaging consists of draping a highly heat–deformable film over the product, while carrying out a vacuum pumping sequence at the same time. The base support is generally rigid or semi-rigid.

This technique allows the film to mould perfectly around the shape of the product, which can be in relief compared with the rim of the receiving tray. It can only be implemented with thermoforming or tray-sealing machines.

The products packaged by this technique are particularly attractive and provide a clear difference in terms of marketing on the supermarket shelf. The cost of packaging can only be justified by using products with high added value. Figure 12 shows how skin packaging forms around the product.

This technique is used extensively in southern Europe for the packaging of deep frozen shellfish. The film used is a made from a special material, which becomes extremely stretchable when heated. The machines are also specifically adapted to this technology. They must be equipped with a system for guiding and heating the top film. Figure 13 shows examples of some skin packaged products.

Note: Using the same basic technology as vacuum packaging, skin packaging consists of draping a highly heat-deformable film over the product, while carrying out a vacuum pumping sequence at the same time. The base is generally rigid or semi-rigid.

FIGURE 12
Skin packaging

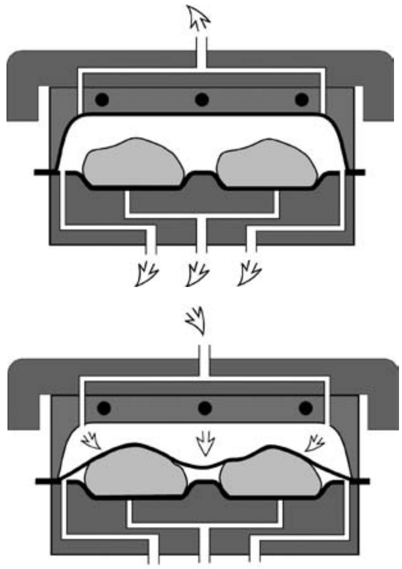


FIGURE 13
Some samples of skin packaging products, mainly used in frozen products

PACKAGING MACHINES FOR VACUUM AND MODIFIED ATMOSPHERE PACKAGING

Vacuum chamber machines

These machines are used for packing products using plastic sachets that are specially designed for vacuum conditions. These sachets are barriers to gas and consist of several layers of various composition. (polyamide, polyethylene and aluminium, amongst others).

The packaging is flexible, because the thickness of the material used rarely exceeds 120 microns. The primary function of this equipment is to remove the air contained in the packaging. After evacuation of the air by means of a vacuum pump, which is incorporated in the machine or is located nearby, the open end of the filled sachet is sealed. The product can be inserted by itself into the sachet, or it can be placed on a tray or a cardboard base prior to insertion into the sachet. An example of the latter is sliced cold smoked salmon. Figures 14 and 15 show examples of vacuum packaging machines.

FIGURE 14
Whole Inox double chamber machine

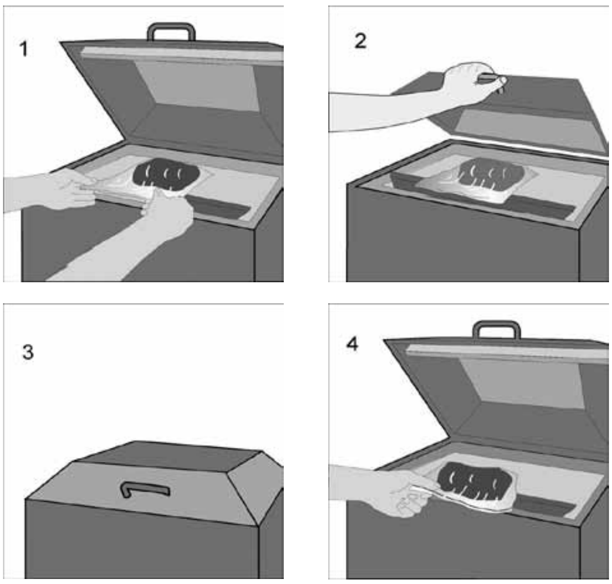
Note: While vacuum pumping and sealing action are carried out in the closed chamber, unloading and reloading of product are done in the other one. The surface of each chamber allow also to run many packs together. This allows a high production with a single person to run the machine.

FIGURE 15
Whole Inox double chamber machine

The operation of a vacuum chamber machine is simple (Figure 16):

1. Place the bag with product in the machine;
2. Close the chamber;
3. Vacuum and sealing are done automatically;
4. Re-opening of the chamber. The bag is vacuumed packed.

FIGURE 16
Operation of a vacuum chamber machine



Some sachets are designed to be shrinkable. Using such sachets offers the possibility to shrink the film around the product by a thermal treatment, generally with hot water (either through sprinkling or by immersion). This technique provides for an attractive presentation for certain products and can help in preventing the exudation of fluids. The following figures (Figures 17 and 18) show examples of sachets and of vacuum packaged product.

FIGURE 17
Vacuum packaging sachets: aluminium and plastic sachets

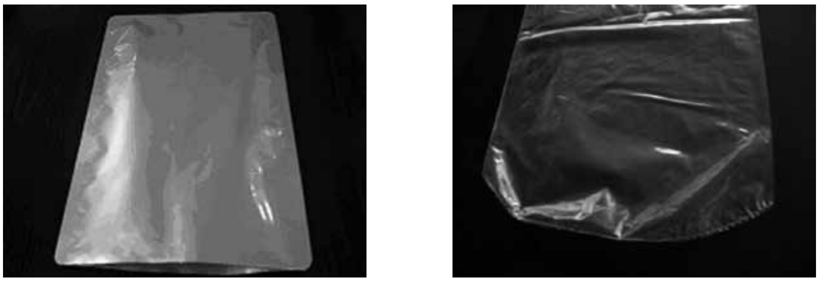


FIGURE 18
Some samples of package made with bags and chamber machine

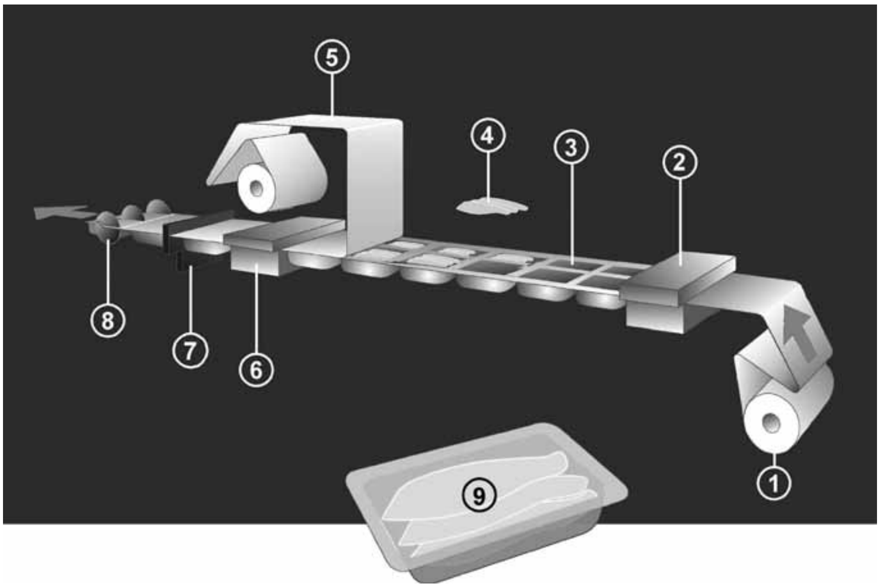
Thermoforming machines (Form Fill Seal)

Intended for industrial production, these machines form, fill and seal packaging materials which are run from reels of film of various thicknesses. They are generally used to carry out packaging under vacuum or modified atmospheres.

By mean of specific tooling, thermoforming machines can run flexible or rigid materials with packaging dimensions that are fully adapted to the packaged product. Feeding of the product into the machine is facilitated by the design of the loading area, and by the loading from above.

The use of film reels has a cost advantage over packaging using preformed packaging such as sachets or trays. The component parts of a typical thermoforming machine is shown in Figure 19 and a typical machine in Figure 20.

FIGURE 19
Thermoforming machine



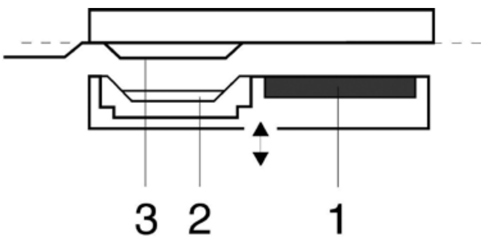
Note: Diagram of operation
1: Reel of lower thermoformable film; 2: Station for heating and thermoforming lower film. Depending of the type of film there may be several heating stations; 3: Filling station; 4: Product loaded manually or automatically; 5: Reel of top film (can be printed film); 6: Station of vacuum, re-injection of gas (if necessary) and sealing; 7: Cross cutting station; 8: Length cutting station; 9: Finished package with product inside.

FIGURE 20
Thermoforming machine

The lower film is gripped as it is fed into the machine. The film is conveyed to the thermoforming station where, after heating, it will be formed according to form inserts which define the depth and shape of the package to be realized. The following figures show various functions (forming and sealing) of a typical thermoforming machine.

Forming station (Figures 21 and 22).

FIGURE 21
Forming station

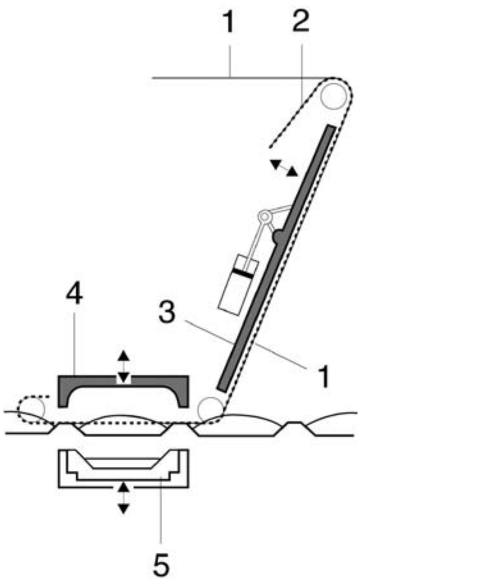


Note: 1) Pre-heating film plate; 2) Form inserts; 3) Thermoformed package.

FIGURE 22
Forming insert designing the form of the final pack

Sealing station (Figure 23).

FIGURE 23
Sealing station on a thermoforming machine



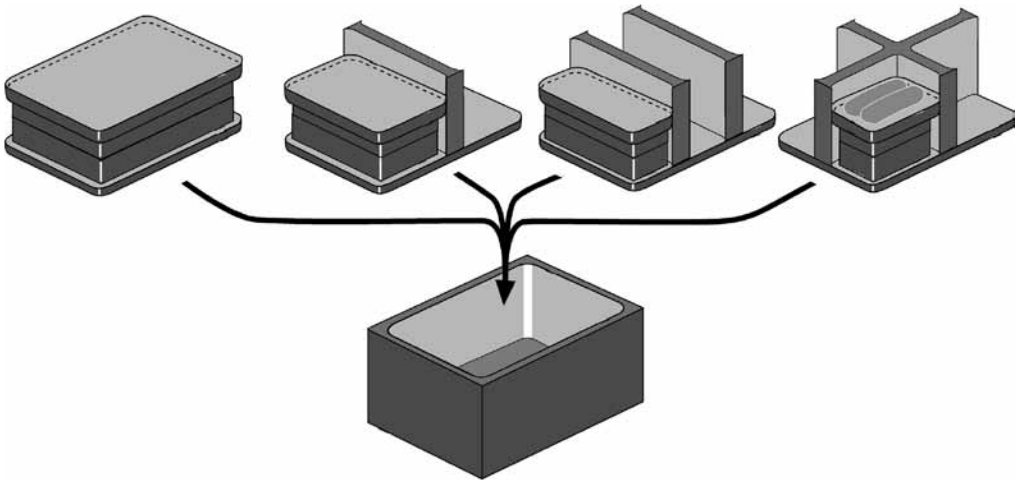
Note: 1) Top film; 2) Top film conveyor chain (for specifics applications); 3) Heating plate; 4) Sealing station; 5) Lower part of the mould with height inserts to maintain the product.

The cells thermoformed in this way are conveyed to the loading point where the products are inserted, either manually or by using robots. The cells then move towards the sealing station, where air evacuation and, possibly, gas re-injection are carried out, and then the package is sealed on four sides. The packages are conveyed to the cutting stations to be separated from the film substrate and then moved onto a discharge belt.

Intermediate stations for marking, labelling and weighing can be set up on the machine, making it possible to work in concurrent operations without re-handling of the product at the discharge end. Machines are generally equipped with modular tooling, which allows the dimensions and depth of the packaging to be varied rapidly and economically.

Several different types of packaging can thus be carried out on the same machine, owing to modular inserts as explained in the diagram below (Figure 24).

FIGURE 24
Modular inserts for use in a thermopackaging machine



Tray sealing machines

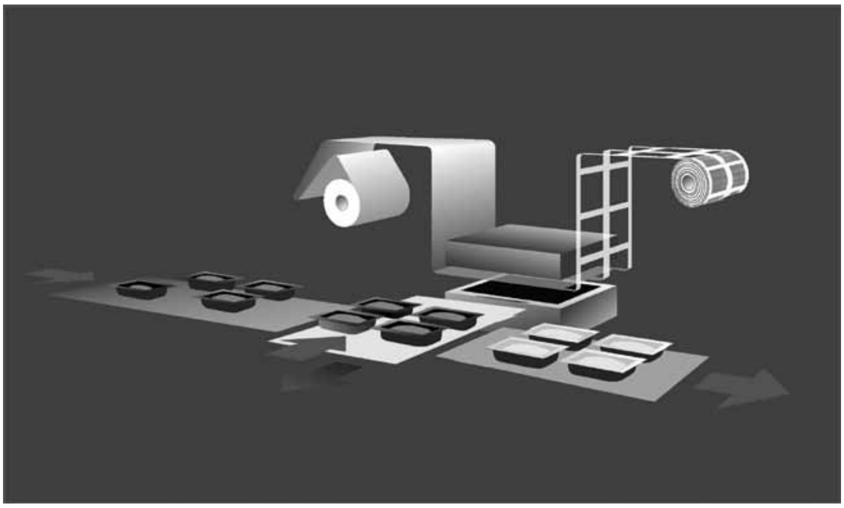
In contrast to thermoforming machines, tray sealing machines do not thermoform the lower part of the packaging, but instead make use of preformed trays which can be composed of various materials e.g. plastic, cardboard, lacquered aluminium, etc. (Figure 25).

FIGURE 25
Examples of products in preformed trays

There are machine of various sizes meeting different production needs, ranging from manually operated machines to fully automatic lines mainly used for MAP packaging.

On automated lines, the trays can be placed manually on the conveyor chain or set down using an automatic unstacking machine. In the case of manual loading, the product can be put in the tray before it is placed on the conveyor chain. As regards sealing, these machines have generally the same functions as the thermoforming machine describe above. Figure 26 shows a diagram of the components of a typical tray sealing machine.

FIGURE 26
Diagram of the components of a tray sealing machine



The operation is not complex. Filled trays are introduced by a conveyor towards the loading point which transfers them to the vacuum , gas re-injection, sealing and cutting sections, and finally onto the discharge belt.

These machines (Figure 27) are more flexible to use than thermoforming machines, as it is much simpler and faster to change the format of the die. A range of small machines also allows the development of highly market-orientated products for a relatively low investment, which is not possible with thermoforming techniques.

FIGURE 27
Tray sealers

Note: Clockwise: Semi-automatic tray sealer; Fully automatic machine.

Trays can also be manufactured in various materials which are non thermoformable or are thermoformable only with difficulty, like cardboard, aluminium, crystallized polyester, very thick plastic and special shapes. Some examples of non thermoformable trays using Form Fill Seal are shown in Figure 28.

FIGURE 28
Examples of non thermoformable trays

Note: Clockwise: PETC difficult to thermoform; Very special shape; Injected rigid plastic; Thickness over 1200 microns (injected).

However, it is important to note that the price of the trays and the volume of storage needed compared with reels of thermoforming film can increase the price of the packaging up to a ratio of one to three.

CONCLUSION

Everywhere in the world, where there is a supermarket in a city you will find vacuum or modified atmosphere packaged products. The more sophisticated and competitive a market is, the more there will be sophisticated designs in packaged products, for instance, for shrimp and mussel product offerings.

Consumers continually want more convenient packaging for their products that will give improved shelf-life and also be easy to handle. The trend over the next 10 years will be further development of packaging techniques and for an increasing diversity of products.

It is important that packaging is always considered as one of the most important components of any new product development process.

Second International Congress on Seafood Technology on Sustainable, Innovative and Healthy Seafood

FAO/The University of Alaska
10–13 May 2010
Anchorage, the United States of America

These are the proceedings from the Second International Congress on Seafood Technology on Sustainable, Innovative and Healthy Seafood held in Anchorage, the United States of America, from 10 to 13 May 2010, organized by the University of Alaska in collaboration with the FAO Fisheries and Aquaculture Department.

The meeting included a range of views regarding the opportunities and the recent developments in sustainable, innovative and healthy seafood, with thoughts from government officials, business representatives and academia.

The meeting highlighted that the seafood industry is in a position to take advantage of the many positive aspects that consumption of seafood offers to consumers, while recognizing that there are still challenges ahead to realize fully the potential that seafood can achieve in international and national trade and in meeting consumer expectations.

ISBN 978-92-5-107108-3 ISSN 2070-6103

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