Review

Fish and its multiple human health effects in times of threat to sustainability and affordability: are there alternatives?

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Fish (finfish or shellfish) has been classified as healthy by health professionals despite containing contaminants, since fish is high in long-chain n-3 polyunsaturated fatty acids which have multiple beneficial health effects such as decreased risk of stroke via anti-thrombotic and vasodilative effects, increased heart rate variability, reducing serum triacylglycerol and blood pressure, anti-inflammatory activities, improving visual function, improving attention-deficit conditions/ hyperactivity disorder, schizophrenic and dementia; and may be effective in managing depression in adults. All these beneficial effects are thought to be mediated through altering cell membrane composition, fluidity, receptors and membrane-bound enzymes, gene expression and eicosanoid production. However, natural marine and freshwater fish populations are declining as a result of over-fishing, temperature and climate changes etc. To re-establish and maintain the fish population in China, fishing has been banned for 2-3 months during specified periods of the year, which differs depending on the area, since 1995. The fish population has recovered since implementation of these banned fishing periods, and thereby maintaining the sustainability and affordability of fish. Aquaculture products have had a significant contribution to China's food system, with significant increase in output over the past few decades, from one million tons in 1978 to 32 million tons in 2007. Aquaculture fish represents a higher portion of total aquatic products compared with natural marine and freshwater fish, which has only been achieved in China, and this has contributed greatly to food and health security. China's success in this area is a good model for other developing countries.

Key Words: aquatic products, aquaculture, fishing moratorium, sustainability, contaminant

INTRODUCTION

In recent years, factors such as: changes to the international food market, climate factors, structure of agriculture labor as well as decreased governmental incentives, and the increase in demand, have imposed increasing pressure on food security, of which fishery plays a vital role. Fish (finfish or shellfish) has long been recognized as healthy. Fish is low in saturated fatty acids, and high in protein, selenium, zinc, vitamin A and D compared with meat, poultry, eggs and dairy products. In addition, fish, especially oily fish, is an excellent source of long-chain n-3 polyunsaturated fatty acids (n-3 PUFA), predominantly eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3).

OMEGA-3 POLYUNSATURATED FATTY ACIDS AND THEIR MULTIPLE HUMAN HEALTH EFFECTS

Main n-3 PUFA in food sources are alpha-linolenic acid (ALA; 18:3n-3), DHA, EPA, and docosapentaenoic acid (DPA, 22:5n-3). Alpha-linolenic acid is an essential fatty acid, it is present in relative high proportions in some vegetable oils such as perilla, flaxseed, canola, soybean and walnut oils, and is the precursor of C20 and C22 long chain (LC) n-3 PUFA. DHA and EPA are predominant LC n-3 PUFA found in fish, fish oils and other marine organisms. Docosapentaenoic acid is a major LC n-3 PUFA found in meat, meat products, and some seafood such as shell fish, seal and seal oil. Fatty acids are major components of most biological membrane phospholipids and LC n-3 and n-6 PUFA are important in membrane structure and function.[1] DHA is highly concentrated in the retina and the brain in humans and other mammals, and is essential for normal visual function[2,3] and brain function[4,5] where it has a primary role via effects on membrane fluidity (membrane order) which can influence the function of membrane receptors such as rhodopsin,[1,5] regulation of membrane-bound enzymes (Na/K-dependent ATPase), and in signal transduction via effects on inositol phosphates, diacylglycerol (DAG) and protein kinase C.[6] DHA directly influences neurotransmitter biosynthesis, signal transduction, uptake of serotonin, binding of β-

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adrenergic and serotonergic receptors and mono amine oxidase activity.[5,7] The role of EPA and DHA in cells include regulation of eicosanoid production from arachidonic acid (AA, 20:4n-6), whereby EPA competes with AA to produce various eicosanoids such as 3-series of prostaglandins, prostacyclin, and thromboxane, and 5 series of leukotrienes etc.[8] Interest in the role of n-3 PUFA in human health has continuously increased over the last three decades. N-3 PUFA can alter gene expression, such as down-regulating proteoglycan degrading enzyme (aggrecanases), inflammation-inducible cytokines (interleukin (IL)-1 α and tumor necrosis factor (TNF)-α), cyclooxygenase 2 (COX-2),[9] fatty acid synthase (FAS), acetyl-CoA carboxylase (ACC), S14 protein and stearoyl-CoA desaturase (SCD),[10,11] up-regulating lipoprotein lipase (LPL) fatty acid-binding protein, acyl-CoA synthetase (ACS), carnitine palmitoyltransferase 1, acyl-CoA dehydrogenese, acyl-CoA oxidase, cytochrome P450 4A2 and peroxisome proliferator-activated receptor α,[12,13] tumor necrosis factor receptor and cytochrome c.[14] Epidemiological and clinical studies have shown positive roles for n-3 PUFA and n-3 PUFA enriched fish on cardiovascular disease and risk factors, inflammation and neuropsychiatry disorders etc. However, results on the relationships between diabetes mellitus, cancers and n-3 PUFA intake are less convincing.

Beneficial effect of LC n-3 PUFA from fish on cardiovascular diseases and risk factors

LC n-3 PUFA supplementation can decrease serum/plasma triacylglycerol concentrations,[15,16] blood pressure[17,18] and resting heart rate,[19,20] and increase heart rate variability.[21,22] LC n-3 PUFA supplementation enhanced endothelium-dependent vasodilation via increased forearm blood flow in chronic heart failure patients,[23] and reduced the incidence of postoperative atrial fibrillation (AF) in patients who had coronary artery bypass graft surgery.[24] Clinical trials showed that LC n-3 PUFA can be effectively used for secondary prevention of myocardial infarction.[25,26] In addition, LC n-3 PUFA significantly reduces potentially fatal ventricular arrhythmias[27,28] which suggests that n-3 fatty acids electrically stabilize heart cells via modulation of the fast voltage-dependent Na(+) currents and the L-type Ca(2+) channels.[29]

Inflammation and LC n-3 PUFA from fish

Inflammation is a protective host tissue response to injury or destruction, it is associated with numerous acute and chronic human diseases such as cardiovascular disease, cancer, diabetes mellitus and obesity. Fish oil decreases joint tenderness, duration of morning stiffness, arthritis activity and pain, serum IL-1 beta in rheumatoid arthritis patients[30] as well as serum soluble tumour necrosis factor receptor p55 and C-reactive protein (CRP) levels in active rheumatoid arthritis patients.[31] Fish oil can be used as an adjuvant for non-steroidal anti-inflammatory drug therapy in rheumatoid arthritis patients.[32] Increased n-3 PUFA intake in late pregnancy may carry an important prophylactic potential in relation to offspring asthma.[33] Fish oil supplementation improved pulmonary function to below the diagnostic exercise-induced bronchoconstriction threshold, decreased the concentration of LTC4-LTE4, PGD2, IL-1beta, and TNF-alpha in sputum, and reduced LTB4 and increased LTB5 from activated polymorphonuclear leukocytes in asthmatic patients.[34] LC n-3 PUFA supplementation decreased LTB4 levels in serum and sputum; and TNF-alpha and IL-8 levels in sputum in chronic obstructive pulmonary disease patients.[35] It also reduced the release of IL-1beta, IL-6, and granulocyte colony-stimulating factor from peripheral blood mononuclear cells in Alzheimer disease patients[36] and reduced concentrations of CRP, IL-6 and granulocyte monocyte-colony stimulating factor in hypertriglyceridemic men.[37] Fish oil supplementation was associated with increased TGF-beta mRNA in maternal and cord blood, decreased IL-1 and IFN-gamma in mothers, as well as mRNA levels of IL-4, IL-13, CCR4, natural killer and CCR3+CD8+ T cells in cord blood.[38]

Neuropsychiatric disorders and LC n-3 PUFA from fish

Bipolar disorder (Manic-depressive illness), depression and schizophrenia are common neuropsychiatric disorders. Beneficial effects of n-3 PUFA have been reported in Neuropsychiatric health such as attention-deficit/hyperactivity disorder (ADHD), schizophrenia, and may be effective in managing depression in adults. Decreased LC n-3 PUFA concentration has been reported in serum/plasma phospholipid and cholesteryl esters of depressive patients,[39,40] dyslexic and ADHD male patients,[41] and in erythrocyte membranes of ADHD adults and schizophrenic patients.[42,43] Increased plasma EPA levels have been associated with decreased risk of dementia. Increased ratios of n-3 to n-6 fatty acids and of DHA to AA may also decrease the risk of dementia, especially in depressed older subjects.[44] Increased plasma phosphatidylcholine DHA level was significantly negatively associated with the risk of developing all-cause dementia.[45] LC n-3 PUFA supplementation significantly improved symptoms of psychological distress and depressive scale score in women with moderate-to-severe psychological distress without major depressive episode,[46] childhood depression,[47] and very mild Alzheimer's disease in older patients.[48]

Visual function and LC n-3 PUFA from fish

DHA or DHA and AA-supplementation in infant formula supports visual acuity similar to that of breast-fed infants.[49] Erythrocyte DHA levels was significantly corrected with sweep visual-evoked potential (VEP) acuity in 12 month old infants.[50] Consumption of LC n-3 PUFA from oily fish was inversely correlated with the incidence of neovascular age-related macular degeneration.[51,52] Dietary LC n-3 PUFA intake is associated with a decreased risk of progression from bilateral drusen to central geographic atrophy.[53]

However, the natural marine and fresh water fish population is declining globally as a result of over fishing, temperature and climate changes etc., which results in a serious threat to the sustainability and affordability of fish. To solve this problem, various measures have been adapted by different nations. In the following sections, we will discuss how China is managing this issue.

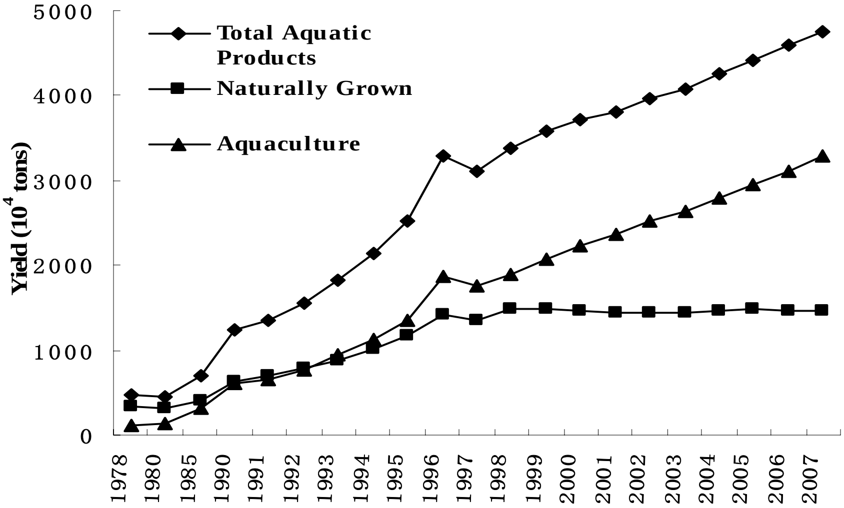

Figure 1. Classification of domestic total aquatic products from 1978 to 2007.

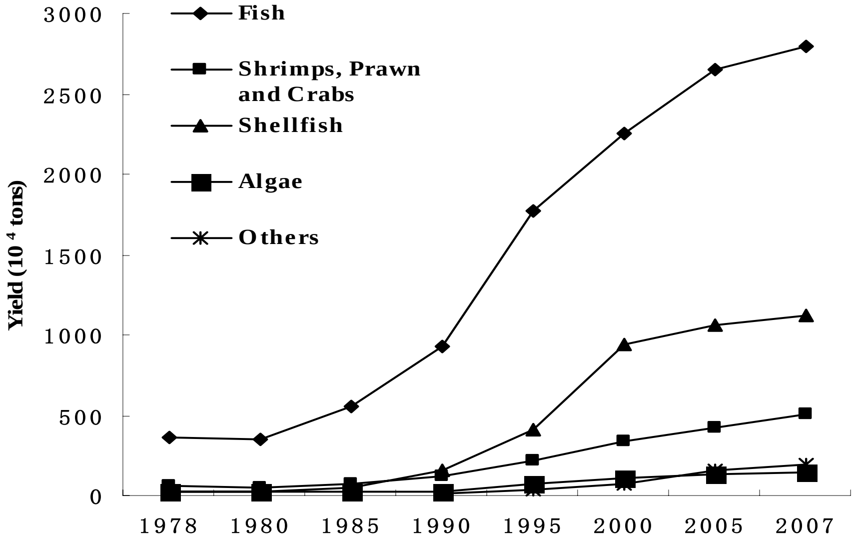

Figure 2. Yield of the main species of aquatic products.

AQUACULTURE

Formerly, the fish industry had been dependent on marine fishing, which was somewhat restricted by its emphasis on fishing and negligence on culture. To overcome declining fish populations and increased demand, the government and the fish industry need to adopt effective measures to solve the problem of sustainability and affordability of fish. Since placing emphasis on fishery development and the aquaculture industry four decades ago, China has achieved tremendous success with respect to maritime fishing, as well as marine and freshwater aquaculture. The output of fisheries has increased continuously in China, which has been ranked number one in the world for 13 years in succession. There was a slow rising trend in natural production from 1978 to 1999, which has plateaued from 1999 to the present. The rise in the amount of total aquatic products after 1999 mainly stems from the increase in aquaculture. In 2007, the total output of aquatic products came to 47.48 million tons, of which 12.43 million tons consisted of maritime fishing, 13.07 million tons of marine aquaculture, 2.26 million tons of freshwater fishing and 19.71 million tons of freshwater aquaculture. Total aquatic products increased 9.2 fold, of which aquaculture output increased 28.1 fold compared with 1978 (Figure 1).[54]

Main aquatic species include fish, shrimp, prawn, crab, shellfish, algae and others. With respect to their yield, there is a significant yield rise of fish from 1985 to 2007, and a similar tendency with shellfish from 1985 to 2000, while shrimp, prawn, crab, algae and others have had a steady growth since 1985 (Figure 2).[55] In 2006, the per capita share of aquatic products in China reached 40.4 kg, which is 10 kg higher than the world's average. Domestic aquatic products are abundant in supply, wide in variety, freely available and affordable to the population. Total aquatic products accounted for more than one third of the domestic production of animal foods, including meat, poultry and aquatic products.[56] Over the past two decades,

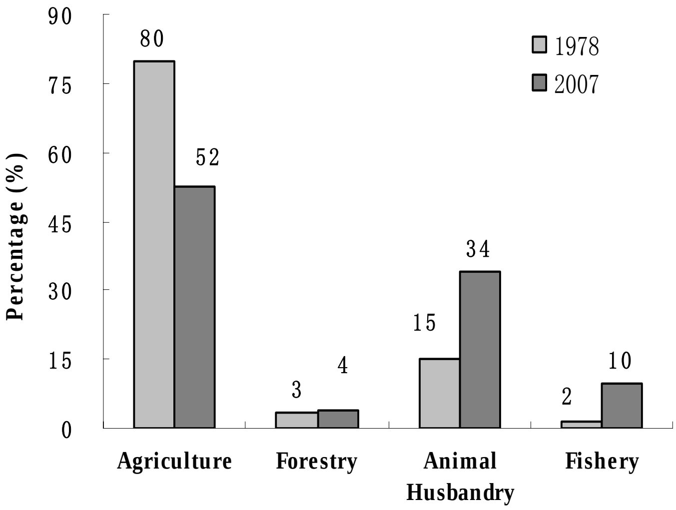

Figure 3. The output value proportion of agriculture, forestry, animal husbandry and fishery.

fishery has become one of the fastest growing industries in the development of agriculture and the rural economy, creating substantial employment opportunities and income. The proportion of fishery is continuously rising, representing 1.6 percent in 1978 and 10.9 percent in 2000 respectively of the total output value of agriculture, forestry, animal husbandry and fishing industry (Figure 3).[55] During these periods, fishery provided more than 10 million jobs, of which 70 percent is engaged in aquaculture.

Foreign trades for aquatic products represent a significant form of trade in China. During the past 30 years, foreign trade of aquatic products has undergone considerable development, with an annual average increase in trade volume of 20 percent. The export value of aquatic products was approximately 9.36 billion US dollars in 2006, which represented about 30.2 percent of the total export of agricultural products and 10 percent of aquatic products of the world respectively, and it was ranked number one in terms of China's primary agricultural products continuously for seven years. Recently, the export amount of aquatic products from China increased annually at a rate of 10 percent, and this is anticipated to develop steadily in the future.[57]

In addition, to maintain the sustainability and affordability of fish, a period of banned fishing has been adopted in China. The next section will be focused on these measures.

FISHING MORATORIUM

While there are vast waters and rich resources for aquatic organisms, over fishing, the development of the economy, raising temperature and climate changes etc. have threatened the marine ecological environment. The resources of aquatic organisms are being damaged and the desertification of aquatic ecosystems is becoming an increasingly serious issue. In order to protect fishery resources and restore the ecological environment of maritime waters, China has established the "Fishing moratorium", whereby fishing is banned for 2-3 months during a specified period of the year, which differs depending on geographical area, from 1995. In 1999, all the maritime zones, including Yellow Sea, East China Sea and South China Sea carried out the fishing moratorium, and it has been fully implemented since 2000.[58]

The Yangtze River is vital for the domestic freshwater fishing industry. In recent years, fish resources have been under threat due to factors such as pollution of waters, water conservancy construction, reclaiming land from lakes and over fishing, which directly has an impact on the sustainability of the fishery economy in the Yangtze River. In order to protect and restore fishery resources, a spring season fishing ban was tried in 2002. In 2003, the fishing ban was implemented in ten provinces along the Yangtze River. Usually, the fishing ban is conducted in spring and summer, from early February to the end of July. It is an effective measure to protect fishery resources. Natural fish population in marine and freshwater has been successful re-established since the implementation of these banned fishing periods, and thereby maintaining the sustainability and affordability of fish. For example in East China Sea, compared with average yield from 1990 to 1994, after the fishing moratorium had been implemented for seven years from 1995 to 2001, the average yield of fishing rose by 2.71 million tons, of which hairtail, small yellow croaker and pomfret, the three main commercial fish, increased by 538 thousand tons annually (Table 1).[59]

OMEGA-3 FATTY ACIDS CONTENT IN COMMON COMMERCIAL AVAILABLE WILD AND CULTURED FRESHWATER FISHES

Consumers traditionally prefer to purchase wild fish since they thought that the wild variety is more nutritious than cultured fish in China. To clarify this issue, we have investigated the n-3 PUFA content in common commercial available natural (wild) and cultured freshwater fishes. Four species of wild and cultured freshwater fishes (crucian crap, mandarin fish, silver fish and snakeheaded fish) purchase from supermarkets in Hangzhou, China, were included. Approximately 5 g of well-grounded samples was extracted with 50.0 mL of chloroform–methanol (2:1, v/v) containing 10 mg/L of butylated hydroxytoluene and

Table 1. Main East Sea commercial fish yield variation from 1990-2001 (10 thousand tons).[59]

Financial year	Total yield	Hairtail	Small yellow croaker	Pomfret
1990	229.71	38.67	0.72	4.98
1991	254.95	45.30	1.70	5.89
1992	278.18	49.23	2.35	3.86
1993	312.75	49.97	2.60	5.60
1994	403.18	65.42	5.05	7.42
1995	418.90	84.92	7.59	13.41
1996	504.71	72.72	9.50	13.78
1997	574.61	74.83	8.71	16.02
1998	615.01	80.50	10.18	19.00
1999	618.40	84.46	13.79	21.13
2000	625.39	90.99	15.95	22.49
2001	612.71	86.74	12.50	22.27

Table 2. Omega-3 fatty acid contents of four species of wild and cultured freshwater fish (mg/100g)

Fatty acids	Crucian carp		Mandarin fish		Silver fish		Snakeheaded fish	
	Wild	Cultured	Wild	Cultured	Wild	Cultured	Wild	Cultured
18:3n-3	33.0±4.9	50.6±4.0	249.6±19.4	170.6±30.7	90.2±55.0	103.3±4.7	148.0±34.6	95.6±15.8
20:5n-3	15.1±3.2	30.0±1.9	116.4±7.6	66.5±10.3	112.0±40.0	250.2±36.8	55.3±9.6	238.6±48.6
22:5n-3	9.4±4.6	16.0±3.3	99.0±6.8	48.0±11.9	27.8±9.3	64.6±10.2	87.2±12.4	173.2±31.7
22:6n-3	41.7±11.3	130.0±13.2	349.5±15.6	157.7±11.0	141.6±67.2	00.0±41.5	220.8±35.2	596.9±115.6

0.1 mg/mL of tricosanoic acid (C23:0, Nu-Chek-Prep, Elysian, MN) as an internal standard. Fatty acid methyl esters (FAMEs) of the total lipid extract were prepared by transesterfication in H_2SO_4 (0.9 mol/L in methanol). The fatty acids were analysed and identified with capillary gas chromatography. Total and individual n-3 fatty acid contents in three of four species of fish, crucian crap, silver fish and snakeheaded fish were higher in the cultured sample than the wild, except for 18:3n-3 of snakeheaded fish, which is higher in wild than cultured (Table 2). We concluded that there is a big variation on n-3 PUFA content in different fish species; it is not necessarily that wild fishes are more nutritious than cultured fishes.

While we have discussed the positive health benefits of fish, and the measures to maintain the fish industry, concerns have arisen over food safety caused by fish contaminants. This will be discussed further in the next section.

Table 3. Fishery drug residue limit in aquatic products in China.[60]

Drug name	Maximum Residue Limit (μg/kg)
Chlortetracycline	100
Oxytetracycline	100
Tetracyclines	100
Chloramphenicol	ND
Sulfadiazine	100
Sulfamerazine	100
sulfamethazine	100
Sulfamethoxazole	100
Trimethoprim	50
Oxilinic acid	300
Furazolidone	ND
Diethylstilbestrol	ND
Olaquindox	ND

ND=Undetectable

SAFETY AND CONTAMINANTS OF FISH

There has been increasing concern over potential harm from contaminants in some fish species. The public is facing bipartite conflicting reports on the benefits and risks of fish intake, resulting in confusion over the role of fish consumption in a healthy diet. However, there is no data to show that certain clinical condition is caused by the fish consumption.

Antibiotics in aquatic products

With the development of the aquaculture industry, there is a high frequency of aquatic diseases, of which antibiotics play a vital role in the control of these diseases. At present, there are six antibiotics most widely used: macrolides, β-lactam, sulfonamides, tetracyclines, furans and quinolones. But the irresponsible usage of antibiotics may lead to drug residues in aquatic products and pose threats to human health (Table 5). In addition, the presence of antibiotics in the environment could be harmful to ecosystems including bacteria, water and soil microorganism and plants, as well as giving rise to antibiotic-resistant pathogens. Therefore, different countries developed their own standards for maximum antibiotics/drug residue in aquatic products. Table 3 is China's national standards for maximum antibiotics/drug residue, and Table 4 is the maximum level chloramphenicol residue in aquatic products and animal derived food in selected countries and regions. Chloramphenicol residue in exporting aquatic products from Fujian Province, China, has been investigated, 189 batches of shrimps both cultured and caught at sea, with the qualification rate of 85.2 percent. With regards to cultured shrimps, chloramphenicol residue is mainly due to the usage of this drug for the treatment of bacterial diseases (Table 5).[60]

Table 4. Chloramphenicol residue maximum level limitation of animal derived food in different regions (μg/Kg).[60]

European Union	America	Japan	Canada	Korean	Hong Kang	China
<0.1	<0.3	<10	<0.1	ND	<1	ND

ND= Undetectable

Table 5. Chloramphenicol residue in exported aquatic products in Fujian.[60]

Category	Sample size	Sample numbers >0.3μg/Kg	Qualification rate † <0.3μg/Kg
Roast eel	374	42	88.8
Eel	130	8	93.8
Shrimps	189	28	85.2
Clams	158	14	91.1
Crabs	45	3	93.3
Tilapia	43	0	100.0
Yellow croaker	25	1	96.0
Squid	60	6	90.0
Octopus	13	1	92.3

† Qualification rate based on the America limitation of chloramphenicol residue in animal derived food.

Table 6. Dioxin content of 31 batches of different commercial fish samples from Guangzhou and Shenzhen (pg/g wet weight).[64]

Compounds	Mean Concentration	WHO-TEF	TEQ
2, 3, 7, 8 - TCDF	0.31	0.10	0.031
1, 2, 3, 7, 8-PeCDF	0.12	0.05	0.006
2, 3, 4, 7, 8-PeCDF	0.19	0.50	0.097
1, 2, 3, 4, 4, 8-HxCDF	0.04	0.10	0.004
1, 2, 3, 6, 7, 8-PeCDF	0.03	0.10	0.003
2, 3, 4, 6, 7, 8-PeCDF	0.04	0.10	0.004
1, 2, 3, 7, 8, 9-PeCDF	0.02	0.10	0.002
1, 2, 3, 4, 6, 7, 8- PeCDF	0.05	0.01	0.0005
1, 2, 3, 4, 7, 8, 9- PeCDF	0.05	0.01	0.00045
OCDF	0.22	0.0001	0.00002
2, 3, 7, 8 - TCDD	0.05	1.00	0.048
1, 2, 3, 7, 8 -PeCDF	0.13	1.00	0.133
1, 2, 3, 4, 7, 8 -HxCDD	0.11	0.10	0.012
1, 2, 3, 6, 7, 8 -HxCDD	0.08	0.10	0.008
1, 2, 3, 7, 8, 9 -HxCDD	0.04	0.10	0.008
1, 2, 3, 4, 6, 7, 8-HpCDD	0.24	0.01	0.002
OCDD	0.67	0.0001	0.0001
Total PCDF	1.06		0.15
Total PCDD	1.32		0.21
Total Dioxin	2.38		0.35

TEF= Toxic equivalency factor
TEQ= Toxic Equivalents

Dioxin in aquatic products

PCDD/Fs (Polychloro dibenzo-p-dioxin and polychloro-dibenzofuran), toxic compounds found in the environment, are environmental endocrine disruptors, with a high chemical stability, which can cause severe harm to multiple human systems. Due to the high toxicity of 2,3,7,8-tetrachloro dibenzo-p-dioxin (2,3,7,8-TCDD), much attention has been paid in recent years. Recent research demonstrates that 95 percent of PCDD/Fs are derived through the diet, while the enrichment of PCDD/Fs in fish by food chain accounts for a considerable proportion of human diet exposure.[61,62] In order to investigate the degree of contamination of dioxin in fish in China, Zhang et al analyzed 31 different commercial fish samples from Guangzhou and Shenzhen, China. The average concentration of 31 different fish samples was 2.38 pg/g wet weight, and the average Toxic Equivalents (TEQ) was 0.35 pg/g wet weight, which is under European Union maximum limit of 3.0 pg WHO-TEQ/g.[63] The PCDD/Fs contamination level was different among samples. A congener-specific profile dominated by 1,2,3,4,6,7,8,9-octachloro dibenzo-p-dioxin (1,2,3,4,6,7,8,9-OCDD) and 2,3,7,8-TCDF was found, and the main contributor of toxicity was 1,2,3,7,8-PeCDD, 2,3,7,8–PeCDF. The average pollution concentration level of OCDD exceeded 20 percent, showing a high consistency with the distribution pattern of PCDD/Fs in the environment, which indicates that PCDD/Fs in fish mainly derive from the environment (Table 5).[64]

Table 7. The heavy metal content of aquatic products on market in the main cities of Zhejiang province (mg/kg wet weight) [68]

Products	Sample size	Content of heavy metal (Mean ± SD)				
		Pb	Cd	Cr	As	Hg
Bream fish	6	0.125±0.139	0.004±0.001	0.094±0.106	0.134±0.078	0.004±0.002
Large yellow croaker	14	0.072±0.031	0.015±0.006	0.465±0.257	0.298±0.112	0.022±0.015
Frozen shelled shrimp	13	0.100±0.029	0.011±0.008	0.196±0.071	0.310±0.063	0.009±0.004
River crab	14	0.071±0.028	0.032±0.016	0.446±0.172	0.305±0.076	0.040±0.014
Snakehead	13	0.079±0.041	0.005±0.002	0.155±0.035	0.091±0.081	0.022±0.016
Mud eel	8	0.142±0.110	0.006±0.003	0.046±0.042	0.153±0.076	0.075±0.041
Crucian	13	0.100±0.141	0.007±0.006	0.060±0.037	0.102±0.075	0.015±0.010
Turtle	24	0.095±0.068	0.011±0.007	0.131±0.108	0.062±0.056	0.035±0.030
White shrimp	10	0.056±0.110	0.011±0.013	0.046±0.060	0.130±0.140	0.028±0.025
Green crab	12	0.077±0.052	0.033±0.019	0.275±0.129	0.455±0.203	0.038±0.011
Portunid	7	0.083±0.038	0.110±0.040	0.166±0.075	0.419±0.244	0.027±0.009
Freshwater shrimp	5	0.113±0.082	0.008±0.004	0.118±0.071	0.208±0.065	0.002±0.003

Table 8. Maximum limit of heavy metals in aquatic products in China (mg/kg) [68]

Heavy metal	Limitation
Hg	≤0.3 (MeHg 0.2)
As	≤0.5 (freshwater fish) ≤0.5 (marine fish) ≤1.0 (shellfish, crustacean) ≤2.0 (algae)
Pb	≤0.5
Cd	≤0.1
Cr	≤2.0

Dioxin-like polychlorinated biphenyls

Polychlorinated Biphenyls (PCBs) is a synthetic organic compound, which does not readily decompose under natural conditions. Its residues in the environment and can be accumulated in fats of animals and plants, leading to teratogenicity, carcinogenesis and mutagenicity.[65] Polychlorinated Biphenyls have many similar physicochemical properties with PCDD/Fs, and a considerable amount of research shows that global aquatic organisms have been polluted by PCBs to various extents. Some countries such as Europe, America and China have developed regulations on the content of PCBs in aquatic products. In America, the content must be less than 2.0 mg/kg and 0.5 mg/kg in importing and pelagic aquatic products respectively; and it must be undetectable according to European Union regulations. In China, the content must be less than or equal to 2.0 mg/kg, and measured by the total amount of most common compounds, including PCB28, PCB52, PCB101, PCB138, PCB153 and PCB180, moreover the content of PCB138 and PCB153 should be less than or equal to 0.5 mg/kg.[66] A method for determining contents of PCBs in mussel and oyster has been developed by using capillary gas chromatography. Ten polychlorinated biphenyls (PCB28, PCB52, PCB155, PCB101, PCB112, PCB118, PCB153, PCB138, PCB180 and PCB198) were identified and quantitated. The contents of PCBs ranged from 0.03×10^{-9} to 28.9×10^{-9}(w), and the recoveries of PCBs ranged from 75 percent to 101 percent.[67]

Heavy metal in aquatic products

In recent years, aquaculture was directly affected by the heavy pollution of water resources, especially in some offshore areas. Heavy metals found in aquatic products have caused wide public concern. Therefore, an investigation was made on 139 samples to determine the content of heavy metal in 12 aquatic products categories (including marine and freshwater products) in Zhejiang province in 2003. From the analysis on the content of heavy metallic elements, we can see a high Pb content in mud eel, bream fish, freshwater shrimp and crucian. A high Cd content was found in portunid, green crab, river crab, large yellow croaker and frozen shelled shrimps. A high Cr content was found in large yellow croaker, river crab, green crab, frozen shelled shrimps and portunid. A high As content was found in green crab, portunid, frozen shelled shrimps, river crab and large yellow croaker. A high Hg content was found in mud eel, river crab, green crab, turtle and white shrimps (Table 7).[68] According to the standards of hygienic tolerance limit in foods (Table 8), of the aquatic products, the percentage of products over the standard limit of Pb, Cr and Hg is zero, it is 4.3 percent and 3.6 percent for Cd and As, respectively, which indicates that the metallic pollutant most abundant in aquatic products is Cd and As, and crabs and shrimps contain relatively more metallic pollutants.

IMPACT OF CONTAMINANTS ON FISH EXPORT

After the issue concerning chloramphenicol levels over the standard acceptable level in frozen shelled shrimps from Zhoushan in the latter half of 2001, the European Union put forward the complete prohibition of importing animal derived food from China. Recently in Japan, an antibiotic substance was detected in canned roasted eel produced in China. Since then, Japan has strengthened the safety inspection system on canned eel made in China. Korean custom detected lead and other heavy metal in some aquatic products imported from China. These series of events has led to export obstacles for aquatic products in China, which is being seriously and thoroughly addressed. As a result, some enterprises lost their license to export aquatic food products while all aquatic product enterprises received a general hygienic survey.[69]

CONCLUSIONS

Fish is high in long-chain n-3 PUFA, which have multiple beneficial health effects such as cardiovascular protection, anti-inflammatory effect, improving visual function and neuropsychiatry disorders. However, the sustainability and affordability of fish has been threatened globally by declining natural marine and freshwater fish populations. China has successfully solved this problem by adopting measures such as banning fishing for a specified period of the year and the development of aquaculture technology. China's success has contributed greatly to food and health security and will serve as a good model for other developing countries.

AUTHOR DISCLOSURES

Authors have no conflict of interest.

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Review

Fish and its multiple human health effects in times of threat to sustainability and affordability: are there alternatives?

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鱼对人体健康有诸多有益影响，但在这威胁漁獲永续性和人们支付能力的时代，有替代方案吗？

虽然鱼类受到各种污染，但鱼类仍然是一种健康食品，因为鱼富含长链n-3不饱和脂肪酸，这些脂肪酸对人体有诸多方面的有益影响，比如通过抗血栓形成和血管扩张作用降低脑卒中的风险，增强心率变异性，降低血压和血清中甘油三酯水平以及抗炎活性，改善视觉功能，改善多动症或活动过度症、精神分裂症和痴呆症状，在缓解成人抑郁症方面可能也有一定的作用。所有这些功能是通过改变细胞膜成分、流动性、受体和膜结合酶活性，基因表达以及类二十烷酸产物而实现的。然而，天然海洋和淡水鱼的数量正由于过度捕捞、温度和环境变化等而不断减少。为了恢复和维持鱼类数量，中国从1995开始，根据地域差异，在每年的特定时期都实行两三个月的禁渔期措施。禁渔期实施以后，鱼类数量得到了恢复，同时也保证了鱼类的永续性和價格穩定。水产养殖对中国的糧食体系做出了重大贡献，在过去的三十年里养殖产量从1978年的100万吨增长到2007年的3200万吨。與天然海洋和淡水漁獲相比，养殖鱼类在总水产品产量中占有较大的比重，目前只有中国实现了这一目标，这对中国的糧食和健康安全意义重大。对其他发展中国家来说，中国是在这一领域的一个成功典范。

关键词：水产品、水产养殖、禁渔期、永续性、污染物