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Safety and Sustainability of Seafood: Lessons from the Literature

by

Huiqiang Wang

URI Sustainable Seafood Fellow and Ph.D. Candidate

Department of Environmental and Natural Resource Economics

University of Rhode Island, USA, huiqiang_wang@my.uri.edu

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Introduction

Sustainable production of seafood is threatened by multiple factors, including lack of sufficient governance globally to account for the tight coupling of production systems with coastal and marine ecosystems and dependence upon common-pool resources (Smith et al. 2010). As a result, the full costs of production (including environmental costs) are not generally included in the prices paid by consumers for seafood. Some seafood production systems have been identified as sustainable, such as fisheries or aquaculture certified in independent third-party schemes to standards created by particular programs (e.g. the Marine Stewardship Council (MSC) or Global Aquaculture Alliance (GAA)) or evaluated in alternative processes by groups such as Monterey Bay Aquarium (MBA) or other environmental non-governmental groups (FSIG, 2009).

Buyers within the supply chain (e.g. retailers, restaurants, processors, distributors) are made aware of which species, or products from specific sources, are 'sustainable' and which are not and may use these to influence their purchasing decisions. Consumers are informed of sustainable seafood via labels (e.g. ecolabels of the MSC or Best Aquaculture Practices (BAP) the certification arm of the GAA), wallet cards or on-line sources, or even through telephone applications.

Jointly with information on sustainability, eNGOs are increasingly informing consumers about possible health risks associated with ranked seafood. For example, the Blue Ocean Institute (BOI) sustainable seafood guides provide a color-coded ranking for sustainability as well as 'flagging' certain species with a red flag and told "these fish contain levels of mercury or PCBs that may pose a health risk to adults and children. Please refer to http://www.edf.org/seafood for more details" (www. blueocean.org/seafood/seafood-guide). Are these guides providing accurate risk information? Are the health benefits of consuming seafood given equal weight, or is risk communication used selectively as a means of steering consumers away from 'unsustainable' seafood? For example, in spite of considerable scientific evidence that consumption of fish rich in 'omega-3' (EPA/DHA) improves cardiovascular health, the environmental community has recently raised the concern that touting health benefits from consuming seafood is jeopardizing the sustainability of fisheries (Jenkins et al. 2009).

The purpose of this paper is to review the scientific literature on health risk/risk comparisons related to seafood; in particular, how do health risks from consumption of chemical and inorganic contaminants relate to risks from health deterioration as a result of non-consumption of beneficial nutrients from seafood. Specifically, the report will present a general overview of the scientific evidence comparing the risks primarily regardless of species or production process, but draw implications for two of the most controversial species in the sustainable seafood movement – farmed salmon and tuna – which also happen to be among the most interesting in the health risk/risk discussion. In contrast to previous literature which has presented similar compilations of scientific literature, this paper will also review the economic literature of analyses related to consumer demand for seafood, perception of seafood safety or benefits, and influence of risks on demand. The report will highlight not only the results of the economic literature but also present the approaches taken in the economic literature to analyze health risks (benefits) specifically for seafood by consumers, and extent that to which that literature illuminates risk-risk trade-offs between seafood and other non-seafood goods.

The report is divided into three sections. The first section is a review of previous studies of the health benefits, risks and their tradeoffs. The second section briefly reviews and discuses implications of these issues for sustainable and aquacultured seafood, including farmed salmon and tuna. The third section summarizes the economic literature in evaluating health benefits and risks, factors influence seafood choice, consumer attitudes and perceptions, and the effects of seafood advisories or warning information on consumer demand for seafood.

1. Seafood Benefits and Risks

1.1 The benefits from seafood consumption

With many nutritional attributes, seafood is a desirable component of a healthy diet (Nesheim and Yaktine 2007). Seafood is a good source of unsaturated fat, high-quality protein, minerals and vitamins (Chan et al. 1999; EPA 2004; Mozafarian and Rimm 2006; Domingo et al. 2007a; Budtz-Jørgensen et al. 2007; Engeset 2008; Castel-Roberts et al. 2010). In comparison to red meat and poultry, fish and shellfish contain similar amino acids, but have more unsaturated fat. In addition, fish and shellfish are rich in many minerals and vitamins, more so than many other sources of protein, such as meats. For example, some seafood species are rich in minerals such as calcium (e.g. salmon and sardine), iron and copper (e.g. oysters) and iodine (saltwater fish and shellfish). Additionally, fish and shellfish are rich in vitamins B6 and B12, biotin and niacin (Parker 2001).

The most remarkable health-beneficial nutrients of seafood are the poly-unsaturated fatty acids (PUFAs). As early as 1940s, evidence suggested that the deficient intake of some fatty acids would lead to the coronary heart disease (Lee and Lip 2003). Researchers at first found that the occurrence of cardiovascular disease was relatively lower in those populations with higher fish and seafood consumption Then, it was proved that it was the PUFAs in seafood which helped to reduce the risk of heart diseases mortality and other nonfatal cardiac diseases (Whitaker et al. 1979; Bang et al. 1980; Harris 1989; Lee and Lip 2003; Young et al. 2005; Sioen et al. 2007; and Leaf 2008). The PUFAs are the fatty acids which contain two or more double carbon bonds (Wall R. et al. 2010). Two important PUFAs are n-6s (omega-6s) largely from plant sources and n-3 (omega-3s) mainly obtained from seafood and fish supplements. In chemical structure, they are different in the location of the double carbon bonds. However, both omega-3 and omega-6 are health essential, as they are essential to the functional development of brain, and are not synthesized in the body (Leaf 2008). Therefore, dietary intake becomes the major source to supply omega-3s and omega-6s (Hedelin et al. 2010)

Despite structural differences, omega-3 and omega-6 contain the same amount of energy, and go through the same oxidation pathways during the process of being metabolized in the body (Jordan et al. 2004). However, it is only omega-3 which positively contributes to cardiovascular and neuropsychiatric health (Young et al. 2005). Compared with early human diets, the intake of fatty acids has experienced large changes over the years. First, the portion of saturated fatty acids has increased considerably. Second, the ratio of omega-6 to omega-3 has also risen, from ratios of 1:1 or 2:1 to 20-30:1 in some western foods (Simopoulos 1999). According to Ruxton (2004), the omega-6 to omega-3 ratio is about 4: 1 in Japanese food but it is closer to 17: 1 in U.S. diets. The changes in omega-6 to omega-3 ratio can be explained by the decreasing omega-3 food intakes and more uses of omega-6-rich vegetable oil (Kris-Etherton et al. 2002). In fact, omega-6 functions differently to omega-3 in human body, and under certain circumstances, omega-6 works in opposition to omega-3 (Simopoulos 1991; Leaf 2008). Therefore, consuming more marine food is recommended as an efficient way to correct the omega-6 to omega-3 ratio.

Extensive research strongly supports health benefits of omega-3 from seafood consumption. These benefits include prevention of coronary heart disease, hypertension, diabetes, stroke, arthritis, cancer and benefiting fetus and infants (Connor 2000; Simopoulos et al. 2000; Kris-Etherton et al. 2002; Kris-Etherton et al. 2003; Ruxton 2004; Cohen et al. 2005; Mozaffarian et al. 2005; Mozaffarian and Rimm 2006; Nesheim and Yaktine 2007; Mozaffarian 2008). Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are the two pillars of omega-3. Indeed, all omega-3s fatty acids, includes DHA, can be elongated, desaturated or retroconverted into EPA (Harris 1989). The function of EPA has been long identified as contributing to prolong bleeding time and to decrease platelet aggregation (Holub 1988). As for DHA, it benefits the developing of brain and eyes, and particularly the neurologic development of infants (Uauy et al. 2000; Lewin et al. 2005; Mozaffarian and Rimm 2006; Oken and Bellinger 2008). While the potential separate health effects of EPAs and DHAs cannot be measured in most observational studies, Mozaffarian (2008) noted that DHA may be more preferable in reducing the risks of coronary heart disease (CHD). Even so, most omega-3 studies just focus on the combined effects of EPA and DHA (EPA+DHA). Even given the obvious cardioprotective effects of EPA+DHA, dietary EPA+DHA consumption in the North America does not reach the level recommended by American Heart Association (AHA) for prevention of coronary heart disease (Holub D. and Holub B., 2004).

In practice, omega-3 is found to be helpful in ameliorating atherosclerotic and thrombotic factors related with cardiovascular diseases (Gibson 1988). In addition, omega-3 is able to lower hypertension, and could be an adjunct therapy in hypertension treatments (Howe 1995). Nestel (2001) also confirmed the benefits of moderate omega-3 intakes to patients with cardiovascular disease risks. In a study of 20,551 male physicians in U.S., fish consumption at least once a week reduced the risk of sudden cardiac death (Albert et al. 1998). In a study of 84,688 female nurses, a similar conclusion was found, that more fish consumption and omega-3 intakes reduce the risks of CHD and CHD deaths (Hu et al. 2002). Dewailly et al. (2003) conducted a study on the relationship between fish intake and blood lipids in three Canadian ethnic groups. The results indicated the Inuit have a higher obesity rate than the Québecers, and Cree. But with more fish consumption, the Inuit have the lowest risks of cardiovascular disease (CVD). As a result of the scientific evidence, many researchers recommended fish oils and omega-3 fatty acids as the non-prescription approach for improved cardiovascular health (Artz et al. 2006). Use of omega-3 has been accepted by European and U.S. cardiac societies in the treatment guidelines for myocardial infarction, ventricular arrhythmias, prevention of heart diseases and sudden cardiac death (Schacky 2007). The prospective study of Levitan et al. (2009) on middle-aged and older men suggested even though the correlation is less statistically significant, even moderate intake of fatty fish and omega-3 may help to lower the occurrence of heart failure. This study also indicated that there is a threshold above which a larger intake of fish was not associated with more benefits to heart diseases, also noted by other researchers (Mozaffarian and Rimm 2006; Mozaffarian 2008).

Researchers have also reported on the beneficial effects of omega-3 in ameliorating *diabetes mellitus*. However, excessive doses of fatty acids are reported to lead to potential deleterious effects (Axelrod 1989). Adler et al. (1994) found that the risk of non-insulin-dependent diabetes mellitus (NIDDM) is noticeable low among Alaska natives, since they have higher omega-3 intakes from the consumption of seal oil and salmon. To insulin-dependent diabetes mellitus (IDDM), Bagdade (1996) pointed out the cholesteryl ester transfer (CET), which is the symptom of IDDM, was significantly decreased by marine lipids intakes. The results implied these lipids could contribute in reduction of IDDM. Krishna and Das (2001) recommended that omega-3 and omega-6s prevent alloxan-induced diabetes mellitus, and help the antioxidant to reach normal levels. In a review of previous epidemiologic studies, it was perceived that omega-3 have positive contributions to type-2 diabetes patients without negative effects on glucose control and insulin activity (Nettleton and Katz 2005).

In consideration of omega-3 supplements as cancer prevention aids, more observations are needed to obtain consistent conclusions. Laboratory evidence to supports the anticarcinogenic role of omega-3 in decreasing the risks of colorectal cancer, prostate cancers and breast cancer, however, other contributing factors must be considered for any conclusive statements may be made (Terry et al. 2003; Astorg 2004; Thiébaut et al. 2005; Pauwels and Kairemo 2008; Spencer et al. 2009).

Previous studies revealed nutrition during the first weeks of life have a critical influence on brain development. High omega-6 to omega-3 ratios could be damaging to the fatty acid composition of the developing human central nervous system (Simopoulos 1991). The health of the next generation largely depends on maternal nutrition status, including the intake of fatty acids and other lipids associated nutrients (Crawford 1992). The less sufficient omega-3 status of the mother will be passed to the fetus and infant (Otto et al., 1997). Certain studies have examined the benefits of unsaturated fatty acids to visual acuity and cognitive development. However, the conclusions seem less consistent (Ruxton 2004). Jørgensen et al. (2001) supported the improvement of infant visual acuity are connected with maternal milk DHA contents. And, maternal milk DHA depends on mother's fish consumption. To the relation between omega-3 and children intelligence quotient (IQ) there was a positive relation reported but this view was not supported by other studies (Ruxton 2004). Likewise, Assisi et al. (2006) denoted that an optimal balanced omega-6 to omega-3 ratio is critical to proper neurodevelopment and cognitive functions, but more confirmed results are required to support the effects. Regarding other roles of omega-3 to mental health, Peet and Stokes (2005) pointed out omega-3 could be an adjunctive therapy to unresponsive depression and schizophrenia. Accordingly, it was also advised to provide education programs to women of childbearing age about health benefits of omega-3 to the brain (Katz et al. 2007). As reported earlier, omega-3 is also beneficial to cognitive abilities of the aged population (Dangour and Uauy 2008).

1.2 The risks involved in seafood consumption

Dietary seafood intake benefits human health, but it is not always risk-free. The potential risks include contaminants from chemicals, heavy metals, chemicals, marine toxins, and inorganic compounds (Hites et al, 2004a; Nesheim and Yaktine 2007; Iwamoto et al. 2010). To limit the scope of this paper, this report only focuses on the risks of inorganic compounds such as mercury, polychlorinated biphenyls (PCBs) and dioxins.

1.2.1 Mercury

There are two forms of mercury in the environment, namely inorganic and organic mercury (primarily in the form of methylmercury) (US EPA 2001). For the general population, fish and fish product consumption are the major source of mercury and methylmercury exposure (Inskip and Piotrowski 1985; Bernier 1995; Mahaffey 1999; Järup 2003; Elhamri et al. 2007). Once released into water, inorganic mercury will be transformed into organic methylmercury through the process of methylation by bacteria, and then be absorbed by organisms in the water. After consumption by fish and shellfish, methylmercury is accumulated in bodies of these species (Hughner et al. 2008). Then, the methylmercury concentrations are gradually magnified through the food chain. Hence, the higher methylmercury contents are found in the longer-living, larger, and predatory species on higher levels of the food chain, e.g. swordfish and shark. Similarly, some smaller species have relatively lower methylmercury concentrations (U.S. EPA 2001; Gochfeld 2003). Unlike PCBs, mercury is distributed throughout the fish body, and cannot be reduced by removing skin and fats (Kris-Etherton et al. 2002). From the perspective of human health, negative effects of mercury are trivial compared with methylmercury, as the latter is more easily absorbed into human blood stream (CA BCSF 2007). With the lipophilic attribute, methylmercury is able to pass through lipid membranes of cells, could become distributed to all tissues, and crosses the placental, blood and brain barriers (U.S. EPA 2001).

With differences in seafood consumption frequencies, the amount of fish consumed per meal and species implies that the mercury concentration levels and human mercury exposure could be varied (Weihe et al. 1996; Mahaffey 1999). Currently, the health effects of mercury exposures have been identified in many studies. For example, previous research claimed prenatal mercury exposures would lead to high risks to brain damage (Fitzgerald and Clarkson 1991). An investigation of Faroe Islands marine food consumption and contaminants exposure found that prenatal mercury and PCB exposure led to children's neurobehavioral dysfunctions (Weihe et al. 1996). In addition, methylmercury could cross the placenta and blood-brain barrier, and become toxic to nervous system of fetus. It was reported high methylmercury exposures lead to mental retardation and cerebral palsy (Myers and Davidson 1998). The study of Oken et al. (2005) also showed mercury exposure contributes to negative cognitional effects. By applying an IQ index, an estimate of infant neurodevelopment, it was found that maternal mercury had negative influence on IQ points. The IQ points reduce -0.18 with one more part per million of hair mercury of the mother (Axelrad et al. 2007). Therefore, methylmercury is viewed as one strong neurotoxicant, particularly on fetuses (Díez 2009).

Aside from the negative impacts to neurologic development, mercury exposure also has other detrimental effects to human health, such as the gastrointestinal, respiratory, hepatic, immune, dermal, and renal systems (Risher et al. 2002). Reportedly, mercury and other heavy metal exposures are detrimental to human immune system, and leads to autoimmune diseases and allergic manifestations (Bernier et al. 1995). Moreover, mercury exposure can induce syndromes as paresthesias, ataxia, and sensory abnormalities to adults, and delay the cognitive and neurodevelopment of fetus (Gochfeld 2003; Mozaffarian and Rimm 2006). According to Chan and Egeland (2004), high mercury exposure may negatively affect cardiovascular health. However, the evidence to support the relationship is still less sufficient. The finding of Hansen and Gilman (2005) implied that public health authorities could lower guidelines for mercury intakes as mercury may also be a factor contributing to ischemic heart disease, which leads to reduced blood supply to the heart muscle, more than neurological effects. One possible explanation to the mercury exposure and cardiovascular diseases risk is due to the effects of mercury in oxidative stress propagation (Virtanen et al. 2007). More than neurobehavioral deficits, with high dietary mercury exposures, symptoms as cytogenetic damage, immune alterations, and cardiovascular toxicity were reported in several Amazon countries (Passos and Mergler 2008).

1.2.2 PCBs and Dioxins

More than mercury, organic contaminants such as PCBs and dioxins are potential risks to seafood consumers (Ahmed et al. 1993). PCBs and dioxins exist in natural water bodies at low levels. However, with less degradable and lipophilic attributes, PCBs and dioxins become bio-accumulated through food chains, and are at much higher levels in the bodies of large, predatory fishes and other seafood species, and then in the body of human (Tryphonas 1995; Kris-Etherton et al. 2002). Similar to mercury, food intake is the major source of

PCBs and dioxins exposures. Actually, the risk of PCBs and dioxins is not primarily from seafood, as more dietary PCBs and dioxins are supplied from sources other than seafood (Mozaffarian 2009).

Experimental studies have shown the adverse health effects of PCBs, including toxicity to liver, blood, skin, gastrointestinal system, endocrine system, immune system, nervous system, and reproductive system (UK SACN 2004; Costa 2007). As PCBs widespread in the environment in the U.S., fish advisories usually recommended consumers to limit intake of fish species of high PCBs concentrations (U.S. EPA 1999a). Dioxins have shown similar health effects as PCBs in animal experiments. Moreover, some studies suggest there are threats of liver damage and cancer to human with exposures of dioxins (U.S. EPA 1999b). Even with many potential adverse health effects, consumers primarily worry about the cancer risks from PCBs and dioxins. Considering the developmental effects and liver cancer that have been reported to PCBs and dioxins, the US EPA has classified the two contaminants as probable human carcinogens (Group B2) as of the late 1990s (U.S. EPA 1999a; U.S. EPA 1999b).

PCBs and dioxins are toxic to the human immune system, particularly to the fetus and newborn (Tryphonas 1998). The "Yusho" disease in Japan and "Yu-Cheng" disease reported in Taiwan are the typical cases of the effect of PCBs. Symptoms include dermal and ocular lesions, irregular menstrual cycles and altered immune responses (Aoki 2001). Kimbrough and Krouskas (2001) indicate there was no clinical evidence to identify the effects of PCBs to immune system, thyroid function, and birth weight in infants. Furthermore, the cardiovascular system is also very sensitive to the influence of PCBs and dioxins. Some studies indicated developmental human dioxins exposure increases heart disease risks in later life. Animal research also confirmed adult dioxin exposure can lead to hypertension and cardiovascular disease (Kopf and Walker 2009).

To understand the neuro-toxic effects of PCBs and dioxins, human and animal studies have been conducted. For human studies, the focus is the possible neurological damage to newborns and young children. Evidence indicates consumption of fish with PCB contamination may lead to neurobehavioral alterations (Faroon et al. 2001). For infants, exposure to methylmercury and PCBs has been related to retarded neurodevelopment (Halldorsson 2008). Compared with adults, fetus and infants are more vulnerable to PCBs and dioxins, as the concentration of these contaminants per unit body weight will be much higher with considerably small body size. To adults, it was reported that increasing PCBs concentration could reduce verbal learning ability of adults in ages 55-74 (Fitzgerald et al. 2008).

For pregnant women, it is possible to reduce methylmercury intake before and during pregnancy. But it is less likely to reduce the maternal PCBs and dioxins exposure by temporary diet changes, since it needs several years to decrease the level of these substances in human body (U.K. SACN 2004; EFSA 2005; Dovydaitis 2008). With lipophilic attributes, the concentrations of PCBs and dioxins are much higher in fatty fishes than lean fishes (Halldorsson 2008). It was reported removing skin and fats of the fishes before cooking could decrease exposures to these contaminants (Roeder et al. 1998). However, some studies indicated skin-removal may not reduce PCBs content in salmon fillet (Shaw et al. 2006). Similar to metals, particularly arsenic and cadmium, PCBs and dioxins were found of higher levels in large crustaceans than fish (Guldner et al. 2007).

1.3 Balance of the benefits and risks

There is a classic dilemma in consumer's food choice, to trade off between health benefits and potential risks (Yaktine et al. 2008). Especially in seafood, this tradeoff is even more complicated as the contaminants and nutrients may affect the same epidemiological outcomes (Choi et al. 2008). The health benefits of seafood could be offset by the presence of contaminants (Costa 2007). For instance, the increased mercury contents in fish function opposite to benefits of omega-3 to human health (Smith and Guentzel 2010). However, to consumers, achieving the balance of health benefit and risk is not easy, as most consumers do not have the knowledge, expertise or even time to evaluate the trade-offs. Therefore, outside resources are often created to assist them in making right choices (Nesheim and Yaktine 2007). Concern about health-risk contaminants, such as mercury, PCBs and dioxins leads to many fish advisories, just as the fish recommendations focus on health benefits. However, consumers may feel very confused since the recommendations and advisories sometimes cannot be reconciled.

Generally, recommendations encourage more seafood consumption because they are focused on nutrients. One widely cited recommendation is the AHA's 'no less than two 3-ounce servings of seafood per week.' But, possible negative health impacts of the contaminants should not be ignored (Levenson and Axelrad 2006). On the other hand, fish advisories focus on limiting the seafood intake and reduction of the exposure of certain species with potential health risks (Park and Johnson 2006). But researchers have argued that excessive limitation of fish and seafood consumption may induce more harm to human health as the health benefits from seafood consumption will also be decreased (Egeland and Middaugh 1997; Arnold et al. 2005; Hibbeln 2007). The public should be informed that fish is a part of healthy diet if consumed with moderation (Smith and Sahyoun 2005).

Seafood is an important source of nutrient intake for children and women in pregnancy and lactating ages. However, at the same time, these populations are also more vulnerable to the exposure of contaminants such as mercury, PCBs and dioxins (Yaktine et al. 2008). Thus, children and childbearing women have come under special attention in designing the fish or seafood advisories. In 2004, the U.S. FDA and U.S. EPA jointly published an advice for mercury in fish and shellfish. This advice stressed the positive role of fish and shellfish consumption, and recommended which species provide source of nutrients, while also low in mercury content. It also recommended populations in particular life stages, as pregnancy, nursing and young child to alter certain species to avoid negative exposure of mercury (U.S. FDA and U.S. EPA 2004). Likewise, Scientific Advisory Committee on Nutrition of United Kingdom (U.K. SACN) suggested pregnant and nursing women need to avoid some species, such as the oily or large predatory fish with high mercury, PCBs and dioxin concentrations. However, other population groups (e.g. men, women who are not of childbearing years) can consume these species within guideline values (U.K. SACN 2004).

Considering the pros and cons of seafood, the health effects of seafood consumption largely depends on consumers how to balance the risk-benefit or risk-risk tradeoff (Teutsch and Cohen 2005). Therefore, net public health effects are decided by subpopulations' seafood consumption choices. For example, a quantitative analysis of Cohen et al. (2005) found that substitution of high mercury fish toward low mercury fish would increase the health benefits of women in childbearing age. If the women reduce fish intake, the health benefits will be reduced. However, the net public health impact will become negative if all adults reduce fish intake.

To identify the “zone of benefit” in seafood consumption, which is defined as the range between the benefit threshold and the harm threshold, Gochfeld and Burger (2005) conducted a composite dose-response curve in their study. The results showed the observable benefits of pregnancy and birth weight could be achieved by 8-15 g/day maternal fish intake. As for adult cardiovascular benefits, the expected fish intake range from 7.5 to 22.5 g/day bracket. Based on the daily methymercury intake threshold from U.S. EPA, the harm threshold cover the range of 27 g/day of common commercial fishes to 65 g/day of the species in low methylmercury. With reviewing previous studies, Mozaffarian and Rimm (2006) argued the risks involved fish consumption should be considered together with the health benefits. One distinguishing point in the paper is a comparison of health beneficial nutrient and risky contaminant contents of major commercial seafood and other animal source food. Mercury seems to be the special risk of seafood. But, unlike the commonly hold view, the PCBs risk is not seafood exclusive. In fact, other animal source products, such as beef, butter and chicken are of much higher PCBs than many seafood species. However, EPA and DHA are at noticeable high level of many seafood species but of zero content in those non-seafood items. Therefore, this paper supports the benefits of modest fish consumption outweighs the health risks. In addition, this paper also put forward the controversial role of the farmed salmon, which is of much higher PCBs in many previous studies. However, without the PCBs concern, salmon, especially farmed salmon as a good candidate for seafood consumption (Smith and Guentzel 2010). By comparing the limits of mercury servings per month and the servings per month for omega-3, the authors suggested salmon, trout, and shrimp are good seafood choices, and while shark, swordfish and wild ahi tuna should be avoided by at-risk populations.

One frequently mentioned approach to avoid risks of contaminants and to achieve the nutrient value of seafood consumption is to vary the species diet. Consumers could change the types of fish, and avoid species with a high level of contaminants (Virtanen et al. 2007). Thus, consumers can meet their nutritional needs, and reduce significant exposure to the single type of contaminants (Yaktine et al. 2008). Another possible method to achieve risk-benefit balance is to combine regular seafood intakes with the supplementation of major nutrients from seafood, as omega-3 (Kris-Etherton et al. 2002; Sioen et al. 2007). In addition, some studies suggest omega-3 can be obtained from the non-seafood sources, primarily the plant sources, as flaxseed, soybean and walnuts (Mahaffey et al. 2008).

Recent studies agree the balance of health benefits and risks in fish consumption is decided by more than one factor. The European Food Safety Authority (EFSA 2005) pointed out that nutrients and contaminants in fish depends upon season, diet, location, life-stage and age. For seafood consumption,, the consumer needs to consider the size of the fish (e.g. swordfish and tuna vs. sardines and herring), portion size, and the frequency of consumption Given that the effects to human health status are affected by overall diet composition, genetic makeup and individual lifestyles (NSCFS/VKM 2006; Kuntz et al. 2010). These considerations are reflected in seafood guidelines (e.g. Committee on Nutrient Relationships in Seafood of U.S. National Academy of Sciences) differentiating populations on factors of age, gender, pregnancy possibility and risk of coronary diseases (Nesheim and Yaktine 2007).

In addition to what has been discussed above, some studies stressed on other particular points in the health benefit/s and risks tradeoff of in seafood consumption. First of all, it shows seafood advisory may not cover the whole picture of health effects. For example, the benefits information is less emphasized (Scherer et al. 2008) in some U.S. fish advisories. Secondly, consumers may not be aware of how their cooking methods influence their health. As discussed, removing skin and fats in the body of some oily fishes will reduce PCBs and dioxin concentrations. Similarly, the health benefits of fried and non-fried fish are varied. Chung et al. (2008) indicated non-fried fish provides beneficial effects to reduce cardiovascular diseases, while the fried fish does not lower cardiovascular risks. Third, some health benefit/risk balances may be altered, if the effects of other potential environmental contaminants are considered. Domingo et al. (2007a) suggested that the recommended intake frequency and meal sizes of some seafood species should be changed if of other organic contaminants than PCBs and dioxins are considered. More than that, there is no clear specification of species differences, frequency of consumption, and meal size in the American Heart Association Nutrition Committee's (AHA NC) recommendation (Domingo et al. 2007b). Furthermore, consumers may be not informed that not all fish are the good sources of omega-3. Many fish contain relatively lower levels of omega-3, as catfish and tilapia (Weaver et al. 2008). Finally, current seafood consumption advices, advisories, recommendations, guidelines and factsheets seem less consistent (Ginsberg and Toal 2009), which may confuse the public in their consumption choices. Consumer advice from the government sources and private or non-government organizations (NGOs) are fragmented (Nesheim and Yaktine 2007).

2 Sustainability and Safety: The role of sustainable seafood

Unsustainable production practices exist in both capture fisheries and aquaculture (Smith et al. 2010). From the mid-1990s, approaches to achieve sustainable production began being introduced in the seafood industry (Roheim 2009). These measures included boycotts, seafood guides, and ecolabeling, which expected to create consumer and buyer demand for sustainable seafood (Roheim and Sutinen 2006). In theory, these programs create economic incentives to encourage more sustainable production practices, and thus healthier oceans (Downes and van Dyke, 1998). In particular, ecolabeling and some other certifications reward producers with price premiums that consumers are willing to pay for their sustainable practices (Roheim, 2008). Seafood guides provide a ranking system to mark the status of wild and aquaculture production and inform consumers and buyers which species, production methods, and production areas to purchase (Roheim 2009). Some common guides in the U.S. are those of the Monterey Bay Aquarium (MBA), Blue Ocean Institute (BOI), and Environmental Defense Fund (EDF) (Roheim 2009).

With public concerns regarding health effects of seafood consumption, many sustainable seafood initiatives have set up notices to remind consumers about the health risks of certain species. For example, EDF uses a health alert to indicate mercury levels of some species, (http://www.edf.org/page.cfm?tagID=17694) such as tuna. Likewise, BOI provides the public with a health alert index of the number of meals that are safe consume per month for each species (http://www.blueocean.org/seafood/seafood-guide). MBA also offers a consumption limit notice for mercury (http://www.montereybayaquarium.org/cr/seafoodwatch.aspx) and other contaminants. Other efforts exist to link ocean health with human health outside of environmental groups (e.g. Harvard's Center for Health and the Ocean Environment)

Jacobs et al. (2002) analyzed the contaminants levels of selected persistent organic pollutants in farmed salmon. One key report on contaminants in farmed seafood was provided by Hites et al. (2004 a). This paper indicated methylmercury levels are also similar between farmed and wild salmons, but organochlorine contaminants are much higher in farmed salmon than the wild. Among the farmed salmon, the ones from Europe contain more contaminants than those from North and South America. On the whole, farmed salmon contains higher levels of PCBs, dioxins and dieldrin than the wild. The results indicated farmed salmon contain unusually high levels of PCBs, around 16 times the PCBs found in wild salmon, 4 times the levels in beef, and 3.4 times the levels found in other seafood (Hites et al. 2004a). As for the factors influence contaminants in farmed salmon, the study implied the accumulation of PCBs and other potential carcinogenic agents is decided by the fishmeal and fish oil used in salmon feeds. A similar study focusing on contamination from polybrominated diphenyl ethers (PBDEs) also suggested the farmed salmon present higher risk of contamination than the wild. The diversified PBDEs concentrations in the farmed salmon come from their feed (Hites et al. 2004b).

Based on previous studies, Foran et al. (2005) carried out a quantitative benefit-risk analysis to the farmed and wild salmon consumption. The farmed salmon was found to contain more organic contaminants than the wild. However, the farmed salmon contain more fatty acids, which yield higher health benefits. To reduce the risks, it was suggested that the salmon farming industry reduce contaminants in fish feeds. Obviously, the health benefit of higher total lipid and n-3 fatty acids in the farmed salmon was offset by the higher organic contaminants content (Hamilton et al. 2005). The findings of Shaw et al. (2006) supported the idea that organic contaminants are higher in the farmed salmon, but varied significantly in different regions. However, opposite to the commonly-held idea skin removal of salmon fillet could reduce overall contaminants content, this study found some skin-off salmon are of higher contaminants as well. It implied skin removal may not be effective in protecting consumer from PCBs and other organic contaminants.

Fish feed is often the center in the debate around sustainability of salmon farming. Some studies point out it is environmentally and human-safety beneficial to replace the current salmon feed by some “sustainable feeds”, as mixture of vegetable and vegetable oil. Bell et al. (2005) found PCBs and dioxins in farmed salmon are positively correlated with the concentration of these contaminants in the fish feed. Replacing the fish oil feed with vegetable oil feed in certain stages of the farming cycle could reduce the contaminants in the farmed fish. But Berntssen et al. (2010) pointed out that sustainable fish feeds could reduce the levels of some but not all contaminants. In addition, some ingredients of traditional fishmeal are the necessary nutrients to salmon.

Another seafood often finding itself in the debates around both sustainability of its production, as well as the human health implications from consumption is tuna, of several species. Tuna is frequently associated with mercury. In the US, tuna products including canned light, canned albacore and fresh/frozen varieties, accounts for 37.4 percent of total mercury inputs (Groth 2010). Burger and Gochfeld (2004) analyzed the mercury level of the canned tuna sold in the US. The study showed the white tuna (generally albarcore) is of much higher total mercury than the light tuna (most frequently yellow fin and skipjack). The average total mercury content of white tuna also significantly exceeds the U.S. FDA risk assessment standard. To reduce mercury risk, frequent tuna consumers are suggested to choose the canned light tuna over white. The mercury content in tuna may not be due to human influences, but rather from methylmercury existing in open oceans that may be formed in the deep sea or in sediments. This is based on research that showed that mercury content in yellow fin tuna has remained constant in Hawaii remained constant from 1971 to 1998 (Kraepiel et al. 2003).

3 Economics of balancing seafood health benefits and risks

3.1 Benefits and risk in theory

The health benefits and risks involved in seafood consumption has become a concern of the public (Roosen et al. 2009), and analyzed in the economic literature. With the non-market nature of the health and risk issues, economic analysis should be helpful in understanding these issues, and identification of the impacts of relevant policies (Buzby 1998). In economic perspective, the risk and benefit characteristics are the intrinsic attributes of seafood. These attributes can be search, experience and credence goods. Similar to other food, consumers' seafood purchasing decision is based on these intrinsic attributes, extrinsic quality indicators and the other information or cues they get from the product (Wessells 2002; Caswell 2006). One's perceptions about these attributes will then decide whether to consume the seafood and how much to consume (Lin and Milon 1993). However, it is difficult in general for consumers to understand these attributes and make choices.

The limited cognitive ability and bounded rationality in consumer behavior have been reported by some researchers. In many cases, consumers can not make right estimation of health risks in the food they consumed, even take food recommendation as warnings (Shimshack and Ward 2010). In the 'prospect theory' of Kahneman and Tversky (1979), consumers evaluate gains and losses differently relative to the reference point, and they have different risk preferences to gains and losses. Facing multiple risks, individuals are liable to take non-linear reactions (Huang et al. 2004). Miles and Frewer (2003) denoted the uncertainty involved risk perception is not affected by the type of uncertainty, and the perception will become serious if consumers feel they have little personal control to the risk or hazard. Accordingly, public communication programs could reduce the uncertainty in food consumption by providing the accurate health benefit and risk information (Marette et al. 2007). But information from these programs should be well-designed before coming to the public. In addition, the outcomes of these programs are reported could be altered by expression ways (Knuth et al. 2003), and designing the order of information to the subject (Marette et al. 2007). Furthermore, the study of Nganje et al. (2007) argued some policies to improve food safety may be dissipated by the "offsetting behavior" (OB) which makes consumers to lower their care with the policy. Besides the non-market attributes, there are also public goods characteristics in the issue of seafood health benefits and risks (Unnevehr 2006). Especially to the efforts of reducing seafood consumption risks, e.g. reducing mercury, PCBs and dioxins contaminants.

3.2 Seafood benefits and risks valuation in practice

The health benefit and risk tradeoff can be analyzed using traditional economic models which result in consumers placing values on goods with health benefit and risk attributes. To measure these economic values, researchers generally use the methods that provide revealed preferences, such as contingent valuation (CV) or conjoint analysis (CA) methods, and choice modeling etc. (Hanley, Shogren and White 2007) or hedonic pricing.

For example, Lin and Milon (1993) applied the double-hurdle model in evaluation of the influences of safety perception and other product attribute perceptions to shellfish demand. The results indicated safety conceptions to shellfish have influence to both participation and consumption decisions. However, the inspection program for shellfish has little direct influence on the demand. In some cases, it is also necessary to incorporate consumer's response into demand function. In another study, sales losses due to a toxic algal bloom were estimated demand for mussels in Montreal (Wessells et al. 1995). In this study, consumer's perception toward seafood quality was assumed to be a function of media information provided about the contamination. Results indicated there were some decreases in demand and sales losses resulting.

In opposite to those risk occurring scenarios, Buzby et al. (1995) used contingent valuation method to measure consumer's willingness to pay (WTP) to a risk reducing case, namely banning a postharvest pesticide used in fresh grapefruit. The results implied the estimated benefits still outweigh the estimated costs. As for seafood, this approach could also be applied to estimate consumer and producer surpluses in the target markets. Parsons et al. (2006) used the contingent behavior analysis method in the discussion of the influence of fish kills information to seafood demand. Based on subjects' response to seafood consumption questions, this study estimated a set of demand difference models. It was found the information of fish kills has significant impacts to seafood demand. And consumers are less responsive to professional information to assure seafood safety.

One popular assumption in risk-benefit valuation is the risk choice relies on the absolute risk levels. Huang et al. (2004) argued that the choice of consumption of risky goods depends on both absolute and relative risks to other goods with the risk as well. The results of Huang et al. (2004)'s study to seafood demand with presence of risk substitute indicated seafood consumption is correlated with the absolute risk and its relative risk to poultry. Consumer's response to food scare information is also the concern of certain studies. In econometric approach, Mazzocchi (2004) measured the demand recovery patterns of food scares. The results showed the marginal effect of food scare information is gradually decreasing. Consumers' reaction to farmed salmon reports is a good case to explain demand and food scare patterns. In the study to Canadian consumers' response to the risks of BSE and farmed salmon, it denoted the exposure of the scientific studies to chemical contaminants leads to considerably adverse consumer response (Leiss and Nicol 2006). Shimshack et al. (2007) used the parametric and nonparametric methods investigated consumer's response to US national FDA mercury advisory. The results stated aims of the issuing agency could be achieved by the information-based policies. Chase et al. (2007) used the probit model in the estimation of factors influencing functional omega-3 products in Canada. It shows the aging population is the most frequent omega-3consumer. Families with children also have high omega-3 products intakes.

3.3 Factors influencing seafood consumption

Many papers have studied the product attributes and other factors that influence consumers' decisions regarding seafood consumption. It has often been found that seafood consumers may not place price as the primary attribute that affects their seafood consumption. Instead, healthfulness of the products they consume may play a large role in decision making. For example, Myrland et al. (2000) analyzed determinants of and barriers to seafood consumption in Norway, and confirmed price is not the first concern in seafood choices, but some experience-related product attributes, such as the smell, taste and easiness to cook. This pattern is even more obvious in households of higher educational background. Also, this study suggested that households with children may have a certain resistance against consumption of seafood. The authors implied these households may have different tastes or preferences. Trondsen et al. (2004) investigated the health perception and seafood consumption of a specific age-group women in Norway. The finding denoted seafood consumption is positively related with health concern, cardiovascular diseases prevention medicine intake, healthy diet and age etc. Lean fish intake is closely connected with traditional food, and processed fish consumption is correlated to fast food.

Using the theory of planned behavior (TPB) and the cross-sectional data collected in Belgium, Verbeke and Vackier (2005) examined the factors determining fish consumption patterns. The authors concluded taste matters more than health in shaping fish consumption patterns. This study supports the conclusion of Trondsen et al. (2004) that fish consumption increases with age, and confirms the finding of Myrland et al. (2000) that the households with children tend to have lower fish consumption. Similarly, consumption of other health beneficial foods, e.g. the functional omega-3 products, also increases with increased health awareness, population age, and health information access (Chase et al. 2007). However, the study of Chase et al. (2007) indicated omega-3 will be consumed more in the household with children. This pattern could be explained by higher health concern. Pieniak et al. (2008) analyzed the effects of cross-cultural differences to fish consumption frequencies, and the impacts of cardiovascular disease history to fish intake motivation in five European countries. The outcome stated fish consumption is more related to tradition than disease history, particularly with respect to fatty fish. In this study, other factors influence fish consumption, including attitudes toward fish, ease of preparation and cooking, taste preferences and price.

3.4 Consumer attitude and perception toward health benefits and risk information

Lin and Milon (1993) indicated the attribute perceptions did have significant impacts on participation and consumption decisions. In comparison, one's shellfish demand might be less influenced by risk reduction information. Huang et al. (2004) maintained consumers' risk perception for seafood is also related with risks of other meats. On the benefit side, similarly, it can be assumed that one's health benefits perception is also connected with the benefits consumers can get from other foods. Moreover, in this study the authors assumed that the absolute risk reduction is dependent on the perceived absolute risk by respondents' own definition. Mazzocchi (2004) argued the judging of positive and negative information is highly subjective. In the real world, consumers' perception to health benefits and risks may not be consistent with scientific evidence (Verbeke et al. 2005). The consumer survey in five European countries of Verbeke et al. (2005) showed even with very high concerns about health effects, consumers' knowledge of the benefits and risks in fish consumption are poor. Nearly half respondents believed the health benefits of fish come from fiber than omega-3. Moreover, respondents have shown better knowledge about risks than the benefits of fish intake. Parsons et al. (2006) proposed consumers sometimes take irrational reactions to risk information, even they know the risk is less or may be of no influence to safety. In that study, respondents significantly reduce their fish demand, even if the fish kills did not influence the safety of seafood. In addition, consumers neglected the information regarding assurances of seafood's safety. Mandatory inspection programs could be effective in saving the welfare loss from reducing seafood consumption. But the gains of the inspection program will be attenuated if it will cause a price increase. In addition, it indicated there are some threshold points to trigger consumers' response to the negative information.

Shimshack et al. (2007) pointed out education and access to information, such as reading the newspaper, are critical factors influencing consumers' response to risk exposure. It implied consumer's risk avoiding reaction largely depends on their ability to use information. For example, the respondents with college education had stronger reactions to risk information than other groups. Both lab and field experiments in the study of Marette et al. (2007; 2008a; 2008b) showed health information did have impacts on consumer's seafood choice. For example, the order of health and risk information recommended to consumers influence the efficiency of the information. It would be more efficient if discuss benefit first and then the risk. In addition, the value of the health information could be determined by the results of the experiment and partial equilibrium model. Marette et al. (2008b) mentioned medical warning or recommendation is better for pregnant women and women of childbearing age, since the health benefit and risk information is transparent. Scientific evidence pointed out fatty fish generates a lower risk of coronary heart diseases leading to death, however, consumers may not believe so. Some consumers did not think fatty fishes are healthier, as they thought "fatty fish" may not be fatty (Pieniak et al. 2008). It can be concluded that consumers' perceptions are based on not only the information within availability, but also their previous knowledge and experience (Kole et al. 2009). Product perception is affected by the belief that cue contains information of evaluative aspects of the product. In addition, this study showed that many consumers have strong beliefs relating to the effects of production method on fish product characteristics, both sensory and credential.

3.5 Effects of fish advisories

The fish advisories are expected to provide consumers with advice regarding benefits and risks or suggestions regarding the consumption of certain species. In a study on the U.S. FDA mercury advisory (Shimshack et al. 2007), results indicated FDA's objective is achieved, as some consumers made a significant reduction in fish purchases. However, the advisory also leads to unintended effects, i.e. consumers who are not at risk also decreased their fish purchases. Moreover, the study suggested the less educated and informed population need more attention, as they are less able to get and use risk information. Public health communication programs play a critical role in altering public fish consumption behaviors, as the balance of fish choices is difficult to achieve which requires a balance of both health benefits from nutrients and risks of toxins (Marette et al. 2007). The cross-sectional survey in five European countries carried out by Pieniak and Verbeke (2008) indicated that labels of fish packages and shelves are potentially good information source for consumers. Consumers suppose the fish label can assure them the product quality, and they have more interest in to safety labels. One field experiment of Roosen et al. (2009) depicted the fish risk warning label did not have significant effects in reducing consumption of some highly contaminated fish species. While risk information was provided by many health organizations, the warning message is not risk-alerting to consumers. Therefore the study suggested fish warnings or recommendations could be complemented by some mandatory labeling or information on the product.

3.6 Preferences for farmed and wild seafood

Knapp, Roheim and Anderson (2007) show the market interactions of farmed and wild salmon, with discussion of several consumer surveys completed over the years related to consumers' relative preferences for the two. Holland and Wessells (1998) found that consumers in the eastern U.S. preferred fresh farmed salmon to fresh wild salmon, using a conjoint designed experiment. However, this experiment occurred prior to much of the media attention on the negative environmental attributes of farmed salmon, as well as prior to the release of the Hites et al. (2004a) study of PCB contamination of farmed salmon. Maynard et al. (2008) indicated Canadian consumers significantly reduced their salmon expenditure after the articles of PCBs finding in farmed salmon in 2004. The market data indicated the price premium of wild salmon, depending upon species, over farmed comes from both health benefits and better flavor considerations. After the release of the 2004 PCBs study, wild salmon sales experienced noticeable growth. However, as common consumers are not able to tell the visual difference of farmed and wild salmon, some farmed salmon was intentionally mislabeled as wild. In the study of Kole et al. (2009), the descriptions of advantages of fish farming influenced consumer's evaluations.

4. Conclusions

Seafood is a critical component of healthy diets, which is more clearly demonstrated by the high omega-3 (DHA+EPA) content in some species. One obvious health benefit of omega-3 is the protective function against risk of heart disease. The other important contribution of omega-3 is the favorable effect for human neurological development, especially to infants. In addition, omega-3s are found to be beneficial in ameliorating diabetes mellitus. While benefits in consuming seafood have been supported by numerous studies, seafood consumption may contain some risks. The long-term health risks are mainly from exposures to heavy metals, particularly mercury in certain species, and organic contaminants, such as PCBs and dioxins.

For human health, methylmercury is far more harmful than the inorganic mercury. The risks of mercury exposure include damage to brain and neurologic development, and negative impacts to the human immune system and cardiovascular health. Similar to mercury, PCBs and dioxins are gradually accumulated through the food chain, and of much higher contents in the bodies of larger, longer-lived and predatory seafood species. Potential adverse effects of PCBs are threats to liver damage and risk of cancer, damaging human immune system, and create neuro-toxic effects. However, it is critical to note that risks of PCBs and dioxins exposure are not seafood specific. Other food products have higher levels of PCBs and dioxins than seafood and yet are below the U.S. FDA threshold level.

Given the complexity of tradeoff the health benefits and risks of seafood consumption, there are many seafood recommendations and advisories available to assist consumers to make their seafood choices, while sometimes they are less well reconciled. Recommendations usually encourage more seafood consumption, but advisories tend to limit seafood consumption, at least of some species. Some studies have been carried out to make qualitative and quantitative analysis to public health effects from alternations in seafood consumption. It should be mentioned that the key in solving the complex is that different seafood consumer populations and in particular life stages have varied risk-benefit balances.

Sustainable seafood productions exist in both capture fisheries and aquaculture. With health concerns of seafood consumption, many sustainable seafood initiatives set up health alert indexes to remind consumers about the health risks of certain species. For farmed seafood, the complexity in balancing the benefits and risks becomes yet more complex as not only are health professionals sending messages to the public about what to eat and what not to eat, but the environmental community is similarly providing advice. The advice is not always congruent.

From an economic point of view, the risk and benefit characteristics are intrinsic attributes of seafood. Consumers' perceptions about these attributes influence their seafood choices. The health benefit and risk tradeoff can be valued by choice models. Analytical methods include stated and revealed preference models using demand analysis, hedonic pricing, contingent valuation or conjoint analysis methods, and experimental markets. Previous economic studies suggest consumption choices of risky goods depend on both absolute and relative risks to other goods with risks. As for factors influencing seafood choices, prices may not always be the first concern to seafood consumers. In certain cases, consumers' previous experiences, preference and health concerns may be of more importance. Other factors influencing fish consumption are attitudes toward fish, ease of preparation and cooking, taste preferences and price. Studies suggest consumers' seafood risk perceptions also depend upon other food products.

Sometimes consumers' perceptions of seafood safety and choices of products even may not be consistent with scientific evidence. They may have unexpected reactions to risk information. Studies indicate consumer's risk avoiding reaction largely depends on their ability to use information. Consumer beliefs depend not just on the information available, but are also influenced by previously acquired knowledge and experience. Less educated and informed populations need more attention, as they have less ability to obtain and use risk information. Fish advisories may cause unintended fish consumption reduction. Likewise fish risk warning labels may not be effective in preventing people from consuming seafood with health risks. In the choice between the wild and farmed salmon, some consumers favor wild salmon, possibly because of health perceptions and taste preferences, although farmed salmon may be a less expensive, highly nutritious, and safe source of protein.

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