Final Report: Sustaining Fisheries for Public Health

Concern about the sustainability of seafood supply and the safety of consuming seafood can make it complicated for consumers to determine what types of fish to eat. In recent years, public attention has focused on environmental contaminants that have been introduced into the world's oceans, which may be toxic to seafood consumers.

A report by Leah Gerber

Concern about the sustainability of seafood supply and the safety of consuming seafood can make it complicated for consumers to determine what types of fish to eat. In recent years, public attention has focused on environmental contaminants that have been introduced into the world's oceans, which may be toxic to seafood consumers. In contrast, nutrients in fish, especially the fish oil omega-3 fatty acids (omega 3's) and docosahexenoic acid (DHA) have been increasingly identified as having public health benefits. At the same time, there is increasing concern about the environmental and health risks and benefits associated with alternative sources or protein, such as beef and poultry. For example, beef contains significant quantities of dioxin, which has been linked to cancer, immune system deficiency, and nerve and blood disorders.

Approach

The ground work for the first stage of this proposed research was initially completed prior to the start of this project, and relied on our existing database of >300 stocks of fish and invertebrates that includes information on omega-3 fatty acids, mercury concentration, fishery status, and sustainability. Preliminary data suggested remarkable consistency in sustainability and human-health seafood rankings, such that seafood items that are relatively low in mercury are also more sustainable. This data suggested a win-win situation in choosing seafood that is deemed 'sustainable' and that is safe and healthy.

To further analyze the preliminary data, we focused our research on the areas below:

1. Conducting a quantitative examination of associations between sustainability and human health-oriented seafood rankings by creating a

database of fish stock that measured omega-3 fatty acids, mercury concentration, fishery status, and sustainability.

Initially, our database focused on stocks of fish and invertebrates primarily in North America. However, we were able to include data on PCBs and other environmental contaminants on both wild and farmed seafood species in the database which also includes up to date data on variability in mercury concentration. After examining the data, we were also able to include the metrics of human well-being thus targeting a larger geographic area globally. By doing this, we were able to develop an inventory of energy and material inputs for different seafood products (described below).

2. Develop a risk analysis framework for analyzing benefits and costs associated with seafood

To accomplish this goal, we used Life Cycle Assessment-type approach developed by Astrid Scholtz at Ecotrust to assess environmental impacts associated with all the stages of a seafood product's life. Going a step beyond, we compiled a comprehensive inventory of relevant energy and material inputs and environmental releases for different seafood products, which allowed us to evaluate the potential environmental consequences impacts, which included:

- Land conversions needed to create and maintain farms or aquaculture endeavors
- Trophic efficiency (e.g. the type and amount of feed needed to produce a measurable quantity of seafood of each type)
- Energy production (e.g. the type and amount of energy needed to produce a measurable quantity of seafood of each type)
- Pollution associated with producing a measurable quantity of each protein source
- Health benefits and costs associated with wild and farmed seafood sources

Using this data and information along with our seafood database, we examined and quantified the health risks (e.g., mercury, PCBs) and benefits (e.g., omegas, protein) to include with our database of seafood. In addition, we were able to quantify the health risks (antibiotics, fat, cholesterol) and benefits (iron, selenium) in alternative sources of protein such as beef.

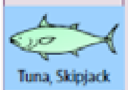
We partnered with Slow Foods International to integrate our scientific results salient to policymakers and consumers to promote healthy and sustainable seafood consumption as well as sustainable fisheries and aquaculture endeavors. As a result, we contributed to the Slow Fish's goals and campaign to include our comprehensive results on seafood health and sustainability. Our goal here is to make scientific results salient to seafood consumers. This research collaboration contributed to Slow Foods International's goals by helping to build seafood awareness and provide consumers with clear information about both the health risks and benefits of seafood consumption.

Findings

Overall we found that vulnerable fish stocks/species are also associated with high Hg levels and lower omega-3 concentrations (albeit the latter relationship is not statistically significant). In general, high (positive) scores for PC1 indicate species with low B_{rel}MSY or high relMSY and high Hg, and represent species that are ecologically vulnerable and pose human health risks (species listed in the Red group in Web Table 1). Examples include bluefin and other species of tuna (Thunnus spp), swordfish, and several species of Pacific rockfish (Sebastes spp). Similarly, there is a group with high-magnitude negative PC1 scores that represent good consumer choices for health and sustainability criteria (species listed in the Green group in Web Table 1). We used PC2 as an indicator of species with high omega-3 relative to Hg. The stocks with high PC2 scores have high ratios of omega-3 to Hg concentrations (Hg can still be high in these stocks).

Our results indicate that stocks with negative scores for PC1 and high positive scores for PC2 are the most likely to maximize health benefits of omega-3s while minimizing risks for the health of consumers (Hg) or the stock. Species with high PC2 scores include Atlantic mackerel (Scomber scombrus), bluefin tuna (Thunnus thynnus), European anchovy (Engraulis encrasicolus), Pacific herring (Clupea pallasi), and sablefish (Anoplopoma fimbria). However, because the PCA groups stocks as Green based on the combination of sustainability (high) and Hg (low), in a few cases we overestimate sustainability because of very low Hg (e.g. blue king crab [Paralithodes platypus]), and in other cases we overestimate threat because of high harvest rate rather than low Hg (e.g. winter flounder [Pseudopleuronectes americanus]). Finally, comprehensive metrics were limited for some species (e.g. Pacific herring, bluefin tuna), and, as a result, their PCA scores may shift as more data become available. For example, while Pacific herring might be expected to be sustainable given life-history traits, our results indicate a near-zero PC1 score and conflicting values for Hg and biomass (both low). Additionally, results for both Pacific herring and several species of rockfish based on PC1 scores should be considered with caution given that Hg values for several different species were identical.

We found a clear association between sustainability and Hg concentration for all metrics of sustainability. Species deemed unsustainable have significantly higher levels of Hg but do not have higher long-chain omega-3 fatty acid concentrations. Thus, if consumers make decisions aimed at minimizing Hg exposure, they will also tend to buy more sustainable seafood but will not necessarily increase intake of desirable omega-3s. Results from PCA through the use of fishery performance indices (Worm et al. 2009) corroborate these simple univariate analyses and allow us to delineate groups of fish based on human health (i.e. Hg, omega-3) and sustainability (_relMSY and BrelMSY). Our first principal component can be used to identify seafood items that both are ecologically vulnerable and pose human health risks (e.g. bluefin tuna, orange roughy). Here, vulnerable stocks are those with low BrelMSY, high _relMSY, or both. With few exceptions, species with negative PC1 scores have lower biomass, higher harvest rates, and higher Hg concentrations, but not significantly different omega-3 concentrations than species with positive PC1 scores (Figure 3). Our second principal component corresponds to stocks that have conflicting Hg and omega-3 concentrations. Within the group of stocks with high vulnerability (as indicated by PC1) there is a trend toward higher omega-3 concentrations (as indicated by PC2), but this increase in omega-3s is almost always offset by increase in Hg (Figure 3). Including both biomass and fishing mortality provides a more robust indicator of sustainability than each of these metrics alone. For example, some species have low harvest rates because they are heavily regulated as a result of high historical fishing pressure and low current biomass (relative to MSY).

Species	Source	MBA Rank	Omega -3	Hg	PCB	Protein	Se
 Orange, Roughy	Wild	Avoid	0.019	0.554			
 Herring, Pacific	Farmed	Alt.	1.571	0.051			
 Tuna, Skipjack	Wild	Best	0.263	0.123			
 Crab, Snow	Wild	Alt.	0.372	0.157			

Benefits and risks http://www.researchgate.net/publication/235971852_Sustaining_seafood_for_public_health

Our PCA offers a rich set of results that provide some insight for consumers. First, of the 44 species in our database that have quantitative measures of _relMSY, BrelMSY, Hg, and omega-3, there is an unmistakable group (with high PC1 scores) that represents poor consumer choices both in terms of ecological sustainability and human health. Within this group, two species (swordfish and orange roughy; Web Table 1) contain mean Hg concentrations that exceed 0.5 parts per million (ppm), the regulatory maximum set by many countries (reviewed in Burger and Gochfeld 2011). Seven species contain mean Hg levels that exceed the US Environmental Protection Agency criterion of 0.3 ppm. Whether or not health consequences result from consuming fish with elevated Hg concentrations depends on many factors, including body weight and the amount of fish consumed. Moreover, some of these same species, notably bluefin tuna, have very high omega-3 relative to Hg. These fish (with high PC2 scores) have substantial health benefits in terms of omega-3 fatty acid concentrations but may not be good choices in terms of Hg and sustainability. Note that several potentially good choices (e.g. Pacific salmon) are absent from our database. These species likely would have low PC1 scores and high PC2 scores reflecting good consumer choices, depending on the stock. We therefore find support for the notion that human health and ecological sustainability go hand-in-hand – some highly vulnerable stocks also carry a health risk; however, this message is not broadly applicable according to metrics of population biomass (BrelMSY) that do not account for the broader ecosystem impacts of fishing.

The correlation between Hg and sustainability rankings is likely because MBA/BOI rankings are in part derived from life-history characteristics. These metrics are based on intrinsic characteristics of fish species that are strongly related to fish Hg concentrations. Specifically, large-bodied, long-lived, or high trophic level species – often highly susceptible to overfishing – tend to have high Hg concentrations due to bioaccumulation over time and bio-magnification through the food web. The link between Hg and sustainability is demonstrated by the high PC1 score of most tuna species. However, there are clear exceptions to the link between sustainability and other health metrics. Omega-3s do not bio-accumulate and biomagnify to the same extent as methyl mercury (Kainz et al. 2006, 2008), which may explain why we see no consistent relationship with omega-3 levels and sustainability rankings. Our analyses provide a powerful tool for seafood consumers to make choices and for policy makers to make recommendations based on multiple preferences. Consumers can use the sustainability rankings to simplify decisions in choosing fish that are both eco-friendly and relatively healthful. While

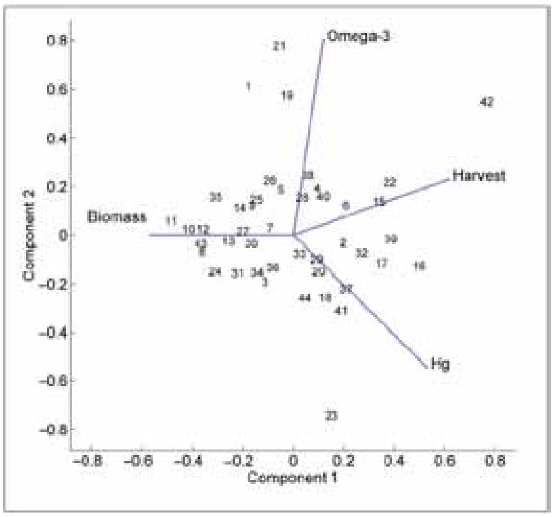


Abbildung 2. Biplot of components 1 and 2 from PCA for four risk metrics (relMSY, BrelMSY, Hg, and omega-3 concentrations). Key of species: (1) European anchovy, (2) Atlantic cod, (3) Pacific cod, (4) blue king crab, (5) red king crab, (6) snow crab, (7) tanner crab, (8) plaice (Alaska), (9) American plaice, (10) Pacific arrowtooth flounder, (11) English sole, (12) flathead sole, (13) Pacific rock sole, (14) yellowfin sole, (15) winter flounder, (16) yellowtail flounder, (17) gag grouper, (18) haddock, (19) Pacific herring, (20) American lobster, (21) Atlantic mackerel, (22) Spanish mackerel, (23) orange roughy, (24) Atlantic ocean perch, (25) Alaska pollock, (26) Atlantic pollock, (27) black rockfish, (28) blue rockfish, (29) bocaccio rockfish, (30) canary rockfish, (31) chilipepper rockfish, (32) cowcod rockfish, (33) darkblotched rockfish, (34) northern rockfish, (35) Pacific ocean perch, (36) widow rockfish, (37) yelloweye rockfish, (38) black cod sablefish, (39) swordfish, (40) albacore tuna, (41) bigeye tuna, (42) bluefin tuna, (43) skipjack tuna, and (44) yellowfin tuna.

our results suggest that people should eat more of the sustainable alternatives to boost omega-3 intake (because omega-3 values are slightly lower on average in these sustainable fish than in the less-sustainable choices), further research should address whether increased demand could be met without compromising sustainability.

Conclusion:

On average, seafood items with greater ecological impacts also present higher health risks (as indexed by Hg concentrations) and do not necessarily provide higher health benefits (as indexed by omega-3 fatty acid concentrations). While there are some important exceptions (e.g. blue rockfish [Sebastes mystinus] is classified as unsustainable but has low Hg), in general, consumers who choose to eat low Hg seafood are more likely to be choosing sustainable seafood at the same time. Moreover, consumers can obtain recommended amounts of omega-3 fatty acids by eating lower omega-3 fish that are also defined as sustainable and low in Hg (Mozaffarian and Rimm 2006). Our analyses suggest that there are many seafood items that are good ecological choices and pose few health risks (low Hg). Our framework could be used to incorporate additional factors, such as other nutrients or environmental contaminants that are important to consumers. The simplicity of the close association between Hg concentration and sustainability should help to inform consumers and policy makers about good seafood choices. Broad dissemination of the message that sustainable fish pose fewer risks will allow citizens to enjoy the benefits of healthful seafood while simultaneously contributing to better fishing and farming practices.

Publications and student theses

1. Gerber, L.R., R. Karimi und T.P. Fitzgerald, 2012: Sustaining seafood for public health. Frontiers in Ecology and the Environment.
2. Noziglia, Andrea: Seafood health and sustainability: Chemical contaminants and evolving environmental education. Honors Thesis, ASU.
3. Burger J and Gochfeld M. 2011. Mercury and selenium levels in 19 species of saltwater fish from New Jersey as a function of species, size, and season. Sci Total Environ 409: 1418–29.
4. Geren, Sarah: Quantifying trade-offs in health, environmental, and socioeconomic factors in decisions about protein consumption. Honors Thesis, ASU.
5. Senko, Jesse, Robert Wildermuth und Leah Gerber: In Vorbereitung. From port to plate: Re-evaluating sustainable seafood reports in the context of biophysical impacts.
6. Kainz M, Arts MT, and Mazumder A. 2008. Essential versus potentially toxic dietary substances: a seasonal comparison of essential fatty acids and methyl mercury concentrations in the planktonic food web. Environ Pollut 155: 262–70.
7. Kainz M, Telmer K, and Mazumder A. 2006. Bioaccumulation patterns of methyl mercury and essential fatty acids in lacustrine planktonic food webs and fish. Sci Total Environ 368: 271–82.

Next steps

- Evaluating relationships between economic subsidies, seafood sustainability, and human health
- Evaluating taxonomic patterns in PCB, flame retardants. Also explore relationship between toxins match up (eg.. high mercury, pcb, flame retardants). Then relate to fish market from NOAA – are consumers getting the right information?
- Ecological factors associated with PCB and flame retardants (trophic level, body size, growth rate to database); examine in multivariate framework
- Given that current thinking is that farmed fish is much more contaminated, are contaminants higher or lower in farmed vs wild fish?

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