The Fish Market Chronicles:
A Pan-Pacific Survey

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1. Status of Global Fisheries Management

One hundred and fifty eight million tons of seafood were harvested globally in 2012. While a significant fraction of this seafood is produced via aquaculture harvests, nearly two thirds of the total yield was wild caught (FAO 2014). Currently, over three billion people depend on seafood for their daily protein intake, (Bonzan 2013) and the continuous increase of human population has led to significant over-fishing. The future of food security will thus depend crucially on the development of truly effective and sustainable practices for fisheries management. There are mounting concerns surrounding the management of global fisheries, notably: how do we maintain or increase global seafood yields while reducing the environmental and ecological impacts these harvests have on the oceans? The asymptotic upper limit of wild capture fisheries production has arguably already been reached. To meet growing demands for seafood, aquaculture operations are ramping up expansion, at a rate of 7% per year. The aquaculture sector, if managed correctly, may prove vital for providing much needed food security given rapid human population growth (FAO 2014).

The currently accepted best practices for wild capture fishery management are species-specific, known as selective fishing. Under selective fishing practices, effort is focused on fishing *target* species and avoiding capture of *non-target* species by increasing the selectivity of the fishing gear used (i.e., mesh size regulations). In practice, a wide range of species are caught, regardless of gear type or fishing method, and non-targeted species are usually discarded as bycatch. These practices remove fish from the oceans that are not sold or eaten, creating needless waste and widespread ecosystem disturbance. Targets tend to be commercial species for human consumption, while bycatch is comprised of anything unlucky enough to find itself caught in the same net: juvenile finfish, invertebrates, seabirds, protected marine mammals, and other non-marketable species.

Management plans for target species are developed in an isolated context, often focusing only the population dynamics of the target species without consideration for the impacts of species-specific removals and fishing methods on environmental or ecological parameters. When considered individually, 61.3% of the world's fish stocks are fully exploited, with 28.8% overfished and 9.9% under development (FAO 2104). It has been shown that selective fishing pressure exacerbates fluctuations in fish abundance, and can lead to boom and bust cycles in fish stocks (Anderson 2008). Fisheries scientists agree that we need to fundamentally reevaluate marine resource management practices (Garcia 2010).

1.1. Theories for Improved Fishery Management Strategies

A logical starting point for reconsidering fishing management strategies is to take stock of what is actually in the ocean. What is the species composition of marine ecosystems? Which species have productivity rates that can handle intensive fishing pressure, and which species need to be relieved of fishing pressure in order to rebuild their populations? How do these species interact with others in their ecosystem, and how can we maintain the functionality of these ecosystems while also feeding ourselves? Surprisingly, many of these questions have not been answered at the ecosystem level.

Studies have demonstrated that the standing biomass distribution (kg/area) in unfished marine reef ecosystems can be represented as an inverted pyramid, with the greatest biomass concentration in the top trophic group of apex predators (Sandin et al 2008, Aburto-Oropeza et al, 2015). At a given moment in time, standing biomass increases with trophic level in an unfished system. The productivity rate (kg/area/time) of individual species is evaluated over time, and decreases with trophic level. Organisms at low trophic levels (the primary producers and herbivores) reproduce and repopulate at a much faster rate than do organisms of higher trophic levels (Pace 1999).

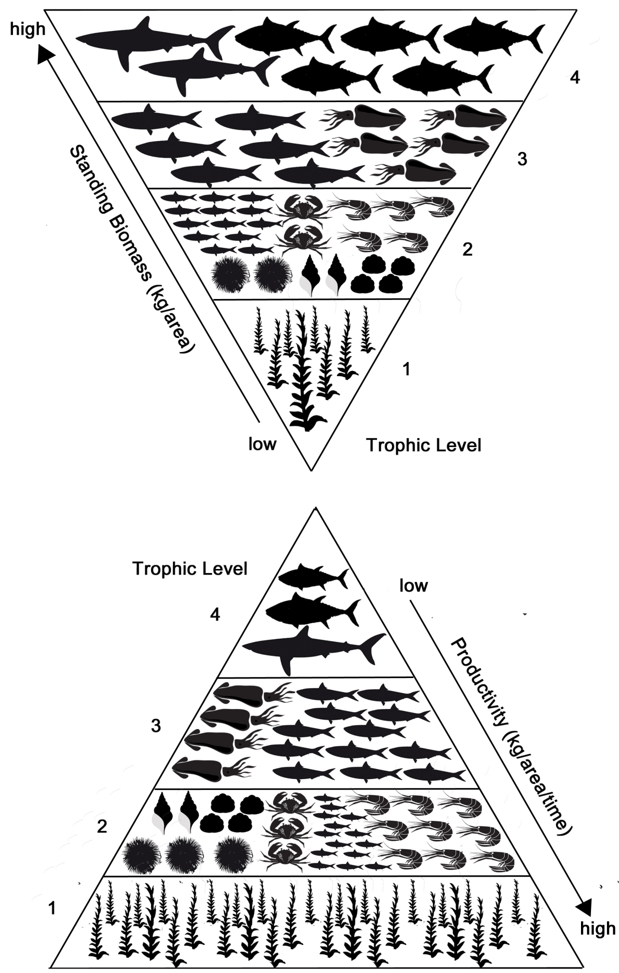

FIGURE 1 The trophic composition of standing biomass (kg/area) above, and that of productivity (kg/area/time) below in a theoretical unfished system. This figure does not refer to data collected in a study, but is a visual conceptualization.

Figure 1 illustrates a simplified model of the biomass and productivity by trophic composition in a theoretical unfished reef ecosystem. Given this, the logical conclusion is that we should be removing species from the ecosystem in accordance with their productivity rates. This implies that fishing pressure should be concentrated more intensively on organisms with a high productivity rate and low trophic level (primary producers, shellfish and herbivorous fish), while reducing pressure on species with low productivity rates and high trophic level (apex predators). Implementing this logic requires approaching fisheries management at the ecosystem level, as opposed to the current selective species-specific approach.

Two theories have emerged for restructuring fisheries management for a full-ecosystem perspective: (1) Ecosystem Based Fisheries Management (EBFM) and (2) Balanced Harvesting Theory (BH) (Garcia 2010). EBFM, as the name implies, advises fisheries management with the ecosystem in mind, and considers the following priorities as described in (Pikitch 2004):

> "In particular, EBFM should (i) avoid degradation of ecosystems as measured by indicators of environmental quality and system status; (ii) minimize the risk of irreversible change to natural assemblages of species and ecosystem processes; (iii) obtain and maintain long-term socioeconomic benefits without compromising the ecosystem; and (iv) generate knowledge of ecosystem processes…to understand the likely consequences of human actions." (Pikitch 2004)

While EBFM is a step in the right direction to minimize the adverse environmental impacts of selective fishing, EBFM offers no framework for increasing yield for the growing human population.

Balanced Harvesting Theory, on the other hand, proposes to both increase yields and decrease environmental disturbance by harvesting in proportion to the productivity of the species in the ecosystem. BH is built on the conclusions outlined above—that low trophic level species generally reproduce at much higher rates than their counterparts at high trophic levels. These species can replenish their populations much faster, and thus can support greater fishing pressure. Removing species in accordance to their productivity in the system and preserving the original proportions of trophic level composition causes fewer disturbances to the structure and function of the ecosystem (Garcia 2010). Yields may increase under this regime as ecosystem functionality is not disturbed. Systems retain higher levels of resilience to natural disturbances and do not experience the 'boom and bust' cycles seen in highly selective fisheries (Garcia 2012).

1.2. Certification Agencies and their Impact on Consumer Behavior

As the general public in developed countries has become aware of the declining status of global seafood stocks, certification agencies have stepped in to fill the information gap between fishers and fish consumers. People increasingly want to eat more seafood (FAO 2014), but feel responsible for the impact their choices are making on the ecosystem. Large commercial chains, including Wal-Mart and Whole Foods in the US, have made commitments to carrying certified seafood products.

The Marine Stewardship Council (MSC), based in London, has recently emerged as the most established fisheries certification agency, and the agency "taken most seriously by scientists" (Jacquet 2010). The MSC website lists 260 certified fisheries, with 113 fisheries currently in assessment, representing 12% of the annual global wild capture harvest (Marine Stewardship Council 2015). Certification agencies like the MSC assess fisheries on a species-by-species basis, and award qualifying fisheries the right to package their products with an *eco-label*. Fisheries are motivated to pursue certification under the assumption that eco-labeled products will command higher prices in the market. A 2011 study found that eco-labeled MSC Alaskan Pollock could command a 14.2% price premium over comparable non-labeled products (Roheim 2011).

However, the certification process can be prohibitively expensive for fisheries seeking certification, and the parameters used to define a 'sustainable' fishery have caused controversy. Fisheries are awarded certification on a species-by-species basis, and the only ecosystem impact considered is the level of bycatch. If the fishery is judged to be at Maximum Sustainable Yield (MSY) and simultaneously maintains low levels of bycatch, the fishery will pass certification standards (Marine Stewardship Council 2015). These loose parameters have raised protests from both scientists and global conservation groups including WWF, Greenpeace, and the Pew Foundation (Jacquet 2010). Complaints about MSC center around the loose interpretation and subsequent lack of enforcement of certification parameters for fisheries (e.g. Alaskan Pollock, which appear to be in decline but still maintain MSC certified status) (Christian et al 2013). Additionally, a financial conflict of interest exists, as the third party certifiers utilized by the MSC are incentivized to certify more fisheries per year to receive more profit (Jacquet 2010). However, a more fundamental problem exists: MSC certifies selective fisheries on a species basis. This sends the wrong message to consumers that want to purchase seafood with minimal environmental impact. Seafood eco-labels should provide information about both the status of the specific stock *and* the impact the harvest has on its system of origin.

2. Research Questions and Experimental Design

To investigate the forces driving fisheries, this research performs a survey of seafood markets. Seafood markets provide a window into revealed consumer preferences in real time, the driving economic force for global fisheries. Seafood markets lie at the intersection of fisheries management, marine conservation, and human consumption patterns. Many previous studies have focused on the effects of different fishery management strategies, and the implications of these strategies for the conservation of marine biodiversity (Garcia 2012). However, until now, these studies have not considered revealed human preferences as an element, which is ultimately the driver behind fishery production trends (Sethi 2010). As discussed, seafood supplies much needed dietary protein for over three billion people globally (Bonzon 2013). Conservation and scientific management for optimal seafood harvest often come as secondary considerations in light of the need to supply protein for the exploding global population. In an ideal world, these three considerations should to be considered simultaneously. This study attempts to propose a balance between exploitation and conservation, between having enough fish to eat and leaving enough fish in the sea.

A number of relevant questions can be investigated by gathering data on both prices and species selection in seafood markets. First, what are we eating? Second, is there a trend of increasing price for desirable species at high trophic levels, and are there any outlier species that do not follow such trends? Finally, do eco-labeled products actually carry a price premium in the market?

I hypothesize that the trophic level distribution of species in the markets will not match the distribution found in nature. I expect that prices will increase with trophic level, but with trend outliers such as high value invertebrates like shrimp, scallops, crabs, and lobsters. Eco-labeled products are expected to carry a significant price premium when compared to unlabeled products. **Box 1** summarizes the hypotheses tested in this work:

Box 1: Research Questions

1. What is the trophic level composition of seafood markets, and how does it compare to what is found in natural systems?
2. Do trophic level or MSC Certification affect seafood prices?
3. Do high value invertebrates (shrimp and scallops) raise prices out of proportion to trophic level?

2.1. Methods

The survey sampled 55 seafood markets in three countries over a six-week period beginning in March, 2015. A total of eleven unique regions were surveyed across California, Mexico, and Japan, and are listed below in Table 1. At each market sampled, the species present and the price per unit weight for each species were recorded. Prices were converted to US dollars per pound at current exchange rates.

A total of 2,393 observations were made, but 358 of these lack price data. The number of observations used to analyze trends in prices was 2,035. Species were identified to taxonomic family, at minimum, and to species where possible with confidence. Labeled seafood products were assumed accurately labeled Trophic level data for each species or family group was accessed after the survey period from Fishbase and the Sea Around Us Project (Froese & Pauly 2014).

Box 2: Regions surveyed in this study

California	**Mexico**	**Japan**
San Diego	Tijuana	Nagasaki
Orange County	Rosarito	Osaka
Los Angeles	Ensenada	Tokyo
San Francisco	San Felipe*	

*No fish observed

The 55 markets sampled were categorized as one of the following types:

1. **Ex Vessel**: Seafood-only market, where fish is sold directly upon landing to either consumers or large-scale buyers.
2. **Grocery Store**: Seafood sold to consumers in a market that also carries other consumer food products.
3. **Retail Market**: Seafood-only market selling either fresh or cooked seafood to consumers in a combined restaurant/market setting.
4. **Wholesale Market**: Seafood sold directly to large-scale buyers.

Hedonic regression was performed to test for statistical significance in the data set compiled during the survey period. The natural log of price per pound was regressed on observation characteristics of products to assess their impact on price. Characteristics tested include the natural log of trophic level, dummy variables for market type, country, region, and month, and MSC Certification. To test for the effects of outliers, shrimp and scallops were separated from the rest of the species. Additionally, a regression was run to assess the interaction of

MSC Certification with trophic level and shrimp + scallop dummy variables. The implication of the use of natural logs for the price and trophic level indicates that the coefficients in the results are interpreted as percentage changes, and not absolute values.

The natural log of price was regressed upon a constant and the trophic level, and sets of dummy variables (Country, Market Type, Region, Month, MSC Certification, Ecosystem, Shrimp & Scallop). The intercept, or base case, represents data from a grocery store in San Diego without MSC Certification. Individual markets were not included to reduce multi-colinearity. Standard errors were clustered on market type, and the interaction of market type and country was done as a check for robustness. The same results were found, indicating confidence and robustness.

The data were a mix of cross section and limited panel data. Due to the short time period of data collection, the panel data were not comprehensive across all markets, so the data were analyzed without serial correlations as cross section.

Finally, an analysis was done to compare the price of seafood in each nation when correcting for the Per Capita GDP (PC-GDP). The values referenced for each nation's annual PC-GDP were accessed from the World Bank's DataBank (World Bank 2014). This value was then divided by 365 to get an estimate value for a *daily PC-GDP* for each nation, in order to quantify the percentage of each nation's citizens daily PC-GDP is spent for an average pound of seafood.

3. Results

Box 2: Results

1. The trophic level composition of seafood markets skews towards high trophic level species. This *does not match* what is found in natural systems.
2. Price increases with trophic level. High value shellfish and crustaceans are outliers.
    a. MSC Certification *raises* prices.
3. MSC Certified shrimp and scallops have a *disproportionate price premium* given their low trophic level.
    a. MSC Certified shrimp and scallops have a *smaller price premium* than other MSC Certified seafood products.

1. The trophic composition of seafood markets was found not to match the distribution found in natural systems (**Figure 2**). The relative sizes of the vertical bars shows the number of species observed at each trophic level in each country, and all countries combined.
    a. The trophic composition was determined by graphing the count of unique species observed from each trophic level group across all market types for each country surveyed. The overall average was computed by the count of unique species observed at each trophic level across all countries surveyed.
        i. The number of unique species observed was used as a proxy for taxonomic biodiversity in the seafood markets.
        ii. Trophic level was used as a proxy for productivity rate.
2. Price was found to increase with trophic level, and MSC Certification was found to raise price (**Figure 2, Table 1**).
    a. There were high-value, low trophic level outliers that did not follow the general trend.
    b. The MSC Certification price premium did not reach the Ex Vessel market level.

3. Shrimp and scallops were high value, low trophic level outlier groups (**Table 1**).
   a. These products command higher prices in the marketplace, at an average price of 104.69% higher than other seafood products, regardless of trophic level.

Characteristic	Price Increase
Trophic Level (+100%)	50.61%
MSC Cert w/Trophic Level (+100%)	54.03%
Shrimp and Scallops	104.69%

TABLE 1 Hedonic Regression results. A trophic level increase of 100% yields a 50.61% price increase over the average. MSC Certified products show a price premium that increases with trophic level. For every 100% increase in trophic level, MSC products show a price increase of 54.03% over the average. Shrimp and scallops are high-value, low trophic level outliers that do not follow the overall price trend, and have a 104.69% price increase over the average.

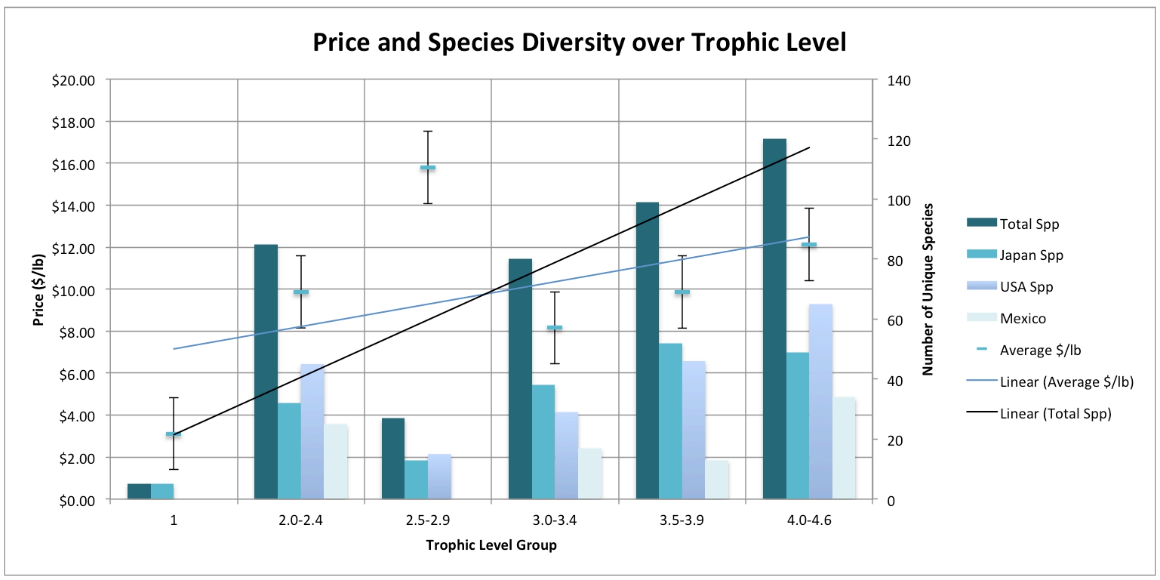

FIGURE 2 The average price of seafood and the species diversity in seafood markets plotted over trophic level group. Price is plotted on the left-hand vertical axis in USD per pound, and the trendline refers to the average price across all countries and markets surveyed. Error bars refer to standard error. The number of unique species observed is plotted on the right-hand vertical axis, and the trendline refers to the number of total species across all countries and markets surveyed.

Additional Results:

1. The price of seafood was also adjusted to correct for purchasing power in each country (**Table 2**).
   a. Japanese consumers are willing to pay more of their daily per capita GDP (daily PC-GDP) for a pound of seafood than consumers in either Mexico or the United States. The purchasing power for each country was calculated using data from the World Bank (World Bank 2014).

	Mexico	**USA**	**Japan**
Annual Per Capita GDP (USD)	$10,307.30	$53,042	$38,633.70
Annual Per Capita GDP/365 = Daily PC-GDP (USD)	$28.24	$145.32	$105.85
Annual Per Capita Seafood Consumption (2005-2007)	26.3 lbs	53.3 lbs	129.3 lbs
Average Price for 1 Pound of Seafood (USD)	$2.49	$12.48	$12.13
Average Pound of Seafood as % of Daily GDP	**8.84%**	**8.58%**	**11.46%**

TABLE 2 Price of seafood adjusted for national per capita purchasing power. Japanese consumers are willing to pay the most per pound of seafood, relative to purchasing power. Mexico and USA have very similar figures.

4. Discussion

The results suggest that seafood markets skew towards stocking high trophic level species. These results refer to the relative frequency of observations at different trophic levels, and not the biomass of the trophic groups. Taxonomic diversity observed in seafood markets was found to increase with trophic level, in opposition to the natural distribution of species over trophic levels. While a comprehensive study has not been done, to our knowledge, to determine the true species diversity across trophic levels for any system, it is generally understood that species diversity is greatest in the microbial and microscopic realms, and assumed to decrease with increasing size and trophic level. Trophic level is considered as a proxy for productivity rate (**Figure 1**), this study finds that the fisheries supplying the seafood markets surveyed are harvesting species in direct opposition to their productivity rates. The trophic level composition of seafood markets *does not match* the composition found in nature.

Statistical analyses showed strong heteroscedasticity, and standard errors were robust to unknown (Huber-White, year?). We experimented with potential clustering on market names using a panel data approach. Statistically significant results for F-tests were found for Country, Market Type, Region, and grouping for Shrimp + Scallops, while F-test statistics were insignificant for Month and Market Type.

In summary, trophic level has a statistically significant impact on price. For each unit of increase in trophic level, the average price per pound of seafood increases by 50.61% (**Table 1**). For example, if a market has seafood products from trophic level 2.0 selling for $10/lb, products at trophic level 3.0 could be expected to command a 50.61% higher price, or $15.61/lb. The trendline in **Figure 2** referring to the Average ($/lb) series shows a positive slope as price increases with trophic level. The price of seafood increases with increasing trophic level, consistent with the hypothesis in Section 2. High value, low trophic level shellfish and crustaceans do not fit this general pattern. The overall trend is consistent with the conclusion that higher trophic level species command higher prices in the marketplace.

Shrimp and scallops command higher prices than those predicted by the model for their trophic level (**Table 1**). Scallops have a trophic level 2.0, and shrimp, depending on life history, species, and size, range from a trophic level 2.0 to 3.3 (Sea Around Us 2014). These species were analyzed separately as they are representatives of the group of high value, low trophic level shellfish and crustaceans that command high prices regardless of country, region, or market type. These two specific groups were selected specifically because they were the only two invertebrate products observed with MSC Certification. Statistical analyses performed in this study suggest that shrimp and scallops could be expected to cost 104.69% more than the average seafood product.

The effects of MSC Certification on prices are not simply predicted as hypothesized in Section 2. MSC Certification interacts with trophic level to raise prices by 54.03% with each unit increase in trophic level. This result differs from those of previous studies which considered frozen seafood products and found that MSC products typically command a 10-15% price premium (Roheim 2011). The results of this study surrounding MSC Certification can be qualitatively explained by the small number of observations (N=17 for MSC Certification out of a total N=2,035 observations). All MSC Certified product observations came from four Whole Foods grocery stores in California. The results may therefore be confounded by the fact that Whole Foods is a luxury American grocery store with a higher price point than other markets, regardless of MSC Certification, and that all seafood considered was fresh, not frozen.

A final analysis was done to compare the price of seafood in each nation when correcting for the Per Capita GDP (PC-GDP). The results in Table 2 illustrate that consumers in Japan are willing to spend more of their daily PC-GDP for a pound of seafood. Mexico and the USA spend nearly equal proportions of their daily PC-GDP for a pound of seafood when adjusted for purchasing power, despite the fact that the price for a pound of seafood in the USA is over five times that in Mexico.

4.1. Ecological Implications for Fisheries Management

Our current fisheries management regime is a piecemeal, incomplete approach to the extraction of marine resources. Returning to the conceptualization used above, our current Selective Fishing strategies leave the oceans looking like Swiss cheese—with so many holes poked out of the ecosystem, how could it possibly retain normal function (**Figure 3.1**)? Using trophic level as a proxy, the evidence from seafood markets in this study found that selective fishing pressure is actually focused more intensively on the upper trophic levels—species that generally have much lower productivity rates than their counterparts in the lower trophic levels. Logically, we should be fishing for species according to the productivity rate of that species, with an eye towards maintaining ecosystem function.

Balanced Harvesting Theory proposes that we structure our harvests with the entire ecosystem in mind. **Figure 3.2** illustrates a conceptualization of what a balanced harvest could look like—a trophically comprehensive slice of an ecosystem. Extracting species in accordance to their productivity rates is theorized to both increase yields and decrease the adverse ecological effects caused by their removal. As a visual analogy, it is simple to comprehend how removing an even slice from a system would allow it to retain higher function and productivity than poking holes throughout its fabric. This pattern of extraction is likely to leave the system more resilient and less prone to boom and bust cycles in populations.

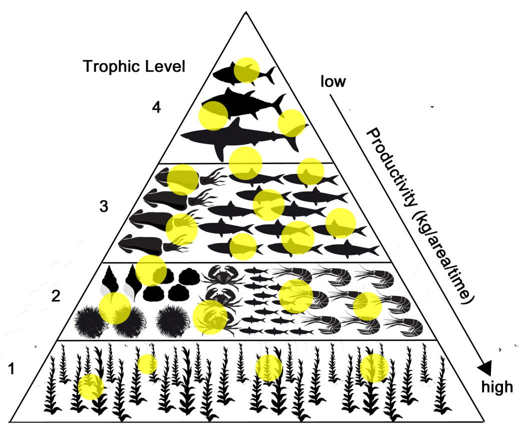

FIGURE 3.1 Visual conceptualization of the Selective Fishing Management approach. Selectively fishing for target species at high volumes leaves a system full of holes, harming overall function and productivity and lowering resilience to disturbance.

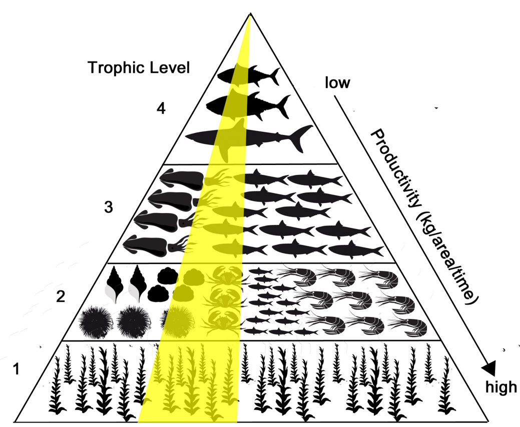

FIGURE 3.2 Visual conceptualization of the Balanced Harvesting Theory approach. Removing a trophically comprehensive slice leaves the system able to retain function, increase overall productivity and yields, and increase resilience to disturbance.

4.2. Economic Implications for Seafood Certification

The statistical regressions on the data collected in this study showed that price increased with trophic level for all products. When MSC products were considered specifically, their price premium was found to increase with trophic level at a faster rate than the general price trend (**Table 1**). **Figure 4.1** illustrates that high trophic level species with low productivity rates have a larger price premium than lower trophic level MSC products. Increasing price premium with increasing trophic level is sending the wrong incentive to consumers that are concerned about the ecosystem impacts of their seafood choices. By incentivizing the certification of high trophic level species with low productivity, the current certification system is discouraging the certification of species with high productivity in the lower trophic levels.

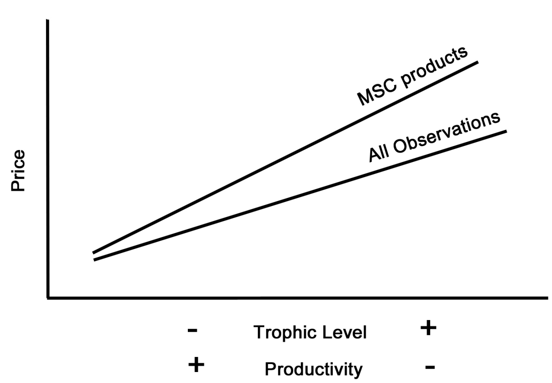

FIGURE 4.1 Visual conceptualization of the regression results from this study. MSC products show a price premium that increases with trophic level a faster rate than the general price trend for all products.

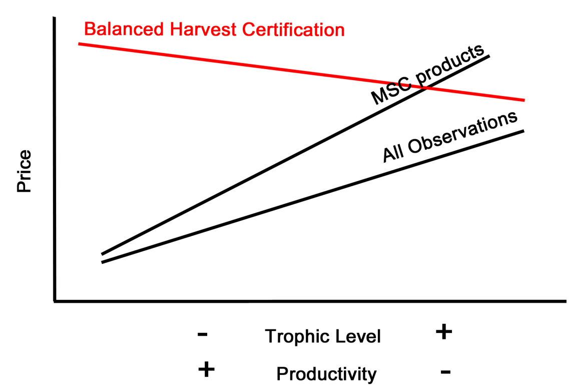

FIGURE 4.2 Visual conceptualization of the regression results from this study, with proposed theoretical "Balanced Harvest Certification" price premium shown in red.

Theoretically, a certification scheme based on balanced fishing parameters would produce the price premium trend shown in red in **Figure 4.2**. This study found that there is a higher price premium for certifying high trophic level products as MSC. This implies that fishers looking to certify their products would receive a higher return on their investment by certifying these high trophic level products and less of profit for certifying low trophic level species. A better model would be to do the opposite. A certification scheme based on Balanced Harvesting theory would encourage low trophic level fisheries to get certified by inverting the incentive—if low trophic level BHC certified products brought more return on the investment for fishers, more of these fisheries would be certified. Once these fisheries are certified and available in the local market, consumer behavior can begin to be affected by the change the trophic distribution of eco-labeled and certified products choices available.

5. Conclusions

These results have significant implications, both ecological and economical. As the first study of its kind to approach questions about human consumption of fish from both an ecological and economical perspective, it is a testament to the power of interdisciplinary work to shed light on complicated problems. Much more work should be done considering species diversity, trophic level composition of ecosystems, and price signals as interrelated factors.

People accustomed to eating tuna or swordfish steaks are not going to simply switch to anchovies and whelks for dinner. This study is not advocating the removal of all low trophic level forage fish—that would simply pull the rug from under the entire system. A first step towards lessening the adverse effects of our seafood consumption would be to even out the trophic composition of products offered in seafood markets. If the local seafood markets were trophically comprehensive, with eco-labeled products priced to encourage people to choose low trophic level products over high, consumers may begin to make choices that trend towards lower ecological impacts. This approach would need to be coupled with outreach programs designed to inform consumers of the ecosystem consequences of their purchasing decisions.

We need to be considering fisheries management from the ecosystem productivity level, with Balanced Harvesting as a theoretical model. The potential to increase harvests while decreasing adverse ecosystem impacts is very powerful, but requires real-world testing before implementation. Lastly, certification agencies should begin incorporating parameters regarding relative productivity in their certification schemes. This is needed to better fill the information gap between managers and the perplexed consumers at their local seafood counter. When fully informed consumers can make ecologically educated choices, we may begin to see the wide-reaching positive ecological effects we are all hoping for.

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