Trophic level links seafood sustainability to human health

Peer-reviewed letter

Gerber *et al.* (*Front Ecol Environ* 2012; **10**[**9**]: 487–493) provided an intriguing assessment of the positive association between seafood sustainability as assessed by the Monterey Bay Aquarium (Dianto Kemmerly 2009) and human health benefits, namely lower levels of methylmercury. Although acknowledging the impact of trophic level (TL) – in that carnivorous species tend to live longer, and hence biomagnify and bioaccumulate methylmercury – the authors did not include this critical trait in their analysis. Understanding the role of TL in the seafood sustainability discussion can improve communicating often complicated information to the general public. Such messaging can be modeled after efforts to inform the public regarding mercury (Hg) contamination in fish as a function of size and age (EPA 2012).

To assess TL as an organizing principle behind sustainability and human health, I analyzed data presented within the National Geographic Seafood Decision Guide (NGSDG; National Geographic 2012). This dataset contains information on TL, sustainability, Hg, and omega-3 fatty acids for 64 production-specific species categories (51 wild and 13 aquacultured species). Species were scored on the NGSDG database as TL2, TL3, or TL4 if they were a herbivore/detritivore, a carnivore, or a top predator, respectively; there were no photoautotrophs (TL1) in this dataset. The sustainability data were generated from the same source as that of the Gerber *et al.* review, and the Hg and omega-3 data of these two datasets were in agreement ($r^2 = 0.56$ and 0.82, respectively; $n = 20$).

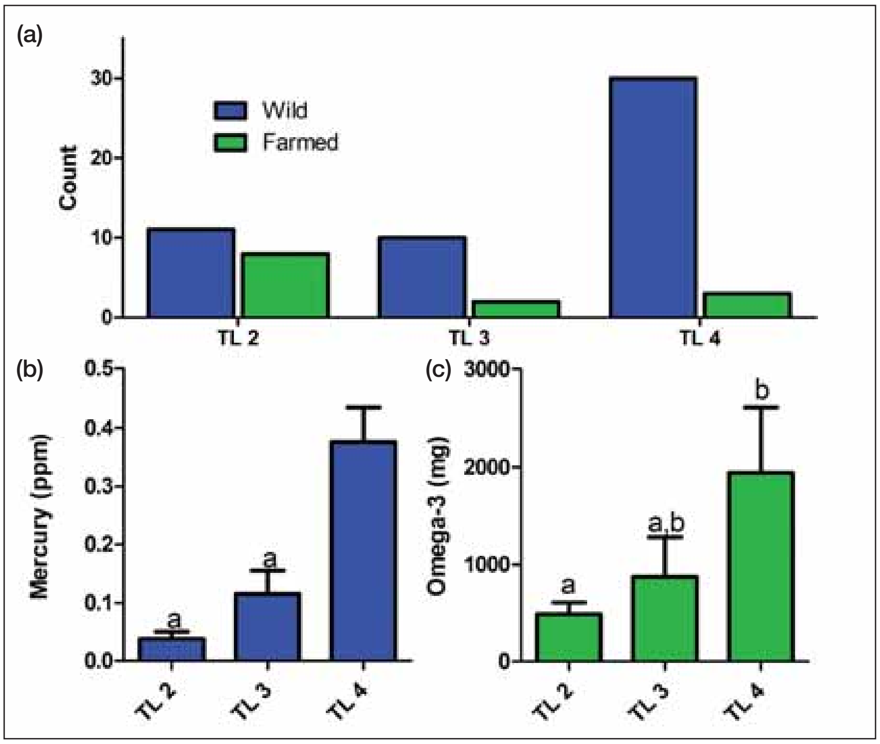

Figure 1. *(a) The number of wild and aquacultured species and their trophic level (TL) represented in National Geographic (2012). (b and c) The relationship between TL and average mercury level of wild species (b) and omega-3 level of aquacultured species (c). Similar letters denote statistical similarity based on a one-way analysis of variance* (P < 0.05)*. ppm = parts per million.*

The NGSDG housed data on both aquacultured and wild species, and the wild category included more high (TL4) species than did the aquacultured category (one-way analysis of variance [ANOVA], $F_{1,62} = 8.56$, $P < 0.005$, power [$\alpha_{0.05}$] = 0.78; Figure 1a), and hence analyses of Hg and omega-3 levels were conducted separately on aquacultured and wild species. The TL of wild species was not associated with sustainability or omega-3 levels (one-way ANOVA, $F_{2,10} < 2.17$, $P > 0.12$). Yet methylmercury increased with TL (one-way ANOVA, $F_{2,44} = 7.65$, $P < 0.001$, power [$\alpha_{0.05}$] = 0.91; Figure 1b). Sustainability of wild species did not correlate with either Hg or omega-3 levels ($r^2 = 0.005$ and 0.08, respectively; Table 1). For aquacultured species, there was no association between TL and sustainability or Hg (one-way ANOVA, $F_{2,48} < 0.36$, $P > 0.5$). Omega-3 levels, however, increased with TL (one-way ANOVA, $F_{2,10} = 5.95$, $P < 0.02$, power [$\alpha_{0.05}$] = 0.67; Figure 1c). Like that of wild species, sustainability of aquacultured species did not correlate with either Hg or omega-3 levels ($r^2 = 0.04$ and 0.005, respectively; Table 1). Although sustainability is a multifactorial problem, the fact that partial correlation values were equivalent to simple correlation values (Table 1) suggests that multicollinearity was inconsequential.

Here, sustainability was found to be unrelated to Hg and omega-3 levels in both wild and aquacultured species (WebFigure 1), which differed from the results of Gerber *et al.* A principal components analysis (PCA) demonstrated that, in wild fish, sustainability and omega-3 trended in opposite directions, whereas TL and H[illegible]ere closely associated (WebFigure 1). This TL–Hg association for wild fish was not a novel result (Mozaffarian and Rimm 2006). For aquacultured fish, PCA again demonstrated sustainability trending opposite the other three variables. The incorporation of Atlantic salmon (*Salmo salar*) in the NGSDG was likely a main factor in elevating the average omega-3 value for the TL4 species; salmon had twice the omega-3 content as that of rainbow trout (*Oncorhynchus mykiss*) and three times that of barramundi (*Lates calcarifer*), the two other TL4 aquacultured species. The lack of association with Hg or omega-3 mirrors the lack of representation of "health" issues on webpages devoted to seafood sustainability (WebFigure 2).

Table 1. Simple (*r*) and partial (in bold) correlation coefficients between trophic level, sustainability score, mercury level, and omega-3 for aquaculture (above diagonal) and wild (below diagonal) species

	Trophic level	*Sustainability*	*Mercury*	*Omega-3*	*PC1*	*PC2*
Trophic level		–0.07 **–0.08**	0.51 **0.44**	0.72* **0.70**	0.92	0.10
Sustainability	–0.16 **–0.18**		–0.21 **–0.18**	0.07 **0.15**	–0.14	0.91
Mercury	0.49* **0.50**	–0.07 **0.07**		0.29 **–0.11**	0.71	–0.35
Omega-3	0.01 **–0.15**	–0.28 **–0.29**	0.21 **0.24**		0.82	–0.35
PC1	0.74	–0.48	0.78	0.47		
PC2	0.46	0.61	0.34	–0.66		

Notes: Statistically significant simple correlations are indicated by an asterisk ($P < 0.01$). The first and second principal components (PC1 and PC2) are unrotated factor patterns based on a principal components analysis (JMP 8.0, SAS Institute Inc, Cary, NC). Data are from National Geographic (2012).

Sustainability is not judged merely at a species level, but on the system that comprises the species along with vagaries of how that species is produced/harvested (Tlusty *et al.* 2012), processed, and distributed to market (Tlusty and Lagueux 2009). One difference between the Gerber *et al.* and the NGSDG data was that the latter listed a single species multiple times, representing different harvest methods and resultant sustainability scores. As an example, Pacific cod (*Gadus macrocephalus*) was present as US bottom longline (Green) and US trawled (Red). There were numerous other examples of species for which there were similar differences in sustainability status based on harvest or production method. By way of comparison, Gerber *et al.* listed each species under a single sustainability score. Such variation needs to be accounted for but will obscure the link between sustainability and human health. Care needs to be taken when selecting species for analysis, because this will substantially influence the outcome of data analyses.

The analysis presented here demonstrates that direct linkages between seafood sustainability and human health are tenuous. In this dataset, health impacts were more closely associated with TL. However, despite the inherent health "risks", it is better to eat seafood than to not (Mozaffarian and Rimm 2006). Overall, the important assertion made by Gerber *et al.* – that eating seafood is essential both for health and for sustainability – is undeniable. Citizens in developed countries should consume more seafood because it is an efficient food source. Seaweed is the most produced aquaculture species, but little is consumed in North America. Thus, citizens in the developed world also need to select seafood choices in a fashion more aligned with global food production. Current US per capita consumption of clams has decreased to 60% of what it was a decade ago (NFI 2012). Increasing consumption of seaweed and clams would be a basic step to take to be more sustainable in our seafood choices. A simple rule of thumb – to eat more low-trophic species – is a means to improve human and ocean health, and doing so will have positive impacts on our health and our journey to sustainability.

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Does trophic level predict seafood sustainability?

We are glad that our recent paper (*Front Ecol Environ* 2012; **10[9]**: 487–493) has stimulated new approaches to communicating seafood sustainability. In his letter, Tlusty proposes that trophic level (TL) is an overlooked predictor of sustainability, and we agree that TL is an important ecological indicator in marine ecosystems. After implying that our analysis did not explicitly include TL, Tlusty used a smaller database (*n* = 64 versus *n* = 362) to suggest that (1) TL is strongly related to methylmercury levels and hence health and (2) the link between health and sustainability metrics is tenuous. We agree with Tlusty's first hypothesis but not with his second.

First, we respectfully disagree that the link between health and sustainability is unsubstantiated. We suspect that the author's statistical power was limited given the smaller size and nature of his dataset. Notably, the National Geographic Seafood Decision Guide (NGSDG) incorporates much of the same information used in the Monterey Bay Aquarium (MBA) sustainability rankings that we used for one of our analyses, and for a largely overlapping mercury (Hg) dataset as well. Tlusty states that his database is stock-specific and that we only used one sustainability metric per species (whereas the NGSDG uses multiple). Both assertions are incorrect: we looked at multiple disparate sustainability metrics for each of our stocks and arrived at similar conclusions. We prefer to rely on the same, larger database to explore additional hypotheses, and continue to build our database to include additional metrics of health and sustainability.

Second, we agree with the importance of TL in assessing fisheries sustainability, although this relationship is more complex than previously thought. While it is commonly assumed that high TL species are more exploited than low TL species, recent data suggest that more populations of low TL species have collapsed as compared with those for large predators (Pinsky *et al.* 2011). That said, there is strong evidence that both body size and TL are positively related to Hg concentration (Cutshall *et al.* 1978; Cabana and Rasmussen 1994; Wiener and Spry 1996; Hammerschmidt and Fitzgerald 2006; Burger and Gochfeld 2011; Figure 1 in Tlusty's letter). In our paper, we discuss TL and body size as possible mechanisms linking Hg and sustainability, explaining that carnivorous species tend to eat higher on the food chain, live longer, and hence biomagnify and bioaccumulate methylmercury. Our study was not designed to test for the effects of body size and TL, and we do not claim to have found direct evidence for their effects. Instead, we offer them as likely possibilities explaining the identified relationship between Hg and sustainability.

Although Tlusty's TL dataset was unavailable, the simple 1–4 scale listed on http://ocean.nationalgeographic.com/ocean/take-action/impact-of-seafood/#/marine-food-chain/ appears oversimplified given the wide range of ecological niches filled by common seafood items found in TL2–TL4. It is also unclear why Tlusty excluded body size from his analysis, since this can be more strongly related to Hg concentration than TL (Burger and Gochfeld 2011). We recognize that including TL and body size in the analysis is inherently difficult because these factors are variable within a species, probably obtained from different datasets, and values are not based on the same stock.

One sector where Tlusty did not find evidence supporting a link between TL, Hg, and sustainability was with farmed fish. Indeed, there are numerous challenges in quantifying TL for farmed fish. Is TL based on their typical trophic role in the wild, even though they are eating from a very different, artificial food chain? Did Tlusty rely on one TL per species or different TLs for farmed versus wild fish? The former would clearly introduce additional bias into the results for farmed fish. Such questions regarding how to compare wild and farmed stocks are challenging but important, given that farmed fish comprise an increasingly larger share of the market.

We encourage continued discussion about effective ways for consumers to make informed decisions about their seafood consumption. While we appreciate Tlusty's suggestion that we focus on TL to simplify seafood awareness initiatives, we question the relevance of this concept to the average seafood consumer. As stated in our paper, consumers interpret sustainability in many ways, so it is important to search for associations that span multiple interpretations. In our view, our paper's original message is unchanged – by choosing sustainable species, you are also likely choosing healthier options, which, incidentally are also generally low TL species. However, both sustainability and TL have complex meanings, and sustainability status for different seafood items may change over time. Additional analyses should examine the extent to which other, simpler variables – such as body size – are associated with both health and sustainability metrics.

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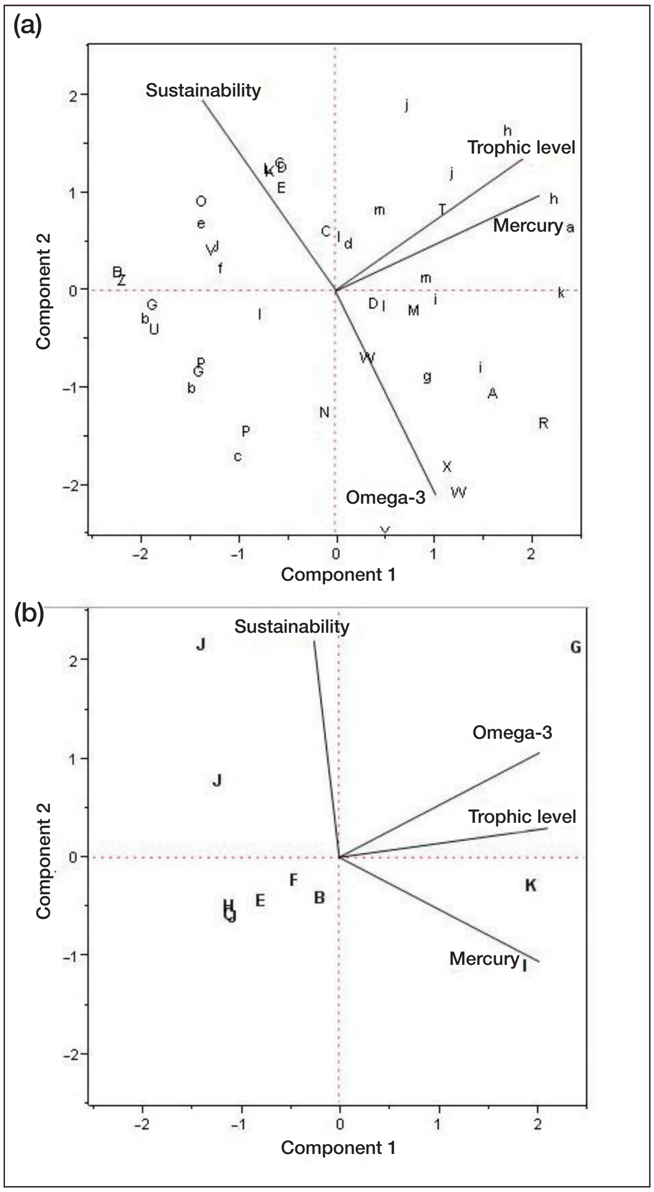

WebFigure 1. *Loading plots from principal components analysis for (a) wild and (b) farmed (bottom) species. (a) Wild species include: A – Chilean sea bass; B – clams; C – Atlantic cod; D – Pacific cod; E – blue crab; F – Dungeness crab; G – king crab; H – stone crab; I – halibut; J – sole; K – summer flounder; L – Atlantic haddock; M – Pacific halibut; N – Atlantic herring; O – American lobster; P – spiny lobster; Q – mahi mahi; R – Spanish mackerel; S – monkfish; T – orange roughy; U – oysters; V – Alaska pollock; W – sablefish; X – Alaska salmon; Y – Pacific sardines; Z – sea scallops; a – shark; b – shrimp; c – pink shrimp; d – red and vermillion snapper; e – Pacific sole; f – squid; g – striped bass; h – swordfish; i – albacore tuna; j – bigeye tuna; k – bluefin tuna; l – skipjack tuna; and m – yellowfin tuna. (b) Farmed species include: A – barramundi; B – catfish; C – clams; D – mussels; E – Atlantic oyster; F – Pacific oyster; G – salmon; H – bay scallops; I – striped bass; J – tilapia; and K – rainbow trout.*

WebFigure 2. *A word cloud based on a Google search of "seafood sustainability" on 8 Aug 2012, and created by www.tagxedo.com. Size indicates the prevalence of the word across websites. The resultant word list (limited to 200 words) was trimmed to omit "seafood", "sustainability", "fish", and all three-letter prefixes. "Health" is emphasized by the red circle.*