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7 **Predictors of Mercury Contamination in Colorado Reservoirs: Implications for**
8 **Improving the Protection of Human Health**
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Abstract

In this study we evaluated a set Colorado waterbodies (primarily reservoirs) with respect to fish consumption advisories associated with mercury (Hg) contamination. We included system-specific data regarding fish consumption advisories, whether or not apex predators were analyzed for Hg, system location, secchi depth, chlorophyll a, total phosphorus, elevation and surface area. With these data we used model selection (Akaike's Information Criterion, corrected for small sample size bias) to determine the relative influence of these factors on Hg contamination in Colorado sport fish. Our findings showed that within our dataset, apex predators from systems west of Colorado Interstate 25 had some probability of having Hg concentrations exceeding 0.5 ppm. Furthermore, system productivity was an important predictor of fish consumption advisories, where apex predators from systems with low productivity had a higher probability of being contaminated than those from high productivity systems. Importantly, our results could aid in the development of relatively easy to understand fish consumption advisories to better protect human health in the western US.

Introduction

Research focusing on anthropogenic impacts affecting freshwater systems has increased in North America since the 1960's, when it was shown that increasing nutrient inputs to freshwater systems alter ecosystem processes (Beeton 1965). At the same time, it became evident that a variety of anthropogenic pollutants were entering the environment and had the potential to impact human health and ecosystem processes. These scientific findings were brought to the attention of the public in such works as *Silent Spring*, written by Rachel Carson in 1962. More recently, mercury (Hg) contamination has been recognized as a threat to human and ecosystem health worldwide (Swackhamer et al. 2004; Driscoll et al. 2007; Mergler et al. 2007). Over the last three decades it has become apparent that atmospheric deposition of Hg plays an important role in delivering Hg in the environment through various activities (e.g., power production and incineration) and as such, even remote, "pristine" systems are at risk from Hg contamination (Hermanson 1991; Fitzgerald et al. 1998).

Mercury contamination has been studied extensively along the East Coast, Midwest and eastern Canada but Hg data are notably lacking in the western United States. Sport fish Hg concentrations are generally the preferred indicator of Hg contamination in freshwater systems because consumption of Hg contaminated sport fish is the major method of transfer of aquatic Hg to humans (Mergler et al. 2007; Driscoll et al. 2007; Lepak et al. 2009b). Investigators have studied a variety of system-specific factors associated with Hg contaminated sport fish in eastern North America and the Midwest; however, these relationships can be highly variable across system types, regions and species (Sorensen et al. 1990; Driscoll et al. 1994). Potentially important

factors include total phosphorous, pH, acid neutralizing capacity, dissolved oxygen, dissolved organic carbon and species composition (Sorensen et al. 1990; Driscoll et al. 1995; Greenfield et al. 2001). These studies all suggest that more work is needed to firmly establish the effect of these and other parameters on Hg concentrations in sport fish across regions and individual landscapes.

In the arid west, artificial, highly fluctuating reservoir systems are the prevalent lacustrine systems on the landscape. Reservoirs tend to have fish and other biota that are particularly high in Hg concentrations (Tremblay and Lucotte 1997; French et al. 1998; Bodaly and Fudge 1999). Most reservoirs serve multiple functions including recreational, municipal and agricultural use. As such, reservoirs tend to be highly managed with respect to their biotic and abiotic characteristics. For example, in the state of Colorado, the Colorado Division of Wildlife (CDOW) maintains an extensive stocking program and closely regulates fish harvest to sustain and enhance fisheries within reservoirs and the Colorado Department of Public Health and Environment (CDPHE) monitors and regulates nutrient inputs (e.g., phosphorus) to reservoirs to ensure the safety and functionality of reservoirs for multiple water users. Importantly, fish species composition, food web structure and nutrient inputs can heavily influence Hg concentrations in fish (Kidd et al. 1999; Essington and Houser 2003; Eagles-Smith et al. 2008).

It has been shown that fish trophic position, species, size and diet are important factors influencing sport fish Hg concentrations (Bodaly et al. 1993; Power et al. 2002; Johnston et al. 2003). Specifically, large, piscivorous sport fish with elevated trophic positions tend to have higher Hg concentrations than small, omnivorous or planktivorous

fish feeding at lower trophic levels. Reservoir food web structure and species interactions are influenced by fisheries management practices. Management practices (e.g., fish stocking and harvest regulations) often effect or dictate the food web structure and species composition in artificial systems like reservoirs and changes in these characteristics can alter sport fish Hg concentrations by changing fish trophic position, species composition, growth and diet (Eagles-Smith et al. 2008; Lepak et al. 2009a). Thus, the food web structure and species composition of a reservoir fish community (i.e., the presence of large, piscivorous apex predators targeted for consumption by anglers) is likely to be an important factor influencing overall Hg contamination of a system and its potential for impacting human health.

Nutrient inputs influence the productivity of reservoirs and the resulting changes in productivity have the potential to alter Hg concentrations in sport fish. Two mechanisms associated with increased productivity can reduce Hg concentrations in organisms. The first, known as “bloom dilution” occurs when high nutrient availability stimulates population growth of algae and subsequently zooplankton resulting in a higher amount of biomass available to accumulate a given amount of Hg (Pickhardt et al. 2002; Chen and Folt 2005). The second process is known as “growth dilution” and can occur in organisms at multiple trophic levels. For example, it has been shown that zooplankton growth increases while Hg concentrations decrease when algae with relatively low C:N:P ratios (and therefore higher quality) are available (Karimi et al. 2007). When relatively high quality diet items are available to organisms, they typically display high rates of somatic growth paired with lower consumption rates. This reduces both Hg concentration in prey and overall intake by predators. In the case of fish, it has been

shown through experimental nutrient additions and observational studies that fish from systems with higher nutrient inputs have relatively low Hg concentrations (Cleckner et al. 1998; Kidd et al. 1999; Essington and Houser 2003). Thus, increased nutrient inputs to reservoirs can reduce Hg bioaccumulation in sport fish within them.

Although nutrient inputs have the potential to lower Hg concentrations in aquatic organisms, they can also increase bioavailability of Hg and subsequently Hg bioaccumulation. Mercury is methylated (becoming bioavailable) under anoxic conditions by sulfate-reducing and iron-reducing bacteria as a byproduct of their energy sequestration pathway (Compeau and Bartha 1985; Fleming et al. 2006). Abundant nutrients can stimulate primary production, some of which decays, creating anoxic conditions conducive to Hg methylation by microbes (Bodaly et al. 1984). For example, Lienesch et al. (2005) found that increased nutrient inputs intended to enhance sport fish populations resulted in increased hypoxia during the summer and winter. Hypoxic conditions have been associated with high concentrations of Hg in water, zooplankton and fish (Driscoll et al. 1994; Slotton et al. 1995). Nutrient inputs may induce changes in community composition, food web dynamics and other ecosystem characteristics (e.g., water clarity) that can complicate the effects of nutrients on sport fish bioaccumulation.

This study provided an opportunity to evaluate a range of systems with respect to fish community composition, nutrient inputs and food web configurations because of the wide variety of biomes, water uses and management practices found in Colorado. We evaluated a set Colorado waterbodies (primarily reservoirs) with respect to fish consumption advisories developed by CDPHE. We included system-specific data provided by CDOW and CDPHE on fish consumption advisories, whether or not apex

predators were analyzed for Hg, system location, secchi depth, chlorophyll a, total phosphorus, elevation and surface area. Using these data we determined the relative influence of these factors on Hg contamination in Colorado sport fish.

Methods

At the time of this study, fish tissue Hg data were available for 95 waterbodies in Colorado. River systems and systems where water chemistry data were not available were excluded from the data set, leaving 46 systems for analysis. The response variable evaluated was whether or not a given system had a fish consumption advisory associated with it. The CDPHE has defined systems with fish consumption advisories as those where any fish tissue sample analyzed exceeded a Hg concentration of 0.5 ppm.

We used multiple logistic regression to determine the influence of various factors on the issuance of fish consumption advisories in the state of Colorado. Our model selection protocol involved developing two model sets including predictors of fish consumption advisories. We developed two model sets to evaluate correlated productivity indices individually and combined as a single multivariate index (explained below). Pearson product-moment correlation coefficients between all independent and dependent variables were calculated to determine the relationship between the covariates using SAS (SAS Institute Inc.). When two or more covariates were significantly correlated they were not included in the same model set and only one of the correlated predictors was retained. We then fit all possible models (excluding interaction terms) by multiple logistic regression using the generalized linear model function in R 2.9.2 (R Development and Core Team 2005). We used AIC_c (Akaike's Information Criterion,

corrected for small sample size bias; Burnham and Anderson 2002) to compare competing models and individual predictors. We tested for overfitting of the data using a Hosmer and Lemeshow Goodness-of-Fit test in SAS (SAS Institute Inc.). We computed ΔAIC_c , the difference in AIC_c for a given model standardized to that of the model with the lowest AIC_c . Models with $\Delta AIC_c \leq 6$ were considered to have substantial evidence to support them (Burnham and Anderson 2002). We used model averaging to develop a predictive model based on the coefficients estimated in each of the two model sets analyzed (Burnham and Anderson 2002). Using the model averaged coefficients we determined point estimates and back-transformed these estimates to obtain results on a probability scale using equation 1:

$$e^{(\text{point estimate})} / 1 + e^{(\text{point estimate})} \quad (1)$$

Covariates analyzed as predictors of systems with fish consumption advisories were whether or not apex predators were analyzed for Hg (“apex”), system location, secchi depth, chlorophyll a, total phosphorus, elevation and surface area. Apex predators were defined as those that are considered primarily piscivorous and non-apex predators were defined as those that are considered primarily omnivorous or planktivorous (Table 1). System location was defined as position east (1) or west (0) of Colorado Interstate 25. This categorized systems into those in mostly agricultural areas (east) and those in mostly mountainous areas (west). Water quality data were compiled and provided by CDOW. We used mean measurements of secchi depth (m), chlorophyll a ($\mu\text{g/L}$) and total phosphorus (mg/L), from May through September from 2000 through 2009. Samples

below the detection limit were “censored” and assigned a value equal to one half of the detection limit (Rao et al. 1991). System elevation (m) and surface area (ha) data were also compiled and provided by CDOW. Fish consumption advisory data (fish Hg concentrations) were provided by CDPHE.

An analysis was conducted using all the system productivity indicators in order to incorporate them into a single model set. To combine correlated water chemistry covariates, (secchi depth, chlorophyll a and total phosphorus) a principal component analysis was conducted to develop a single, multivariate index that could represent differences in system productivity (Niles 1973; Cooch et al. 1999). Due to high correlations among these productivity indicators, they could not be used as independent predictors; however, since each metric has predictive value and is relatively inexpensive to obtain, (when compared to Hg analyses) all three were included in the principal components analysis. The index (referred to as PCA) was used to reduce the amount of information lost when excluding correlated covariates from analyses. A second principal component incorporating these same productivity indicators was developed to explain variation in fish consumption advisories, but this had little to no additional explanatory value (Pearson product-moment correlation coefficient; -0.01, $p = 0.92$) and therefore was not used in further analyses.

Results

Model set 1

Pearson product-moment correlation coefficients showed significant relationships between several covariates. System location was correlated to five other covariates and

system elevation was correlated to four other covariates (Table 2). System location and system elevation were removed from further analyses. The remaining covariates were primarily indicators of system productivity (secchi depth, chlorophyll a and total phosphorus). These covariates were all significantly correlated, thus, chlorophyll a was retained as a productivity indicator. Chlorophyll a was selected because it had the highest correlation coefficient with fish consumption advisories and it is also a direct measure of system primary production.

The model with the most support from the data included apex and chlorophyll a (Table 3). Apex had a cumulative weight (the sum of the weights of the models in which apex appears) of 0.80 while chlorophyll a and surface area had cumulative weights of 0.75 and 0.25 respectively. Surface area appeared to be a “pretending” variable, (ΔAIC_c of approximately 2, signifying little information was gained by adding the covariate; Burnham and Anderson 2002) having small coefficients, low cumulative weight and was not found in the heavily supported top two models. Thus, surface area was not considered in model averaged estimates.

The model averaged (models with $\Delta AIC_c \leq 6$) coefficients and unconditional standard errors for the intercept (-0.24 ± 0.50) and chlorophyll a (-0.04 ± 0.04) were estimated; however, within our dataset there was never a case where a fish consumption advisory was in place due to a non-apex predator. Thus, apex predators were the only species that had tissue Hg concentrations exceeding 0.5 ppm, triggering a fish consumption advisory. In other words, testing non-apex predators had essentially a 0 probability of triggering a fish consumption advisory. Thus, realistic unconditional standard error around the model averaged coefficient of apex (-14.45) using logistic

regression was not calculable unless one or more non-apex predators had triggered fish consumption advisories. We did not include system location in the model set because of its high correlation to other covariates; however it is another example of a covariate where error calculation was not realistic. Within our dataset there was never a situation where a system located east of Colorado Interstate 25 had a fish consumption advisory associated with it. Similar to testing non-apex predators, testing fish east of Colorado Interstate 25 had essentially a 0 probability of triggering a fish consumption advisory. It is important to note that although error was not calculated for these covariates, system location showed the highest correlation with fish consumption advisories, followed by the testing of apex predators (Table 2).

Using the model averaged coefficients we determined point estimates of fish consumption advisories across a range of chlorophyll a values. Using these values we were able to predict the probability that a fish tested would trigger a fish consumption advisory based on mean summer chlorophyll a concentration which varied from 0.5 – 117.5 $\mu\text{g/L}$ empirically (Figure 1). The Hosmer and Lemeshow Goodness-of-Fit test of the most parameterized model showed that there was not significant lack-of-fit (chi-square = 3.21, d.f. = 7, $p = 0.86$).

Model set 2

Pearson product-moment correlation coefficients showed significant relationships between several covariates. System location was correlated to three other covariates and system elevation was correlated to three other covariates (Table 4). System location and system elevation were removed from further analyses.

274 The model with the most support from the data included apex and PCA (Table 5).
275 Apex had a cumulative weight of 0.86 while PCA and surface area had cumulative
276 weights of 0.72 and 0.27 respectively. Surface area appeared to be a “pretending”
277 variable, (ΔAIC_c of approximately 2, signifying little information was gained by adding
278 the covariate; Burnham and Anderson 2002) having small coefficients, low cumulative
279 weight and was not found in the heavily supported top model. Thus, surface area was not
280 considered in model averaged estimates.

281 The model averaged (models with $\Delta AIC_c \leq 6$) coefficients and unconditional
282 standard errors for the intercept (-0.66 ± 0.39) and PCA (-0.46 ± 0.43) were estimated;
283 however, the same situation was encountered as in the first model set where there was
284 never a case where a fish consumption advisory was in place due to a non-apex predator.
285 Thus, realistic unconditional standard error around the model averaged coefficient of
286 apex (-16.15) using logistic regression was not calculable unless one or more non-apex
287 predators had triggered fish consumption advisories. As in model set 1, unconditional
288 error of system location was not realistically calculable. Again, although error was not
289 calculated for these covariates, system location showed the highest correlation with fish
290 consumption advisories, followed by apex (Table 4).

291 Using the model averaged coefficients we determined point estimates of fish
292 consumption advisories across a range of PCA values. Using these values we were able
293 to predict the probability that a fish tested would trigger a fish consumption advisory
294 based on calculations of PCA values which varied from $-2.5 - 4.5$ empirically (Figure 2).
295 The Hosmer and Lemeshow Goodness-of-Fit test of the most parameterized model
296 showed that there was not significant lack-of-fit ($\chi^2 = 2.75$, d.f. = 7, $p = 0.91$).

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298 **Discussion**

299 Our data showed that only apex predators from systems west of Colorado Interstate 25
300 had the potential to exceed Hg concentrations of 0.5 ppm. Furthermore, system
301 productivity was an important predictor of fish consumption advisories, where apex
302 predators from systems with low productivity had a higher probability of being
303 contaminated than those from high productivity systems. This trend is likely related to
304 growth and/or bloom dilution (biomass dilution) of Hg, and suggests that nutrient
305 subsidies could be a means to reduce reduce Hg concentrations in sport fish. More
306 importantly, our results could aid in the development of relatively easy to understand fish
307 consumption advisories to better protect human health in the western US.

308 Covariates excluded from analyses were removed because of significant
309 correlations with other covariates. The high level of correlation between covariates
310 suggests that they are not independent. Systems west of Colorado Interstate 25 tend to be
311 in more mountainous terrain than those in the east, relating this factor to elevation due to
312 the north-south orientation of the Rocky Mountains. Systems west of Colorado Interstate
313 25 tend not to be in agricultural areas relative to those in the east, potentially relating this
314 factor to indicators of productivity. Systems at higher elevations are generally stocked
315 with coldwater species (generally non-apex predators) while warmwater species are
316 stocked at lower elevations, influencing the presence or absence of apex predators
317 available for Hg testing. All of these are potential causes for correlation and these factors
318 could be contributing to sport fish Hg concentrations through multiple mechanisms.
319 Thus, these factors all represent potentially important predictors of fish consumption

advisories in the West. We believe other important predictors of Hg contamination in fish exist and we encourage further exploration of relationships and characterization of western systems.

System productivity was inversely related to the probability of a fish consumption advisory. The high level of correlation between productivity indicators suggests that they are informing the prediction of fish consumption advisories similarly. A principal component analysis is attractive to avoid removing informative data for predictions of fish consumption advisories and identifying important areas for future research. Unfortunately, coefficients estimated for principal components are difficult to interpret. However, principal components analyses may provide a way to combine correlated simple metrics of system productivity that are commonly gathered by agencies to improve prediction of fish consumption advisories and focus future data collection efforts.

Our findings related to system productivity and fish consumption advisories support the findings of previous studies (Essington and Houser 2003; Sorensen et al. 2005). However, elevated system productivity has been shown to increase hypoxia (by increasing Hg methylation) and could result in higher, rather than lower Hg concentrations in freshwater biota including sport fish (Bodaly et al. 1984; Driscoll et al. 1994; Slotton et al. 1995). These types of interactions should be considered carefully and we point out that Hg methylation, cycling, uptake and bioaccumulation are poorly characterized in western systems of North America. We note that during routine sampling in summer 2008 we detected hypoxia in two Colorado reservoirs (Chatfield and Union) that contain walleye (*Sander vitreus*) with low (< 0.15 ppm) Hg concentrations

while we did not detect hypoxia in two Colorado reservoirs (Carter and Horsetooth) that contain walleye with relatively high (> 0.75 ppm) Hg concentrations. This contradicts findings in eastern systems and indicates that Hg is being methylated in systems with and without detectable hypoxia and further research is required to understand mechanisms influencing Hg bioaccumulation in the arid west.

System location and elevation were the covariates most highly correlated to others and were removed from further analyses. System location was significantly correlated to all system productivity indicators and elevation and surface area. However, there were no fish consumption advisories in systems east of Colorado Interstate 25. Although we could not include this factor in our analyses, it represents an important result CDPHE could use to provide a relatively simple and understandable guideline regarding fish consumption and the likelihood of mercury contamination. Similarly, we never observed a case where a non-apex predator triggered a fish consumption advisory. These types of straightforward, binary factors can help anglers identify potential health risks associated with sport fish consumption.

Current fish consumption advisories can be difficult to understand, even in areas where Hg has been studied for decades and advisories have been in place nearly as long. For example, in the US the seven northeastern states have seven different definitions of populations that are “sensitive” to consumption of Hg contaminated fish (Lepak et al. 2009b). Simplifying, standardizing and creating fish consumption advisories that target sensitive human populations have been recognized as some of the most important steps towards developing effective fish consumption advisories (Knuth 1995; Knuth et al. 2003; Burger and Gochfeld 2008). In this study we identified two important, yet

simplistic predictors of fish consumption advisories associated with Hg contamination in Colorado. In our dataset, in order for a given fish to trigger a fish consumption advisory one must have: 1) obtained the fish from a system west of Colorado Interstate 25 and 2) captured a species of fish defined here as an apex predator. While we believe there are a number of mechanistic predictors yet to be discovered that will be informative to management, most anglers that harvest fish for consumption will understand these two factors and be able to identify when they have the potential of harvesting a fish with a Hg concentration exceeding 0.5 ppm.

Acknowledgements

We thank the Colorado Division of Wildlife for valuable guidance and suggestions throughout this project. We also thank the Colorado Department of Public Health and Environment for useful discussions during the project.

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519 Table 1. Apex predator and non-apex predator species list.

		520
Apex predators		521
Largemouth bass	<i>Micropterus salmoides</i>	522
Lake trout	<i>Salvelinus namaycush</i>	523
Northern pike	<i>Esox lucius</i>	524
Saugeye	<i>Sander vitreus/canadense</i>	525
Striped bass	<i>Morone saxatilis</i>	526
Smallmouth bass	<i>Micropterus dolomieu</i>	527
Spotted bass	<i>Micropterus punctulatus</i>	528
Wiper	<i>Morone saxatilis</i> X <i>M. chrysops</i>	529
Tiger muskie	<i>Esox lucius</i> X <i>E. masquinongy</i>	530
Walleye	<i>Sander vitreus</i>	531
Non apex predators		532
Black bullhead	<i>Ameiurus melas</i>	533
Black crappie	<i>Pomoxis nigromaculatus</i>	534
Bluegill	<i>Lepomis macrochirus</i>	535
Brook trout	<i>Salvelinus fontinalis</i>	536
Channel catfish	<i>Ictalurus punctatus</i>	537
Common carp	<i>Cyprinus carpio</i>	538
Drum	<i>Aplodinotus grunniens</i>	539
Gizzard shad	<i>Dorosoma cepedianum</i>	540
Flannelmouth sucker	<i>Catostomus latipinnis</i>	541
Kokanee salmon	<i>Oncorhynchus nerka</i>	542
Longnose sucker	<i>Catostomus catastomus</i>	543
Brown trout	<i>Salmo trutta</i>	544
Pumpkinseed	<i>Lepomis gibbosus</i>	545
Rainbow trout	<i>Oncorhynchus mykiss</i>	546
Green sunfish	<i>Lepomis cyanellus</i>	547
Splake	<i>Salvelinus fontinalis</i> X <i>S. namaycush</i>	548
White bass	<i>Morone chrysops</i>	549
White crappie	<i>Pomoxis annularis</i>	550
White sucker	<i>Catostomas commersoni</i>	551
Yellow perch	<i>Perca flavescens</i>	

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552 Table 2. Pearson product-moment correlation coefficients (followed by parenthetical p-values) between all independent and dependent
553 variables used to develop model set 1. Advis. is whether or not a given system had a fish consumption advisory, Apex is whether or
554 not apex predators were analyzed for Hg, I-25 is system location (east or west of Colorado Interstate 25), secchi is mean summer
555 secchi depth, Chl a is mean summer chlorophyll a, TP is mean summer total phosphorus, Elev. is system elevation and Area is surface
556 area.
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	Advis.	Apex	I-25	Secchi	Chl a	TP	Elev.	Area
Advis.	1	NA	NA	NA	NA	NA	NA	NA
Apex	-0.26 (0.09)	1	NA	NA	NA	NA	NA	NA
I-25	-0.35 (0.02)	-0.20 (0.17)	1	NA	NA	NA	NA	NA
Secchi	0.14 (0.34)	0.35 (0.02)	-0.43 (<0.01)	1	NA	NA	NA	NA
Chl a	-0.25 (0.10)	-0.07 (0.64)	0.61 (<0.01)	-0.51 (<0.01)	1	NA	NA	NA
TP	-0.16 (0.30)	-0.07 (0.66)	0.49 (<0.01)	-0.35 (0.02)	0.66 (<0.01)	1	NA	NA
Elev.	0.13 (0.40)	0.65 (<0.01)	-0.59 (<0.01)	0.67 (<0.01)	-0.38 (0.01)	-0.24 (0.11)	1	NA
Area	-0.04 (0.79)	-0.18 (0.23)	0.34 (0.02)	0.01 (0.95)	0.11 (<0.45)	-0.02 (0.91)	-0.09 (0.54)	1

Table 3. AIC_c results for model set 1. Coefficients and AIC_c results are reported. Apex is whether or not apex predators were analyzed for Hg, Chl a is mean summer chlorophyll a and Area is system surface area.

Intercept	Apex	Chl a	Area	k	Dev.	AIC	AICc	Δ	Weight
-0.08	-18.06	-0.05		3.00	47.21	53.21	53.78	0.00	0.46
-0.62	-16.95			2.00	51.80	55.80	56.07	2.29	0.15
-0.01	-18.11	-0.05	-4.9x10 ⁻⁵	4.00	47.10	55.10	56.08	2.30	0.15
-0.33		-0.05		2.00	52.35	56.35	56.63	2.85	0.11
-0.48	-17.05		-8.6x10 ⁻⁵	3.00	51.44	57.44	58.02	4.23	0.06
-0.83				1.00	56.53	58.53	58.63	4.84	0.04
-0.33		-0.05	-2.8x10 ⁻⁶	3.00	52.35	58.35	58.92	5.14	0.04
-0.77			-4.9x10 ⁻⁵	2.00	56.46	60.46	60.47	6.96	0.01

Table 4. Pearson product-moment correlation coefficients (followed by parenthetical p-values) between all independent and dependent variables used to develop model set 2. Advis. is whether or not a given system has a fish consumption advisory, Apex is whether or not apex predators were analyzed for Hg, I-25 is system location (east or west of Colorado Interstate 25), PCA is the multivariate index developed from the productivity indicators using a principal component analysis, Elev. is system elevation and Area is system surface area.

	Advis.	Apex	I-25	PCA	Elev.	Area
Advis.	1	NA	NA	NA	NA	NA
Apex	-0.26 (0.09)	1	NA	NA	NA	NA
I-25	-0.35 (0.02)	-0.20 (0.17)	1	NA	NA	NA
PCA	-0.22 (0.13)	-0.19 (0.22)	0.63 (<0.01)	1	NA	NA
Elev.	0.13 (0.40)	0.65 (<0.01)	-0.59 (<0.01)	-0.50 (<0.01)	1	NA
Area	-0.04 (0.79)	-0.18 (0.23)	0.34 (0.02)	0.04 (0.79)	-0.09 (0.54)	1

Table 5. AIC_c results for model set 2. Coefficients and AIC_c results are reported. Apex is whether or not apex predators were analyzed for Hg, PCA is the multivariate index developed from the productivity indicators using a principal component analysis and Area is system surface area.

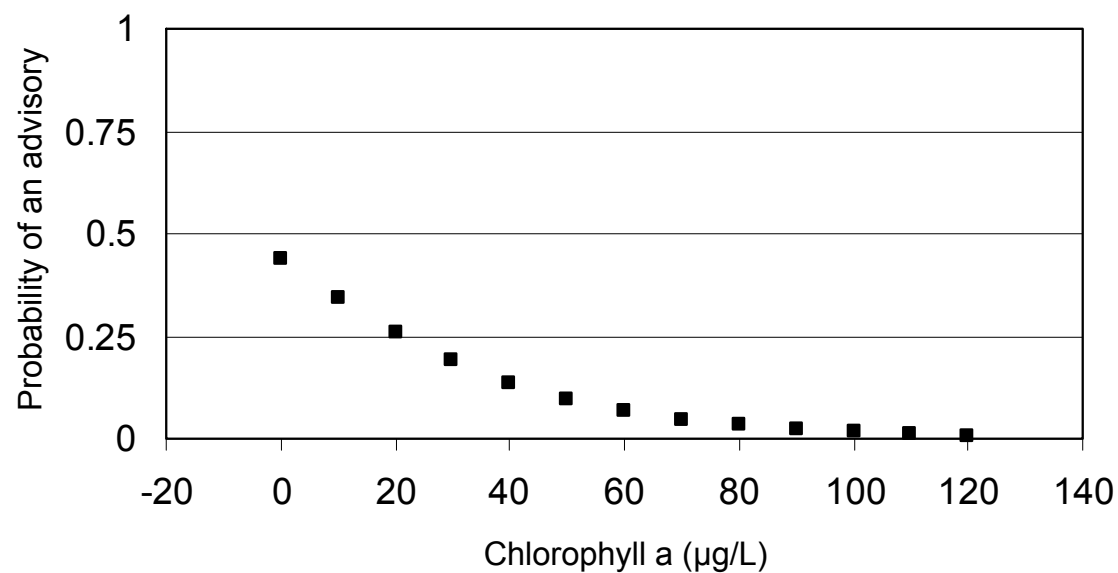
Intercept	Apex	PCA	Area	k	Dev.	AIC	AICc	Δ	Weight
-0.70	-18.45	-0.65		3.00	47.37	53.37	53.94	0.00	0.47
-0.55	-18.58	-0.66	-9.6x10 ⁻⁵	4.00	46.97	54.97	55.94	2.00	0.17
-0.62	-16.95			2.00	51.80	55.80	56.07	2.13	0.16
-0.48	-17.05		-8.6x10 ⁻⁵	3.00	51.44	57.44	58.02	4.07	0.06
-0.91		-0.45		2.00	53.81	57.81	58.09	4.15	0.06
-0.83				1.00	56.53	58.53	58.63	4.68	0.05
-0.86		-0.45	-3.3x10 ⁻⁵	3.00	53.76	59.76	60.33	6.39	0.02
-0.77			-3.9x10 ⁻⁵	2.00	56.46	60.46	60.74	6.79	0.02

Figure captions

Figure 1. Point estimates of the probability of a fish consumption advisory given an apex predator was tested as a function of chlorophyll a ($\mu\text{g/L}$).

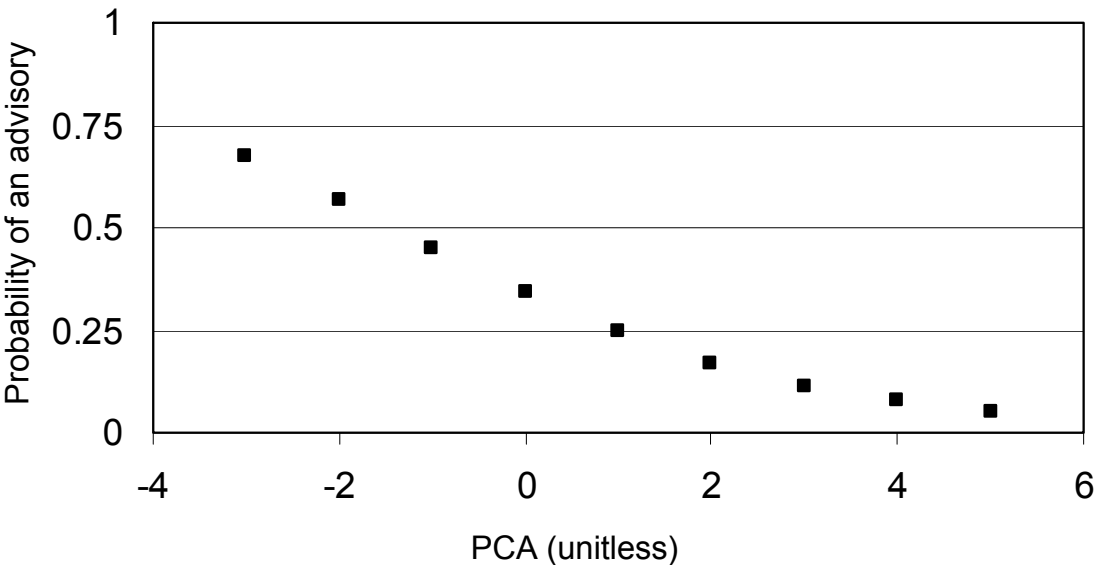
Figure 2. Point estimates of the probability of a fish consumption advisory given an apex predator was tested as a function of PCA (unitless). The coefficients of the multivariate index (PCA) are difficult to interpret but in general, increasing PCA suggests higher system primary productivity and lower probabilities of apex predators being contaminated with Hg.

719 Figure 1.



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748 Figure 2.



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