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**A Natural Experiment Identifying Disease Regulation Effects on Recreational Fishing**

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## Introduction

A primary concern in managing recreational fisheries is the behavioral response of anglers to management actions (Quinn, 1992). Use restrictions on public sport fisheries are often necessary because the demand for a superior fishing experience in terms of catch puts pressure on fish populations and the sustainability of aquatic systems. Efficient fisheries management requires that agencies be able to anticipate angler reactions to new fishing regulations considering they ultimately alter the attractiveness of the affected fishing opportunity (Beardmore et al., 2011). Furthermore, fisheries agencies may also be concerned about the impact of regulations on participation because most of their revenues are derived from license and equipment sales (Ditton and Sutton, 2004).

Prior research demonstrates that fishing regulations can alter the number of trips, site choice, and targeted species of anglers (Beardmore et al., 2011; Post et al., 2002; Beard et al., 2003; Ditton and Sutton, 2004). This may be because management directly impacts the fishing experience by enforcing, for example, bag limits (Carlin et al., 2012) and length restrictions (Pierce, 2010), or because management indirectly affects the fishing experience by altering the access cost, fish quality, angler congestion, and environmental quality of fishing sites (Hunt, 2005). However, the link between fisheries regulations and angler behavior is remains insufficiently researched (Hunt et al., 2013).

The purpose of this paper is to present a model of anglers' reactions to regulations designed to slow the spread of an aquatic infectious disease. This is a critical issue for fisheries managers because aquatic diseases (and, similarly, invasive species) tend to suppress catch rates by increasing the mortality and altering the behavior of fish. Furthermore, anglers that travel between different lakes and rivers become an important vector through which aquatic diseases can spread and thereby trigger reductions in the fishing quality of an entire region. Yet there is little research that addresses disease regulations in fisheries. Jakus et al. (1997) examine fish consumption advisories on angler behavior, although the advisory is for a chemically-induced rather than infectious disease. There is some research on the impacts of wildlife diseases on hunters (Bishop, 2004; Needham et al., 2007), although these studies focus on the impacts of disease presence rather than the regulation per se.

This paper focuses on a set of regulations implemented by the Michigan Department of Natural Resources (DNR) to slow the spread of Viral Hemorrhagic Septicemia virus (VHSv), a non-toxic disease that is damaging fish populations across the Great Lakes region. The goal of this study is to determine whether VHSv regulations have altered angler participation and site preferences for areas that have been infected and if preferences have shifted towards sites that are void of the virus and the regulations. To analyze the effects of VHSv regulations, we estimate a linked participation model using fishing trip data spanning over a five year period, including periods before and after the regulations were implemented. We find that the presence of VHSv and the regulations significantly impact anglers' site choice and trip frequency, and that these impacts vary with the stringency of the regulations. The results also indicate that, consistent with state natural resource agency goals, the VHSv regulations have led to increased use of artificial bait.

**VHSv and Michigan DNR Regulations**

Viral Hemorrhagic Septicemia virus is a deadly fish disease that originated in Europe in the 1930s (Bowser, 2009). In fish, the virus causes hemorrhaging in the eyes, skin, gills, fins, skeletal muscles and internal organs as well as odd sporadic behavior, although consuming VHSv-infected fish is not a threat to human health (Cornell University). In 2005, VHSv was confirmed as a cause of fish mortality in the Great Lakes system. Since then the disease has spread rapidly and become a major concern of Great Lakes fisheries managers (Bowser, 2009). The Great Lakes outbreak is believed to be a new strain that is responsible for the die-offs in several fish species including muskellunge, smallmouth and largemouth bass, northern pike, freshwater drum, gizzard shad, yellow perch, black crappie, bluegill, rock bass, white bass, redhorse sucker, bluntnose sucker, round goby, and walleye (Aphis Veternary Services, 2006). Recently, VHSv infections have been identified in Great Lakes trout and salmon.

A primary factor in the spread of VHSv is the unintentional movement of contaminated water by boaters and recreational anglers (Department of Natural Resources, 2009). The Michigan DNR initially responded to this threat in December of 2008 by implementing regulations intended to slow the rate of VHSv spread. Broadly, the goals of the VHSv regulations are to protect populations of wild fish in inland waters and in VHSv-free areas of the Great Lakes, protect wild populations of fish used for broodstock in fisheries management, and prevent the infection of fish being reared in state-owned fish hatcheries (Department of Natural Resources, 2009).

Fisheries Disease Control Order FO-245.09 is the regulation implemented statewide against this virus. FO-245.09 consists of statewide regulations as well as regulations by management area. There are three management areas as classified by disease status, which are illustrated in Figure 1. VHSv positive (red) is the management area where the presence of the virus has been confirmed. This area includes Lake Huron and all of its tributaries up to the first barrier (i.e. dam) as well as Lake Erie. VHSv surveillance (yellow) is the management area where the virus is likely to spread in the future. This includes all of Lake Michigan and the St. Mary's River system, including most of their tributaries up to the first barrier, as well as all of the waterbodies in the Lake Huron watershed that do not have confirmed disease presence. VHSv free (green) is the management area where the virus is not likely to be confirmed in the near future. This includes the entire Lake Superior watershed and all of the waterbodies in the Lake Michigan watershed that are not currently under surveillance. Each disease management area has a unique set of regulations that target bait use and vary in severity with disease status, which are summarized in Table 1 (Department of Natural Resources, 2009). In addition to these restrictions, every boater in the state is required to drain their live wells and bilges prior to leaving any site and are prohibited from transporting live fish between waters of the state, as well as releasing bait fish to the water unless attached to a hook.

This paper analyzes the effects of the Michigan DNR VHSv regulations on Great Lakes anglers. For this population we have developed the following three hypotheses based upon the restrictions described above:

1. The presence of VHSv coupled with the regulations by management area will have a significant effect on where and how frequently anglers choose to fish. Specifically, anglers will be least likely to select sites in the positive management area, followed

by the surveillance management area. Furthermore, anglers who visit these sites will fish less often.

2. The regulations target natural bait users so the proportion of anglers who use natural bait will decrease after the regulation is put into effect.
3. The statewide regulation requiring all boat owners to drain their live wells will not change the proportion of anglers who use boats for fishing.

Testing the effect that VHSv and the associated regulations have on anglers can provide insights into the effectiveness of fisheries policies. Anglers have two bait options when they go fishing, artificial and natural. We expect that if the value of one option is reduced, due to restrictions on its use, anglers will prefer to switch to the other option, which drives the first and second hypotheses above. The proportion of boat usage is not expected to change after the regulation because boats are high-valued assets that provide anglers more access to the fish in a lake than they would have from fishing on a shoreline or pier, and the statewide draining requirement is a small cost relative to switching to an alternative type of fishing.

**Model**

A linked participation model was used to assess the effects of VHSv regulations on Michigan anglers' fishing participation and location decision. Specifically, the model measures participation and site choice in two stages that are linked by an inclusive value index. The first stage consists of a random utility maximization (RUM) model, which can be used to estimate the probability that an angler visits a specific fishing site or region based on the known characteristics of sites. The RUM model can also be used to calculate an "inclusive value" measuring the relative value of fishing sites for each angler in the sample. This index is used as an explanatory variable in the trip frequency model.

*Site choice model:*

The location choice determines the utility, or benefit, that an angler experiences when they go fishing. A general format for an individual angler $i$ is composed of three basic elements: cost of visiting the site ( $p_{ij}$), a vector of observable attributes such as site amenities ($q_j$), and a random element which includes all unobservable characteristics of the angler and site factors ($\varepsilon_{ij}$). Angler $i$'s general utility function is as follows:

$$U_{ij} = U(z_i, q_j, \varepsilon_{ij}) \quad (1)$$

where $z_i$ represents other goods or activities that the angler could consume besides fishing at site $j$. It is assumed that each angler chooses to fish the site that results in the highest utility over all the other fishable alternatives. While each rational angler strives to maximize their utility when they choose where to fish, they are limited by their budget, represented by the following constraint:

$$\max_j U_{ij}$$

$$s.t. \;\; p_{ij}y_{ij} + z_i \leq M_i \quad (2)$$

where $M_i$ represents the angler's income. Anglers can choose to spend their income on travelling to the fishing site ($p_{ij}$), or on other goods or activities ($z_i$). $y_i$ captures the angler's decision to travel to site $j$ or not, where $y_{ij} = 1$ for the chosen site and $y_{ij} = 0$ otherwise. Conditional on this choice, the constraint in (2) can be rearranged and substituted into the utility function (1) for $z_i$ which results in the conditional indirect utility function:

$$v_{ij} = v(M_i - p_{ij}, q_j) + \varepsilon_{ij} \quad (3)$$

We assume for convenience that $\varepsilon_{ij}$ is independently and identically distributed Generalized Extreme Value (GEV) (Freeman, 2003) to produce a two-level model (McFadden, 1981) in which the top level is a grouping of sites, or nests, and the bottom level consists of the sites themselves. This structure allows the model to control for unobservable similarities between grouped sites. In this analysis sites are grouped by Michigan's three shorelines: east (Lake Huron, Lake Erie and Lake St. Clair), west (Lake Michigan) and north (Lake Superior).

The specific form of the indirect utility function that we adopt for the RUM model is:

$$v_{ijnt} = \beta_{tc} tc_{ijnt} + \beta_{cr} \boldsymbol{CR_{jnt}} + \beta_P D_{jnt}^P + \beta_S D_{jnt}^S + \beta_E E_j + \beta_W W_j + \beta_q \boldsymbol{q_{jn}} + \varepsilon_{ijnt} \quad (4)$$

where the variable $tc_{ijnt}$ is the travel cost of each angler $i$ to site $j$ in nest $n$. This variable is comprised of both distance and time costs. Distance costs are measured in dollars per mile from the angler's primary address to the fishing site. Time cost measures the opportunity cost of choosing to travel to the fishing site, which is estimated using the individual's reported salary range converted into an average hourly wage. The estimated hourly wage is multiplied by the average travel time (Parsons, 2003). The term $\boldsymbol{CR_{jnt}}$ is a vector of targeted hourly catch rates for six species, which vary by time (year and month) and site. The variable $\boldsymbol{q_{jn}}$ is a vector of several physical features that are expected to play a role in site choice.

The effects of the VHSv regulations for each site $j$ are separated into four dummy variables. The variables, $D_{jnt}^P$ and $D_{jnt}^S$, capture the effects of a site being located in the VHSv positive management area and VHSv surveillance management area, respectively, after the regulation was applied. The baseline regulation for these dummy variables includes trips to sites in the time period before the regulations were in effect and within the VHSv free management area. $E_j$ is a fixed effect for sites located along the eastern shores of Michigan and $W_j$ is a fixed effect for sites located along the western shore. The inclusion of these two variables is critical to correctly specify the model. These variables capture any time-invariant regional effects that could be correlated with the disease regulations. The regulation dummy variables ($D_{jnt}^{P}$ , $D_{jnt}^{S}$) then capture the change in site preference after the regulation goes into effect. A regional effect for all sites located along Lake Superior was excluded to avoid perfect multicollinearity in the model.

The GEV error distribution allows the model to be estimated using the following probability structure:

$$P_{ijnt}(y_{ijn} = 1) = \Pr(v_{ijnt} > \forall v_{iknt}) = \frac{\exp\left(\frac{v_{ijnt}}{\theta_n}\right)\left[\sum_{k=1}^{J_n} \exp\left(\frac{v_{iknt}}{\theta_n}\right)\right]^{\theta_n - 1}}{\sum_{m=1}^{N}\left[\sum_{k=1}^{J_m} \exp\left(\frac{v_{ikmt}}{\theta_m}\right)\right]^{\theta_n}} \qquad (5)$$

where $v_{ijnt}$ is the deterministic portion of the angler's indirect utility function from (4). The parameter $\theta_n$ is a measure of the unobserved dissimilarities between sites in the three groups of sites. The coefficients on the variables are then estimated using maximum likelihood estimation using the likelihood function:

$$L = \prod_{i=1}^{N} \prod_{j=1}^{S_i} P_{ijnt}{}^{y_{ijn}} \qquad (7)$$

where $N$ is the total number of anglers in the sample population and $S_i$ is the set of sites in each angler's choice set. The estimates from (7) can then be used to determine where anglers preferred to visit before and after the VHSv regulations went into effect.

The estimated coefficients from (7) can also be used to calculate the inclusive value parameter, the expected utility of taking a Great Lakes trip for each angler in the sample. The inclusive value is defined as:

$$IV_{jnt} = \ln\left[\sum_{j=1}^{Jn} \exp\left(\frac{v_{jnt}}{\theta_n}\right)\right] \quad (8)$$

where $IV_{jnt}$ is a measure of the expected maximum indirect utility (Parsons & Kealy, 1995) summed over all available alternatives in each angler's choice set to obtain one measure per individual per month. $v_{jnt}$ represents an index of desirability of site $j$ located within nest $n$ during month $t$. Therefore, $IV_{jnt}$ can be interpreted as an index of the overall quality of fishing opportunities in each region $n$ (Carson et al., 2009) before and after the VHSv regulations. Once each value is calculated it is used as an independent variable in the participation stage and becomes the linking mechanism between the two models.

*Participation model:*

The inclusive value parameter can be used to predict the mean number of trips occurring over each month in our sample. Trips taken by anglers are unlikely to remain constant as fishing conditions change throughout the year; therefore, it is necessary to estimate each angler's trip frequency over each month and the data was collected by month. We use a Tobit model to estimate trip frequency because it allows for a large occurrence of zeroes in the dependent variable as anglers choose to participate in a given month. The generalized Tobit model is:

$$T_{it} = \max(0, T_{it}^{*}) \quad (9)$$

$$T_{it}^{*} = \boldsymbol{\beta}'\boldsymbol{X_{it}} + \mu_{it} \quad (10)$$

where $T_{it}^{*}$ is a latent variable and $T_{it}$ is the observed number of trips taken by angler $i$ in month $t$. Anglers with $T_{it} = 0$ are considered to be non-participants in month $t$. It is assumed that anglers will optimize the number of trips taken per month over a vector of characteristics ($\boldsymbol{\beta'X_{it}}$), which includes angler demographics, site utility, and the time of year. Specifically:

$$T_{it}^{*} = \alpha + \boldsymbol{\alpha_t M_t} + \boldsymbol{\beta_Z Z}_i + \beta_{IV} IV_{it} + \mu_{it} \qquad (11)$$

where $\boldsymbol{M_t}$ is a vector of seasonal dummy variables that capture preferences for specific seasons, $\boldsymbol{Z}_i$ represents a vector of angler characteristics, and $IV_{it}$ is the estimated inclusive value measure from the site choice model. $\mu_{it}$ is a random error term that is assumed to be independently distributed with a mean of zero and constant variance, $\sigma^2$. The Tobit likelihood function is:

$$L = \prod_{i=1}^{N} \left[1 - F\left(\frac{\boldsymbol{\beta' X_{it}}}{\sigma}\right)\right]^{1-I(T_{it})} \left[\frac{1}{\sigma} f\left(\frac{T_{it} - \boldsymbol{\beta' X_{it}}}{\sigma}\right)\right]^{I(T_{it})} \qquad (12)$$

where $f$ and $F$ are standard normal probability and cumulative density functions, respectively, and $I(T_{it})$ is an indicator function equaling one if angler $i$ fishes in month $t$ and zero otherwise.

**The Michigan Recreational Angler Survey Data**

Data was collected using the Michigan Recreational Angler Survey (MRAS) which was designed to gather information on the status and distribution of angling effort for all of Michigan's recreational fisheries (Simoes, 2009). The sample population of anglers consisted of resident recreational anglers who purchased a Michigan fishing license for the given year. Data was collected beginning in 2008 by drawing a simple random sample of anglers each month from the Michigan DNR Retail Sales System Database. Initially, in July of 2008 the sample size was 5,000 anglers, followed by 6,000 in August. The sample size was reduced to 2,500 from September 2008 to November 2009. From December 2009 to June 2010, the sample size was 1,250. Currently, the random sample is set at 500 anglers per month.

The MRAS uses a monthly mailed questionnaire following the protocol adapted from the method in Dillman (2007). The mailed packed included a four paged questionnaire in booklet form, a personalized cover letter, and a self-addressed postage paid reply envelope (Simoes, 2009). The survey respondents were contacted four times over a two month period. The initial contact included the cover letter, survey, and pre-paid envelope. Five days after the initial contact, a reminder postcard was sent to the respondent. After one month, those anglers who have not yet responded were sent a new cover letter along with a replacement survey. Approximately two weeks following the third contact, a final postcard was mailed thanking them for their participation as well as stating that they will no longer be contacted regarding this project. Over five years of surveying, the average monthly response rate has been 45%.

The MRAS questionnaire asks respondents about their fishing activity over the previous month, as well as the details of their most recent and second most recent fishing trips. Respondents are questioned about the number of fishing trips taken, where the angler fished, what species were targeted and caught, the method of fishing, and household demographics.

*Fishing Trips*

The surveys returned from July 2008 through December 2012 are used to model the effect of the VHSv regulations on angler fishing choices. Post-stratification weights are applied to the survey data to adjust for differences over time in the total number of surveys sent in each month as well as angler characteristics including age, gender, and license type. The choice set within this data includes 72 fishing sites located along the Michigan shoreline including ports on Lake Huron, Lake Michigan, Lake Superior, and in the Lake Erie-St. Clair system. Each site consists of a cold and warm water fishable alternative to account for differences in angler fish preferences and response to the regulations, resulting in a total of 144 possible fishable alternatives. Each of these alternatives has varying travel costs depending on the angler's distance, income and year of trip. The average cost per mile was calculated using annual AAA estimates for a medium-sized sedan published in *Your Driving Costs.* These values were used in accordance with each angler's round trip distance to estimate distance cost to each alternative. Distance traveled from the angler's home to the fishing site was calculated using the PC*Miler software (ALK Technologies , 2010). Income range was a demographic question included in the survey and was used to calculate a wage rate for each individual by taking the midpoint from each range and dividing by 2000 (approximate number of hours worked in one year). Any angler's income that was not reported was proxied by the Census 2012 ZCTA household median income. Unemployed anglers were assigned the Michigan minimum wage of $7.40. The time cost was calculated as one-third of the estimated wage rate multiplied by time spent driving. We use one third of the hourly wage rate because it has been generally accepted as the lower bound by the recreation demand literature as the value of travel time (Parsons, 2003). The average driving speed was assumed to be 45 mph.

*Fishing Sites*

The site characteristics vector $\boldsymbol{q_j}$ from the indirect utility function (5) includes three dummy variables: Highway, Bayorseaway, and Urban. Highway is a variable intended to measure the remoteness of a site, which receives a value of one if the site is located next to a highway and zero otherwise. Bayorseaway captures preferences for fishing in warmer, safer areas of a lake and equals one if the site is located in a bay or seaway. Urban is a dummy variable that indicates whether the alternative lies in an area that the Census 2010 defined as at least partially urban and is used as a proxy for amenities at a site.

Monthly catch rates ($\boldsymbol{CR_{jnt}}$) were calculated using data from the Michigan DNR creel survey program. The catch rates were estimated for six species of fish across all available sites using a series of Tobit regressions (Melstrom and Lupi, 2013).[1] To capture changes resulting from VHSv, we included yearly fixed effects in the Tobit regressions.

*Angler Characteristics*

In the participation model, we include several angler-specific characteristics which might influence the fishing trip decision. In addition to a variable for age, dummy variables are used to measure whether the angler is male, employed full-time, retired, graduated from college and lives with their spouse. Angler income level dummies are included to identify which income group(s) may be more or less inclined to participate. Employment status proxies for how much leisure time an angler has available. Finally, we control for time of year by incorporating seasonal dummy variables, each consisting of three months.

Only anglers who took day trips to the site with the primary purpose of fishing were included in the model (these two factors represented 70% and 88% of the collected sample, respectively). Sites within the choice set for a day trip included all the fishable alternatives within 200 miles of the angler's residence.

[1] The estimated catch rates from Melstrom and Lupi (2013) includes per-hour DNR creel data through 2009. We use creel data through 2013.

*Bait Type and Boat Use*

The MRAS includes data on bait type and boat usage. The corresponding survey question asks anglers to indicate what method of fishing they used in Michigan the past 12 months, including bait type and boat use. Anglers who respond to this question could indicate their bait use by choosing natural (live), artificial, or both bait types. Those who chose only natural or only artificial bait are considered "specialized" anglers since they indicate that they only use one type. The effect of VHSv regulations on bait choice is studied by comparing the proportion of anglers who used natural or artificial bait prior to the regulation in 2008 with the proportion after the regulation.

Anglers could also indicate whether they went fishing by casting from a boat, casting from shore/pier, or trolling. Trolling and casting from a boat both require the individual to use or possess a boat, so these two options were grouped together for the comparison. The impact of the VHSv regulations on boat use is assessed by comparing the proportion of anglers who used a boat to fish before and after the VHSv regulations took effect.

**Results**

*Linked Model*

The linked site choice and participation model was estimated using Stata 12 (StataCorp, 2011). The model was estimated on the sample of 2,802 fishing trips. The results of these models are presented in Tables 2 and 3. The average choice set contained 49 alternatives.

The results indicate that the travel cost variable has a significant negative impact on site choice for all models, as expected. If the cost to travel to a fishing site increases, the angler is less likely to choose that site. All site characteristics are positive and statistically significant at the 0.05 level in the site choice model with the exception of the lake trout catch rate, which is positive but at the 0.10 level. We find that anglers prefer sites that have high catch rates with highway access and are located in a protected area of a lake. The dissimilarity parameter ($\theta_n$) is significantly less than one which is consistent with utility-maximizing behavior (Hunt et al., 2007; Herriges et al., 1999).

The negative estimated effect of the positive management area variable indicates that anglers are less likely to visit a fishing site if it is located in the area affected by VHSv and disease regulations. We also find that all else equal, anglers prefer fishing sites located along the lower peninsula of the state to sites located along the shore of Lake Superior. The relationship between regional and regulatory effects implies that anglers receive negative utility from the inclusion of stringent regulations and presence of VHSv. However, the effect of the surveillance management area restrictions, while negative, is not statistically significant. This suggests that anglers are willing to accept some minimal level of the VHSv regulations and disease risk to continue fishing at their preferred site.

At the participation level, our results are consistent with previous findings. The inclusive value coefficient is both positive and significant. As the value of Great Lakes fishing increases to an individual angler, they are expected to increase the number of trips taken per month. We find that on average older, male anglers earning less than $75,000 take more trips per month, while anglers who are employed full-time and highly educated are expected to take fewer fishing trips per month. Conditional on the age and employment of an angler, retirement status does not have a significant effect on the number of trips taken for Great Lakes fishing. All seasonal dummy variables are significant relative to the omitted winter category, suggesting that anglers take more trips in the spring, summer and fall, with the most trips occurring in summer.

*Bait and boat use restrictions*

The primary focus of the VHSv regulation was to target the movement of natural bait which can spread the virus across waterbodies. Our hypothesis was that the targeting of those who use natural bait such as roe or baitfish would lead to a reduction in natural bait use. The results in Figure 2 show that the proportion of specialized anglers (those who use *only* natural or *only* artificial bait) has decreased by about 3% and 1%, respectively, while those who use both types has increased by 4%. This suggests that the regulation has had an impact on those who used natural bait, apparently pushing them to use both types of bait. A chi-square test for independence was used to test if the proportion of bait users has changed after the regulation or if there was an insignificant change. The chi-square statistic was calculated as:

$$\chi^2 = \sum \frac{(f_0 - f_e)^2}{f_e} \qquad (13)$$

where $f_0$ is equal to the observed frequency from each category (both, artificial, natural) and $f_e$ is equal to the expected frequency, which was calculated by multiplying the total users from each category by the total before and total after, then divided by the sample size (n=26,568). Note that the large sample size for this test reflects that fact that all anglers in the data are included in the analysis, whereas the site choice model reported above is only for Great Lakes anglers. For the proportion of bait users the p-value from the chi-square test was <0.001.

Therefore, the null hypotheses that the proportion of bait users is the same before and after the regulation can be rejected.

As mentioned earlier, one section of the VHSv regulations included a statewide requirement that each angler using a boat drain all live wells and bilges prior to leaving a fishing site. We tested whether this part of the regulation affected anglers' boat use, specifically whether we observe a shift from boat use to shore or pier fishing. The results illustrated in Figure 3 show that there was little change in boat use after the regulation was put into effect. Before the regulation, 69.4% of anglers reported using a boat to fish in 2008, while 68.8% reported that they used a boat after the regulation went into effect. Shore or pier fishing increased somewhat from 12.2% to 12.8% and those who used both methods also increased, albeit slightly, from 18.4% to 18.5%. The chi-square test for independence was used to test if this change was significant (n = 21,775). In this case, the p-value from the chi-square test was equal to 0.727, which exceeds the critical p-value of .05, suggesting that the observed change was likely due to chance.

**Conclusion**

Policy makers and fisheries managers often have to impose regulations to protect natural resources and make assumptions about the impacts of proposed regulations on behavior. Understanding how anglers respond to regulations is therefore crucial in protecting the value of a fishery. The goal of this paper was to investigate and quantify the impacts of a new disease and accompanying agency regulations for a recreational fishery by estimating a linked participation model for Michigan anglers. The results demonstrated that anglers significantly alter their behavior at the site choice and participation levels in response to a new disease and its regulations. Specifically, we found that disease regulations implemented by the Michigan DNR to slow the spread of VHSv have had an impact on angler behavior for areas where the virus is present and most heavily regulated. Anglers were less likely to visit a site considered to be VHSv positive and subject to bait use restrictions and more likely to choose a site free of disease regulations. This suggests that the VHSv regulations have been successful in reducing the opportunities for the disease to be spread by anglers. Furthermore, there is evidence that the presence of these regulations affected how anglers fished the Great Lakes through their choice of bait, but not through boat use.

To be clear, we cannot explicitly distinguish among two possible effects driving these results: the influence of VHSv on resource quality and the influence of the disease management zone restrictions on angler actions per se. Moreover, we cannot measure the extent to which the regulations have prevented damage to the fishery by limiting the spread of VHSv.

Our investigation into the effects of fishing regulations was made possible by a statewide multi-year surveying effort. Both spatial and temporal dimensions were used to identify the effects of new fishing regulations on angler behavior. To our knowledge, this is the first such study to apply a multi-dimensional database to modeling wildlife disease regulations. Furthermore, this database continues to be updated with new monthly angler surveys. This will make it possible to capture the effects of future changes in disease regulations, which may lead to more robust predictions from the model.

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**Figures**

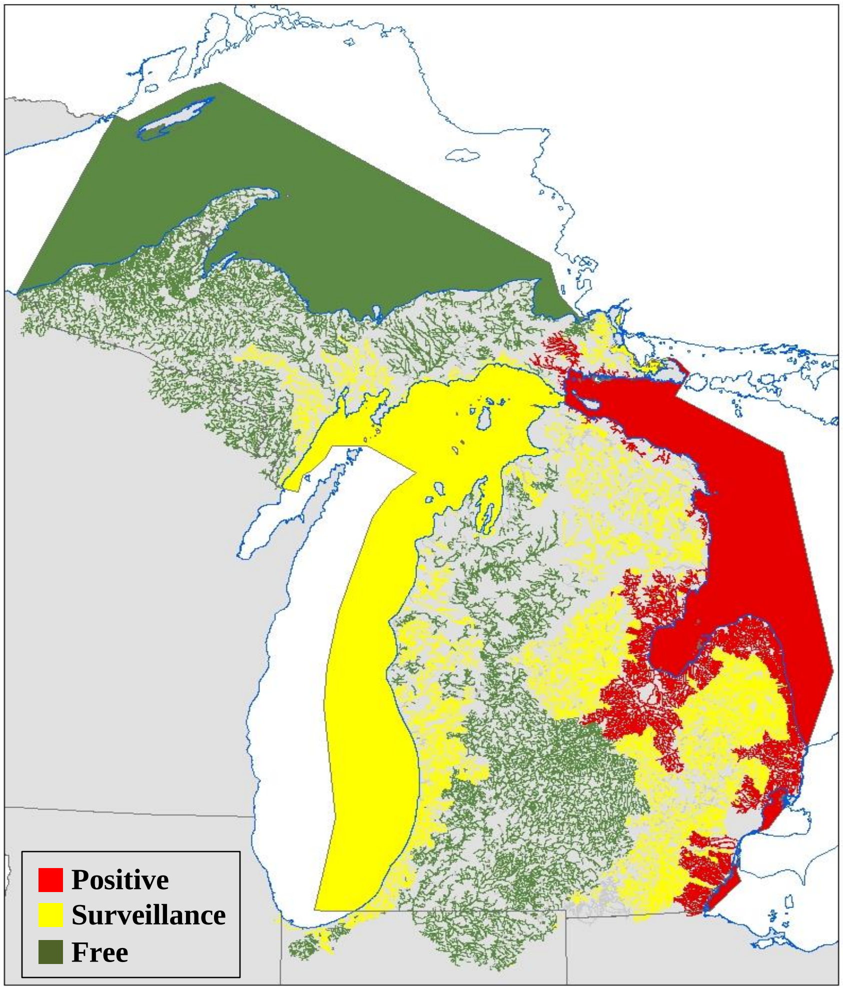


Figure 1: Map of VHSv management areas.

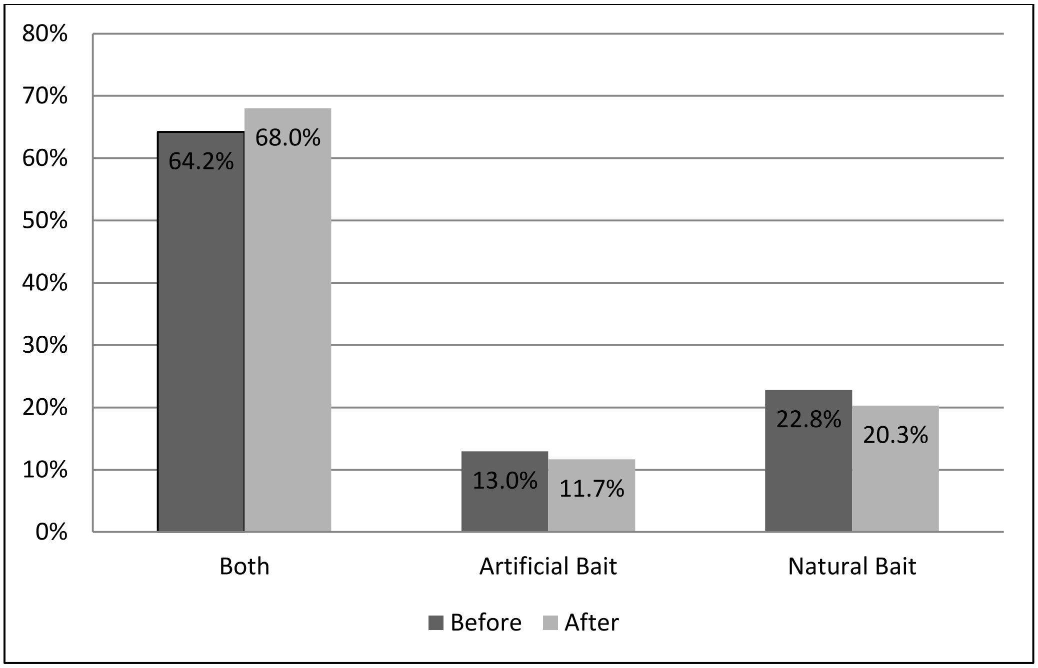

Figure 2: Angler's bait use before and after statewide VHSv regulations were implemented.

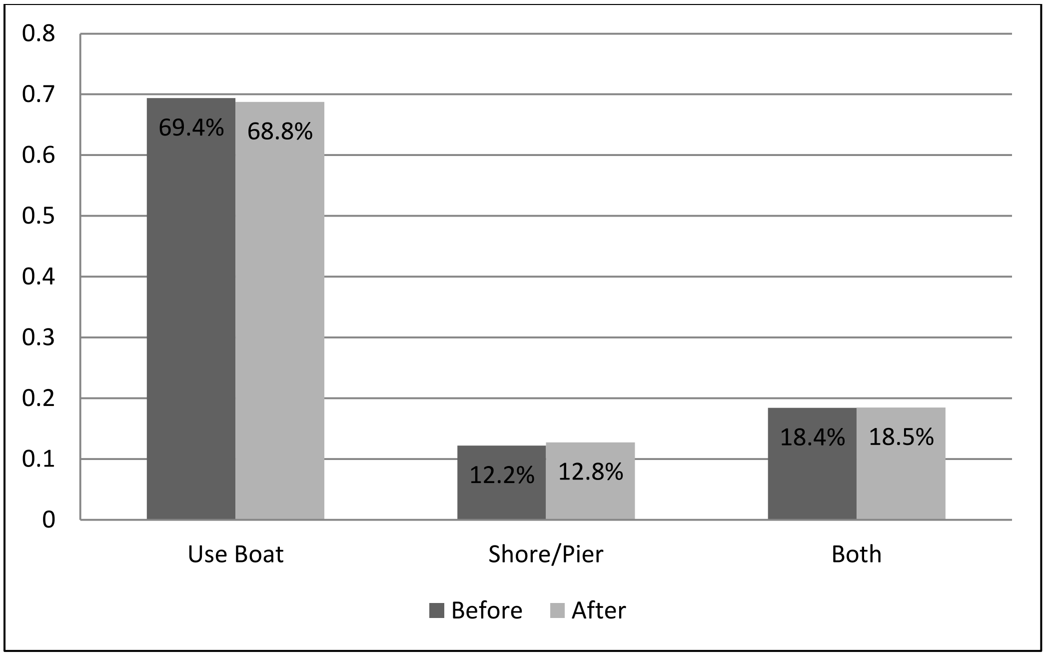

Figure 3: Change in proportion of boat and/or shore use before and after statewide VHSv regulations were implemented.

**Tables**

Table 1: Regulation by management area

| VHSv management area | Restrictions | Number of affected RUM sites |
|---|---|---|
| Positive ($D^P$) | All live bait collected or purchased from this region can only be used within the management area. | 62 |
| Surveillance ($D^S$) | Live bait collected or purchased from this region can only be used in the positive and surveillance areas. | 58 |
| Free | Live bait collected or purchased from this region can be used anywhere in the state. | 24 |
| Statewide | All boaters must drain their live wells and/or bilge tanks prior to leaving the waterbody site. Transportation of live fish is not allowed. | 144 |

Table 2: Site choice model results

| Variables | Coefficient | Robust Standard Errors |
|---|---|---|
| Travel Cost | -0.0294*** | 0.0015 |
| Positive zone $D^P$ | -0.834** | 0.409 |
| Surveillance zone $D^S$ | -0.352 | 0.364 |
| East | 1.158*** | 0.323 |
| West | 0.660** | 0.299 |
| $CR$ chinook | 8.427*** | 0.715 |
| $CR$ coho | 7.423*** | 1.142 |
| $CR$ lake trout | 0.797* | 0.421 |
| $CR$ rainbow trout | 2.941*** | 1.109 |
| $CR$ walleye | 2.998*** | 0.230 |
| $CR$ yellow perch | 0.557*** | 0.043 |
| Bayorseaway | 0.089** | 0.044 |
| Highway | 0.843*** | 0.163 |
| Urban | 0.535*** | 0.053 |
| $\theta_n$ | 0.635*** | 0.0382 |
| $N$ | 2802 | |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Participation model results

| Variables | Coefficient | Robust Standard Errors |
|---|---|---|
| IV | 0.017*** | 0.005 |
| Male | 0.224*** | 0.016 |
| Age | 0.015*** | 0.003 |
| $Age^2$ | -0.0002*** | 0.00003 |
| Employed full-time | -0.068*** | 0.016 |
| College | -0.106*** | 0.014 |
| Spouse | 0.012 | 0.017 |
| Retired | 0.015 | 0.025 |
| Income1[a] | 0.062** | 0.025 |
| Income2 | 0.089*** | 0.021 |
| Income3 | 0.058*** | 0.021 |
| Income4 | 0.013 | 0.024 |
| Income5 | 0.038 | 0.025 |
| Spring | 0.659*** | 0.023 |
| Summer | 0.786*** | 0.023 |
| Fall | 0.147*** | 0.024 |
| Constant | -1.037*** | 0.065 |
| Standard Error ($\sigma$) | 0.785*** | 0.011 |
| *N* | 24184 | |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

[a] Annual incomes ($) categories are defined as: 0-24,999; 25,000-49,000; 50,000-74,999; 75,000-99,999; 100,000-120,000; Incomes> 120,000 were used as the baseline.