Economic Damages of Impingement and Entrainment of Fish, Fish Eggs, and Fish Larvae at the Bay Shore Power Plant

Gentner Consulting Group
9007 Eton Road
Silver Spring, MD 20901
May, 2010

Table of Contents

Acknowledgements

This report was prepared by Brad Gentner with the assistance of Mike Bur.

Brad Gentner is president and Chief Economist for Gentner Consulting Group an Economics and Public Opinion consulting firm specializing in fisheries policy and damage assessment. Before starting Gentner Consulting Group, Brad Gentner was a Senior Research Economist for the National Marine Fisheries Service for eight years. For more information on Gentner Consulting Group and Brad Gentner please visit www.GentnerGroup.com.

Mike Bur is recently retired after 32 years with the Great lakes Science Center, USGS as both the Lake Erie Biological Station's supervisor and research fisheries biologist. His career started with the National Marine Fisheries Service in San Diego in 1977, and after one year he transferred to the Lake Erie Biological Station in Sandusky, Ohio.

Gentner Consulting Group thanks Frank Lupi, Ph.D., for his input on the fish valuations. Frank Lupi is a professor of natural resource and environmental economics at Michigan State University and has a PhD in Applied Economics from the University of Minnesota. His research and teaching addresses the valuation of ecosystem goods and services, and he has over 15 years of applied research experience in the Great Lakes.

Executive summary

First Energy's Bay Shore power plant is located in Oregon, Ohio (east of Toledo), near the outfall of the Maumee River in Maumee Bay. The 130 mile long Maumee River is at the heart of the Great Lakes' largest watershed and is also known as the Great Lakes' most biologically productive river. The Maumee River flows into Maumee Bay and then the Western Basin of Lake Erie. Lake Erie has more consumable fish than all the other Great Lakes combined, and over half of these fish are in the Western Basin. Studies by the Ohio Department of Natural Resources show that walleye populations in Lake Erie have declined from an estimated 80 million in 2004 to an estimated 20 million in 2010. Yellow perch populations in the Western Basin are also low enough that the commercial fishery for them in the Western Basin has been closed for the last three years.

The Bay Shore power plant (BSPP) draws 650 million gallons of water from a narrow intake channel that connects to Maumee Bay every day. The intake waters travel through a cooling process, which discharges to Maumee Bay at 5-12 degrees Fahrenheit warmer than intake temperatures. To compound this thermal pollution, the BSPP kills a large quantity of fish through impingement and entrainment in its cooling system.

The BSPP impinges 46-52 million fish annually, representing 270.3 metric tons of biomass. In addition, it entrains 208.6 million eggs, 2.2 billion larval fish and 13.8 billion juvenile fish. This report explores the economic importance of Lake Erie commercial and recreational fisheries, estimates the adult equivalents of impinged and entrained fish and uses those estimates to derive the economic damages accruing only to fishery users resulting from the intake of cooling water at the BSPP.

The Maumee River and Maumee Bay are economically and ecologically important for fisheries production in Lake Erie. Lake Erie-wide commercial fisheries generate $25.8 million in landings revenue annually, with Ohio responsible for $4.0 million of those landings revenue in 2009. Commercial fishing in Lake Erie generates $22.0 million in total sales, $12.3 million in income and supports 524 jobs from the harvester through to the consumer.

Recreational fishing in Lake Erie has an even larger economic footprint. Anglers fishing in Lake Erie spent $518.9 million pursuing their sport in 2009. That level of recreational expenditures supports $1.2 billion in total sales, $632.7 million in personal income and 10,708 jobs. Walleye and yellow perch are the most popular target species. All together, commercial and recreational fishing generate $1.4 billion in total sales, $711.1 million in personal income and support 14,052 jobs.

The biological assessment utilized published studies on fish mortality from egg to adult to estimate adult equivalents. Across both impinged and entrained fish, the BSPP prevents 54.5 million predator and prey species from reaching adulthood. Of that total, 8.5 million fish are predators targeted by commercial and recreational fishermen. A separate prey analysis indicates that the 46 million prey fish would support an additional 407,645 walleye.

Economic damages stemming from both predator and prey impingement and entrainment were estimated based on the biological assessment using benefit transfer techniques. Recreational values were taken from studies conducted in the Great Lakes where possible. Commercial value proxies were taken from economic impact models of the US fisheries industry and include values from the harvester through to the consumer.

Applying the commercial and recreational benefits transfer estimates per fish results in annual economic damages of $21.4 million per year, for just the predator species impinged and entrained at BSPP. The BSPP also impinges and entrains a large quantity of prey fish. If the value of the walleye that could be supported by the lost prey fish are valued using those same benefit transfer estimates, the losses climb by $8.3 million annually for a total annual loss of $29.7 million. The net present value of a 20 year stream of the losses discounted at the government-recommended 7% discount rate yields $315.0 million or $22.1 million more than the cost of implementing cooling towers at the Bay Shore Power Plant.

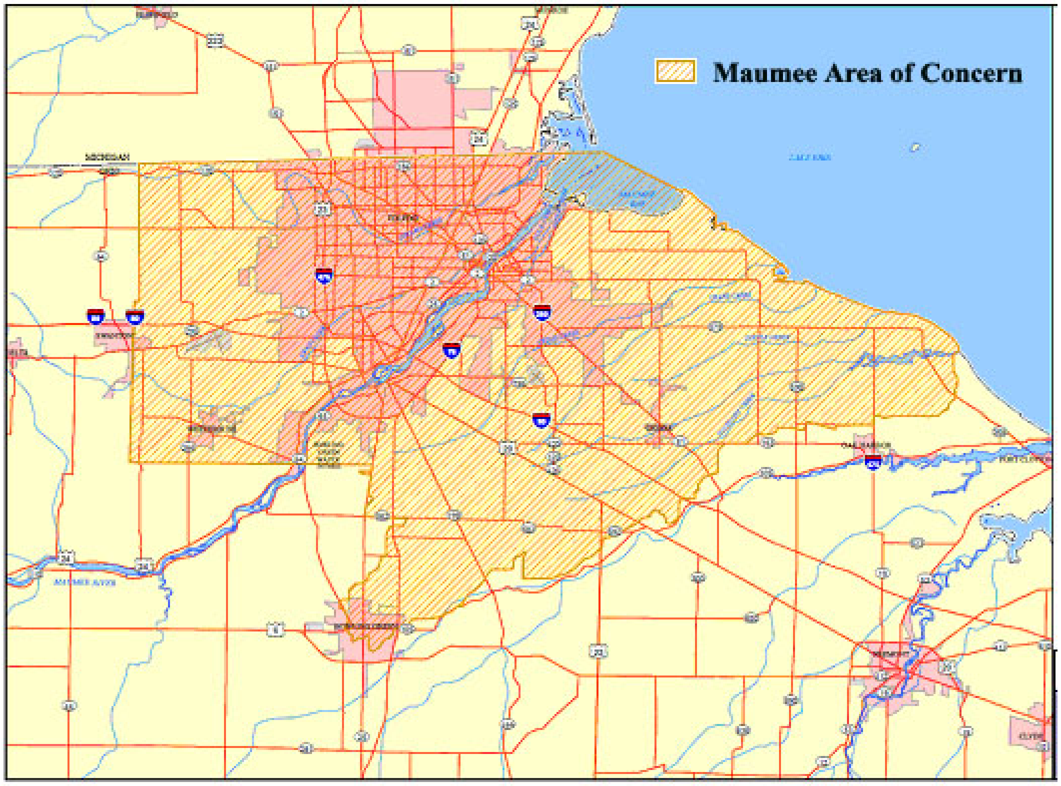
Mid-range values per fish were used for the recreational calculations and upper bound estimates were used for the commercial values per fish. Damages resulting from other uses, like bird watching or hunting were not included in this analysis. Additionally, non-use damages from fish impingement and entrainment were not estimated nor were health or non-use damages from increased algal blooms and other damages from the thermal plume. Finally, there is evidence that the actual impingement and entrainment estimates from the plant are higher than those estimated by the plant. Had any of these other use and non-use values and higher impingement and entrainment estimates been included, the economic damage estimates would be higher than those presented here, all else being equal.

Introduction

The Maumee River and the Western Basin of Lake Erie (WBLE) are ecologically and economically important to the state of Ohio and the Great Lakes region. The Maumee River flows into the Maumee Bay and the Western Basin of Lake Erie in Toledo and Oregon, Ohio. Please see Figure 1 for details on its location. The Maumee River is an important spawning river for yellow perch, walleye, white perch, white bass and many other economically important fish species and forage species.

The US EPA has determined that a portion of the Maumee River and its watershed constitute an area of concern (AOC). This designation was applied due to the high and increasing levels of phosphorous pollution, other nutrient pollution, sources of thermal pollution and sedimentation. All of these factors contribute to increasing algal blooms, some of them harmful such as Microcystis and Lyngbya. In addition to the problems of thermal pollution, impingement and entrainment of fish, fish larva and other benthic organisms threaten economically important fish species that depend on the Maumee for reproduction.

Figure 1. Environmental Protection Agency Maumee Area of Concern.[1]



FirstEnergy operates the Bay Shore Power Plant (BSPP) in the city of Oregon, Ohio. The BSPP utilizes a conventional steam boiler with a 631 megawatt rated generating capacity (Tetra Tech 2009). The BSPP burns coal and petroleum coke for fuel and draws water primarily from the Maumee River for cooling and discharges warmed water into Maumee Bay and the WBLE.

---

[1] Personal communication from Ohio Environmental Protection Agency. 2009.

In 1978, the Ohio Environmental Protection Agency (OEPA) listed the BSPP as a high risk facility (OEPA 1978, p. 38). On average, the BSPP draws 650 million gallons of water from the Maumee River, daily releasing the cooling water 5-12 degrees Fahrenheit hotter into the WBLE. This heated water is discharged into a shallow, low-oxygen environment only 2' to 3' deep, compounding the impact of thermal pollution (Tetra Tech 2009). At the highest flows, this represents 30% of the instream flow of the Maumee River. At the lowest flows, this represents 100% of the instream flow. At the lowest flows, this level of withdrawal has its highest impact, particularly with regard to thermal pollution.

Figure 2 displays the intake and outflow configuration of BSPP. The intakes of the BSPP are at the entrance to an important upstream spawning area for many fish species, and the impingement/entrainment rates for this facility are high. The BSPP intakes impinge 46-52 million fish (270.3 metric tons) and entrain 208.6 million fish eggs, 2.2 billion larval fish and 13.8 billion juvenile fish. The BSPP does very little to mitigate impingement and entrainment. From the Tetra Tech report: "BSPP does not employ any technologies that are typically considered effective for reducing impingement mortality, although FirstEnergy contends that the cooling water intake structure, as currently configured, partially reduces impingement and does not result in 100 percent mortality for all impinged fish as had long been assumed" (Tetra Tech 2009, p. 11).

Figure 2. Bay Shore Power Plant (BSPP) Location (Tetra Tech 2009).

The purpose of this report is to detail the economic importance of both the commercial and recreational fisheries in Lake Erie and assess the economic damages associated with the high rates of impingement and entrainment from the BSPP. The report will begin by detailing the economic impacts of the commercial and recreational fisheries as a matter of context on the importance of these fisheries to the state of Ohio and the local community. Next, impingement and entrainment estimates will be used to model the number of equivalent adults that could generate economic value had they not been impinged or entrained. Along with those estimates, the counts of prey species impinged and entrained will be used to estimate the potential additional fisheries production that could have been supported had those species not been impinged or entrained. To determine economic damages, a benefit transfer methodology will be used to determine the economic value of each adult fish that has been removed from the ecosystem by the BSPP and the net present value of those losses will be calculated based on a 20 year time horizon. Finally, this report focuses only on the damages associated with fisheries use. The economic use damages accruing to other activities, such as bird watching and wildlife watching, are not included, nor are non-use values for ecosystem services foregone because of the BSPP's water intake.

Economic Impacts of Lake Erie Fisheries

While the focus of this report is estimating economic damages, economic impacts provide important context regarding the economic activity supported through the use of natural resources in local communities. Economic impact models are a representation of all the transactions in an economy and allow analysts to outline the relationships between the production of goods and their final consumers.

Economic impacts begin with an angler's purchase of fishing tackle or a consumer's purchase of a yellow perch fillet. Those initial expenditures constitute the direct impact. From that initial purchase, the store purchases its inventory and labor, as do the suppliers of those goods and services required by the store. When businesses and suppliers import goods from outside the economy, that money, called a leakage, leaves the economy and is not considered in further calculations. Tracking purchases of supplies and labor by business continues until all the original purchase amount is exhausted by leakages. The sum of all this activity is called the indirect impact. The portion of laborer's income and business owner's profits from the indirect phase that is then re-spent on goods and services in the normal course of that consumer's life is considered the induced impact. The sum of direct, indirect and induced impacts describes the total impact of consumer expenditures in an economy. These impacts can be denominated by the number of jobs supported, income or the total output in an economy. For this study, IMPLAN software and modified IMPLAN models were used to calculate impacts (MIG 2008).

Lake Erie supports a vibrant commercial and recreational fishery. Lake Erie has more consumable fish than all the other Great Lakes combined.[2] The Western Basin and the Maumee River play an important role in both fisheries as a major spawning river for many species. Lake-wide commercial fisheries generate $25.8 million in revenues with the majority of that harvest being landed by Canadian commercial fishermen ($21.3 million)[3], followed by Ohio fishermen with $4.0 million in 2009.[4] Due to low abundance, the Western Basin has been closed to yellow perch harvest the previous two years.

Total Ohio landed value by species over the last 10 years is captured in Table 1. In 2009, the most valuable species landed commercially was yellow perch, even with the Western Basin closure. While walleye cannot be landed commercially in Ohio, it is a commercially important

---

[2] Personal communication, Jeff Reuter, Ohio Sea Grant

[3] Personal communication, John Johnson, Ontario Ministry of Natural Resource

[4] Personal communication , Travis Hartman, Ohio Department of Natural Resources

species to Ontario. As stated, economic impact models are formulated to utilize final consumer purchases to track industry in the supply chain backwards from the consumer. Unfortunately, retail data on consumer purchases of fish is impossible to obtain, particularly from restaurants. Instead, this analysis only has access to purchases made at various places in the supply chain before the product reaches the consumer. As a result, a special economic impact model has to be constructed to examine the typical economic linkages down the supply chain from the fisherman as well as the linkages forward in the supply chain to the consumers. Additional detail regarding landings in pounds and fish prices per pound can be found in Appendix 1.

Table 1. Landed Value for Ohio Commercial Fishes Harvested in Lake Erie, 2000-2009 (2009 dollars).

Year	Carp	Channel Catfish	Freshwater Drum	White Bass	White Perch	Yellow Perch[ab]	Others	Total Value
2000	$100,868	$196,947	$64,813	$322,667	$131,652	$3,159,363	$165,887	$4,142,197
2001	$104,638	$236,061	$34,755	$174,125	$67,384	$3,142,824	$160,292	$3,920,080
2002	$84,157	$224,513	$37,027	$97,490	$80,584	$3,008,543	$175,561	$3,707,875
2003	$92,872	$62,180	$38,338	$214,705	$136,938	$2,669,126	$164,085	$3,378,243
2004	$80,913	$124,949	$41,944	$251,935	$178,423	$2,973,794	$174,821	$3,826,778
2005	$56,677	$137,691	$65,568	$280,969	$189,513	$3,731,801	$164,421	$4,626,639
2006	$41,538	$135,315	$60,803	$356,462	$274,040	$2,570,129	$209,463	$3,647,750
2007	$40,361	$107,673	$58,948	$254,601	$220,416	$4,675,235	$210,029	$5,567,264
2008	$40,120	$148,377	$72,506	$231,708	$221,528	$2,494,234	$244,056	$3,452,530
2009	$51,925	$134,987	$102,210	$510,092	$287,516	$2,427,503	$535,327	$4,049,560
Mean	$69,407	$150,869	$57,691	$269,475	$178,799	$3,085,255	$220,394	$4,031,892

[a] A spring (March - April) closure on commercial yellow perch harvest was enacted in 1993.

[b] Management unit 1 (the western basin) was closed to commercial yellow perch harvest in 2008 and 2009.

The yellow perch task group (YPTG) three years ago found that the stock of yellow perch in the Western Basin was lower than desired, primarily due to excessive mortality. The YPTG was faced with reducing commercial and/or recreational harvest. Because ODNR had recently reduced yellow perch bag limits from 50/day to 25/day, ODNR felt that reducing recreational limits again would be unfair. Additionally, ODNR felt that it would be easier to achieve a reduction in mortality by targeting the commercial fleet because monitoring and enforcement would be easier (YPTG 2007). While walleye cannot be harvested by commercial fishermen in Ohio, studies by the Ohio Department of Natural Resources show that walleye populations in Lake Erie have declined from an estimated 80 million in 2004 to an estimated 20 million in 2010.[5] Clearly, ODNR would prefer to see more yellow perch and walleye in the Western Basin.

To examine economic impact forward of the landed value from Table 1 above, margins or price mark-ups for the sectors forward in the supply chain are used to determine the value entering the next industry link forward. For instance, the nationwide average processor mark-up is used to increase the landed price to the value the wholesale sector would pay the processor. This procedure is repeated until the value paid by the consumer is estimated.

---

[5] Personal communication, Jeff Tyson Ohio Department of Natural Resources

Commercial fisheries sectors are not well described in the standard IMPLAN industry classifications due to the relative small size of the fishing industry and the lack of standardized cost and earnings data on fisheries sectors. Therefore the analysis here uses a mixture of models and data sources, where necessary, to calculate the economic impacts. The model developed by Kirkley, Duberg, and Gentner (2004) was adapted for use across the fisheries wholesale sector backwards. Data regarding the consumption of fish in restaurants versus other retail outlets as well as margins for the retail sectors were taken from the value added model in Fisheries of the United States (FUS 2009) and from Fisheries Economics of the United States (FEUS) (NMFS 2006). Economic impacts of the retail trade sectors were calculated in IMPLAN using the margined expenditures.

Table 2. Economic Impacts of the Commercial Fisheries Sector in Lake Erie.

Industry Sector	Total
Harvesters	
Employment impacts (FTE jobs)	48
Income Impacts (1000s of dollars)	$1,159
Output Impacts (1000s of dollars)	$3,034
Primary dealers/processors	
Employment impacts (FTE jobs)	34
Income Impacts (1000s of dollars)	$1,213
Output Impacts (1000s of dollars)	$1,749
Secondary wholesalers/distributors	
Employment impacts (FTE jobs)	29
Income Impacts (1000s of dollars)	$1,508
Output Impacts (1000s of dollars)	$3,014
Grocers	
Employment impacts (FTE jobs)	18
Income Impacts (1000s of dollars)	$671
Output Impacts (1000s of dollars)	$1,136
Restaurants	
Employment impacts (FTE jobs)	395
Income Impacts (1000s of dollars)	$7,747
Output Impacts (1000s of dollars)	$13,102
Harvesters and seafood industry	
Employment impacts (FTE jobs)	524
Income Impacts (1000s of dollars)	$12,298
Output Impacts (1000s of dollars)	$22,035

Table 2 contains the economic impact estimates for commercial fishing in all of Lake Erie. The Western Basin accounts for about 46.7% of the total Lake Erie commercial harvest by volume and 20.1% by value in 2009.[6] Lake Erie-wide, commercial harvest generates $22.0 million in total sales, $12.3 million in income and supports 524 jobs.

---

[6] With the closure of yellow perch fishing in the Western Basin in 2008, the percentage of value landed in the Western Basin has dropped significantly as commercial fishermen have shifted their harvest to higher volumes of less valuable species to make up the difference.

Recreational fishing in all of Lake Erie is big business. Using data from the United States Fish and Wildlife Service 2006 survey (USFWS 2006) and data from the Ontario Ministry of Natural Resources (OMNR 2009), recreational anglers take 5.2 million fishing trips on Lake Erie each year. This level of activity generates $708.8 million in recreational trip expenditures annually.[7] Table 3 contains the expenditures and economic impacts of recreational anglers from Ohio only.

Ohio Lake Erie recreational expenditures were taken from the USFWS (USFWS 2006) and inflated to 2009 dollars using the consumer price index. Economic impacts were calculated using US level multipliers from Gentner and Steinback (2008). These multipliers were estimated at the US level for all recreational angling and, while based on the IMPLAN model, were modified specifically for recreational fishing based on survey data. All Ohio trips generated $518.9 million in expenditures, including equipment purchased in Ohio, which supports $1.2 billion in total sales, $632.7 million in personal income and 10,708 jobs. By far, the most popular target species are walleye and yellow perch (ODW 2009). Using Table 2 and 3, total commercial revenue and recreational expenditures in the Ohio portion of Lake Erie generate $1.4 billion in total sales, $711.1 million in personal income and support 14,052 jobs.

Table 3. Recreation Expenditure and Economic Impacts Resulting from Ohio Recreational Fishing Trips (2009 dollars).

Impact	Recreational (1000s of US$)
Ohio Lake Erie Total	$518,920
Total Sales	$1,218,378
Personal Income	$632,732
Jobs	10,708

Biological Assessment of Impingement/Entrainment

Estimating damages from entrainment and impingement first involves the evaluation of the loss of eggs, larvae, juvenile fish, adult fish, and benthic organisms. It is beyond the scope of this project to estimate those losses directly at the BSPP, and therefore estimates from previous studies of BSPP impingement and entrainment will be used to establish fish and benthic species loss. These studies will be summarized and used to generate separate estimates of catchable and juvenile fish. Catchable sized fish will be used in the evaluation of use values, while juveniles, eggs, larvae and benthic species will be used for the assessment of the loss of ecosystem services. Additionally, recruitment models (survival and/or mortality) will be used to estimate the adult equivalent for eggs, larvae, and juvenile fish to be used in the use value assessment. Finally, the quality of these industry sponsored studies will be evaluated.

Data for this effort was taken from the Kinetrics report written by Ager et al (2008). Tetra Tech deemed these data insufficient to fully estimate impingement and entrainment for a number of reasons (Tetra Tech 2009). Kinetrics performed 104 impingement sampling events between

---

[7] Total Great Lakes expenditures from USFWS 2006 were multiplied by the percentage of total Great Lakes effort (26%) attributable to Lake Erie. Canadian Lake Erie expenditures were calculated by taking the per trip expenditures from OMNR (2009) and multiplying those by total Canadian Lake Erie effort and converted to 2009 US dollars using current exchange rates.

May of 2005 and December 2006. They then averaged the numbers of impinged fish by month and summed those numbers into an annual estimate. Tetra Tech found that the more typical average of the sums technique yields impingement estimates 13% higher than those published by Kinetrics. While Kinetrics classified impinged fish as alive and healthy, alive but stressed, recently dead and long dead, all impinged fish used for this analysis are assumed to be dead or die shortly after impingement. Standard BSPP practices involve the use of high pressure water to remove fish from the intake screens, likely killing or stressing all impinged fish. Fish were also sampled before transiting the debris sluiceway. Additionally, the return conduit is rough textured, contains many sharp turns and involves a long drop into the discharge sluiceway. Finally, fish are released into the thermal plume and end up in the shallow, warm and often low-oxygen portion of Maumee Bay. Table 4 contains the total number of fish impinged at BSPP from the Kinetrics study. Overall, 45.8 million fish are impinged at the BSPP facility annually. Both common and scientific names are given in Table 4, but only common names with be used hereafter.

Table 4. Total Impingement Estimates from Ager et al (2008).

Type	**Species**		**Total Fish Impinged**
	Scientific Name	**Common Name**	
Prey	*Osmerus mordax*	Rainbow smelt	12,923
	Dorosoma cepedianum	Gizzard shad	5,992,629
	Notropis atherinoides	Emerald shiner	32,688,994
	Notropis hudsonius	Spottail shiner	341,718
	Neogobius melanostomus	Round goby	106,890
Predator	*Cyprinus carpio*	Carp	6,837
	Catostomidae spp.	Sucker spp.	9,041
	Ictalurus punctatus	Channel catfish	73,040
	Morone chrysops	White bass	1,577,083
	Morone americana	White perch	4,669,894
	Micropterus salmoides	Largemouth bass	4,251
	Micropterus dolomieu	Smallmouth bass	2,760
	Sander vitreus	Walleye	25,454
	Perca flavescens	Yellow perch	71,348
	Aplodinotus grunniens	Freshwater drum	227,504
Total			45,810,366

To ascertain the full extent of fish losses by entrainment and impingement at the BSPP, the number of adults and adult-equivalents (AE) were determined. A direct count of adults was achieved by using impingement data from the Kinetrics report (Ager et *al*. 2008). To calculate AE, survival rates for different species and life stages of fish (i.e. egg, larvae, juvenile, and adult) were used in conjunction with data from the Kinetrics report (Ager et *al*. 2008). Survival rates were taken from literature for Lake Erie or bodies of water in similar latitudes. When survival or mortality rates were not available in the literature or reports, rates from similar species were substituted (e.g., white bass survival rates for white perch) or, if not available, an average of published rates for a particular life stage for known species was substituted.

Prey fish are important for the growth and survival of predator species. Many of the species in Lake Erie are piscivorus, at least during some portion of their life cycle. Increasing the prey base typically has the effect of increasing growth and fecundity while decreasing mortality. As a result fishing quality and fish quantity would increase. Typically, models of predator/prey interaction and bio-energetic models are used to quantify the ecosystem benefits of prey fish. Unfortunately, estimating these complex models were beyond the scope of this analysis. Instead, published walleye stomach content analysis was used to estimate the number of adult walleye the prey fish could technically support. Walleye was chosen because stomach content data were available, it is a piscivorus fish and it is the most popular recreational target species in Lake Erie.

Estimation of fish population abundance is indispensable for understanding changes in population numbers and composition for estimating yield and as a basis for good management (Everhart 1975). Occasionally there is an opportunity for direct counting when a population is concentrated and is available during some life history stage. More often, indirect methods must be employed individually or in combinations to minimize errors in estimation. Although direct enumeration is the most accurate method, the expense may exceed natural resource budgets, which is one reason for indirect methods. Indirect methods usually employ a combination of direct (e.g., use of trawls) and indirect (e.g., computer generated population models). Some common methods to assess fish populations are: trawling (a cone-shape net towed behind a boat to collect fish), gill netting (a net used to entangle fish, usually by their gills), fyke netting (passive cages with openings for fish to swim inside), echo sounding (a technique of using sound pulses directed from the surface toward the bottom to measure fish abundance and spatial distributions vertically), and electro-shocking (the use of electricity to stun fish before they are caught with dip nets).

The most effective scenario for determining how many adults will survive from an egg for each fish species would entail raising them (starting from a known number of eggs) in a pond with similar conditions to those existing in western Lake Erie (e.g., similar water temperature and fish community composition). At the end of this experiment (when the egg has finally metamorphosed into an adult), counting all adults of each species ascertains what the actual survival from egg to adult life stage will be. The next best scenario is to calculate adult equivalents (AE) from fish population models, similar to walleye and yellow perch task group models (Walleye Task Group. 2007, Yellow Perch Task Group 2007). But due to constraints of time and money this analysis employed a review of the literature (including published scientific papers, theses/dissertations, and state or federal reports) to find suitable survival/mortality rates for each species to calculate an estimate of AE. The survival rate (e.g., S=0.67) is the proportion of the population that survives after a set amount of time (i.e., one year). Mortality rate is calculated similarly (e.g., 1.0 - 0.67=0.33=M). As an example, estimates of AE from eggs of a fish species, which were entrained through the intake screens, was determined primarily with survival rates of eggs to larvae, larvae to juveniles, and juveniles to adults [(S_{eggs} x # eggs) + (S_{larvae} x # larvae) + ($S_{juvenile}$ x # juvenile) = # adults]. Table 5 contains the results of the analysis of entrained eggs.

Similarly, estimates of AE from larvae entrained were calculated using survival rates for life stages: larvae to juveniles and then juveniles to adults. For estimates of juveniles entrained or impinged, survival rates for juveniles to adults were employed. When survival or mortality rates were not available in the literature or reports, rates from similar species were substituted or, if not available, an average of published rates at a particular life stage for known species was substituted. Table 6 contains the estimates of adult equivalents from entrained larvae.

Table 5. Estimates of Adult Equivalents from Entrained Eggs.

Species	Eggs to Age 1					Age 1 to Adult			
	Total eggs		Survival rate		Age 1 equivalents		Survival rate		Age 2+ equivalents
Freshwater drum	21,576,285	x	0.00004	=	863	x	0.73	=	630
Catostomidae	25,319	x	0.057	=	1443	x	0.634	=	915
Morone spp	8,404	x	0.057	=	479	x	0.634	=	304
Total	**22,434,637**				**2,785**				**1,849**

A review of the literature was completed and survival or mortality rates were identified for most of the fish species and life stages of those fish that were entrained or impinged at BSPP's intake structure. When a species and life stage's survival/mortality rate were not available in the literature, a similar species survival/mortality was substituted. If a species did not have a survival/mortality rate available for similar taxa, then an average survival/mortality rate of all species at a particular life stage was substituted. Appendix 10 in the Kinetrics report (Ager et al. 2008) listed live-healthy, live-stressed, recently dead, long dead, and total of eggs. All eggs other than 'long dead' were considered dead for the estimation of AE. Studies indicate that capture and handling of fish induces some level of mortality. Due to these studies and the typical poor handling of impinged species documented by Tetra Tech (2009), it is assumed here that all impinged and entrained fish are killed.

Walleye AE were based on survival rates from both larvae (entrained) and juveniles (impinged) in published literature (Forney 1976 and Walleye Task Group 2007), as well as direct counts of impinged adults from Ager et al. (2008). Forney (1976) studied survival of both larvae (13.2%) and juveniles (33.3%) in Oneida Lake, N.Y., which has a similar latitude and comparable fish community to western Lake Erie. The survival from age 1 to adult walleye was taken from a report by the Lake Erie Committee's Walleye Task Group (2007). The survival rate for age 1 (63.7%) was not found in the literature, so the rate for age 2 and older (Walleye Task Group 2007) was used as a substitute. The calculation of AE from entrained larvae are shown in Table 6. The AE results from impinged juveniles and adults are in Table 4, and the total number of AE is in Table 7.

The AE for yellow perch was derived from entrained larvae and impinged juveniles and adults. Indirect counts were derived from calculating AE from both larvae and juveniles from survival rates from bodies of water of similar latitude (Clady 1976 [10.5%] and Patterson 1976 [26%]). The survival rate for larvae for age 1 equivalents is 45.7%, taken from the Lake Erie Yellow Perch Task Group report (2007). The AE results from larvae entrained are in Table 6. Yellow perch AE were also calculated from impingement, which included both juveniles and adults. Survival rate for juveniles is 26% (Patterson 1976) and for age 1 is 45.7% (Yellow Perch Task

Group 2007). The AE results from impinged juveniles are in Table 4, while the total AE for yellow perch is listed in Table 7.

Freshwater drum AE were derived from estimates of entrained eggs (Table 5) and larvae (Table 6), and impinged juveniles and adults (Table 4). Adult equivalents were estimated from entrained eggs to age 1 with a survival rate of 0.004% (Ager et al. 2008), and entrained larvae with survival rate to age 1 of 0.04% (USEPA 2004). The survival rate for age 1 equivalents to adult is 73% (USEPA 2004). Freshwater drum were also impinged on the intake screens and AE were estimated from both juveniles and adults. Survival rates are the same for juvenile and age 1 for the impinged fish. The total AE for freshwater drum is listed in Table 7.

The AE for rainbow smelt were derived from entrained larvae (Table 6) and from impinged juveniles and adults (Table 4). All survival rates came from a report by the USEPA (2004), with survival rates of 8% for larvae, 57.2% for juveniles, and 79.5% for age 1 to adults.

Gizzard shad survival rates were from three sources: survival from larvae (6.8%) from Michaeletz (1997), survival from juveniles (16%) in Michaeletz (2010), and survival to adults (63.4%) is from a mean of survival rates. The AE from entrainment is listed in Table 6, the AE from impingement is in Table 4, and total AE is in Table 7.

Emerald shiner AE from entrainment is based on survival rates for larvae (10.2%) and juveniles (30.3%), derived from the mean of survival rates. The survival rate for age 1 is from a mean of survival rates (63.4%), since one was not listed in the literature. A direct count of adults was taken from impinged emerald shiners. Again, AE for entrained fish are in Table 6, adults from impingement are contained in Table 4, and total AE from all sources are in Table 7.

The AE for entrained and impinged spottail shiners were calculated from survival rates for larvae (10.2%), for juveniles (30.3%), and age 1 to adults (63.4%). There were no available survival rates for spottail shiners, hence all survival rates were derived from a mean of available species in this report. The AE for entrained fish are listed in Table 6, AE for impinged fish in Table 4, and total AE in Table 7.

The AE for carp and goldfish are based on a mean survival rates for all species and life stages listed in this report (larvae=10.2%, juveniles=30.3%, age 1=63.4%). The AEs are listed in Tables 4, 6 and 7.

Catostomidae AE were based on entrainment survival rates from eggs to age 1 (5.7%, which is a mean of all species in this report); larvae (10.2%, a mean of all species in this report); juveniles (30.3%, a mean of all species in this report); and age 1 (63.4%, a mean of all species in this report). A direct count was made of all Catostomidae from impingement, since all were adults. The AEs are listed in Tables 4, 6 and 7.

The AE for channel catfish, white bass, and white perch are based on mean survival rates for all species at each life stage listed in this report (10.2% for larvae, 30.3% for juveniles, and 63.4% for age 1). The AEs are listed in Tables 4, 6 and 7.

Table 6. Estimates of Adult Equivalents from Entrained Larvae.

Species	Larval to Juvenile					Juvenile to Age 1					Age 1 to Adult				
	Survival Rate		Larvae		Juvenile Equivalents	Survival Rate		Juvenile Equivalents		Age 1 Equivalents	Survival Rate		Age 1 Equivalents		Adult Equivalents
Gizzard shad	0.068	x	590,567,582	=	40,158,596	0.160	x	40,158,596	=	6,425,375	0.634	x	6,425,375	=	4,073,688
Rainbow smelt	0.080	x	65,618,620	=	5,249,490	0.572	x	5,249,490	=	3,002,708	0.795	x	3,002,708	=	2,387,153
Emerald shiner	0.102	x	19,001,574	=	1,938,161	0.303	x	1,938,161	=	587,263	0.634	x	587,263	=	372,325
Spottail shiner	0.102	x	79,825	=	8,142	0.303	x	8,142	=	2,467	0.634	x	2,467	=	1,564
Common carp	0.102	x	2,180,081	=	222,368	0.303	x	222,368	=	67,378	0.634	x	67,378	=	42,717
Catostomidae	0.102	x	1,277,487	=	130,304	0.303	x	130,304	=	39,482	0.634	x	39,482	=	25,032
Channel catfish	0.102	x	70,390	=	7,180	0.303	x	7,180	=	2,175	0.634	x	2,175	=	1,379
Yellow perch	0.105	x	4,323,595	=	453,977	0.260	x	453,977	=	118,034	0.457	x	118,034	=	53,942
Walleye	0.132	x	14,371,888	=	1,897,089	0.333	x	1,897,089	=	631,731	0.637	x	631,731	=	402,412
White bass	0.102	x	132,478,763	=	13,512,834	0.303	x	13,512,834	=	4,094,389	0.230	x	4,094,389	=	941,709
White perch	0.102	x	3,800,385	=	387,639	0.303	x	387,639	=	117,455	0.535	x	117,455	=	62,838
Freshwater drum						0.0004*	x	977,426,912	=	390,971	0.730	x		=	285,409

*Survival rate from larval to age 1

Table 7. Adult Equivalents of Fish Impinged and Entrained at the BSPP by Species.

Type	Common Name	Adult Equivalent Estimates			
		Egg Entrainment	Larval Entrainment	Impingement	Total
Prey	Rainbow smelt		2,387,153	12,923	2,400,076
	Gizzard shad		4,073,688	5,992,629	10,066,317
	Emerald shiner		372,325	32,688,994	33,061,318
	Spottail shiner		1,564	341,718	343,282
	Round goby			106,890	106,890
Predator	Carp		42,717	6,837	49,554
	Sucker spp.	915	25,032	9,041	34,988
	Channel catfish		1,379	73,040	74,419
	White bass		941,709	1,577,083	2,518,792
	White perch		62,838	4,669,894	4,732,732
	Morone spp.	304			304
	Largemouth bass			4,251	4,251
	Smallmouth bass			2,760	2,760
	Walleye		402,412	25,454	427,866
	Yellow perch		53,942	71,348	125,290
	Freshwater drum	630	285,409	227,504	513,543

Prey fish constitute an invaluable source of food for many piscivorus (predator) fish, such as walleye, which account for the majority of prey fish consumed. Hartman and Margraf (1992) estimated that walleye consumed from 83,700 tonnes in 1987 to 94,300 tonnes in 1986.

Prey fish are not a limiting factor in the survival or growth of walleye, nor is the walleye population reaching a carrying capacity. The visceral fat content in fall-caught walleyes is indicative that prey fish are not limiting growth.[8] During the warmer months of the year when the water temperature approaches 25C^{o},most walleyes move east into the cooler waters of central Lake Erie.

As a means to express the loss of prey fish through entrainment and impingement, the number of potential walleyes that could consume those lost prey fish in one year was calculated. An examination of the fall walleye diet in 2008-09 from a gill net survey (unpublished data from Ohio DNR, Sandusky, OH) allowed for the determination of the mean number of prey fish, by species, for both years combined. The number by suitably sized prey fish (Knight et al. 1984) for each species was taken from Tables 4 and 5. For this activity we considered all ages of smelt and emerald shiners, and only young-of the-year for gizzard shad, white perch, and yellow perch as potential prey fish for walleye. To estimate how many potential walleye could feed on the available prey fish in one feeding season (175 days, Hartman and Margraf 1992), the number of prey fish (by species) was divided by the mean number of prey per stomach and that number was

---

[8] Personal communication with Chris Vandergoot, Ohio DNR.

divided by 175 (days) to equal the potential number of walleyes that could feed on each prey species.

In order to express the loss of potential prey fish, a mean was calculated for the potential walleye that could consume all prey species combined. Using these techniques, the mean number of walleye that could be supported by the impinged/entrained prey species is 407,645 additional walleye. Since prey fish at this time are not a limiting factor in either the survival or growth of walleye, this section presents a way to indicate how many potential walleyes could be fed by the prey that died as a result of entrainment or impingement. If at some point the prey fish do become a limiting factor, the loss of up to one million prey fish could negatively impact the population size or growth of walleye and other predaceous fish (e.g., smallmouth bass, yellow perch, and white bass).

Economic Damages of Impingement and Entrainment

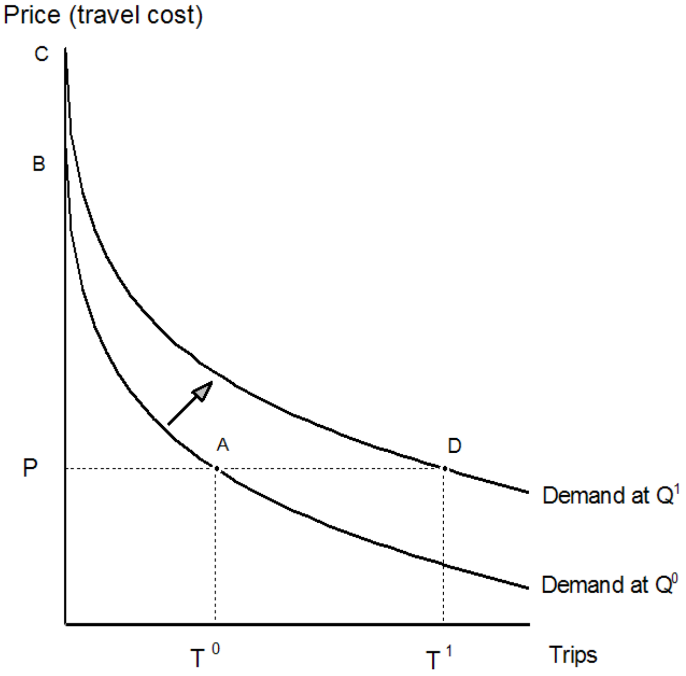
Economic value is based on people's willingness to give something up in order to obtain something else; economic value has nothing to do with money, *per se*. Value could be translated into any standardized units, but placing values on a dollar scale makes them comparable with other market activities (e.g., the costs of a program or the cost of a changing technology at a power plant). To infer economic value, economists rely on the choices made by individuals. Since many goods are traded in markets, the "market" is a convenient mechanism for revealing economic values. However, the fact that something does not have a market price does not mean that it does not have economic value. Economists have developed a suite of valuation techniques for non-market goods or services. In the case of recreation activities such as fishing, economists can use observations of individuals' willingness to spend time and money to get to a recreation site to estimate willingness to pay for the recreation trips. This technique is referred to as the travel cost method (TCM).

The essence of the travel cost method is to determine statistically the relationship between price (travel costs) and quantity (the number of visits to some site); this relationship is referred to as the "demand curve." Figure 1 presents a graph of two hypothetical recreational demand curves for trips to a recreation site. The two demand curves are linked to two different levels of environmental quality at the site ($Q^0<Q^1$). The price (travel cost) per trip is on the vertical axis, and the number of trips is on the horizontal axis. As the price decreases, we expect anglers to take more trips to the site.

The travel cost demand curve reveals two key pieces of information. First, it shows the number of trips an individual will make at any given price. In the figure, when the price of a trip to the site is P, the number of trips taken by anglers is T^0 and T^1, respectively. Second, the demand curve shows the maximum amount individuals would be willing to pay to take each trip. For the initial trips taken by anglers, the amount they would be willing to pay exceeds the price. Anglers will take trips until their benefit (willingness to pay) for an additional trip just equals their cost -- see points A and D for the two demand curves in Figure 3. Note from Figure 3 that the benefit for each trip is higher under level of quality, Q^1, than under Q^0. That is, the demand curves show that willingness to pay for each trip is larger when the level of quality at the site is higher. The total amount the anglers actually pay to take T trips is equal to P×T which is less than total willingness to pay. The total difference between what individuals would pay and actually pay is referred to as consumer surplus (the areas PAB and PDC in Figure 3). If access to the recreation site were eliminated, the anglers would lose the consumer surplus associated with the site. Consumer surplus is the appropriate measure of economic value associated with the use of any good such as a recreation site (Freeman 1993). Note that while the amount expressed by P×T is a measure of the expenditures at the site, it is not a measure of economic value. This money may be important to a local economy surrounding the recreation site, but the money (and the other opportunities it can provide) is not lost to the individual should the site close.

We note that the travel cost method is used to estimate the use value of fishing. The method cannot measure all the general values associated with fishing. Moreover, since the method is based on relationships between recreational *use* and price and quality of a fishing site, factors that are not revealed through anglers' fishing behavior cannot be measured. For this reason, the values are referred to as *use-values*. The fact that TCM can only measure use values does not preclude other non-use values from being held by individuals.

Figure 3. Hypothetical Recreational Demand Curves.



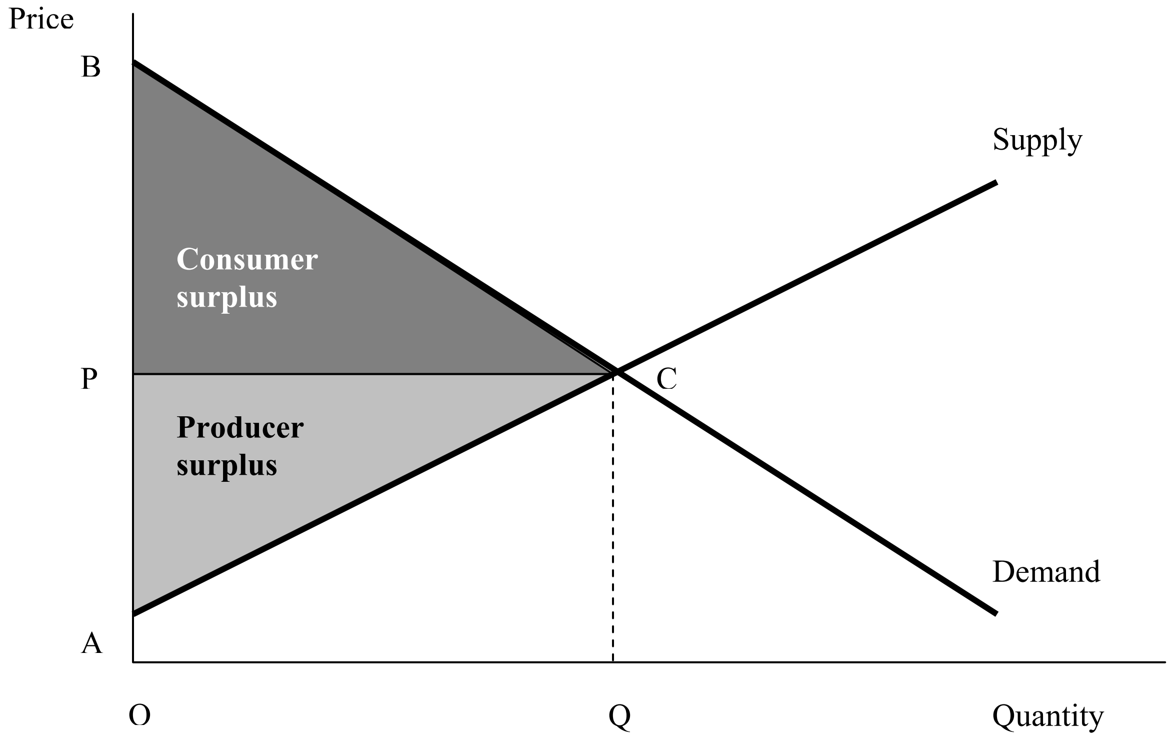
We have illustrated how TCM can be used for estimating the value associated with access to some recreation site, but in the case at hand we are interested in how value is related to the number of fish that can be caught. Establishing this change in value is more difficult than simply establishing the value of access to a site (given by the consumer surplus). When catch rates change, the benefits or losses are given by the *change* in the consumer surplus. To measure changes in value associated with changes in quality, one needs to know how the demand curve shifts when quality changes. The value is then given by the change in consumer surplus. The two demand curves shown in Figure 3 illustrate the idea. Consider two levels of quality ($Q^0<Q^1$) at the site. The lower demand curve in Figure 3 represents the demand under the baseline level of quality, Q^0, and the upper demand curve reflects the upward shift in demand under some

increased level of quality, Q^1. The value of the change in quality (Q^0 to Q^1) is given by the change in the consumer surplus, the area ABCD.

On the commercial fisheries side, the supply curve traces the locus of all profit maximizing production points for a given set of production costs. While a production decision is always the result of a market transaction, calculating producer surplus requires detailed data on the costs and earnings structure of individual firms in the fishery. Figure 4 contains a representation of a producer surplus under the typical upward sloping supply function. Under perfect competition, the output supply function is equal to the marginal cost function of the firm. In most cases, perfectly competitive firms face increasing marginal industry costs and therefore have upward sloping supply functions.

To illustrate producer surplus in a competitive market, in Figure 4, the price of a good such as fish flesh is a function of its supply and demand in the market where producers supply their products. In Figure 4, the quantity of good demanded is shown to decrease as price increases, as is typical under diminishing marginal utility as described above. The supply of the good relates to the costs of its production (e.g., fuel to catch fish). At low prices only the most efficient producers are able to operate, but as the price increases, less efficient producers enter the industry, resulting in increased supply. As a result, the supply of the good increases with increasing price and marginal cost is an increasing function of quantity supplied. In perfectly competitive markets, market price is set at the intersection of supply and demand at price P and quantity demanded Q. Consumer surplus is the darker shaded triangle PCB.

Figure 4. Commercial Fisheries Producer and Consumer Surplus.



Total revenue in Figure 4 is the rectangle OPCQ. The total cost of producing the good by all producers is given by the area under the supply curve, OACQ. The difference between the total revenue generated from sales and the total costs of production, given by the area APC, is a surplus accruing to the production industry. This producer surplus (PS) represents benefits accruing to the producers from being able to sell the good at market price P. In essence, it is the return earned by the firm selling fish products. Total surplus or the total value of fish in this illustrative market is the sum of both the producer and consumer surplus or the area ABC.

Estimating Values per Fish

On the recreational side, it was beyond the scope of this study to establish recreational fishing values using original angler surveys or observation of actual fishing trips. Instead, to establish values for fish, a literature review was conducted and the benefits transfer approach was applied. Benefits transfer refers to the process of identifying value estimates from existing literature and applying them in a new context. That is, benefit estimates are "transferred" from one site to another.

In the present analysis, we have reviewed literature on changes in consumer surplus as a result of changes in the number of fish so that we can derive values per fish. In all the literature examined, the conceptual notion of value is, as described above, the change in consumer surplus associated with catching an additional fish.

To begin the benefits transfer, the economic literature on valuation of sport fish was reviewed. In particular, I have reviewed dozens of studies on fish valuations. Most of the studies are based on the travel cost method for estimating the value of non-market goods and services associated with recreation. About half those studies were specific to the Great Lakes. Although all of the studies provided valuation information related to fishing, not all studies provided sufficient information to obtain estimates expressed as "values per fish. "

Several studies are of note here because they were conducted in the Great Lakes and involve similar species to those at issue in the present case: Breffle et al, 1999; Lupi et al, 2001; Murdock, 2001; and Besedin et al, 2004. Furthermore, all of these studies use contemporary valuation methods based in random utility theory, making the results readily comparable. Although Breffle et al (1999) is based on a stated preference method, the others are based on travel cost models that include a broad range of substitute fishing sites. Further, the values derived from these studies are well within the ranges reported in the literature and consistent with the general species-specific patterns in values reported by the analysis of Johnston et al (which includes many studies outside the Great Lakes area).

After review of these studies, the values reported by Besedin et al (2004) are suggested for use in benefit transfers to value fish lost due to entrainment and impingement. The reasons for this suggestion include: the Besedin et al (2004) estimates were developed with this use in mind; the estimates cover a range of species that reasonably matches those considered in the present analysis; the results fall roughly in the middle of the range of values reported by other studies (that is, they are not the lowest or the highest values found in the literature); and the preference rankings of species implied by the values are generally consistent with other findings reported in the literature.

Estimating the producer surplus, or value per fish, that accrues to commercial fishermen in the study area requires detailed cost and earnings data for individual fishing vessels, processors, distributors, grocers and restaurants. Estimating consumer surplus of Lake Erie seafood consumers requires detailed data on seafood consumption. Unfortunately neither type of data is available. Instead income impacts can be used as a proxy measure of both producer surplus and consumer surplus in the total commercial fisheries supply chain.

While total output impacts are clearly inappropriate for estimating the economic value in the commercial fishery, income impacts have been used as a proxy for consumer and producer surplus (Kirkley et al 2000). It is widely acknowledged, however, that income impacts overstate estimates of consumer and producer value (Edwards 1990). Because of the lack of data, income impact multipliers, from the commercial fisheries model above, were used as proxies for producer surplus from the consumer back to the retailer (Kirkley et al. 2004). As a result, the estimates presented in Table 8 for the commercial fishery are assumed to be upper bounds on the true economic damages facing the commercial fisheries in Lake Erie.

Findings

Table 8 reproduces the Besedin et al (2004) values, updated to 2010 dollars using the Bureau of Labor Statistics inflation calculator and the commercial values described above.[9] In addition to adjusting for inflation, the values in Table 8 have been transformed from the Besedin et al (2004) numbers to take the average values across all modes of fishing (boat, shore, and ice) where the averages are computed using the reported distribution of trips by each of these modes. Note that the white bass, white perch and yellow perch share the same value, as the Besedin et al (2004) study grouped those species together. Freshwater drum and channel catfish were taken from the "General" category. The Lake Erie commercial fisheries do not land largemouth bass, smallmouth bass or walleye so there is no commercial value for these species. Catostomidae, or suckers, are only landed by commercial fishermen for sale mostly in the bait market and therefore do not have a recreational value. Carp is currently only landed by the commercial fleet and therefore only has a commercial value. There is anecdotal evidence of a nascent and growing recreational carp fishery in the Western Basin, but carp landings by recreational fishermen do not appear in the Ohio Department of Wildlife Data.

To calculate total damages, total commercial and total recreational harvests from 2008 were used to calculate the proportion of annual total harvest taken by each sector (ODW 2009). Adult equivalents estimated above were distributed to each sector based on these proportions and the WTP values from Table 8 were applied to the sector totals. Overall, the economic value of the damages caused to predator species from the BSPP are $21.4 million dollars annually. This technique assumes that any increase in production of predator fish will be distributed to the sectors following the current harvest distributions. The largest damages are from losses of walleye, $8.7 million, and losses of white perch, $8.3 million, each year. It is assumed that Lake

---

[9] http://data.bls.gov/cgi-bin/cpicalc.pl

Erie's current ecosystem is currently not prey limited and these additional predator species would be able to find enough prey to consume in the current ecosystem.[10]

Table 8. Recreational and Commercial Values per Fish for use in Benefits Transfer of Great Lakes Fish Values (adapted from table 6 of Besedin et al 2004, adjusted to 2010 dollars).

Species	Commercial	Recreational
Catostomidae	$0.49	n/a
Carp	$0.24	n/a
Channel catfish	$0.71	$2.41
White bass	$1.13	$2.86
White perch	$1.73	$2.86
Largemouth bass	n/a	$16.77
Smallmouth bass	n/a	$16.77
Walleye	na/	$20.38
Yellow perch	$3.45	$2.86
Freshwater drum	$0.24	$2.41

Table 9. Economic Damage Estimates For Commercial and Recreational Target Species.

Species	Adult Equivalents	Total
Catostomidae	34,988	$17,021
Carp	49,554	$11,972
Channel catfish	74,419	$54,865
White bass	2,518,792	$3,621,561
White perch	4,733,036	$8,327,796
Largemouth bass	4,251	$71,289
Smallmouth bass	2,760	$46,285
Walleye	427,866	$8,719,918
Yellow perch	125,290	$394,847
Freshwater drum	513,543	$160,048
Total	**8,484,500**	**$21,425,603**

While the authors readily acknowledge that the prey fish analysis presented above likely presents an upper bound on the number of walleye that could be supported by the prey species killed by the BSPP, these estimates remain as the only available technique to assess the economic damages due to the loss of prey species. Walleye were selected because they are the most popular target species, they are piscivorus and stomach content data was available. They are also the highest valued species and the values calculated here would be less if other species were used such as largemouth bass, smallmouth bass or white bass.

It is more likely that the effect of increased prey availability would be to increase walleye growth and fecundity while reducing mortality, thereby increasing both the numbers and the value of each fish caught (larger fish are preferred to smaller fish), but estimating those biological relationships were beyond the scope of this project. The current carrying capacity for walleye in Lake Erie is far from its maximum, so the ecosystem could support additional walleye.[8] From the

---

[10] Personal communication with Chris Vandergoot, Ohio DNR.

discussion above, 407,645 additional walleye could be supported by the impinged/entrained prey species. Applying the values per fish from Table 8, the value of prey species in the production of walleye increases the damage estimate $8.3 million in additional damages each year. Because Lake Erie is neither prey limited nor near its carrying capacity for walleye it is believed that this additional fish production could be supported. If prey species are included, total damages equal $29.7 million annually.

These damage estimates were used to estimate the net present value (NPV) of the stream of damages identical to the length of time used in the Tetra Tech report to model the life cycle of cooling tower installation (Tetra Tech 2009). For this analysis, it was assumed the damages presented here would be exactly the same, year in and year out for 20 years into the future. The same discount rate, 7%, was used for this analysis as was used in the Tetra Tech report. This is also the discount rate recommended by the Office of Management and Budget (2007). Using this methodology the NPV of just the predator losses would be $227.0 million in 2010 dollars. Taking the prey losses into consideration increases the NPV of the stream of fish damages $88.0 million over twenty years. Taking both streams of losses represents an NPF of $315.0 million over 20 years. The Tetra Tech estimate places the NPV of cooling tower installation at $292.9 million over twenty years.

Conclusion

The estimates of adult equivalents killed by the impingement and entrainment of predators and prey by the BSPP are large and significant. Each year, the BSPP impinges at least 46 million fish and entrains 208.6 million eggs, 2.2 billion larval fish and 13.8 billion juvenile fish. These impinged and entrained fish equate to 54.5 million adult fish removed from the ecosystem each year with 8.5 million fish being adult predator fish targeted by commercial and recreational fishermen. The per year economic damages of this level of mortality equal $29.7 million per year with prey losses included and the NPV of a twenty year stream of these losses equals $315.0 million, or $22.1 million more than the cost of the cooling towers. This level of damages clearly supports the installation of cooling towers from the fisheries use damages alone. Some caveats apply to these estimates.

Mid-range Values: The values per fish used above are suggested for use for this benefit transfer. As in any scientific study, there are sources of error within any benefits transfer. One source of error is the possibility that the context surrounding the study site (BSPP and the Western Basin) is very different than the context of the study sites used in the research studies that have been suggested here for benefit transfer. For that reason, only Great Lakes fishing studies were considered for transfer. However, the economic literature review did not identify a large number of studies with values from the Great Lakes that had suitable information to derive values in per-fish units. The sample size of studies adds another element of uncertainty to the values. For that reason, values were selected that reasonably fell in the middle of the range of values and that were consistent with other values found in studies conducted outside the Great Lakes. Thus, the values in Table 8 are suitable for benefits transfer and reveal values that are in the middle of the range of values found in the literature.

Other Economic Values: The benefits transfer approach taken here relies on studies of recreational fishing values to determine values for catching fish that can be applied to the losses in fish. The values that are estimated are only for fish and are only for the use of these fish via recreational and commercial harvests. There are likely other values that are affected by the lost fish that were not quantified here. For example, there would be losses in use values associated with wildlife viewing such as bird-watching to the extent that populations of migratory and resident birds that prey on Lake Erie fish are affected by the impinged and entrained fish. Similarly, if the impinged and entrained fish affect the quality of waterfowl hunting, there would be lost values for hunting.

In addition to possible other lost recreational use values, there may be lost non-use value associated with the foregone fish and their ecological consequences. Non-use values refer to the values for the losses that are not in any way tied to one's own use of the resource. For example, if a person who does not engage in any outdoor recreation, does not eat fish, and does not in any way use the resource, were nonetheless willing to pay higher energy bills to reduce the fish losses, then we would refer to that willingness to pay as a non-use value. There is nothing in economic theory that precludes the existence of such non-use values, though the measurement of non-use values can be challenging and was not addressed within this analysis.

In addition, there are damages that are caused by the thermal pollution from the BSPP that are not accounted for here. Thermal pollution may induce additional fish mortality during the warm summer months. Thermal pollution may also increase the incidence and severity of algal blooms. Algal blooms have the potential to have negative health impacts and local residents certainly have a positive willingness-to-pay to avoid health problems from algal blooms. Additionally, local residents and visitors may have a willingness-to-pay to avoid algal blooms for reasons beyond adverse health consequences. None of these damages have been examined in this analysis.

Also, the Tetra Tech report (2009) found that using a more typical estimation routine would have yielded 13% more impinged fish than the Ager et al (2008) study reported. The Tetra Tech report also suggested that seasonality may not have been adequately accounted for during the Ager et al (2008) study, meaning actual impingement and entrainment rates may be higher. If the impingement and entrainment estimates used are lower than the actual number of impinged and entrained fish, the economic damages would be higher than those presented here.

As with losses in non-fishing uses, any loss of non-use value has not been quantified here due to limited information on the necessary ecological linkages as well as few economic valuation studies to apply to such losses. Had these other use and non-use values been included, the damage estimates would have been higher than those presented here, all else being equal.

References

Ager, D.D., I. Cord, S. Rkman-Filipovic, and P.H. Patrick. 2007. Bay Shore Power Plant Fish Entrainment and Impingement Study Report. Kinetrics report 112026-005-RA-0001-R00. 163pp.

Ager, D., D. Marttila, and P. Patrick. 2008. Bay Shore Power Plant cooling water intake structure**.** Kinectrics Report: 112026-005-RA-0002-R00

Besedin, E., M. Mazzotta, D. Cacela, and L. Tudor. 2004. "Combining Ecological and Economic Analysis: An Application to Valuation of Power Plant Impacts on Great Lakes Recreational Fishing," Paper presented at American Fisheries Society Meeting, August 2004.

Breffle, W., E. Morey, R. Rowe, D. Waldman and S. Wytinck. 1999. Recreational Fishing Damages from Fish Consumption Advisories in the Waters of Green Bay. Report to U.S.FWS, U.S.DOJ, and U.S.DOI by Stratus Consulting Inc., Boulder, CO, 1999.

Clady, M.D. 1976. Influence of temperature and wind on the survival of early stages of YP. Journal of Fisheries Research Board of Canada 33:1887-1893.

Clady, M.D. 1975. Early survival and recruitment of smallmouth bass in northern Michigan . The Journal of Wildlife Management, Vol. 39, No. 1 (Jan., 1975), pp. 194-200.

Edwards, S.F. 1990. An Economic Guide to Allocation of Fish Stocks between Commercial and Recreational Fisheries. NOAA Technical Report NMFS 94. US Department of Commerce.

Everhart, W.H., A.W. Eipper, and W.D. Youngs . 1975. Principles of fishery science. Cornell University Press, Ithaca, NY.

Forney. 1976. Year-class formation in the walleye *(Stizostedion vitreum vitreum)* population of Oneida Lake, New York 1966-73. Journal of the Fisheries Research Board of Canada 33:783-972.

FUS. 2009. Fisheries of the United States 2008. Current Fishery Statistics No. 2008. Editor Elizabeth Pritchard. Commerce Dept., NOAA, National Marine Fisheries Service, Office of Science and Technology, Fisheries Statistics Division. July 2009.

Freeman, A.M. III. 1993. The Measurement of Environmental and Resource Values: Theory and Methods. Resources for the Future. Washington, DC. 516pp.

Gentner, B. and S. Steinback. 2008. The Economic Contribution of Marine Angler Expenditures in the United States, 2006. U.S. Department of Commerce, NOAA Tech. Memo. NMFS F/SPO-94, 301p.

Hart, T.F. and R.G. Werner. 1987. Effects of prey density on growth and survival of white sucker, *Catostomus commersoni*, and pumpkinseed, *Lepomis gibbosus*, Larvae. Environmental Biology of Fishes Vol. 18:41-50.

Johnston, R., M. Ranson, E. Besedin, and E. Helm. 2006. “What Determines Willingness to Pay per Fish? A Meta-Analysis of Recreational Fishing Values,” Marine Resource Economics, 21(1): 1-32, 2006

Kirkley, J.E., K.E. McConnell, and W. Ryan. 2000. Economic Aspects of Allocating Striped Bass Among Competing User Groups in Virginia. Virginia Marine Resources Report No. 2000-05. 79p.

Kirkley, J.E., J. Duberg, and B. Gentner (2004). The Economic Contributions of the Commercial Fisheries of the United States: A User’s Guide to the National Input/Output Model. Final report, contract DG133F-02-SE-0908.

Knight, R.L., Margraf, F.J., Carline, R.F., 1984. Piscivory by walleyes and yellow perch in western Lake Erie. Trans. Am. Fish. Soc. 113, 677–693.

Kramer, R.H. and L.L. Smith, Jr. 1962. Formation of year classes in largemouth bass. *Transactions of the American Fisheries Society.* 91: 29-41

Lupi, F., J. Hoehn, H. Chen and T. Tomasi. 2001. "The Michigan Recreational Angling Demand Model," in Macrobehavior and Microresults: Proceedings of International Institute of Fisheries Economics and Trade, (Ann Shriver, ed.), Oregon State University, Corvalis, 2001.

Michaletz, P.H. 1997. Factors affecting abundance, growth, and survival of age-0 gizzard shad. *Transactions of the American Fisheries Society* 126:84-100.

Minnesota IMPLAN Group, Inc. (MIG), 2008. IMPLAN System.1725 Tower Drive west, Suite 140, Stillwater, MN 55082, www.implan.com, 1997.

Murdock, J. 2001. Valuing Recreational Fishing Opportunities While Catching Unobserved Characteristics. Unpublished Report, Yale University, New Haven, CT. 2001.

National Marine Fisheries Service (NMFS). 2006. Fisheries Economics of the United States, 2006: Economic and Sociocultural Status and Trends Series. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Office of Science and Technology. Division of Economics and Social Analysis. Pp166.

OEPA (Ohio Environmental Protection Agency). 1978. Guidelines for the Submittal of Demonstrations Pursuant to Sections 316(a) and 316(b) of the Clean Water Act and Chapter 3745-1 of the Ohio Administrative Code. Columbus, OH.

Ohio Division of Wildlife (ODW). 2009. Ohio’s Lake Erie Fisheries, 2008. Annual status report. Federal Aid in Fish Restoration Project F-69-P. Ohio Department of Natural Resources, Division of Wildlife, Lake Erie Fisheries Units, Fairport and Sandusky. 115 pp.

OMB (U.S. Office of Management and Budget). 2007. Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs. Circular No. A-94, Revised January 2006. U.S. Office of Management and Budget, Washington, DC.

Ontario Ministry of Natural Resources (OMNR). 2009. 2005 Survey of Recreational Fishing in Canada: Selected Results for Ontario Fisheries. Fish and Wildlife Branch. Ontario Ministry of Natural Resources. Peterborough, Ontario. 24 p. + appendices.

Oregon Department of Fish and Wildlfie. 2006. Oregon Administrative Rules. Available online at http://www.dfw.state.or.us/OARs/410.pdf Last accessed 5/26/2010.

Patterson R. 1976. Analysis of losses in standing crop and fishery yields of yellow perch in Western Lake Erie due to entrainment and impingement mortality at Detroit Edison Monroe Power Plant.

Schutz, R.D. and D.A. Robinson. 2002. Exploitation and mortality rates of white bass in Kansas reservoirs. *North American Journal of Fisheries Management* 22:652–658.

Talhelm, D.R., C.R. Bishop, K.W. Cox, N.W. Smith, D.N. Steinnes, and A.L.W. Tuomi. 1979. Current Estimates of Great Lakes Fisheries Values: 1979 Status Report. Great Lakes Fishery Commission, Ann Arbor, ME, mimeo. Rep. 79. 79-1:17pp.

Tetra Tech. 2009. Bay Shore Power Plant Intake and Thermal Discharge NPDES Compliance Option Evaluation. Contract Ending Report to US EPA Contract Number EP-C-05-046. Final Report February 27, 2009. 43 pp.

United States Fish and Wildlife Service (USFWS). 2006. 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau.

USEPA (US Environmental Protection Agency) 2004. *Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule*. EPA 821-R-04-007. U.S. Environmental Protection Agency, Washington, DC.

Wallace. 1971. Age, growth, year class strength, and survival rates of the white perch, Morone americana (Gmelin) in the Delaware River in the vicinity of Artificial Island. Chesapeake Science Vol. 12, No. 4, p. 205-218.

Walleye Task Group. 2007. Report of the Lake Erie Walleye Task Group to the Standing Technical Committee, Lake Erie Committee of the Great Lakes Fishery Commission. 25 pp.

Yellow Perch Task Group (YPTG). 2007. Report of the Yellow Perch Task Group, March 2007. Presented to the Standing Technical Committee, Lake Erie Committee of the Great Lakes Fishery Commission. Ann Arbor, Michigan, USA.

Appendix 1: Commercial Fisheries Detail

Table A1. Annual commercial harvest (pounds) from the Ohio waters of Lake Erie, by species, 2000-2009.

Year	Carp	Channel Catfish	Freshwater Drum	White Bass	White Perch	Yellow Perch[ab]	Other	Total
2000	956,218	260,512	428,660	317,336	182,254	962,841	438,382	3,107,821
2001	857,694	322,488	284,883	226,664	155,555	1,089,247	540,809	2,936,531
2002	523,539	311,824	248,567	161,664	269,512	1,438,215	1,070,475	2,953,321
2003	582,035	319,378	261,068	318,327	312,240	1,505,840	587,910	3,298,888
2004	469,059	271,627	298,336	358,810	386,800	1,577,113	593,205	3,361,745
2005	340,399	310,115	438,589	347,657	428,822	1,563,200	813,191	3,428,782
2006	271,190	385,134	411,840	483,314	655,551	1,050,614	660,906	3,257,643
2007	322,323	341,843	320,747	334,721	573,996	1,950,661	649,055	3,844,291
2008	198,616	447,232	423,705	424,225	545,138	1,515,666	628,935	3,554,582
2009	249,417	407,386	543,409	671,151	680,125	1,450,646	1,012,225	4,002,134
Mean	477,049	337,754	365,980	364,387	418,999	1,410,404		3,374,574

[a] A spring (March - April) closure on commercial yellow perch harvest was enacted in 1993.

[b] Management unit 1 (the western basin) was closed to commercial yellow perch harvest in 2008 and 2009.

Table A2. Ohio Dockside Prices, 2000-2009 (2009 dollars).

Year	Carp	Channel Catfish	Freshwater Drum	White Bass	White Perch	Yellow Perch	Others
2000	$0.11	$0.76	$0.15	$1.02	$1.26	$3.28	$0.38
2001	$0.12	$0.73	$0.12	$0.77	$1.22	$2.89	$0.30
2002	$0.16	$0.72	$0.15	$0.60	$1.20	$2.09	$0.16
2003	$0.16	$0.19	$0.15	$0.67	$1.18	$1.77	$0.28
2004	$0.17	$0.46	$0.14	$0.70	$1.15	$1.89	$0.29
2005	$0.17	$0.44	$0.15	$0.81	$1.11	$2.39	$0.20
2006	$0.15	$0.35	$0.15	$0.74	$1.08	$2.45	$0.32
2007	$0.13	$0.31	$0.18	$0.76	$1.05	$2.40	$0.32
2008	$0.20	$0.33	$0.17	$0.55	$1.01	$1.65	$0.39
2009	$0.21	$0.33	$0.19	$0.76	$1.01	$1.67	$0.53
Mean	$0.16	$0.46	$0.15	$0.74	$1.13	$2.25	$0.32