DEVELOPMENT OF FISHING POWER CORRECTIONS FOR 12-m YANKEE AND 21-m WING BOTTOM TRAWLS USED IN LAKE HURON

TECHNICAL REPORT 68

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December 2009

DEVELOPMENT OF FISHING POWER CORRECTIONS FOR 12-m YANKEE AND 21-m WING BOTTOM TRAWLS USED IN LAKE HURON

Jean V. Adams[1] **and Stephen C. Riley**
U.S. Geological Survey
Great Lakes Science Center
1451 Green Road
Ann Arbor, MI, 48105, U.S.A.

Sara A. Adlerstein
University of Michigan
School of Natural Resources and Environment
138 Museum Annex
Ann Arbor, MI, 48109, U.S.A.

Citation: Adams, J.V., S.C. Riley, and S.A. Adlerstein. 2009. Development of fishing power corrections for 12-m Yankee and 21-m wing bottom trawls used in Lake Huron. Great Lakes Fish. Comm. Tech. Rep. 68.

Great Lakes Fishery Commission
2100 Commonwealth Blvd., Suite 100
Ann Arbor, MI 48105-1563

December 2009

ISSN 1090-1051

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[1] Corresponding author: jvadams@usgs.gov.

Printed on recycled paper.
TR68/12-2009/600

TABLE OF CONTENTS

ABSTRACT

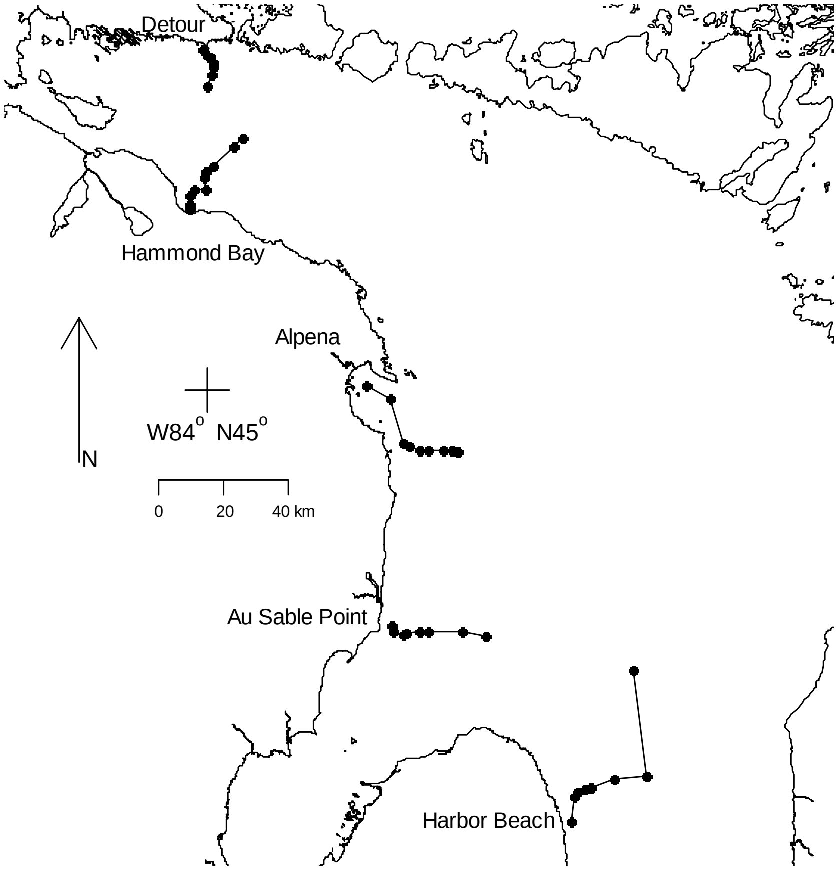
The U.S. Geological Survey's (USGS) Great Lakes Science Center (GLSC) has monitored fish abundance in Lake Huron annually from 1973 to the present by bottom trawling in Michigan waters during fall. The survey net was changed from a 12-m (headrope) Yankee trawl to a 21-m (headrope) wing trawl in 1992, creating a need for fishing power corrections (FPCs). To develop FPCs, we applied generalized additive models to the catch rates of fishes commonly taken in 75 pairs of experimental tows of both trawls during fall 1979-1988. Catch rates from the 21-m wing trawl were considered the standard; catch rates from the 12-m Yankee trawl were to be adjusted by multiplying them by a FPC, if needed, to maintain the continuity of the time series. We were able to develop FPCs for young-of-the-year (YOY) and yearling-and-older (YAO) alewife (*Alosa pseudoharengus*) and bloater (*Coregonus hoyi*); YAO rainbow smelt (*Osmerus mordax*); and all ages combined of lake whitefish (*Coregonus clupeaformis*), slimy sculpin (*Cottus cognatus*), and deepwater sculpin (*Myoxocephalus thompsonii*). Our results suggest that FPCs >1 should be applied to the catch rates of four non-benthic species (alewife, YAO rainbow smelt, bloater, and lake whitefish), and FPCs <1 should be applied to the catch rates of two benthic species (slimy sculpin and deepwater sculpin). No FPC was needed for trout-perch (*Percopsis omiscomaycus*), and insufficient data were available to develop FPCs for YOY rainbow smelt and ninespine stickleback (*Pungitius pungitius*). We recommend that no further changes be made in the vessel or net used to conduct the fall trawl survey in Lake Huron without first estimating reliable FPCs.

INTRODUCTION

The U.S. Geological Survey's (USGS) Great Lakes Science Center (GLSC) has monitored fish abundance in Lake Huron annually from the 1970s to the present by bottom trawling at up to eleven depths (9, 18, 27, 36, 46, 55, 64, 73, 82, 92, and 110 m) at five fixed transects (Detour, Hammond Bay, Alpena, Au Sable Point, and Harbor Beach) in Michigan waters (Fig. 1). Bottom-trawl surveys on Lake Huron have been conducted during spring and fall, but the fall survey has the longest time series and, thus, the most value for tracking changes in the fish community.

Fall bottom trawling on Lake Huron was conducted primarily from the USGS R/V *Grayling,* although the R/V *Kaho* was used during 1973-1977, and some trawl tows were made from the R/V *Cisco* during 1990. Tows were made using a 12-m (headrope) Yankee trawl from 1973 to 1991 and a 21-m (headrope) wing trawl from 1992 to 2008. Fishing power should be standardized when comparing catch per effort (CPE) of trawl tows from different vessels or nets (Gulland 1983; Pelletier 1998); therefore, analyses of bottom trawl catches from fall 1973-2008 have been confounded by potential fishing power differences between the vessels and nets used to conduct the surveys. Although fishing power of the two nets can be compared by use of a series of tows with both nets conducted from the R/V *Grayling* in the 1970s and 1980s, to our knowledge no data were collected for comparing the fishing power of the different vessels used in the survey. Therefore, our focus is on corrections for the two nets employed in the survey but not the vessels. The purpose of this report is to use the tows made from the R/V *Grayling* in the 1970s and 1980s to determine the need for and magnitude of fishing power corrections that will make catches from the 12-m Yankee trawl comparable to those from the 21-m wing trawl and, thus, allow for analysis of the whole fall time series from Lake Huron.

Fig. 1. Location of paired bottom-trawl tows taken along five fixed transects in Lake Huron during fall 1979, 1980, and 1988 by the USGS R/V *Grayling*.



Methods

During 1979-1988, a total of 150 paired trawl tows were conducted at selected transects in Lake Huron using either the 12-m (headrope) Yankee trawl or the 21-m (headrope) wing trawl (75 tows each) (Table 1).

Table 1. Year, transect (see Fig. 1), and bottom depth where 75 paired trawl tows (each x represents a single pair of tows) were conducted in Lake Huron. The two trawl tows in each pair were conducted fewer than eight days apart during 8 October-12 November.

		Bottom depth (m)										
Year	**Transect**	**9**	**18**	**27**	**36**	**46**	**55**	**64**	**73**	**82**	**91**	**110**
1979	Detour	x		x		x		x			x	
	Hammond Bay			x	x	x	x	x	x		x	x
1980	Detour	x	x	x	x	x	x	x	x		x	
	Hammond Bay			x	x	x	x	x	x		x	x
	Alpena	x	x	x	x	x	x	x	x	x		
	Au Sable Point	x	x	x	x	x	x	x	x			
	Harbor Beach		x	x	x	x	x	x	x		x	
1988	Detour					x	x	x	x			
	Hammond Bay					x	x	x	x			
	Alpena					x	x	x	x			
	Au Sable Point					x	x	x	x			
	Harbor Beach					x	x	x	x			

Paired trawl tows along bottom contours and in daylight hours coincided with the fall trawl survey and were conducted from the R/V *Grayling* during 7-12 November 1979, 23 October-7 November 1980, and 8 October-3 November 1988. Both trawl nets had cod ends of 13-mm (stretch measure) knotless nylon. Trawling was conducted across a range of depths from 9 to 110 m at all five transects normally fished each fall (Fig. 1), but not every transect-depth-year combination was sampled (Table 1). Tows made at the same depth and transect with one net (the Yankee trawl was towed first 88% of the time) were followed by tows made with the other net no more than eight days later (97% within 0-2 days). For each combination of year, transect, and depth, only one pair of tows was made. All fish captured were identified to species, counted, and weighed in the aggregate. Water temperatures were measured at the lake bottom after each trawl tow.

We attempted to develop FPCs for species that were present in both trawls for at least 20 paired tows. For alewife (*Alosa pseudoharengus*), bloater (*Coregonus hoyi*), and rainbow smelt (*Osmerus mordax*), separate FPCs were developed for young-of-the-year (YOY) and yearling-and-older (YAO) fish. Life stages were separated by use of length-frequency histograms. We used ≥100 mm total length as a demarcation between YOY and YAO for alewife, ≥90 mm for rainbow smelt, and ≥120 mm for bloater. For the other species, we combined all age-classes for analyses, because sufficient length-frequency data were unavailable.

Information from trawl mensuration studies conducted with the R/V *Grayling* was used to calculate the area swept by each net during a standard tow of 10-min duration. For the 21-m wing trawl, the actual time the net was on bottom during a standard tow was estimated for depths ranging from 9 to 100 m in Lake Michigan off of Ludington, MI, using a SCANMAR[1] trawl mensuration system during 7-18 August 1991. Trawl widths were measured at depths ranging from 9 to 100 m in Lake Huron off Hammond Bay, Detour, and Alpena, MI, using a NetMind[1] trawl monitoring system during 2-6 May 2005.

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[1] Reference to trade names does not imply endorsement by the USGS.

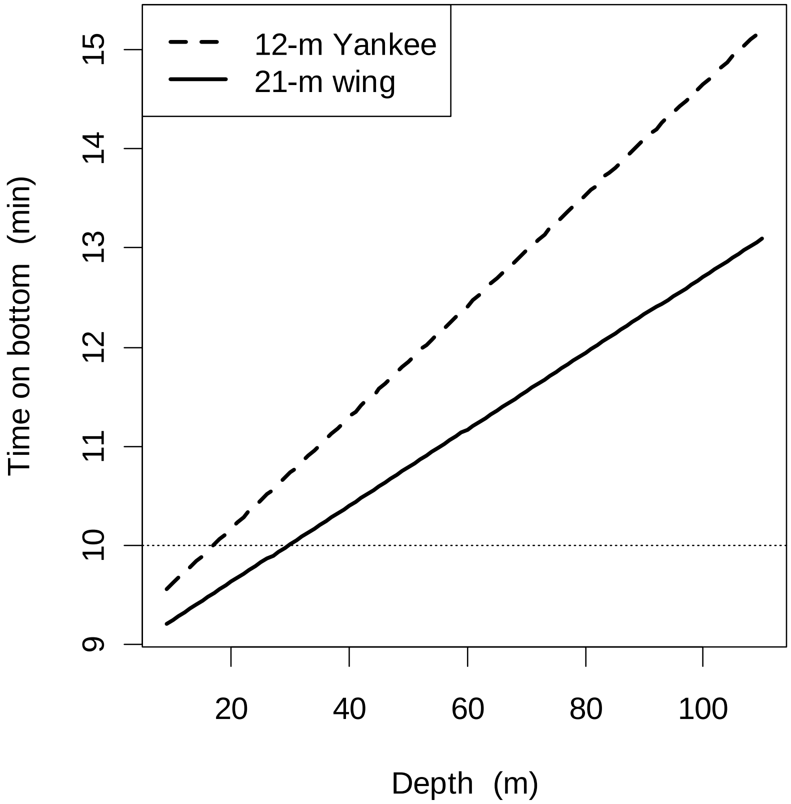
For the 12-m Yankee trawl, time on bottom and trawl width were estimated at depths ranging from 9 to 110 m in Lake Huron off Cheboygan, MI, using a NetMind trawl monitoring system during 17-21 June 2009. The net was defined as being on bottom when measures of trawl width and headrope depth were stabilized.

Catches for each species and life stage were adjusted for the area swept by the trawl as

$$CPE = \frac{10{,}000\, Catch}{T'SW},$$

where *CPE* is the adjusted catch-per-unit effort (in number·ha^{-1}), *Catch* is the number of the given species and life stage captured in the trawl, *T’* is the time on bottom (in min), *S* is the vessel speed over ground (in m·min^{-1}), *W* is the trawl width (in m), and 10,000 is a unit conversion factor (in m^2·ha^{-1}). The trawl mensuration studies conducted in 1991 and 2009 found that the amount of time a net was on bottom during a tow increased with fishing depth (Fig. 2).

Fig. 2. The relation between bottom depth and the estimated time the net was on bottom during a standard 10-min tow for each of two bottom trawls fished in fall surveys of Lake Huron by the U.S. Geological Survey. For the 21-m wing trawl, the relations were based on estimates from a SCANMAR trawl mensuration system deployed from the USGS R/V *Grayling* in Lake Michigan off Ludington, MI, during 7-18 August 1991. For the 12-m Yankee trawl, the relations were based on estimates from a NetMind trawl monitoring system deployed from the R/V *Grayling* in Lake Huron off Cheboygan, MI, during 17-21 June 2009. The horizontal dotted line represents the relation for which actual time on bottom was equal to the onboard tow time.



Onboard tow times (the interval of time between when the maximum length of warp was shot and the start of warp retrieval) were adjusted to the actual time the net was on bottom by

$$T' = 0.0560\ Depth - 0.94 + T$$

for the 12-m Yankee trawl and

$$T' = 0.0385\ Depth - 1.14 + T$$

for the 21-m wing trawl, where *Depth* is the bottom depth where the trawl is fished (in m) and *T* is the onboard tow time (in min). Vessel speed was not measured for individual tows; instead, propeller speed was held to a constant 150 rpm for the 12-m Yankee trawl and 230 rpm for the 21-m wing trawl. The speed at which each net was towed over ground was estimated from tows conducted by the R/V *Grayling* during 1993, 1995, and 1996 by dividing the distance between vessel position (determined by GPS) at the start and end of the onboard tow time. This calculation yielded an average speed of 61 $\mathrm{m \cdot min^{-1}}$ (11 tows with a mean of 3.6 and a SD of 0.6 $\mathrm{km \cdot hr^{-1}}$) for the Yankee trawl and 80 $\mathrm{m \cdot min^{-1}}$ (38 tows with a mean of 4.8 and a SD of 0.5 $\mathrm{km \cdot hr^{-1}}$) for the wing trawl. Widths of the trawl nets when they were towed along the bottom were estimated from relations developed from the 2005 and 2009 trawl mensuration studies as

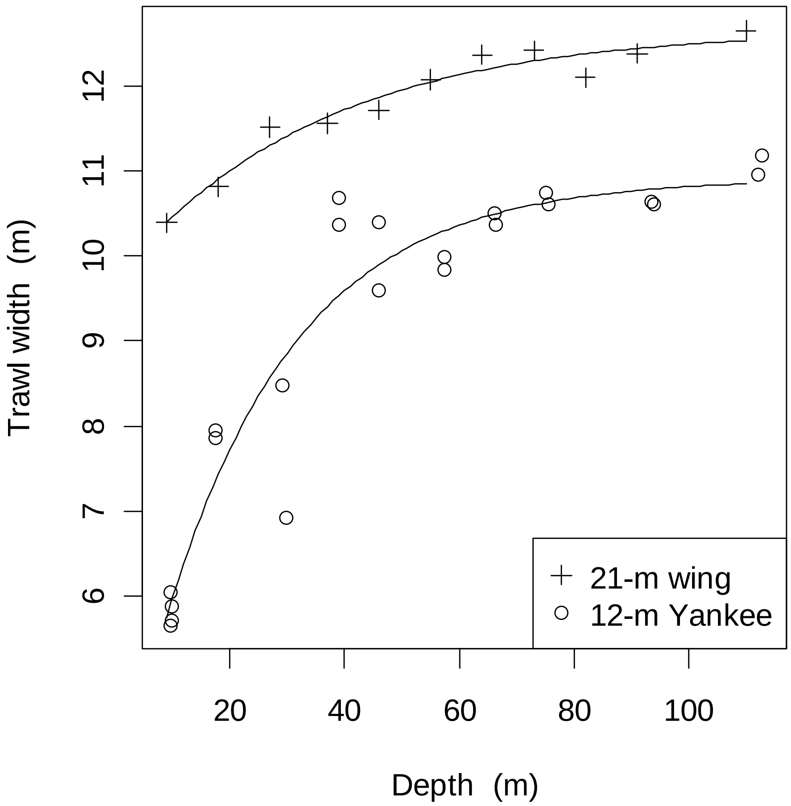
$$W = 3.23 + 7.68(1 - e^{-0.0440\ Depth})$$

for the 12-m Yankee trawl and

$$W = 9.73 + 2.93(1 - e^{-0.0285\ Depth})$$

for the 21-m wing trawl (Fig. 3). Time on bottom, vessel speed, and net configuration for the R/V *Kaho* (1973-1977) and R/V *Cisco* (1990) were assumed to be similar to those of the R/V *Grayling,* although no measurements were available for the *Kaho* or *Cisco*.

Fig. 3. The relation between bottom depth and trawl width for each of two bottom trawls fished in fall surveys of Lake Huron. For the 21-m wing trawl, the relations were based on measurements from a NetMind trawl monitoring system deployed from the USGS R/V *Grayling* in Lake Huron off Hammond Bay, Detour, and Alpena, MI, during 2-6 May 2005. For the 12-m Yankee trawl, the relations were based on measurements from a NetMind trawl monitoring system deployed from the R/V *Grayling* in Lake Huron off Cheboygan, MI, during 17-21 June 2009.



We used generalized additive models (Wood 2006) to determine the need for and magnitude of FPCs for each species and life stage, using only those paired tows in which both nets caught a given species and life stage. The base model contained only two main effects:

$$\ln(CPE) = pair + net + \varepsilon$$

where *pair* is a *k*-level factor identifying each unique pair of tows (*k* is the number of paired tows), *net* is a two-level factor identifying the trawl used (12-m Yankee or 21-m wing trawl), and ε is the normally distributed error. We compared this base model to the null model (which contained only the main effect of pair) and to 14 other models, each of which added up to three of four possible interaction terms to the base model, including: *net*×*year*, where *year* is a three-level factor (1979, 1980, and 1988); *net*×*transect*, where *transect* is a five-level factor (Detour, Hammond Bay, Alpena, Au Sable Point, and Harbor Beach); *net*×s(*depth*), where *depth* is the bottom depth fished (in m); and *net*×s(*temp*), where *temp* is the water temperature at the lake bottom (in °C). A thin-plate regression spline (Wood 2003), indicated by s(), was fit to both continuous variables (*depth* and *temp*), to allow for unspecified non-linear relationships. Main effects for *year*, *transect*, *depth*, and *temp* need not be specified in the model, because they are already contained in the main effect of *pair*. Model fitting was conducted using the gam() function in the mgcv (multiple generalized cross validation) package (Wood 2000, 2003, 2004, 2006) of R (R Development Core Team, 2007). Akaike's information criterion (corrected for sample size, AIC_c) was calculated for all 16 models, and the model with the lowest AIC_c was selected as the best one for each species (Burnham and Anderson 2002). The Akaike weights were calculated to quantify the weight of evidence in favor of the selected model relative to the other 15 models.

If the null model is identified as the best model, CPEs from both trawls are similar, and no FPC is required. If the base model is best, a FPC is required, and it is calculated as the exponent of the estimated coefficient for *net* in the model, i.e., e^{coef}. If one of the nine models with one or more interaction terms not including *net*×*year* is best, a FPC is required, but its value will vary across transects, depths, or temperatures. If one of the five models including the *net*×*year* interaction term is best, catchability in the two trawls (expressed as the ratio of the CPEs) is different, but the difference varies among years in an unpredictable way (unexplained by transect, depth, and temperature). In this case, further investigation is required to develop a satisfactory FPC.

Catches from the 21-m wing trawl are considered the standard in this analysis, i.e., CPEs from the 12-m Yankee trawl will be corrected by multiplying them by the FPC to make them comparable to CPEs from the 21-m wing trawl. Thus, a FPC value >1 for a given species and life stage indicates that CPEs of this species and life stage were greater in the 21-m wing trawl than in the 12-m Yankee trawl. A FPC value <1 indicates that CPEs of this species and life stage were lower in the 21-m wing trawl than in the 12-m Yankee trawl. To apply a correction factor to catches from the 21-m trawl, i.e., treating the 12-m Yankee trawl as the standard, the inverse of the FPCs reported herein should be used.

RESULTS

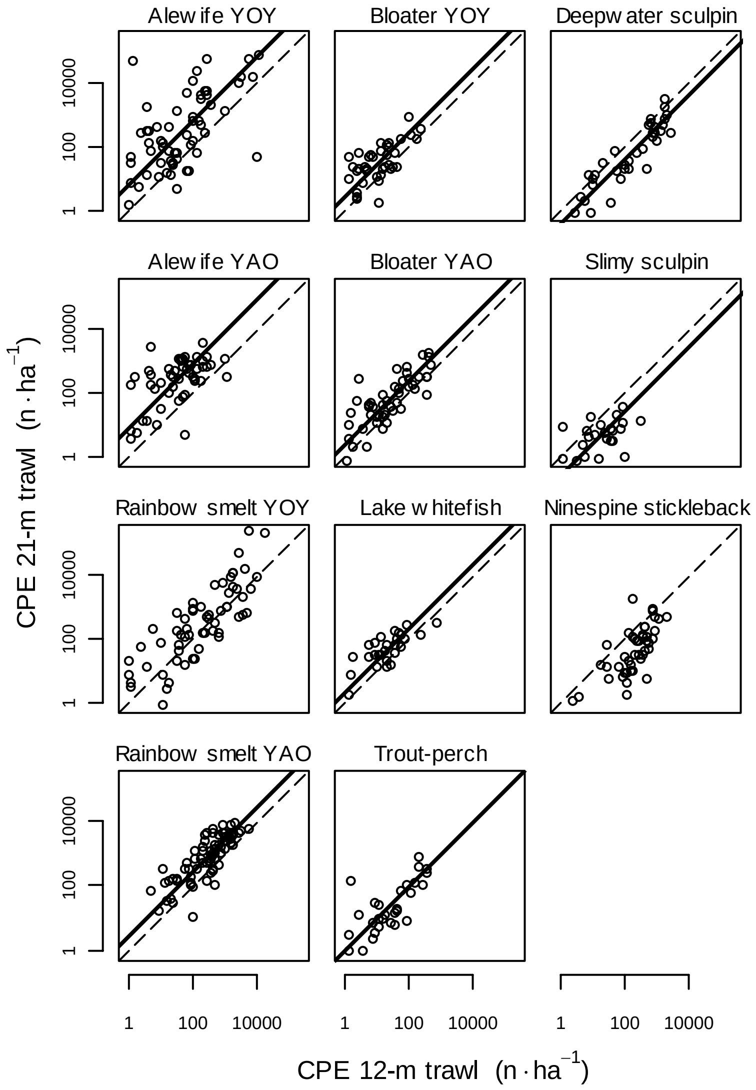
Alewife (YOY and YAO) and rainbow smelt (YOY and YAO) were captured in both trawl nets in at least 50 paired tows ($N \geq 100$, Table 2, Fig. 4), which corresponds to the recommended minimum needed to determine the need for and magnitude of FPCs (Gulland 1967; Wilderbuer et al. 1998).

Table 2. Best generalized additive models based on Akaike's information criterion (AIC) for predicting catch per unit effort ($n \cdot ha^{-1}$) of various fish species and life stages in two different bottom trawls. Models are described as one of three types: (1) base, relating the natural log CPE to tow pair and trawl net, $\ln(CPE) = pair + net + \varepsilon$; (2) null, relating CPE to tow pair alone; or (3) base + additional interactions terms in the model. Also reported are the total number of tows (N), model degrees of freedom (Df), the corrected AIC (AIC_c), and the Akaike weight (AIC_{cw}).

Species and life stage	**Model**	**N**	**Df**	**AIC$_c$**	**AIC$_{cw}$**
Alewife YOY	Base	118	59	617	0.97
Alewife YAO	Base	100	50	452	0.99
Rainbow smelt YOY	Base + *net*×*year* + *net*×s(*depth*)	120	63.6	517	0.98
Rainbow smelt YAO	Base	144	72	504	0.60
Bloater YOY	Base	78	39	301	0.97
Bloater YAO	Base	96	48	370	0.98
Lake whitefish	Base	54	27	194	0.99
Trout-perch	Null	58	28	235	0.98
Deepwater sculpin	Base	70	35	248	0.99
Slimy sculpin	Base	48	24	206	0.62
Ninespine stickleback	Base + *net*×*year* + net×s(depth)	88	47.9	339	0.60

Six other species were captured in both trawl nets in at least 20 paired tows ($N \geq 40$, Table 2, Fig. 4): lake whitefish (*Coregonus clupeaformis*), bloater (YOY and YAO), trout-perch (*Percopsis omiscomaycus*), deepwater sculpin (*Myoxocephalus thompsonii*), slimy sculpin (*Cottus cognatus*), and ninespine stickleback (*Pungitius pungitius*).

Fig. 4. Catch per effort (CPE) of various fishes and life stages in paired tows of two different bottom trawls in Lake Huron during fall 1979, 1980, and 1988. The one-to-one relations are denoted by dashed lines and the model-predicted relations are denoted by bold solid lines (models for rainbow smelt YOY and ninespine stickleback are too complex to be represented by a line). All plots are on the same scale.


Alewife YOY
Bloater YOY
Deepwater sculpin
Alewife YAO
Bloater YAO
Slimy sculpin
Rainbow smelt YOY
Lake whitefish
Ninespine stickleback
Rainbow smelt YAO
Trout-perch
1
100
10000
CPE 21-m trawl (n · ha^{-1})
CPE 12-m trawl (n · ha^{-1})

Model selection based on AIC_c tended to yield a single superior model with Akaike weights ranging from 0.60 to 0.99 for each species and life stage (Table 2). The base model, relating CPE to tow pair and trawl net, was the best model for eight species and life stages (Table 2), indicating that a FPC is required. Six species and life stages had FPCs >1: alewife YOY, alewife YAO, lake whitefish, bloater YOY, bloater YAO, and rainbow smelt YAO (Table 3, Fig. 4).

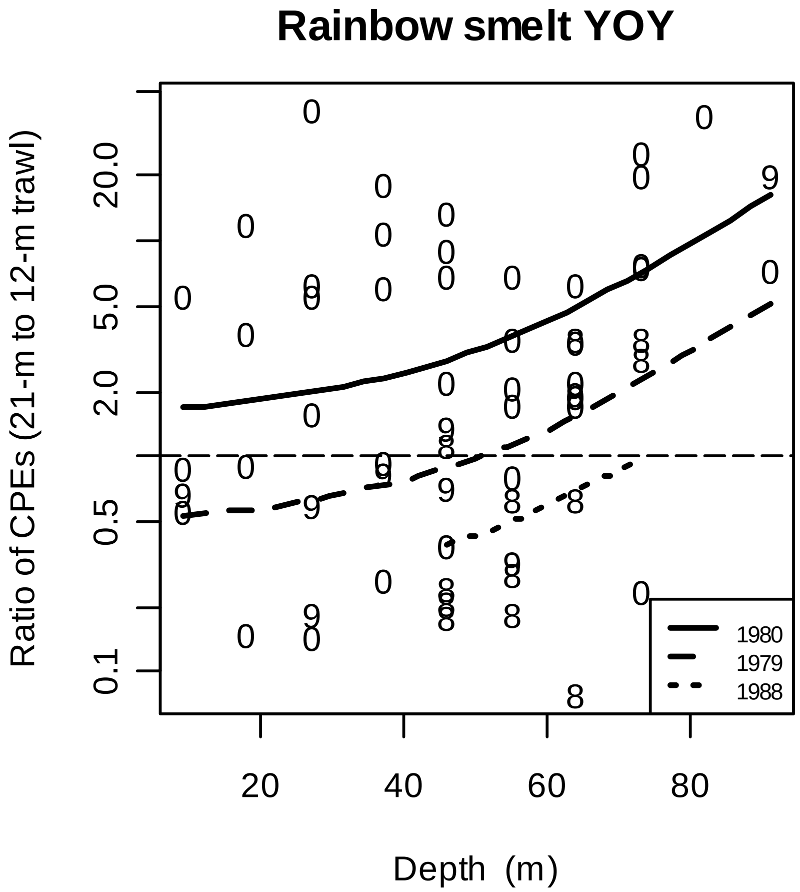
Table 3. Estimated fishing power corrections (FPCs) for those fish species and life stages for which a FPC could be estimated [all from the base model relating the natural log CPE ($n \cdot ha^{-1}$) to tow pair and trawl net, $\ln(CPE) = pair + net + \varepsilon$] from paired trawl tows performed in Lake Huron during fall 1979, 1980, and 1988 with a 12-m Yankee trawl and a 21-m wing trawl (the standard net) from the R/V *Grayling*. Also given are the estimated coefficient for effect of the trawl net (coef. *net*) with its standard error (SE) and the estimated FPC with lower and upper 95% confidence limits (LCL and UCL).

Species and life stage	**Coef. *net***	**SE**	**FPC**	**LCL**	**UCL**
Alewife YOY	1.93	0.30	6.89	3.78	12.58
Alewife YAO	2.06	0.23	7.85	4.98	12.36
Rainbow smelt YAO	1.02	0.12	2.79	2.21	3.51
Bloater YOY	1.11	0.18	3.02	2.09	4.36
Bloater YAO	0.94	0.17	2.57	1.84	3.58
Lake whitefish	0.90	0.18	2.47	1.70	3.60
Deepwater sculpin	-0.89	0.16	0.41	0.30	0.57
Slimy sculpin	-1.31	0.27	0.27	0.15	0.48

Two species had FPCs <1: deepwater sculpin and slimy sculpin (Table 3, Fig. 4). The null model, relating CPE to tow pair alone, was the best model for trout-perch, indicating that the catch rates of this species by the two trawls were similar, and, therefore, no FPC is required (Table 2, Fig. 4).

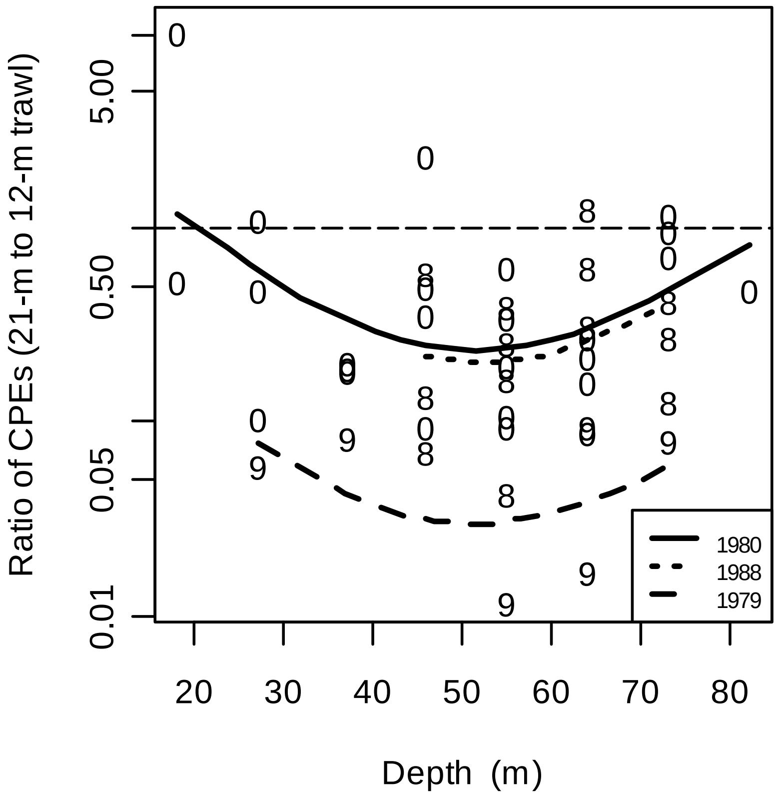
For rainbow smelt YOY and ninespine stickleback, the best model was one relating CPE to tow pair, trawl net, and two interactions: net by year and net by fishing depth (Table 2). The inclusion of the net-by-year interaction in the model indicates that a single FPC would not be appropriate for data from multiple years. For rainbow smelt YOY, the relative catchability of the 21-m wing trawl to the 12-m Yankee trawl (expressed as the ratio of the CPEs) increased with fishing depth and was highest in 1980 and lowest in 1988 (Fig. 5). For ninespine stickleback, the relative catchability of the two trawls was lowest at bottom depths of 40-60 m, higher at shallower and deeper depths, and higher in 1980 and 1988 than in 1979 (Fig. 5).

Fig. 5. Relation between catchability ratio (CPE of 21-m wing trawl divided by CPE of 12-m Yankee trawl, where CPE is in $n \cdot ha^{-1}$) and bottom depth in each of three years for rainbow smelt YOY and ninespine stickleback captured in paired trawl tows in Lake Huron during fall 1979, 1980, and 1988. Plot symbols represent observed tow pairs (9 for 1979, 0 for 1980, and 8 for 1988), and lines represent model predictions.



Rainbow smelt YOY

Ninespine stickleback



DISCUSSION

Our comparisons of catch rates in paired tows of the 12-m Yankee and 21-m wing bottom trawls used to assess fishes in the Michigan waters of Lake Huron indicate that catch rates of four non-benthic species were greater in the 21-m wing trawl used for assessments during 1992-2008. Catch rates of two benthic species were greater in the 12-m Yankee trawl used for assessments during 1973-1991. The 21-m wing trawl had a greater vertical opening than the Yankee trawl (GLSC, unpublished data) and a wider horizontal opening (this study). These results suggest that FPCs >1 should be applied to catches of four non-benthic species (alewife, YAO rainbow smelt, bloater, and lake whitefish) and FPCs <1 should be applied to catches of two benthic species (slimy sculpin and deepwater sculpin) caught in the 12-m Yankee trawl so as to make abundance and biomass estimates for 1973-1991 comparable to those of 1992-200, when the 21-m wing trawl was used to conduct assessments. Net effects were not included in the best model for trout-perch, and the 95% confidence intervals for the trout-perch FPC included 1, which makes a FPC inappropriate for this species.

For ninespine stickleback and YOY rainbow smelt, the best models included net-by-year interactions, which indicates that the differences in catch rates for the two nets varied unpredictably among years and that further investigation would be required to estimate valid FPCs for these species and life stages. The catch data were insufficient to estimate FPCs for four other common species in Lake Huron (those caught in at least 10% of all bottom-trawl tows over the history of the survey (GLSC unpublished data)): lake trout (*Salvelinus namaycush*), spottail shiner (*Notropis hudsonius*), johnny darter (*Etheostoma nigrum*), and burbot (*Lota lota*).

After the experimental trawl tows were conducted, Lake Huron was invaded by dreissenid mussels (*Dreissena* spp.) (Nalepa et al. 2007). The mussels, which have proliferated in many areas of the lake, drastically changed the lake bottom and, in so doing, may have changed the catchability of at least some species by the trawls. Thus, conducting additional tows with both nets now would not aid in developing FPCs for application to 1973-1991 bottom-trawl catches. In Lake Ontario, the proliferation of dreissenids changed the distribution of at least three fish species (O'Gorman et al. 2000) and forced researchers to abandon the use of Yankee bottom trawls for fishery assessment due to severe fouling of the nets with dreissenid mussels (O'Gorman et al. 2005). Net fouling and potential changes in fish distribution may have also affected the catchability of fishes by bottom trawls in Lake Huron.

The FPCs estimated here are directly applicable to indices of prey fish abundance in Lake Huron, only if the indices incorporate the same adjustments we used for time on bottom, vessel speed, and trawl width. These adjustments are themselves estimates and, therefore, contain error, which contributes unavoidable variability to our FPCs. Tow-specific measures of tow length and trawl width at various fishing depths may have yielded more precise estimates of FPCs.

Our FPCs should be applicable to the Lake Huron fall survey because the experimental trawl tows used in their estimation were conducted at the same transects and depths and during the same time period as the fall-survey trawl tows. We took advantage of the paired nature of the tows in our analysis, which allowed us to account for substantial pair-specific variability. Although a paired design is intended to sample the same fish density and distribution twice, there is always some spatial or temporal variability introduced, because two trawls cannot be towed along the exact same path at the exact same time. Greater separation in time and space may introduce greater variability, depending on the movement rates and the patchiness of the spatial distributions of the various species (Pelletier 1998; Salthaug and Godø 2001; Lewy et al. 2004), which are poorly understood in Lake Huron. However, greater separation may also alleviate some of the potential effects of disturbance by the first tow on the second tow (Lewy et al. 2004).

Trawl tows that yielded no catch of a given species were excluded from our estimation of a FPC for that species. Ideally, FPCs should be estimated from paired trawl tows in which the given species is known to be present in the trawl path. Typically, however, presence in the trawl path is unknown. Thus, a zero catch can be the result of no catch in the presence of fish or of no fish in the trawl path. Some studies have included zero catches in their estimation of FPCs (Gulland 1967; Sissenwine and Bowman 1978; Byrne and Fogarty 1985; del Rio et al. 2003; Tyson et al. 2006), others have not (Cotter 2001; González Troncoso 2003; Cooper et al. 2004). If tows with zero catch are used in the estimation of FPCs, the inclusion of tows in which no fish were in the trawl path will certainly add bias and variance to the estimate. In addition, Cotter (2001) suggests that the inclusion of zero abundances may worsen the bias due to the added constant required prior to log transformation. Tyson et al. (2006) noted that high incidences of zero catches sometimes resulted in unreasonably large FPCs. Pelletier (1998) noted that low and zero catches are less informative in estimating FPCs. If tows with zero catch are not used in the estimation of FPC, the exclusion of tows in which fish were in the trawl path but no fish were captured will only add bias and variance to the estimate if the relation between the catch rates of the two nets changes with the size of the catch, an assumption implicit in the FPCs we estimated.

The recommended minimum number for estimating FPCs has been set at 50 paired trawl tows (Gulland 1967; Wilderbuer et al. 1998). Four of the six species for which we recommend FPCs (bloater, lake whitefish, deepwater sculpin, and slimy sculpin) did not meet this criterion; however, their FPCs were relatively precise with standard errors on the log scale ranging from 0.17 (bloater YAO) to 0.27 (slimy sculpin). These estimates were more precise than the estimate for alewife YOY (59 paired tows), which had a standard error of 0.30. As well, the estimates were within the range of precisions reported in other studies: standard errors from 0.05 to 0.24 (Sissenwine and Bowman 1978), 0.13-0.33 (Cotter 2001), 0.09-0.33 (Lewy et al. 2004), 0.05-0.38 (González and Paz 2003), 0.09-0.40 (Pelletier 1998), and 0.05-0.62 (Tyson et al. 2006).

The results of this study illustrate the difficulty of developing trawl FPCs for non-benthic fishes in the Great Lakes, particularly if the FPCs have to be developed post hoc. Despite having data from 75 pairs of trawl tows, we were able to develop valid FPCs for only half of the species that were common in trawl catches.

Because changes in survey vessels or nets require substantial investments of time and resources to develop valid FPCs, we advise maintaining continuity in vessels and nets for time-series surveys. If changes in vessels or nets are necessary, properly designed trawl-comparison experiments should be conducted prior to any anticipated changes. Although changes in survey vessels might be expected to have less effect on catch rates than changes in nets, vessel effects can nevertheless be significant (Cooper et al. 2004; Tyson et al. 2006), so FPCs should be developed if changes in survey vessels are anticipated.

In summary, 75 pairs of experimental tows conducted with 12-m Yankee and 21-m wing bottom trawls during the Lake Huron fall survey were sufficient to develop FPCs for the catch rates of YOY and YAO alewife and bloater, YAO rainbow smelt, lake whitefish, slimy sculpin, and deepwater sculpin. We recommend that our FPCs be applied to the catches of these species and life stages made with the 12-m Yankee trawl in Lake Huron during the 1973-1991 fall surveys. The fishing power of the two nets was the same for trout-perch, and no FPC should be applied to the catches of this species. Common species and life stages for which insufficient data were available to develop FPCs included YOY rainbow smelt, ninespine stickleback, lake trout, spottail shiner, johnny darter, and burbot. Because of more recent changes in the lake bottom and potential changes in fish distribution owing to the dreissenid invasion, no additional paired tows are recommended for those species with no or poorly known FPCs, We recommend that no further changes be made in the vessels or nets used to conduct the fall bottom-trawl survey in Lake Huron without first developing FPCs.

ACKNOWLEDGEMENTS

We thank C. Wilson, W. Boyle, R. Stedman, S. Baker, S. Harrington, J. Bruce, A. Bozymowski, R. Nester, and C. Bowen for collecting the comparative trawl data analyzed here. We thank D. Bunnell, M. Ebener, J. Savino, R. O'Gorman, R. Eshenroder, and two anonymous reviewers for comments on an earlier version of this report. This is contribution 1465 of the USGS Great Lakes Science Center.

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