Instruction Manual for the Lake Michigan Chinook Salmon-Alewife Predator-Prey Ratio Analysis

by

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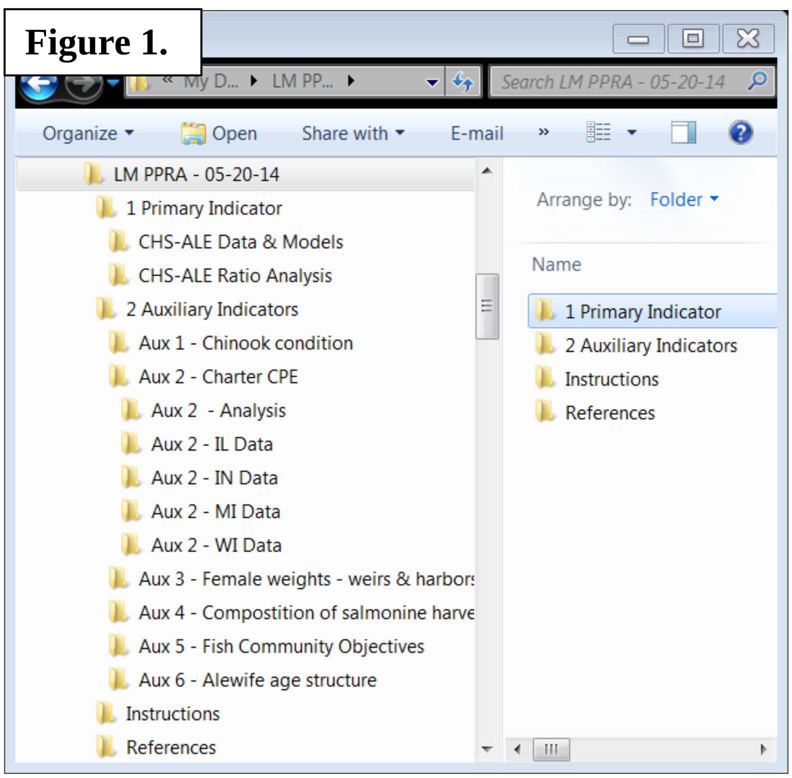
Introduction

The Lake Michigan Chinook salmon-alewife predator-prey ratio analysis (PPRA) was developed in a series of workshops in 2013 (Lake Michigan Salmonid Working Group and Collaborators 2014; Jones et al. 2014). The purpose of this report is to provide instructions for running the PPRA.

The primary purpose of the PPRA is to monitor the Chinook salmon-alewife predator-prey balance in the lake to help evaluate Chinook salmon stocking rates. The PPRA uses data collected by multiple government agencies: the Departments of Natural Resources for Illinois (ILDNR), Indiana (INDNR), Michigan (MIDNR), and Wisconsin (WIDNR), the US Geological Survey (USGS), and the US Fish and Wildlife Service (USFWS). The overall procedure involves: 1) assembling the necessary biological data; 2) estimating current-year values for each of the biological indicators and updating the time series of historical values; and 3) using the biological indicators and the projection model to judge the performance of the stocking policy.

Biological data, spreadsheets, Statistical Catch at Age models (SCA), scientific references, and these instructions are all organized in computer files within a main folder named "LM PPRA – 05-20-14" (Figure 1). The actual computer files for the current version can be obtained from the Chairs of the Salmonid (SWG) or Planktivore (PWG)

Figure 1.



Working Groups for Lake Michigan or from the Quantitative Fisheries Center (QFC), Michigan State University.

Most of the PPRA calculations are made within spreadsheets, but abundance estimates for Chinook salmon and alewife are made in AD Model Builder (ADMB) (Fournier et al. 2012). The person(s) running this analysis should have a basic knowledge of MS-Excel and ADMB, and these programs must be on the computer being used for the analysis. In addition to the instructions in this manual, many notes and comments are imbedded in the spreadsheets and ADMB .dat and source code files to help those running the analysis. The plan developed by SWG and PWG was to have members of their respective committees run the PPRA each year with the assistance of the QFC as needed. SWG would be responsible for completing the Chinook salmon SCA and associated indicators, and PWG would be responsible for completing the alewife SCA and associated indicators. Ideally, the committee Chairs should designate specific member(s) to be responsible for completing the PPRA each year.

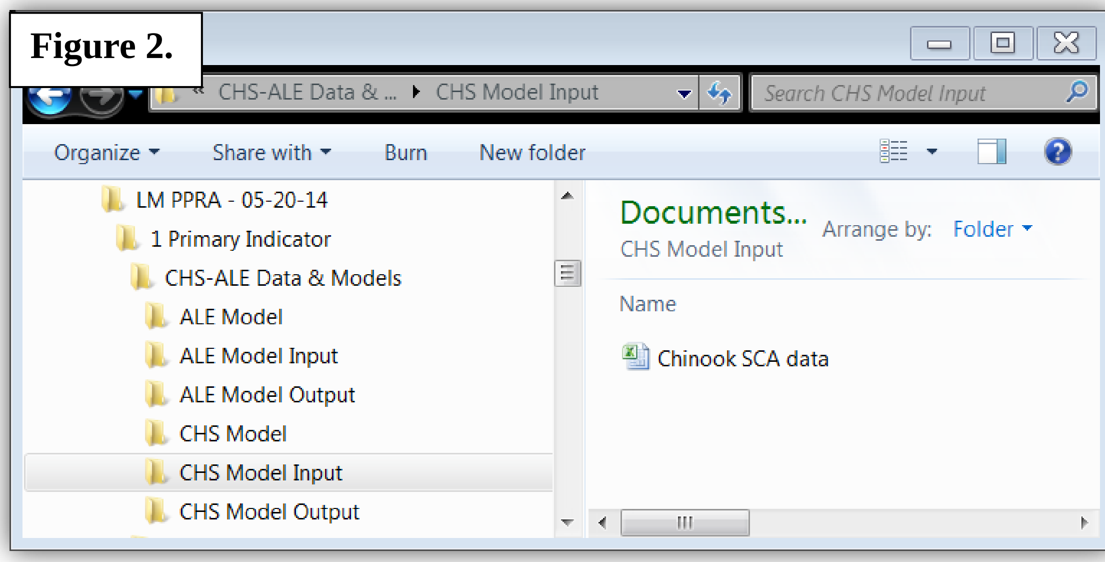
The data and results of the PPRA will change continuously through time. It will be very important to rigorously track and identify the official, current version of the software and analysis. In addition, we expect it will be necessary to make error corrections and analytical improvements to the PPRA as time goes on. Even the underlying software, MS-Excel and ADMB, will be revised into new versions, some of which could require changes to the PPRA. We suggest changing the date in the main computer folder name (Figure 1) when an official change is made to the analysis. This date could serve as a "stamp" to identify the PPRA version. Persons using data or results from the PPRA in future reports, papers, or other presentations should be encouraged to cite the date of the version they used in their references. To that end, we report here that we will be viewing the 05-20-14 version of the PPRA in these instructions. In addition, we will maintain a version date for these instructions on the cover page and footer of this report.

Step 1 – Request and assemble biological data

The PPRA is designed to assemble biological data for Chinook salmon and alewives on a lake-wide basis and to use it to assess the predator-prey balance. No data are collected specifically for the PPRA. The PPRA uses data collected for other purposes by the cooperating agencies. Data are requested from state and federal agencies by sending the spreadsheet templates included in the PPRA computer files and asking agency representatives to enter their data in appropriate cells. This process is described in detail below. An attempt should be made to have the analysis completed before the annual meeting of the Lake Michigan Committee (LMC) in late March.

A. Data for the predator-prey ratio indicator – The Chinook-Alewife predator-prey ratio (P-P ratio) is the primary biological indicator. It is estimated as (weight of age-1-and-older Chinook) / (weight of age-1-and-older alewives). These weight estimates are for the standing stocks of Chinook and alewives in spring of the year. First, the numbers by age are estimated for each population using the SCAs described in (Tsehaye et al. 2014a; and 2014b). Then, the numbers are multiplied by average weights at age to estimate the weights of the populations.

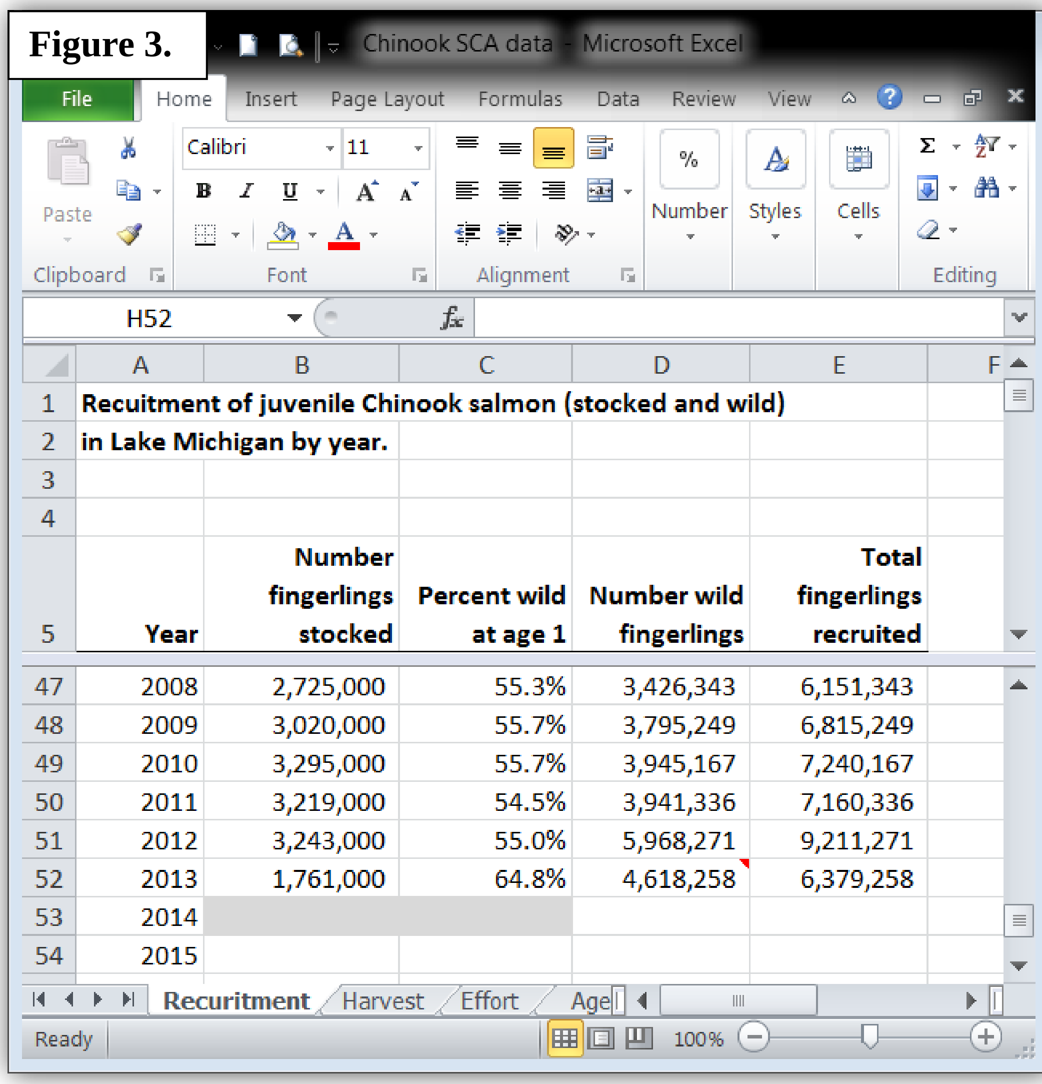
Chinook SCA – The "Chinook SCA data" spreadsheet contains much of the data needed to estimate the abundance of Chinook salmon in the SCA. It is located in the "CHS Model Input" folder (Figure 2).



The "Chinook SCA data" spreadsheet contains tables with data from 1986 to present, and these tables must be updated for the current year. Throughout the rest of this manual, 2014 will be considered as the current year to be updated and the spreadsheet cells that need to be updated will be indicated with gray shading.

Under the “Recruitment” tab, enter the number of Chinook stocked and the percent wild age-1 fish for the current year (Figure 3). Note that the percent wild in the current year is for age-1 fish, so it is used to estimate the number of wild fingerlings for the year before. Estimate the number of wild recruits in the current year as the average of the previous 3 years (see formulas and comments in spreadsheet).

Figure 3.



Recuitment of juvenile Chinook salmon (stocked and wild) in Lake Michigan by year.

Year	Number fingerlings stocked	Percent wild at age 1	Number wild fingerlings	Total fingerlings recruited
2008	2,725,000	55.3%	3,426,343	6,151,343
2009	3,020,000	55.7%	3,795,249	6,815,249
2010	3,295,000	55.7%	3,945,167	7,240,167
2011	3,219,000	54.5%	3,941,336	7,160,336
2012	3,243,000	55.0%	5,968,271	9,211,271
2013	1,761,000	64.8%	4,618,258	6,379,258
2014				
2015				

Under the "Harvest" tab, enter the total number of Chinook salmon harvested in each state, by stat district (Figure 4). These include all modes of lake fishing (boat, shore, and pier) for both "Charter" and "non-Charter" fishing. Note that to obtain complete estimates for Michigan waters, "expansions" must be added to direct creel survey estimates. These "expansions" were developed to adjust for statistical districts that were under-sampled for the given year. They use ratios between districts from previous years. For more information on "expansions", contact MIDNR.

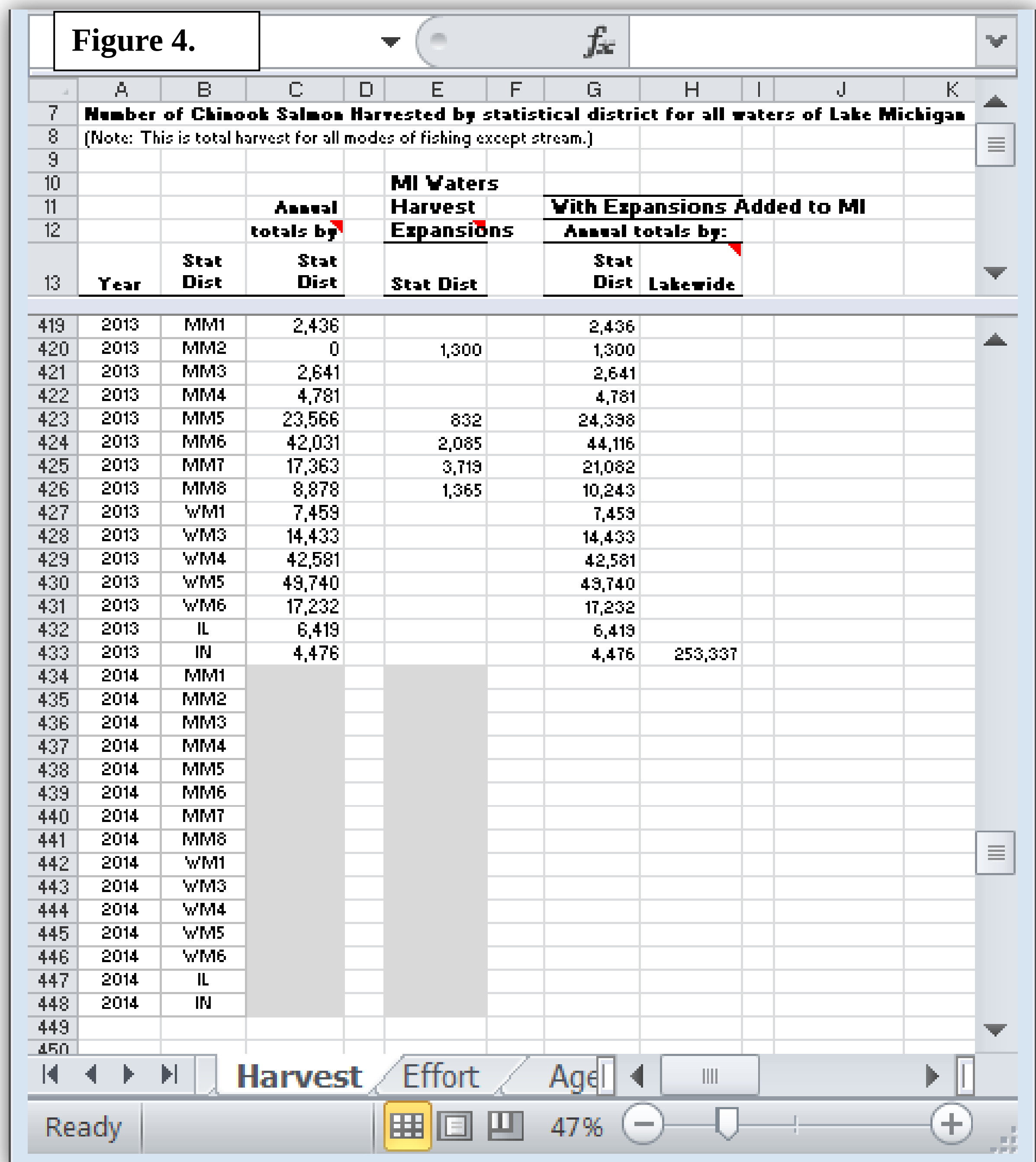


Figure 4.

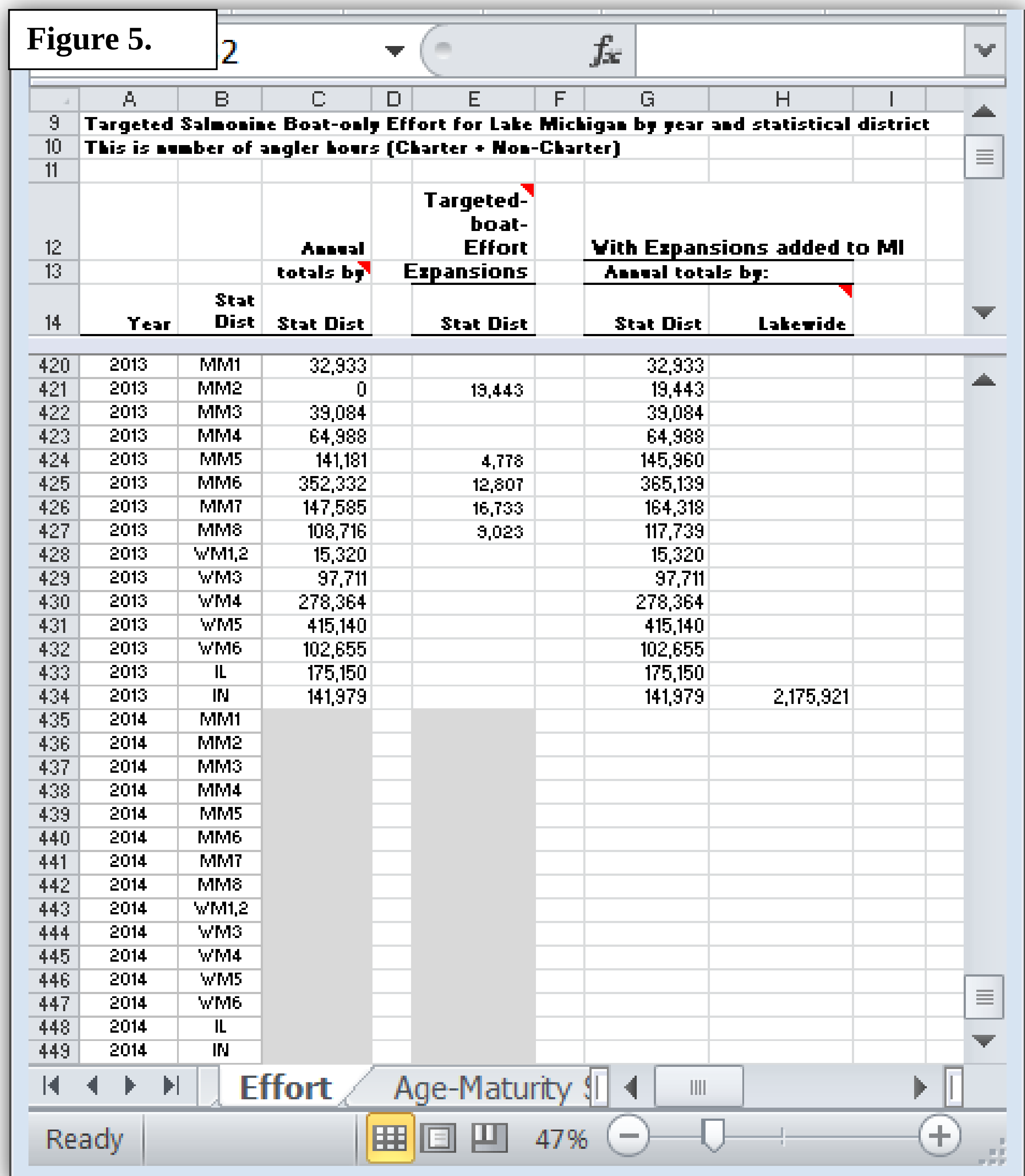
Number of Chinook Salmon Harvested by statistical district for all waters of Lake Michigan

(Note: This is total harvest for all modes of fishing except stream.)

	Year	Stat Dist	Annual totals by Stat Dist	MI Waters Harvest Expansions Stat Dist	With Expansions Added to MI Annual totals by: Stat Dist	Lakewide
419	2013	MM1	2,436		2,436	
420	2013	MM2	0	1,300	1,300	
421	2013	MM3	2,641		2,641	
422	2013	MM4	4,781		4,781	
423	2013	MM5	23,566	832	24,398	
424	2013	MM6	42,031	2,085	44,116	
425	2013	MM7	17,363	3,719	21,082	
426	2013	MM8	8,878	1,365	10,243	
427	2013	WM1	7,459		7,459	
428	2013	WM3	14,433		14,433	
429	2013	WM4	42,581		42,581	
430	2013	WM5	49,740		49,740	
431	2013	WM6	17,232		17,232	
432	2013	IL	6,419		6,419	
433	2013	IN	4,476		4,476	253,337
434	2014	MM1				
435	2014	MM2				
436	2014	MM3				
437	2014	MM4				
438	2014	MM5				
439	2014	MM6				
440	2014	MM7				
441	2014	MM8				
442	2014	WM1				
443	2014	WM3				
444	2014	WM4				
445	2014	WM5				
446	2014	WM6				
447	2014	IL				
448	2014	IN				

Under the “Effort” tab, enter the boat-mode-only, targeted fishing effort for each state (Figure 5). Note that to obtain complete estimates for Michigan waters, “expansions” must be added. Currently, expansions are only estimated in terms of total effort (all modes of angling), but boat-only effort is needed for the SCA. To estimate expansions in terms of boat-only effort, one must multiply the total effort expansion times the ratio of (boat effort) / (total effort) from the direct creel survey estimates for the statistical district in question. If that statistical district was not sampled at all for the current year, as MM2 in 2013 (Figure 5), then use the ratio from the most recent year for which it can be calculated.

Figure 5.



Targeted Salmonine Boat-only Effort for Lake Michigan by year and statistical district

This is number of angler hours (Charter + Non-Charter)

Row	Year	Stat Dist	Annual totals by Stat Dist	Targeted-boat-Effort Expansions Stat Dist	With Expansions added to MI Annual totals by: Stat Dist	With Expansions added to MI Annual totals by: Lakewide
420	2013	MM1	32,933		32,933	
421	2013	MM2	0	19,443	19,443	
422	2013	MM3	39,084		39,084	
423	2013	MM4	64,988		64,988	
424	2013	MM5	141,181	4,778	145,960	
425	2013	MM6	352,332	12,807	365,139	
426	2013	MM7	147,585	16,733	164,318	
427	2013	MM8	108,716	9,023	117,739	
428	2013	WM1,2	15,320		15,320	
429	2013	WM3	97,711		97,711	
430	2013	WM4	278,364		278,364	
431	2013	WM5	415,140		415,140	
432	2013	WM6	102,655		102,655	
433	2013	IL	175,150		175,150	
434	2013	IN	141,979		141,979	2,175,921
435	2014	MM1				
436	2014	MM2				
437	2014	MM3				
438	2014	MM4				
439	2014	MM5				
440	2014	MM6				
441	2014	MM7				
442	2014	MM8				
443	2014	WM1,2				
444	2014	WM3				
445	2014	WM4				
446	2014	WM5				
447	2014	WM6				
448	2014	IL				
449	2014	IN				

Under the “Age-Maturity” tab, enter the total numbers of all Chinook by age, the numbers of immature Chinook by age, and the numbers of mature Chinook by age (Figure 6). The spreadsheet uses these numbers to calculate the proportion mature by age and the overall proportion by age (Figure 7). These proportions are input to the SCA. Since 1986, these data have been provided by MIDNR from their creel bio-data files. However, data from other states could be added if available, but make sure the criteria for identifying immature and mature fish are consistent.

Figure 6.

k Aged

	Year	Month	Number Chinook by age: 1	2	3	4	5+	Total number aged
201	2012	4	5	11	6	1	0	23
202		5	34	80	21	1	0	136
203		6	38	114	112	9	0	273
204		7	42	131	169	5	0	347
205		8	31	154	189	7	0	381
206		9	11	82	146	4	0	243
207		10	0	3	5	0	0	8
208	2013	4						0
209		5						0
210		6	14	36	26	1	0	77
211		7	31	59	95	4	0	189
212		8	31	59	125	4	0	219
213		9						0
214		10						0
215	2014	4						
216		5						
217		6						
218		7						
219		8						
220		9						
221		10						

Immature Chinook Aged

Year	Month	Number Immature by age: 1	2	3	4	5+	Total number aged
2012	4	1	2	0	0	0	3
	5	11	50	3	0	0	64
	6	28	32	1	0	0	61
	7	27	46	10	1	0	84
	8	18	49	1	0	0	68
	9	4	8	2	0	0	14
	10	0	0	0	0	0	0
2013	4						0
	5						0
	6	10	14	0	0	0	24
	7	22	24	4	0	0	50
	8	19	21	3	0	0	43
	9						0
	10						0
2014	4						
	5						
	6						
	7						
	8						
	9						
	10						

Mature Chinook Aged

Year	Month	Number Mature by age: 1	2	3	4	5+	Total
2012	4	0	8	6	1	0	15
	5	0	25	17	1	0	43
	6	1	55	83	6	0	145
	7	7	70	141	4	0	222
	8	5	91	182	6	0	284
	9	6	73	141	3	1	224
	10	0	3	5	0	0	8
2013	4						0
	5						0
	6	4	22	26	1	0	53
	7	9	35	91	4	0	139
	8	12	38	122	4	0	176
	9						0
	10						0
2014	4						
	5						
	6						
	7						
	8						
	9						
	10						

Harvest | Effort | **Age-Maturity** | Weight at age | Indiana Fix | Illinois Fix

Ready 60%

Figure 7.

Proportions for Jun-Aug (Note: SCAA uses Jun-Aug data.)

(Note: Data for proportions below in are in columns A: to H:)

Maturity by Year (Jun-Aug) / **Age Structure by Year (Jun-Aug)**

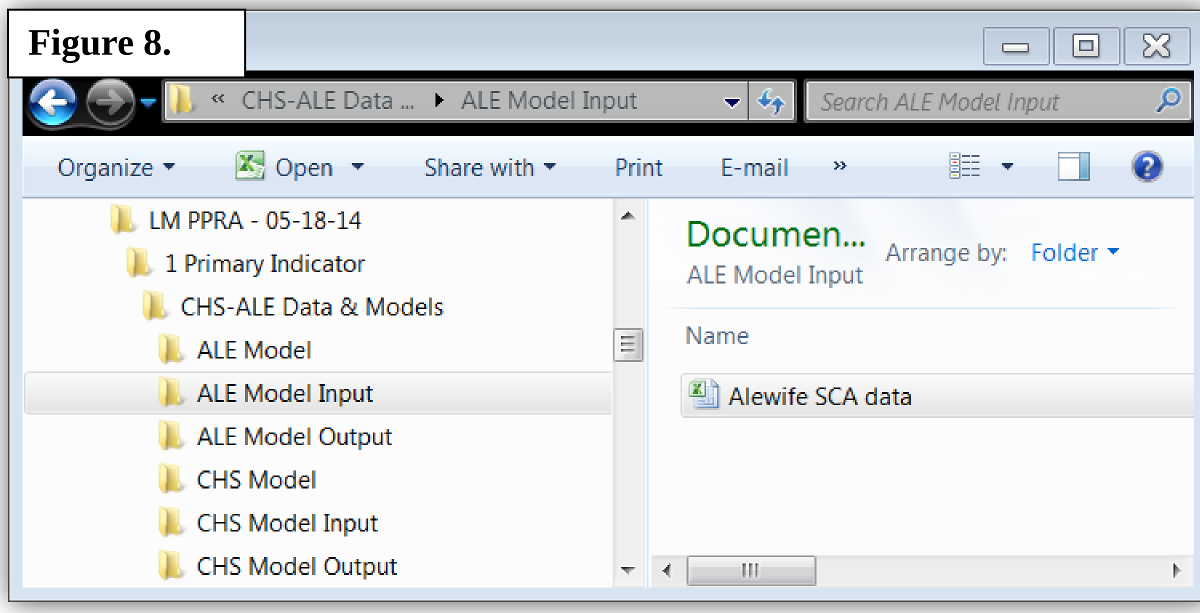
	Year	Proportion Mature by age: 1	2	3	4	5+	Year	Proportion of Harvest at age: 1	2	3	4	5+
31	2004	0.258	0.643	0.959	1.000	na	2004	0.111	0.255	0.522	0.112	0.000
32	2005	0.279	0.580	0.962	0.980	na	2005	0.123	0.406	0.381	0.090	0.000
33	2006	0.304	0.613	0.964	1.000	1.000	2006	0.105	0.468	0.377	0.049	0.001
34	2007	0.176	0.447	0.944	0.953	1.000	2007	0.030	0.293	0.606	0.070	0.002
35	2008	0.194	0.388	0.946	1.000	1.000	2008	0.073	0.397	0.460	0.066	0.004
36	2009	0.157	0.624	0.922	0.978	1.000	2009	0.092	0.371	0.475	0.058	0.004
37	2010	0.406	0.755	0.947	0.941	1.000	2010	0.089	0.374	0.477	0.058	0.002
38	2011	0.253	0.695	0.955	0.923	1.000	2011	0.168	0.463	0.342	0.023	0.003
39	2012	0.151	0.630	0.971	0.941	na	2012	0.111	0.399	0.470	0.021	0.000
40	2013	0.329	0.617	0.972	1.000	na	2013	0.157	0.318	0.507	0.019	0.000
41	2014						2014					
42												
43	Average:	0.157	0.432	0.881	0.973	1.000	Average:	0.180	0.364	0.374	0.079	0.002

Harvest | Effort | **Age-Maturity** | Weight at a

Ready 60%

Alewife SCA – Indices of abundance from three sources are used to estimate alewife abundance: trawl surveys, hydroacoustic surveys, and predator consumption estimates. The USGS Great Lakes Science Center in Ann Arbor, MI conducts the trawl and hydroacoustic surveys. The consumption estimates for Chinook salmon are part of the output of the Chinook SCA. This means that the Chinook SCA must be completed before the alewife SCA. The “Alewife SCA data” spreadsheet should be used to help organize the data needed. It is located in the “ALE Model Input” folder (Figure 8).

Figure 8.



Under the “Salmonid Stocking” tab, update the number of salmon and trout stocked in the current year (Figure 9).

Figure 9.

Numbers of salmon and trout stocked in Lake Michigan
(data from March 25, 2014 version of Salmonid Stocking Totals for Lake Michigan 1976-2013,. USFWS Green Bay National Fish & Wildlife Conservation Office, New Franken, WI 54229)

	Millions of fingerling and yearling stages combined				
Year	**Brown trout**	**Chinook salmon**	**Coho salmon**	**Lake trout**	**Rainbow trout**
2008	1.469	2.725	2.029	3.122	1.618
2009	1.632	3.020	1.746	3.177	2.069
2010	1.426	3.295	2.516	3.432	1.677
2011	1.336	3.219	2.567	3.454	1.833
2012	1.523	3.243	2.743	3.599	1.929
2013	1.443	1.761	2.546	3.571	1.906
2014					

Salmonid Stocking | Sheet1 | Sheet2

Under the “ALE Proportion by age” tab, update the proportion by age of alewives collected in the trawl survey (Figure 10).

Figure 10.

=A7-1

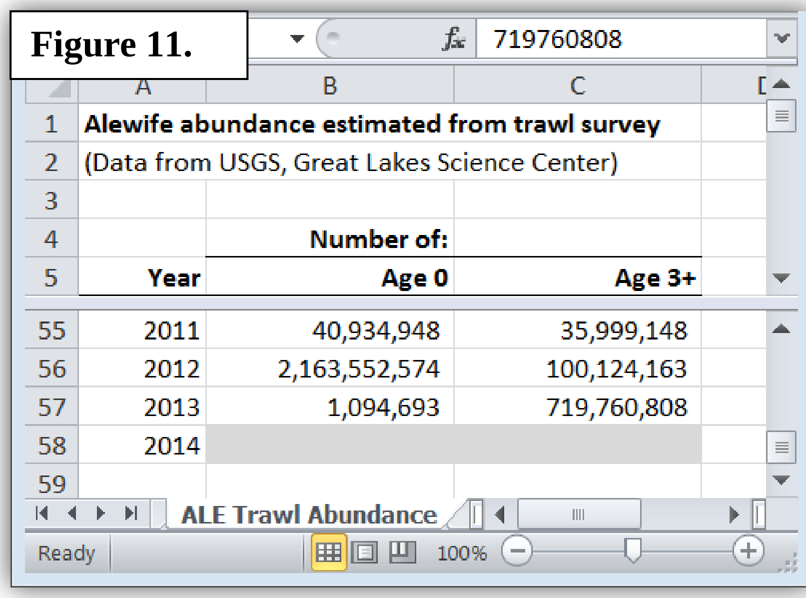
Alewife proportion by age in trawl samples
(Data from USGS, Great Lakes Science Center)

	Proportion at age:					
Year	**1**	**2**	**3**	**4**	**5**	**6+**
2011	0.823	0.123	0.042	0.009	0.002	0.001
2012	0.021	0.882	0.086	0.011	0.000	0.000
2013	0.413	0.101	0.470	0.009	0.008	0.000
2014						

ALE Proportion by age | ALE Trawl ab

Under the “ALE Trawl Abundance” tab, update the abundances from the trawl survey (Figure 11).

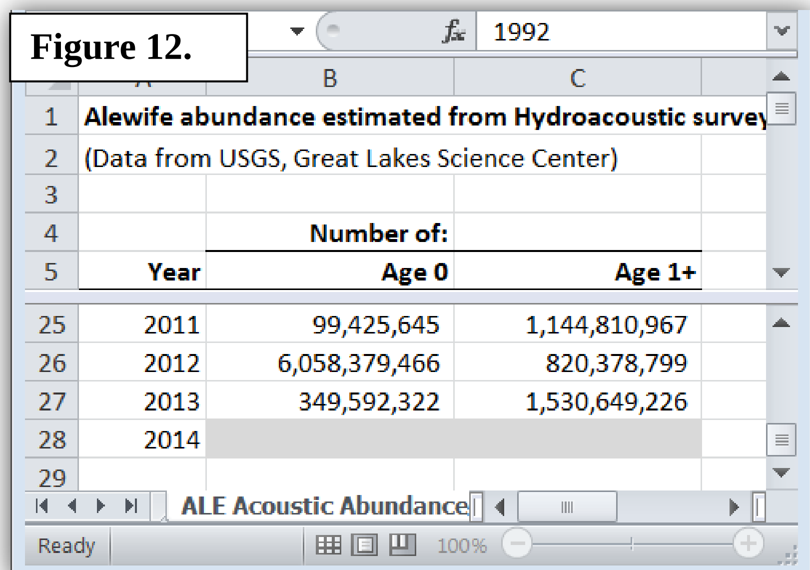
Figure 11.



	A	B	C
1	**Alewife abundance estimated from trawl survey**		
2	(Data from USGS, Great Lakes Science Center)		
3			
4		**Number of:**	
5	**Year**	**Age 0**	**Age 3+**
55	2011	40,934,948	35,999,148
56	2012	2,163,552,574	100,124,163
57	2013	1,094,693	719,760,808
58	2014		
59			

Under the “ALE Acoustic Abundance” tab, update the abundances from the hydroacoustic survey (Figure 12).

Figure 12.



	A	B	C
1	**Alewife abundance estimated from Hydroacoustic survey**		
2	(Data from USGS, Great Lakes Science Center)		
3			
4		**Number of:**	
5	**Year**	**Age 0**	**Age 1+**
25	2011	99,425,645	1,144,810,967
26	2012	6,058,379,466	820,378,799
27	2013	349,592,322	1,530,649,226
28	2014		
29			

B. Data for auxiliary indicators – Six auxiliary indicators are included in the analysis: 1) body condition of Chinook salmon collected from the fishery during July 1 through August 15; 2) charter fishery catch-per-effort (CPE); 3) average weights of age-3+ female Chinook salmon collected at weirs and harbors; 4) percent composition of salmonine species in the harvest; 5) relative success in achieving Fish Community Objectives; and 6) age structure of the alewife population. Data for each are located in the "Auxiliary Indicators" folder (Figure 1).

Chinook body condition indicator – The body condition of Chinook salmon in mid-summer of each year is the first auxiliary indicator. Condition is represented as the predicted weight of a 35-inch fish from a regression of the natural logs of weight (Y) versus length (X). Only fish collected from a relatively short period during summer (July 1 to August 15) are used to calculate the regression. Length-weight data are organized by individual state or agency. For example, lengths and weights from the Illinois creel survey are entered in file "CHS L-W data IL", lengths and weights from Michigan are entered in file "CHS L-W data-MI", and so on. Send spreadsheets to the appropriate agency representative and ask them to enter the individual lengths and weights of fish in their respective spreadsheets. For example, Figure 13 is the spreadsheet for Illinois. The units of measure used in the length-weight regressions are inches and pounds, so unit conversions might be necessary as in Figure 13.

Figure 13.

Illinois data compiled by Charlie Roswell, ILNHS, August 27, 2013.

(Lengths and weights of Chinook salmon July 1 - August 15)

(Note: Please indicate units of measure.)

Row	A	B: Date collected	C: Length (cm)	D: Weight (g)	E	F: Length (in)	G: Weight (pounds)
1946		8/11/2013	75.8	5000		29.8	11.0
1947		8/11/2013	74.5	4750		29.3	10.5
1948		8/11/2013	94	10400		37.0	22.9
1949		8/11/2013	42	1000		16.5	2.2
1950		8/11/2013	69	4250		27.2	9.4
1951							
1952							
1953							

Chinook catch per effort indicator – The catch per effort (CPE) of Chinook salmon in the charter fishery for each year is the second auxiliary indicator. Catch per effort is represented as (number of Chinook salmon harvested) / (targeted, boat-only salmonine effort in angler hours). Catch-per-effort data files are organized by state. For example, data from Illinois is in file "Charter CPE for CHS - IL", data from Michigan is in file "Charter CPE for CHS - MI", and so on. Send spreadsheets to the appropriate agency representative and ask them to enter effort and catch in their respective spreadsheets. For example, Figure 14 is the spreadsheet for Illinois.

Figure 14.

	A	B	C	D	E	F
1	**State of Illinois**					
2	**Charter Fishery Effort and Harvest by Year**					
3	Note: This is for boat mode of charter fishing only.					
4	Do not include charter fishing for shore, pier, or stream fishing modes.					
5						
6	**Year**	**Targeted Salmonine Effort (Angler Hours)**	**Targeted Harvest of Chinook salmon (number)**			
31	2010	96914	12174			
32	2011	95376	9310			
33	2012	98891	12327			
34	2013	98328	6450			
35	2014					
36						

Sheet1 Sheet2 Sheet3

Ready 100%

Female Chinook weights at weirs indicator – The average weight of age-3+ female Chinook salmon collected each year at weirs and harbors is the third auxiliary indicator. Note that these should be weights of "egg full" fish. Do not include weights of spent fish. Weights of individual females sampled are organized by state. For example, data from Illinois is in file "Weights of Age 3+ CHS at IL Harbors". Send spreadsheets to the appropriate agency representative and ask them to enter the ages and weights in their respective spreadsheets. For example, Figure 15 is the spreadsheet for Illinois.

Figure 15.

	A	B	C	D	E	F	G	H
1	**Weights of Age 3+ Female Chinook Salmon at Illinois Harbors returning in fall**							
2	**(Data from Steve Robillard 8/16/13)**							
3	Weir name =	multiple IL harbors						
4		(note: RR and S fish in idnr designation were deleted for this analysis.)						
5								
6	Sample Date	AGE	WEIGHT (g)	Weight (Pounds)	LENGTH (mm)	Length (Inches)	SEX	FUL_SPEN
466	11/13/2013	3	6300	13.9	905	35.6	F	Full
467	11/13/2013	3	7500	16.5	930	36.6	F	Full
468	11/13/2013	3	5620	12.4	865	34.1	F	Full
469								
470								
471								
472								

Sheet1 Sheet2 Sheet3

Ready 100%

Salmonine harvest composition indicator – The composition of the recreational salmonine harvest each year is the fourth auxiliary indicator. Composition is represented as the percent by weight of Chinook salmon, lake trout, steelhead, coho salmon, and brown trout. These same data are already being organized on a lake-wide basis in the "Extractions Database" so it should be requested from the person in charge of updating that database (currently Brian Breidert, INDNR).

FCO performance indicator – A measure of the performance of the stocking policy in achieving the Salmonine Fish Community Objectives (FCO) (Eschenroder et al. 1995) is the fifth auxiliary indicator. The only data required by this indicator are the annual numbers of salmonines stocked and these data have already been assembled for the alewife SCA as described above (Figure 9).

Alewife age structure indicator – The age structure of the alewife population each year is the sixth auxiliary indicator. Age structure is represented as the number and percentage by age for age-1-and-older alewives. This indicator uses the estimated number of alewives by age from the alewife SCA as "data". Thus, the alewife SCA must be completed before this indicator can be completed.

Enter the SCA model estimated number of alewives by age for the entire time series from 1967 to present into the "Alewife percent by age" spreadsheet (Figure 16). Be sure to update this entire time series of estimates rather than the estimates for the current year only. The SCA refits the abundance estimates over the entire time series when the new data are added for the current year. Slight changes in the abundance estimates are likely to occur over all years whenever these new data are added.

Figure 16.

	A	B	C	D	E	F	G	H
1	Age-structure of alewives							
2								
3								
4			Alewife number by age from SCA					
5	Year	0	1	2	3	4	5	6+
45	2006	1.40E+10	9.33E+09	2.49E+09	1.05E+09	5.07E+08	1.18E+08	3.27E+08
46	2007	1.78E+10	5.43E+09	3.85E+09	9.18E+08	3.89E+08	1.90E+08	1.73E+08
47	2008	1.50E+10	6.19E+09	2.18E+09	1.45E+09	3.49E+08	1.50E+08	1.45E+08
48	2009	1.22E+10	5.89E+09	2.41E+09	8.00E+08	5.45E+08	1.35E+08	1.19E+08
49	2010	3.50E+10	4.59E+09	2.35E+09	8.99E+08	3.09E+08	2.17E+08	1.05E+08
50	2011	1.66E+09	1.47E+10	1.92E+09	9.04E+08	3.54E+08	1.25E+08	1.35E+08
51	2012	2.91E+10	3.41E+08	6.53E+09	7.94E+08	3.77E+08	1.50E+08	1.14E+08
52	2013	2.06E+09	9.77E+09	1.26E+08	2.69E+09	3.43E+08	1.68E+08	1.22E+08
53	2014							
54								

Sheet1 Sheet2 Sheet3

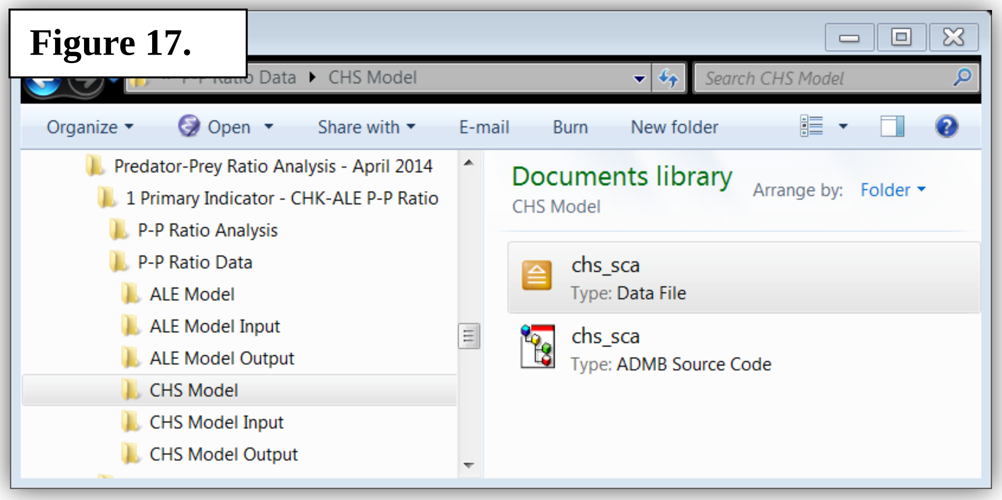
Ready 100%

Step 2 – Estimate current-year values for biological indicators and update time series of historical values

A. *P-P ratio indicator* –

Chinook salmon – Estimate the abundance by age of Chinook salmon using the SCA that is set up in the "CHS Model" folder. Transfer data from the "Chinook SCA data" spreadsheet into the ADMB input data file, which is located in the "Chinook Model" folder (Figure 17). This transfer is not set up to be a simple copy-paste operation. Data must be entered manually.

Figure 17.



The ADMB .dat file is designed to be self-explanatory with text headers and/or notes followed by each category of data. Figure 18 illustrates the first few data arrays in the "chs_sca" data file.

Figure 18.

```
# This is the Chinook SCAA data file - updated for 2013 on Mar 15, 2014
# FIRST AND LAST MODEL AGE

 0 5

# FIRST AND LAST MODEL YEAR (FOR RECRUITMENT)

 1967 2013

# LK MI CHS RECRUITS AT AGE 0
# NUMBERS STOCKED FOR 1967-2013

 801390 687000  718000  1904000 2317000
 2023128 3045767 3578053 4279782 3317057
 2976879 5365263 4984271 6105924 4746993
 6312127 6539413 7709749 5955000 5693000
 5800000 5417000 7859000 7125000 6237000
 5795000 5491000 5894000 6400000 6193000
 5534000 5860000 4212000 4429000 4220000
 4014861 4540000 4305716 4302821 3225000
 3173000 2725000 3020000 3295000 3219000
 3243000 1761000

# NUMBERS OF WILD RECRUITED 1967-2013

 0 0 0 10000 50000
 70000 120000 200000 280000 380000
 480000 580000 630000 800000 1200000
 1300000 1500000 1550000 1600000 1700000
 1750000 1800000 1900000 3839000 2550000
 2139000 2184000 1633000 2563000 2485000
 2888750 3292500 3696250 3696250 6900000
 4600000 2400000 4100000 2867000 3980021
 3922982 3426343 3795249 3945167 4034390
 5968271 4649276
```

When the data file is updated, double click on the “ADMB Source Code” file (Figure 19) to run the SCA. ADMB will generate several new files in the “CHS Model” folder. The estimates of the abundance of Chinook salmon by age will be in the “ADMB Report” file (Figures 19). This output array is designated as “N” in the report file (Figure 20).

Figure 19.

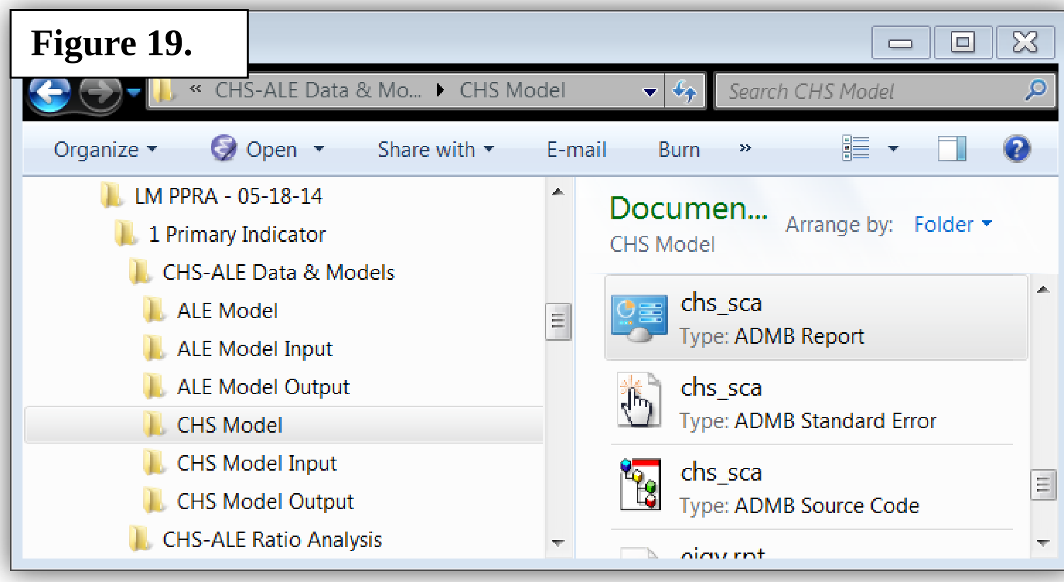
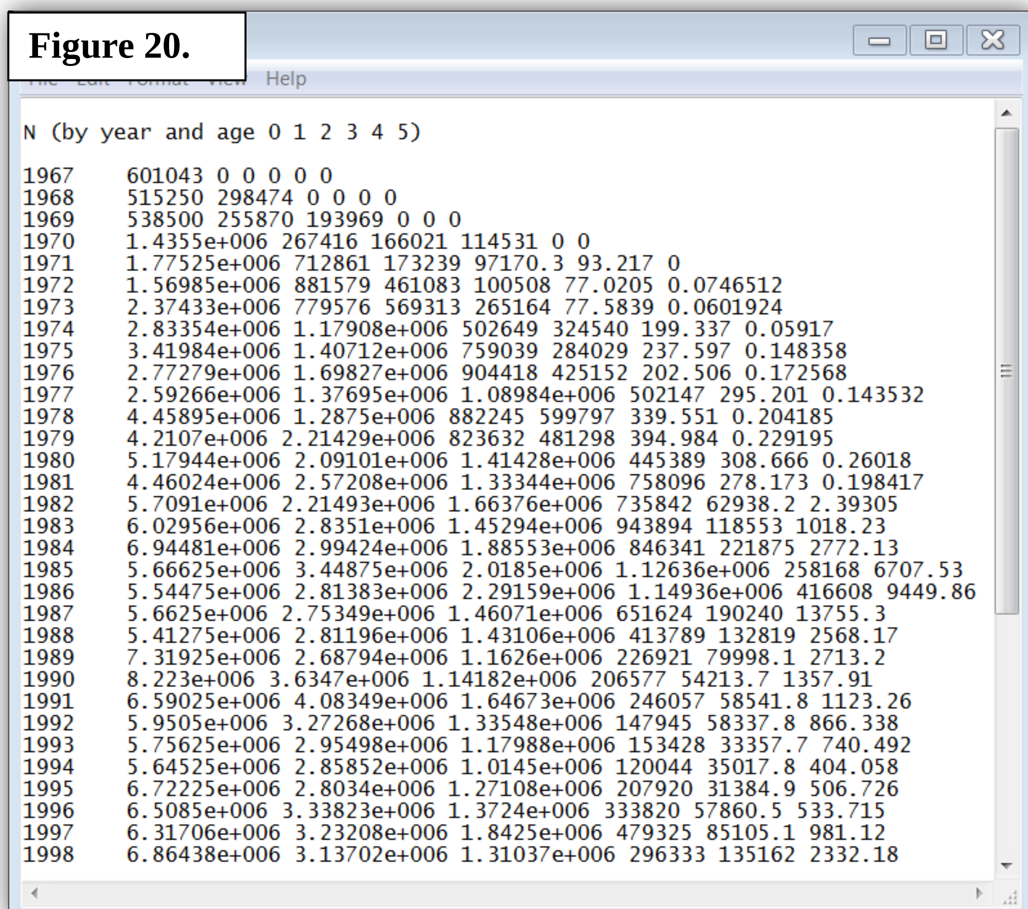


Figure 20.

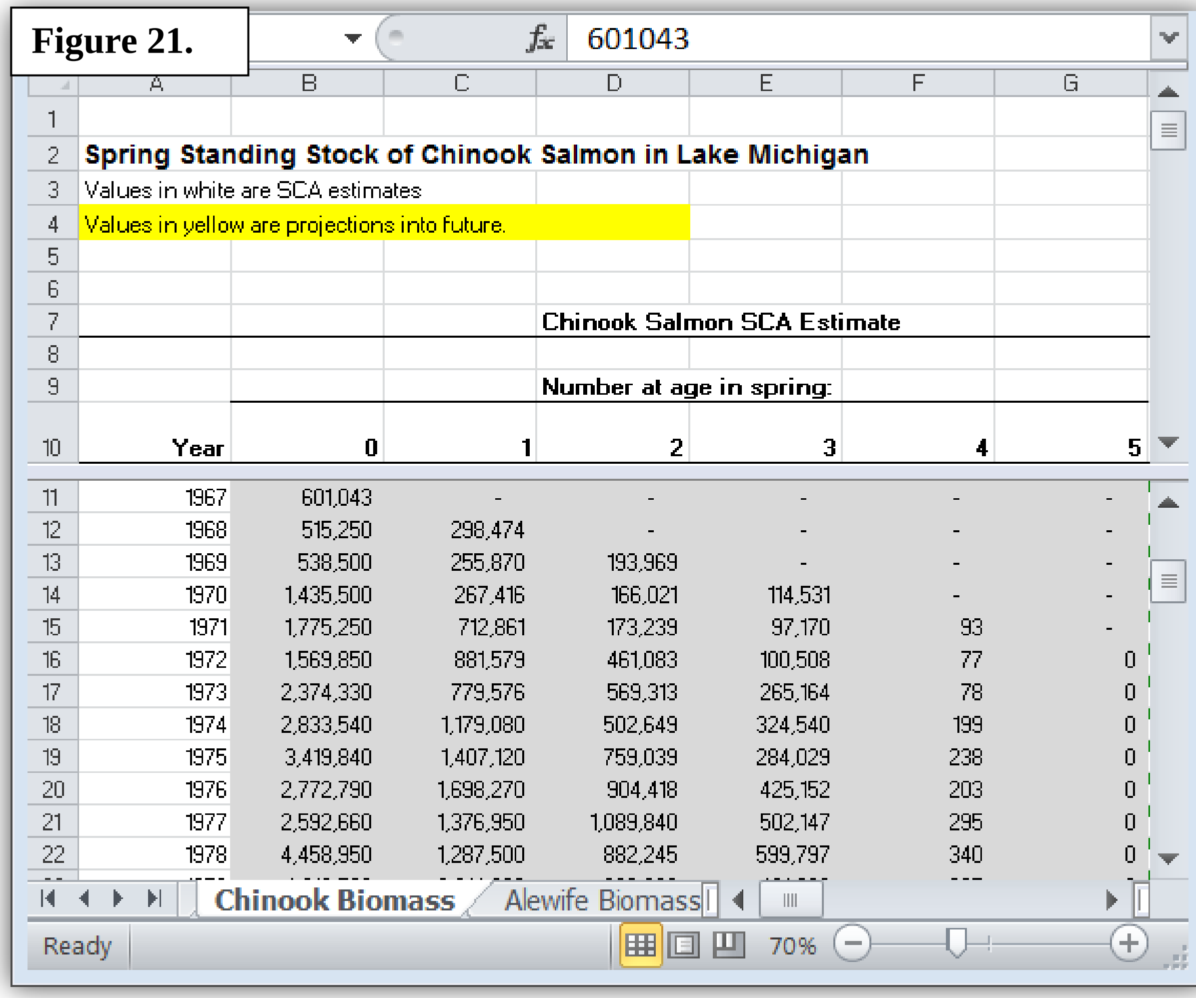



```
N (by year and age 0 1 2 3 4 5)

1967    601043 0 0 0 0 0
1968    515250 298474 0 0 0 0
1969    538500 255870 193969 0 0 0
1970    1.4355e+006 267416 166021 114531 0 0
1971    1.77525e+006 712861 173239 97170.3 93.217 0
1972    1.56985e+006 881579 461083 100508 77.0205 0.0746512
1973    2.37433e+006 779576 569313 265164 77.5839 0.0601924
1974    2.83354e+006 1.17908e+006 502649 324540 199.337 0.05917
1975    3.41984e+006 1.40712e+006 759039 284029 237.597 0.148358
1976    2.77279e+006 1.69827e+006 904418 425152 202.506 0.172568
1977    2.59266e+006 1.37695e+006 1.08984e+006 502147 295.201 0.143532
1978    4.45895e+006 1.2875e+006 882245 599797 339.551 0.204185
1979    4.2107e+006 2.21429e+006 823632 481298 394.984 0.229195
1980    5.17944e+006 2.09101e+006 1.41428e+006 445389 308.666 0.26018
1981    4.46024e+006 2.57208e+006 1.33344e+006 758096 278.173 0.198417
1982    5.7091e+006 2.21493e+006 1.66376e+006 735842 62938.2 2.39305
1983    6.02956e+006 2.8351e+006 1.45294e+006 943894 118553 1018.23
1984    6.94481e+006 2.99424e+006 1.88553e+006 846341 221875 2772.13
1985    5.66625e+006 3.44875e+006 2.0185e+006 1.12636e+006 258168 6707.53
1986    5.54475e+006 2.81383e+006 2.29159e+006 1.14936e+006 416608 9449.86
1987    5.6625e+006 2.75349e+006 1.46071e+006 651624 190240 13755.3
1988    5.41275e+006 2.81196e+006 1.43106e+006 413789 132819 2568.17
1989    7.31925e+006 2.68794e+006 1.1626e+006 226921 79998.1 2713.2
1990    8.223e+006 3.6347e+006 1.14182e+006 206577 54213.7 1357.91
1991    6.59025e+006 4.08349e+006 1.64673e+006 246057 58541.8 1123.26
1992    5.9505e+006 3.27268e+006 1.33548e+006 147945 58337.8 866.338
1993    5.75625e+006 2.95498e+006 1.17988e+006 153428 33357.7 740.492
1994    5.64525e+006 2.85852e+006 1.0145e+006 120044 35017.8 404.058
1995    6.72225e+006 2.8034e+006 1.27108e+006 207920 31384.9 506.726
1996    6.5085e+006 3.33823e+006 1.3724e+006 333820 57860.5 533.715
1997    6.31706e+006 3.23208e+006 1.8425e+006 479325 85105.1 981.12
1998    6.86438e+006 3.13702e+006 1.31037e+006 296333 135162 2332.18
```

Find and open the “CHS-ALE Ratio” spreadsheet. It is located in the “CHS-ALE Ratio Analysis” folder (Figure 19). Copy the Chinook abundance estimates from the ADMB report file and paste them into the “CHS-ALE Ratio” spreadsheet under the “Chinook Biomass” tab (Figure 21). Be sure to update the entire time series, and all age classes.

Figure 21.



601043

Spring Standing Stock of Chinook Salmon in Lake Michigan

Values in white are SCA estimates

Values in yellow are projections into future.

Chinook Salmon SCA Estimate

Number at age in spring:

Year	0	1	2	3	4	5
1967	601,043	-	-	-	-	-
1968	515,250	298,474	-	-	-	-
1969	538,500	255,870	193,969	-	-	-
1970	1,435,500	267,416	166,021	114,531	-	-
1971	1,775,250	712,861	173,239	97,170	93	-
1972	1,569,850	881,579	461,083	100,508	77	0
1973	2,374,330	779,576	569,313	265,164	78	0
1974	2,833,540	1,179,080	502,649	324,540	199	0
1975	3,419,840	1,407,120	759,039	284,029	238	0
1976	2,772,790	1,698,270	904,418	425,152	203	0
1977	2,592,660	1,376,950	1,089,840	502,147	295	0
1978	4,458,950	1,287,500	882,245	599,797	340	0

Chinook Biomass | Alewife Biomass

Ready 70%

Update the projection model which predicts the abundance of Chinook salmon for the next 6 years (2014-2019 in Figure 22). Anyone familiar with MS-Excel should be able to understand the logic behind the projection model by examining the formulas in this spreadsheet. For future survival rates, use the average survival rate for the last 3 years for each age group. For future numbers of wild smolts, use the average number for the last 3 years. For future numbers of stocked smolts, use the anticipated number to be stocked for the current stocking policy.

Figure 22.

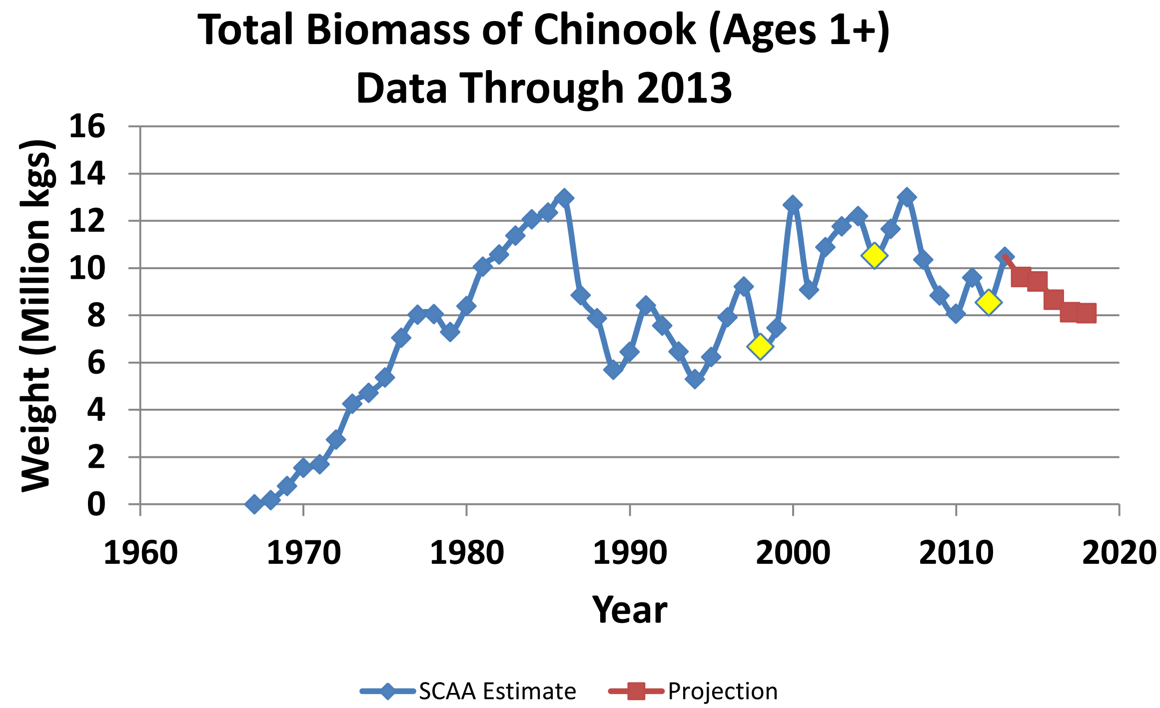
	A	B	C	D	E	F	G	H
57	2013	4,807,710	3,430,700	1,527,040	682,328	248,566	7,682	5,896,316
58	2014	4,715,476	2,387,481	2,074,457	700,780	205,194	8,968	5,376,879
59	2015	4,715,476	2,341,678	1,443,649	951,997	210,743	7,403	4,955,469
60	2016	4,715,476	2,341,678	1,415,953	662,510	286,290	7,603	4,714,035
61	2017	4,715,476	2,341,678	1,415,953	649,800	199,234	10,329	4,616,994
62	2018	4,715,476	2,341,678	1,415,953	649,800	195,412	7,188	4,610,031
63	2019	4,715,476	2,341,678	1,415,953	649,800	195,412	7,050	4,609,893
64								
65	Projection uses last 3-years' (2010-2013) average survival rates as given below.							
66		0	1	2	3	4		
67		0.4966	0.6047	0.4589	0.3007	0.0361		
68								
69				**Recruitment values used in projection**				Number stocked in:
70				Lakewide stocking rate 2010-2012 =	3,277,667			
71				Post-stocking mortality =	25%			
72				Hatchery smolts to lake 2010-2012 =	2,458,250			
73				Percent wild 2010-2012 =	58%			
74				Lake-wide wild smolts for 2010-2012 =	3,394,726			
75								
76								
77				Lake-wide stocking rate for projection =	1,761,000	= Stocking rate 2013 and after		
78				Hatchery smolts to lake for projection =	1,320,750			
79				Lake-wide wild smolts for projection =	3,394,726			
80				Total smolts for projection =	4,715,476			
81								
82								

Chinook Biomass | Alewife Biomass

Ready 70%

The spreadsheet calculates the weight of the Chinook population for all years by multiplying abundances at age by average weights at age. Use these calculations to update the graph of the estimated biomass by year that is generated by the SCA for previous years and the projection model for future years (Figure 23).

Figure 23.



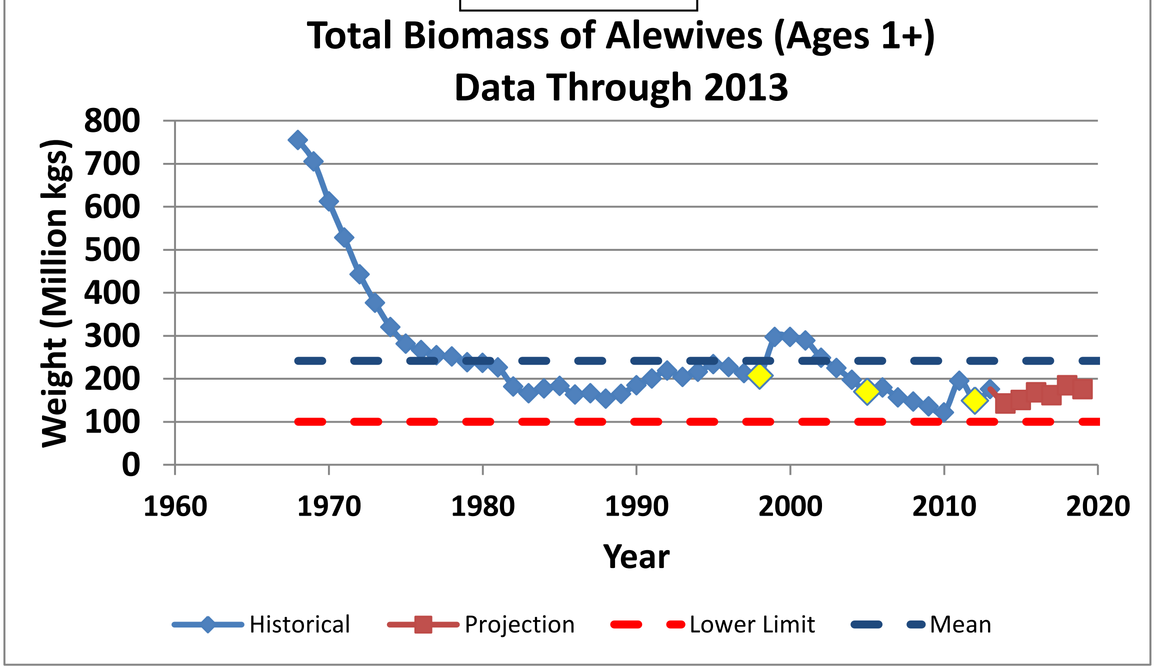
Alewives – Follow the same procedure for estimating alewife biomass as was used for Chinook salmon: 1) estimate abundance up to the current year with the alewife SCA using ADMB; 2) estimate total biomass up to the current year using the spreadsheet; 3) estimate total abundance and biomass for future years using the projection model, and 4) update the graph of biomass by year (Figure 24). The ADMB data file and source code are located in the "ALE Model" folder (Figure 17). The alewife biomass calculations, projection model estimates, and graphic displays are performed in the "CHS-ALE Ratio" spreadsheet file under the "Alewife Biomass" tab (Figure 21).

The projection model for alewives assumes that adult alewife mortality in the future will change in proportion to Chinook salmon biomass. The average alewife mortality for the previous 3 years is used as the initial value, and then it is adjusted up or down based on the projected change in Chinook salmon biomass. For example, if Chinook salmon biomass is projected to increase by 10%, then alewife mortality will be adjusted upward by 10%. These calculations are built into the spreadsheet.

For future numbers of age-0 alewife recruits in the projection model, use the average number for the entire time series as estimated by the SCA.

Figure 24 shows the final results of these procedures. Also, shown is the lower limit and mean (or target) for alewife biomass. The lower limit of 100 kt was identified by biologists and stakeholders using structured decision analysis (Jones et al 2008). They decided that alewife biomass below this level presented an unacceptable risk of population collapse. The target of 240 kt is the mean alewife biomass from 100 runs of the risk assessment model (Szalai 2003) as was used in that analysis to simulate a 50% cut in the stocking rate of Chinook salmon, which is the current stocking policy. The lower limit and target do not change every year, but are used to help judge the success of the stocking policy. For example, if either the observed or projected alewife biomass is below the lower limit, the stocking policy should be reviewed.

Figure 24.



Finally, calculate the P-P ratio for all years in the “CHS-ALE Ratio” spreadsheet under the “Predator-Prey Ratio” tab (Figure 25) and update the graph showing the estimated ratios over time (Figure 26).

Figure 25.

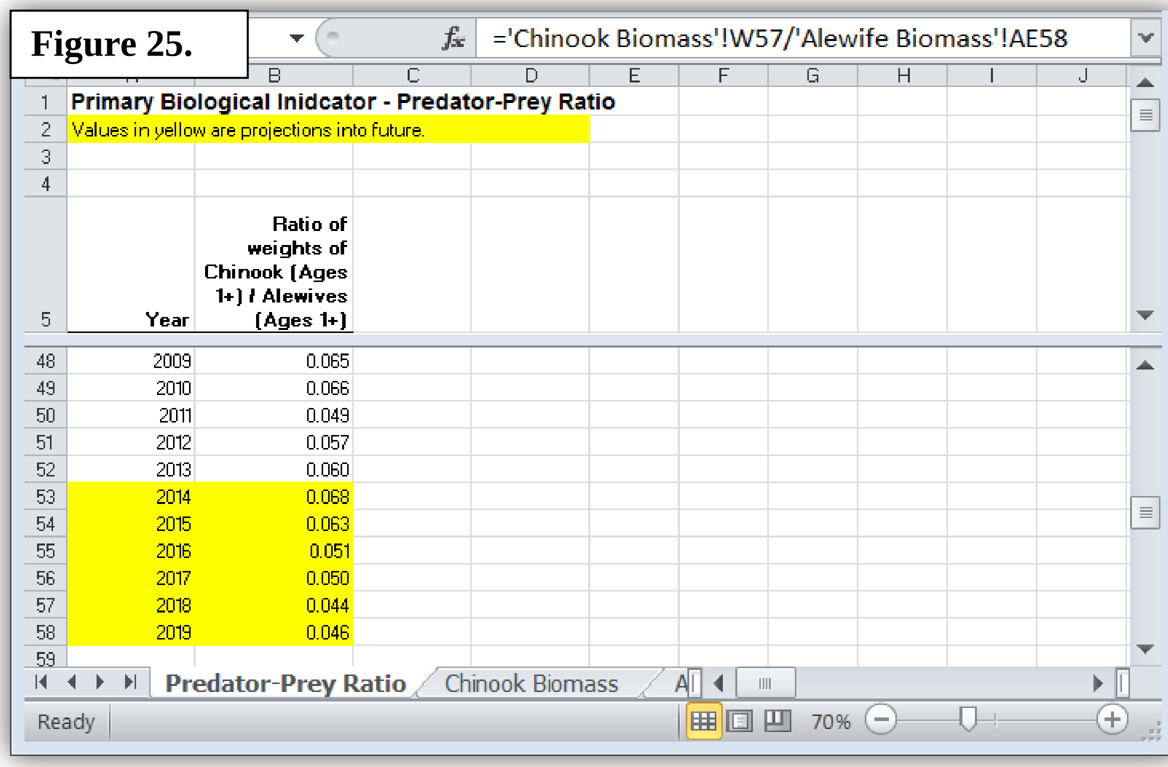
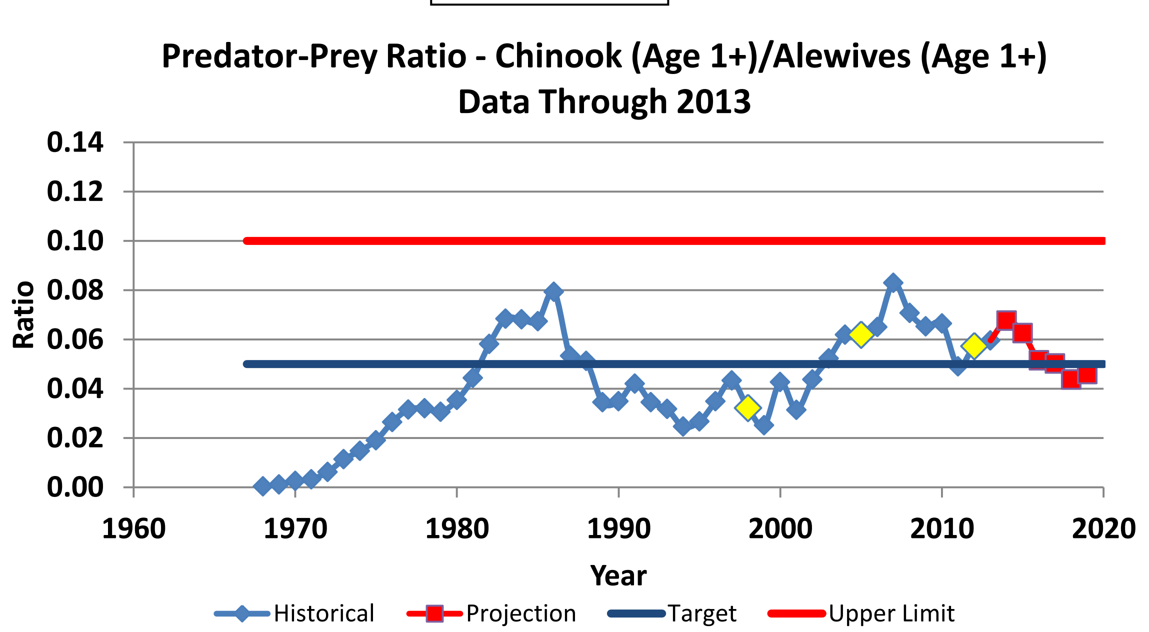


Figure 26.



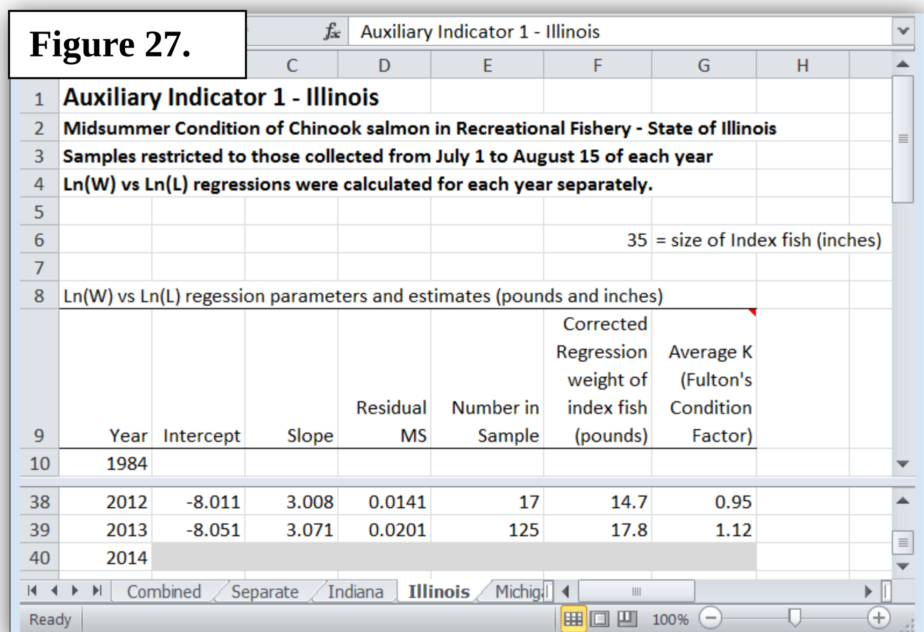
The target and upper limit for the P-P ratio of 0.050 and 0.100, respectively, were recommended by SWG (Lake Michigan Salmonid Working Group and Collaborators 2014; Jones et al. 2014). We will not go into great detail here about how these values were derived, but they were based on runs of the risk assessment model (Szalai 2003) and comparisons of P-P ratios for similar systems in other lakes. Basically, these are the P-P ratios corresponding to the target and lower limit defined for the alewife biomass in Figure 24. Outcomes of the risk assessment model suggest that exceeding a P-P ratio of 0.100, gives the same probability of predator-prey system collapse (15%) as the alewife population falling below 100 kts.

In addition, comparisons of P-P ratios in other lakes seem to support an upper limit near 0.100. The Chinook salmon-alewife P-P ratio in Lake Ontario was well below 0.100, at 0.065 from 1999 to 2005 (based on biomass estimates of Murry et al 2009), and while some concern has been expressed about the sustainability of that predator-prey system, it did not collapse. On the other hand, the Chinook salmon-alewife predator-prey system of Lake Huron did collapse in 2003-2006 (Johnson et al. 2010), and the average P-P ratio for the five years prior to the collapse was 0.112 (James Bence, QFC, Michigan State University, personal communication). Thus, it would seem prudent for managers to avoid P-P ratios near or above 0.100 in Lake Michigan.

B. Auxiliary Indicators –

Chinook body condition indicator – Use the data analysis feature of MS-Excel to calculate linear regressions for the current year from the ln-transformed length-weight data supplied by each agency. Then, accumulate the results for all the agencies in the spreadsheet named "Aux 1 - Trends in Chinook Condition", which is located in the "Aux 1 – Analysis" folder. The spreadsheet has a tab for each agency. Enter the intercepts, slopes, residual mean square (MS), and sample sizes for the regressions for each agency as shown for the State of Illinois in Figure 27. Then, copy down the regression formula in column E to estimate the weight of the standard 35-inch Chinook salmon for the current year. This formula uses the residual MS to correct the bias in the ln-transformed error term as described in Newman (1993).

Figure 27.



Auxiliary Indicator 1 - Illinois

Auxiliary Indicator 1 - Illinois

Midsummer Condition of Chinook salmon in Recreational Fishery - State of Illinois

Samples restricted to those collected from July 1 to August 15 of each year

Ln(W) vs Ln(L) regressions were calculated for each year separately.

35 = size of Index fish (inches)

Ln(W) vs Ln(L) regession parameters and estimates (pounds and inches)

Row	Year	Intercept	Slope	Residual MS	Number in Sample	Corrected Regression weight of index fish (pounds)	Average K (Fulton's Condition Factor)
10	1984						
38	2012	-8.011	3.008	0.0141	17	14.7	0.95
39	2013	-8.051	3.071	0.0201	125	17.8	1.12
40	2014						

Combined | Separate | Indiana | Illinois | Michig

Ready 100%

Estimate the weight of a 35-inch fish for all the agencies separately under the "Separate" tab, and then combine them into a lake-wide estimate by calculating a weighted average under the "Combined" tab. This average is weighted by the number of samples collected by each agency. The formula is built into the spreadsheet. The result is the Chinook salmon condition indicator. Add the current-year estimate to the time series and plot values as in Figure 28. Individual agency estimates are also plotted separately for comparison (Figure 29). Notice that data from the Michigan waters of Lake Huron are also included in the graphs so that one can compare the condition of fish in a lake in which the predator-prey system collapsed (2003-2006).

Figure 28.

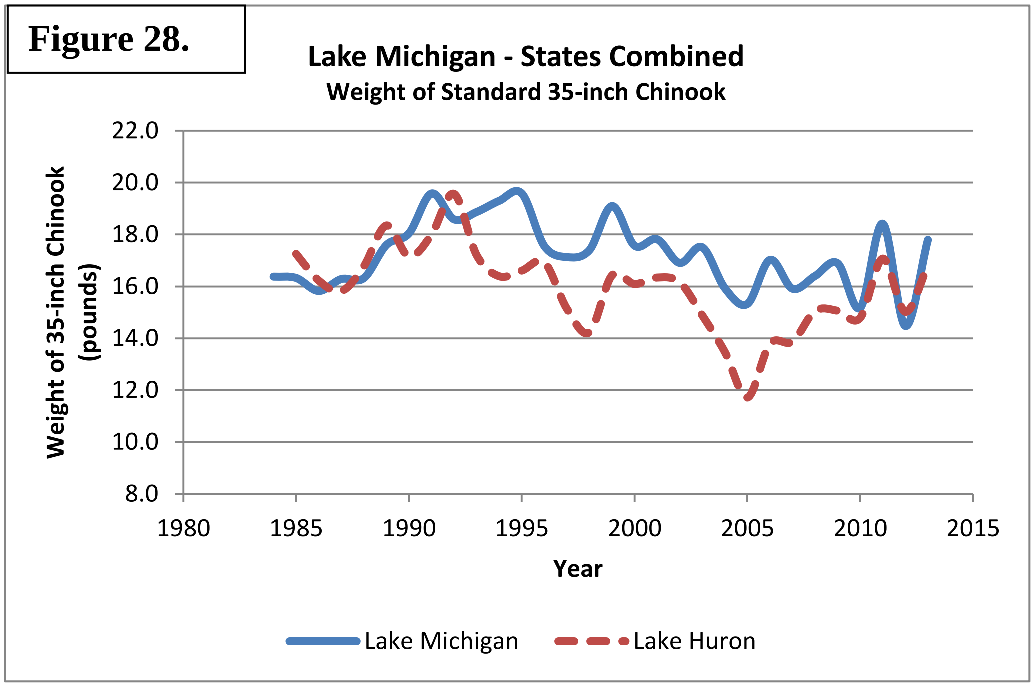
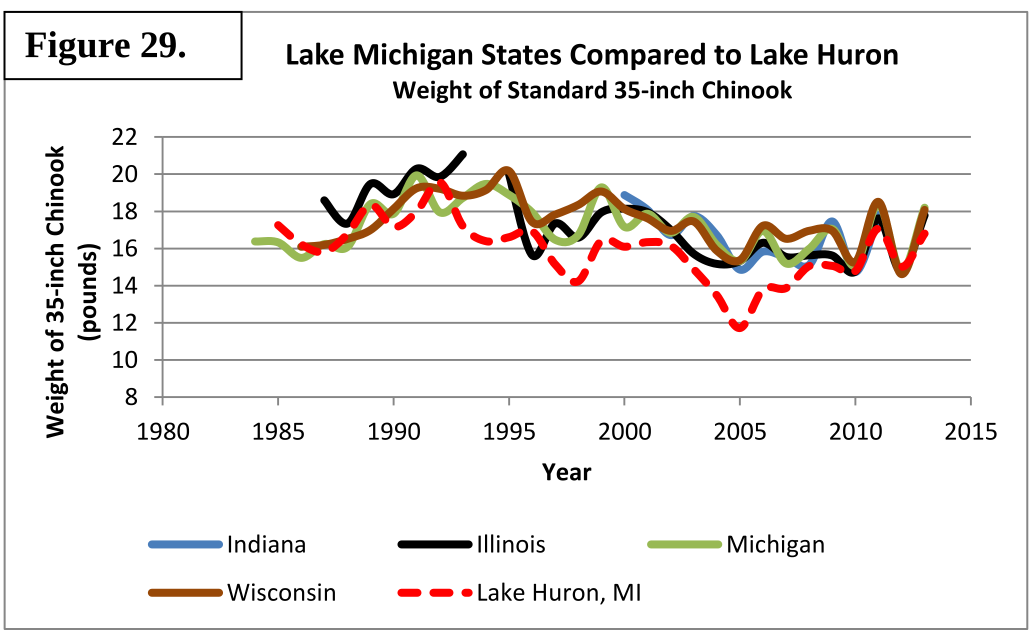
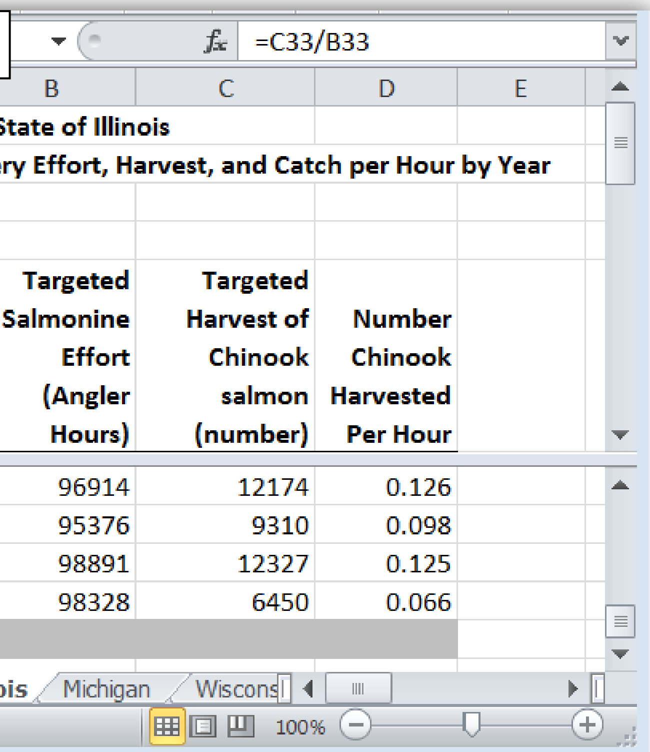


Figure 29.



Chinook catch per effort indicator – Accumulate the charter catch and effort data from the individual states in the spreadsheet named "Aux 2 – Charter CPE for CHS", which is located in the "Aux 2 – Analysis" folder. The spreadsheet has a tab for each agency. Enter the number harvested and targeted effort for each agency as shown for the State of Illinois in Figure 30. Then, copy down the formula in column D to estimate the CPE of Chinook salmon for the current year.

Figure 30.


=C33/B33

Auxiliary 2 - State of Illinois

Charter Fishery Effort, Harvest, and Catch per Hour by Year

Year	Targeted Salmonine Effort (Angler Hours)	Targeted Harvest of Chinook salmon (number)	Number Chinook Harvested Per Hour
2010	96914	12174	0.126
2011	95376	9310	0.098
2012	98891	12327	0.125
2013	98328	6450	0.066
2014			

Estimate the Chinook salmon CPE for all the agencies separately under the "Separate" tab, and then combine them into a lake-wide estimate by calculating the 4-state average under the "Combined" tab. This lake-wide estimate is the sum of the harvests divided by the sum of the efforts. The formula is built into the spreadsheet. The result is the charter CPE indicator. Add the current-year estimate to the time series and plot values as in Figure 31. Individual agency estimates of Charter CPE are also plotted separately for comparison (Figure 32).

Figure 31.

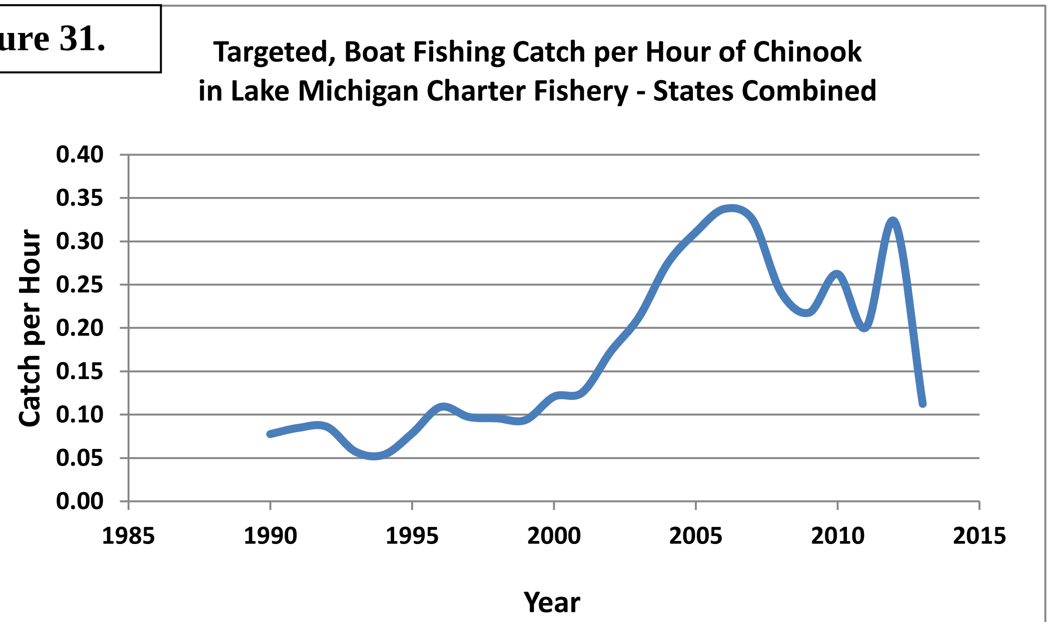
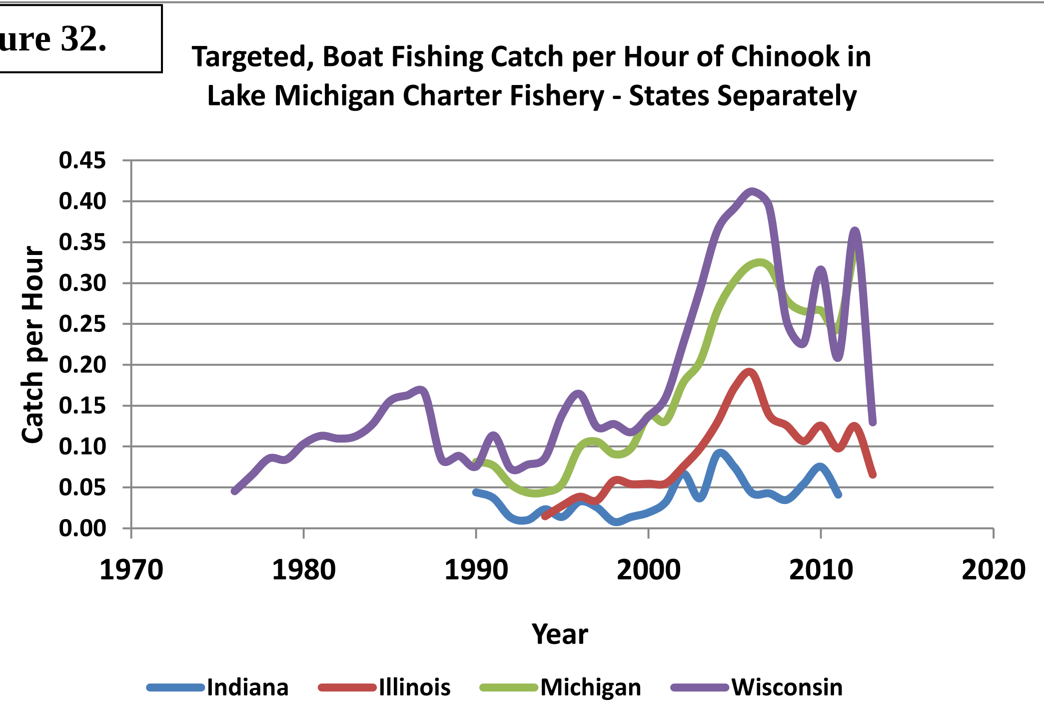
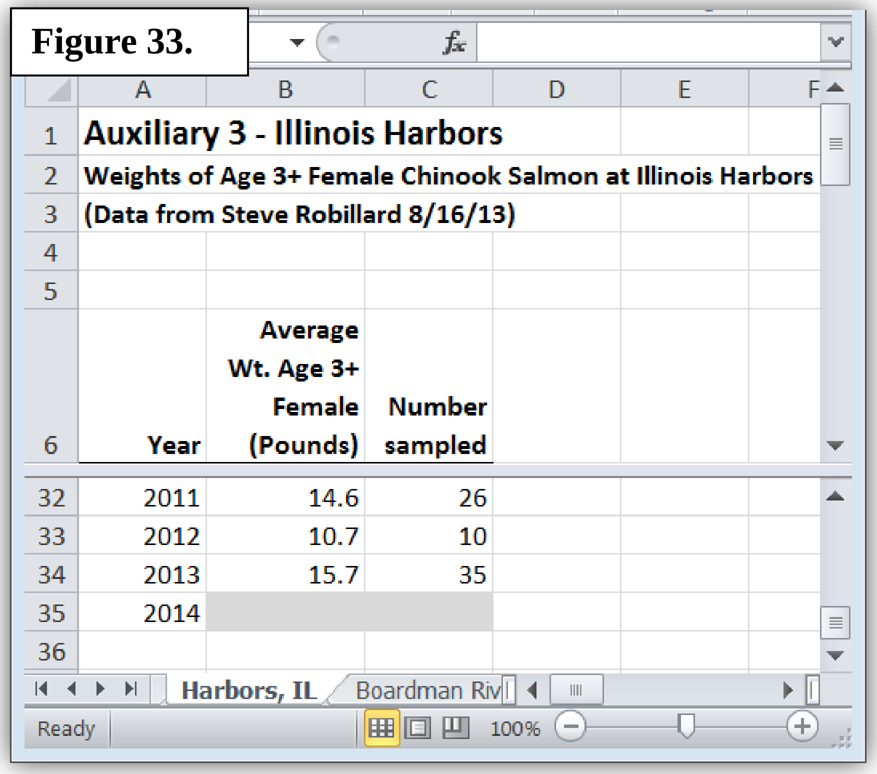


Figure 32.



Female Chinook weights at weirs indicator – Accumulate the age 3+ weights and numbers sampled from the individual states in the spreadsheet named "Aux 3 – Age 3+ Female CHS wts", which is located in the "Aux 3 – Analysis" folder. The spreadsheet has a tab for each weir or agency. Calculate and enter the average weights and numbers sampled for each weir or agency as shown in Figure 33 for Illinois harbors.

Figure 33.



Auxiliary 3 - Illinois Harbors

Weights of Age 3+ Female Chinook Salmon at Illinois Harbors

(Data from Steve Robillard 8/16/13)

Year	Average Wt. Age 3+ Female (Pounds)	Number sampled
2011	14.6	26
2012	10.7	10
2013	15.7	35
2014		

Calculate and assemble the average weights of age 3+ females for all the agencies separately under the "Separate" tab, and then combine them into a lake-wide estimate by calculating a weighted average under the "Combined" tab. This average is weighted by the number of samples by individual weir or harbor. The formula is built into the spreadsheet. This result is the female-weight indicator. Add the current-year estimate to the time series and plot values as in Figure 34. Individual weir or agency estimates of age-3+ female weights are also plotted separately for comparison (Figure 35).

Figure 34.

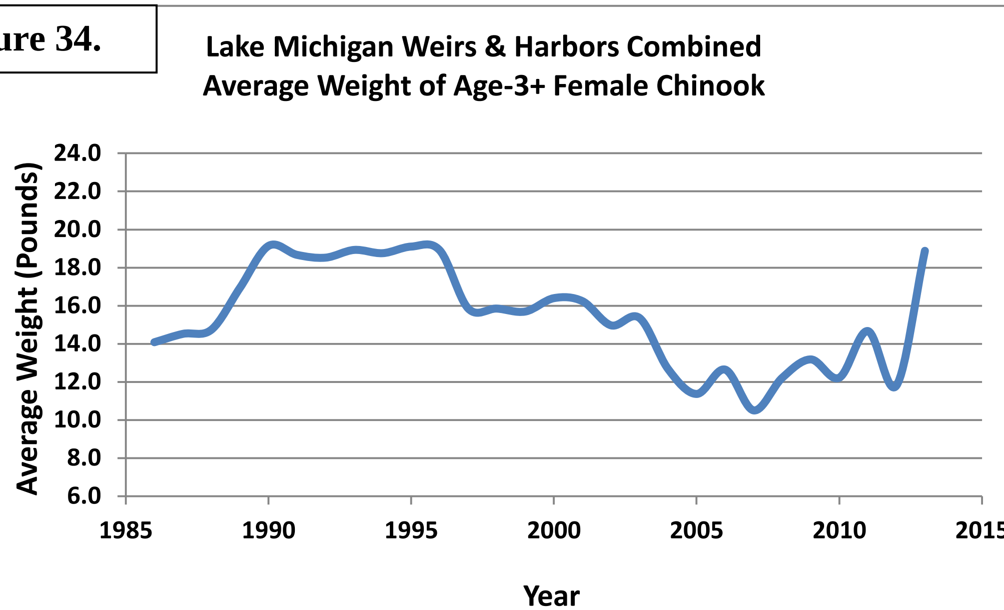
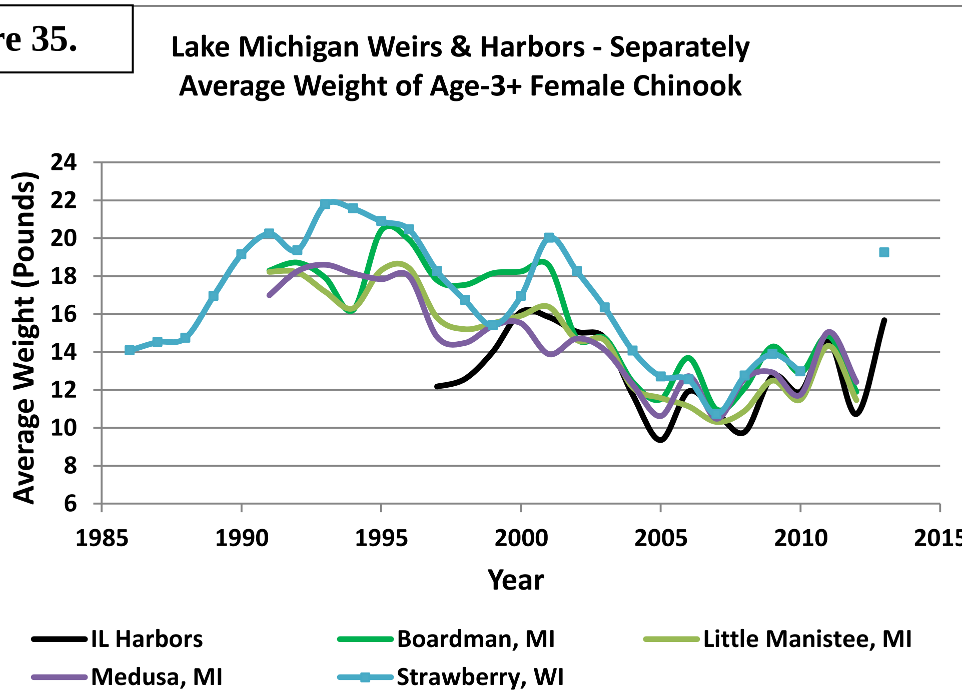
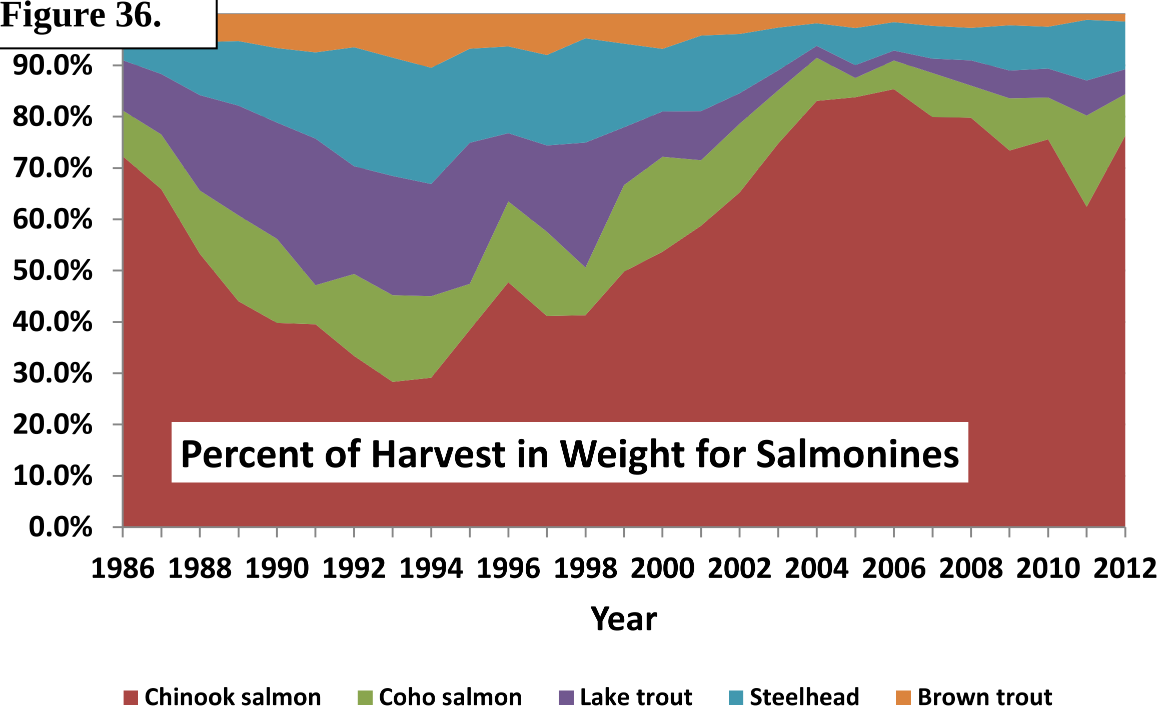


Figure 35.



Salmonine harvest composition indicator – Enter the weights harvested for each salmonine species for the current year in the spreadsheet named "Aux 4 – Harvest Composition - Analysis", which is located in the "Aux 4 – Analysis" folder. Plot the time series as a stacked area plot, as shown in Figure 36.

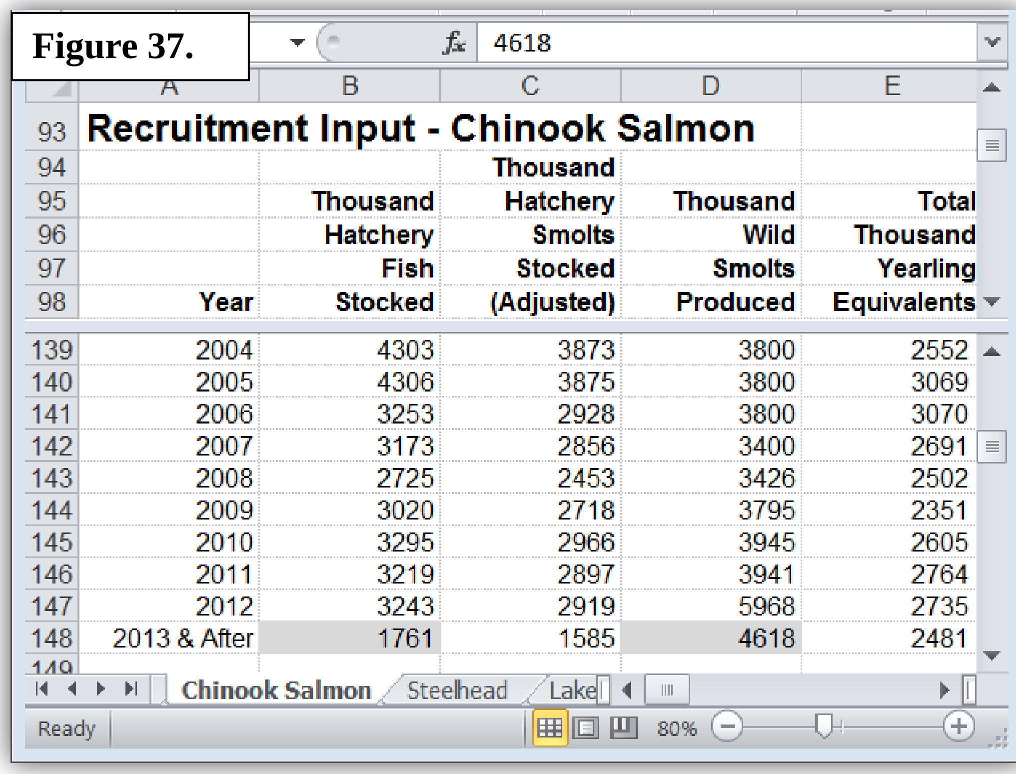
Figure 36.



FCO performance indicator – This indicator is expressed as the “FCO Index”, which is calculated as the sum of the deviations between the salmonine yields from a hypothetical run of the CONNECT model (Rutherford 1997, Lake Michigan Salmonid Stocking Task Group 1998) to the yield expectations identified in the Fish Community Objectives. The hypothetical model run estimates the yields that would have occurred today if the levels of recreational fishing effort during the 1980s had continued to present. In reality, fishing effort has declined, which is why these yield predictions are considered hypothetical. Clark (2012) gives a more detailed description of the “FCO Index” and the reasoning behind it in Recommendation 3 of his report.

To calculate the “FCO Index”, enter the number of Chinook salmon recruits expected (stocked and wild) for the current and future years into the “Connect 4” model spreadsheet (Figure 37). This spreadsheet is located in the “Aux 5 – Data and Model” folder. Enter the same data for each of the other salmonines under the appropriate spreadsheet tabs. The “CONNECT 4” spreadsheet uses this recruitment data to estimate potential yields for each species in age-structured models.

Figure 37.



	A	B	C	D	E
93	Recruitment Input - Chinook Salmon				
94			Thousand		
95		Thousand	Hatchery	Thousand	Total
96		Hatchery	Smolts	Wild	Thousand
97		Fish	Stocked	Smolts	Yearling
98	Year	Stocked	(Adjusted)	Produced	Equivalents
139	2004	4303	3873	3800	2552
140	2005	4306	3875	3800	3069
141	2006	3253	2928	3800	3070
142	2007	3173	2856	3400	2691
143	2008	2725	2453	3426	2502
144	2009	3020	2718	3795	2351
145	2010	3295	2966	3945	2605
146	2011	3219	2897	3941	2764
147	2012	3243	2919	5968	2735
148	2013 & After	1761	1585	4618	2481

Next, open the spreadsheet named "Aux 5 – FCO Analysis", which is located in the "Aux 5 – FCO Analysis" folder. This spreadsheet is linked to the "Connect 4" model spreadsheet, so click "yes" to update the links when opening the file. The yield estimates will be transferred to appropriate cells under the "Tables" tab and the deviations between the potential yields and the FCO expectations will be calculated in column "D" for Chinook salmon, "I" for lake trout, and so on (Figure 38).

Figure 38.

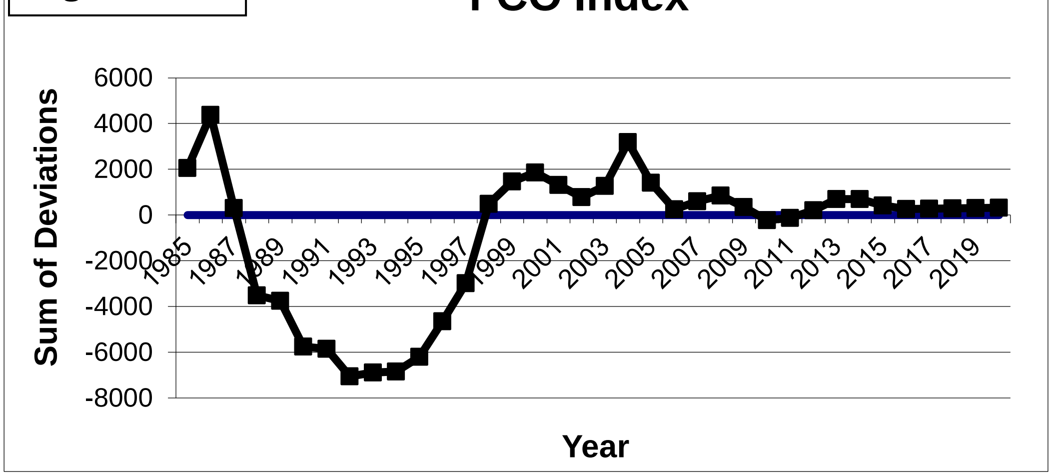
=H37-G37

	Chinook Salmon				Lake Trout		
Year	Chinook Harvest FCO (1000s pounds)	Potential Chinook Harvest (1000s pounds)	Chinook Deviations	Year	Lake Trout Harvest FCO (1000s pounds)	Potential Lake Trout Harvest (1000s pounds)	Lake Trout Deviations
2006	6820	7717	897	2006	2420	1700	-720
2007	6820	8077	1257	2007	2420	1746	-674
2008	6820	8297	1477	2008	2420	1830	-590
2009	6820	7730	910	2009	2420	1982	-438
2010	6820	7107	287	2010	2420	2141	-279
2011	6820	6842	22	2011	2420	2234	-186
2012	6820	7121	301	2012	2420	2268	-152
2013	6820	7504	684	2013	2420	2319	-101
2014	6820	7498	678	2014	2420	2380	-40
2015	6820	7142	322	2015	2420	2438	18

Tables | Chinook | Lake Trout | Steelhead | Coho | Brown Trout | FCO

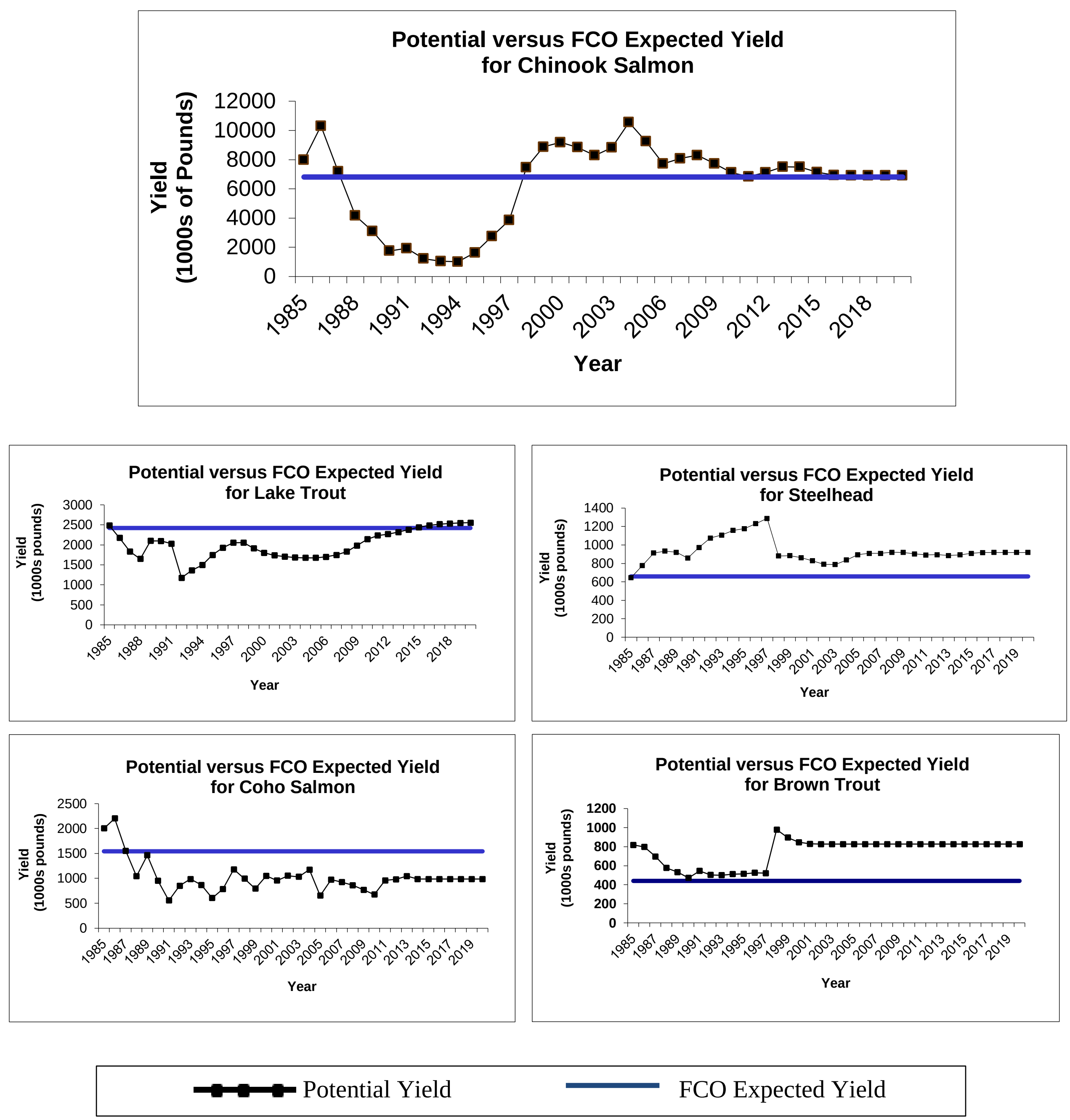
The spreadsheet also plots the FCO Index over time (Figure 39). An index value of zero means that the deviations between the model-predicted and FCO-expected yields sum to zero, which suggests that the stocking policy in place is coming close to achieving the FCO-expected yields. However, a zero value could also occur when the "over stocking" of one species equals the "understocking" of another.

Figure 39.



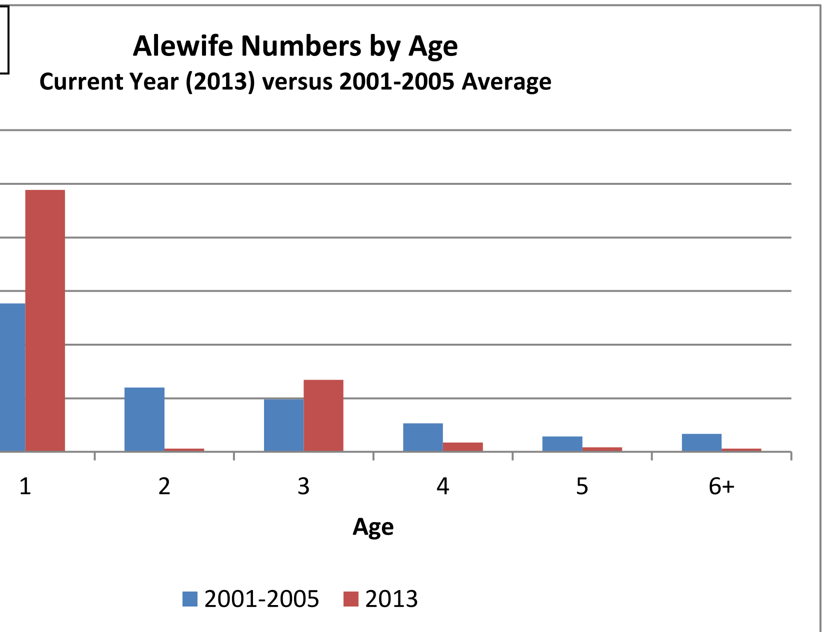
One can examine the yield values for each individual species to determine if they exceed or fall short of their individual FCO expected values. The spreadsheet plots the model-predicted potential yields and the FCO yield expectations for each species so they can be compared (Figure 40). For example, the CONNECT model predicted that the stocking rates in place for Chinook salmon and lake trout should provide potential yields that are fairly close to FCO expectations. However, steelhead and brown trout stocking rates are predicted to provide yields higher than FCO expectations and coho salmon lower.

Figure 40.



Alewife age structure indicator – Update the graph comparing the current year alewife population structure to that of the 2001-2005 average (Figure 41).

Figure 41.

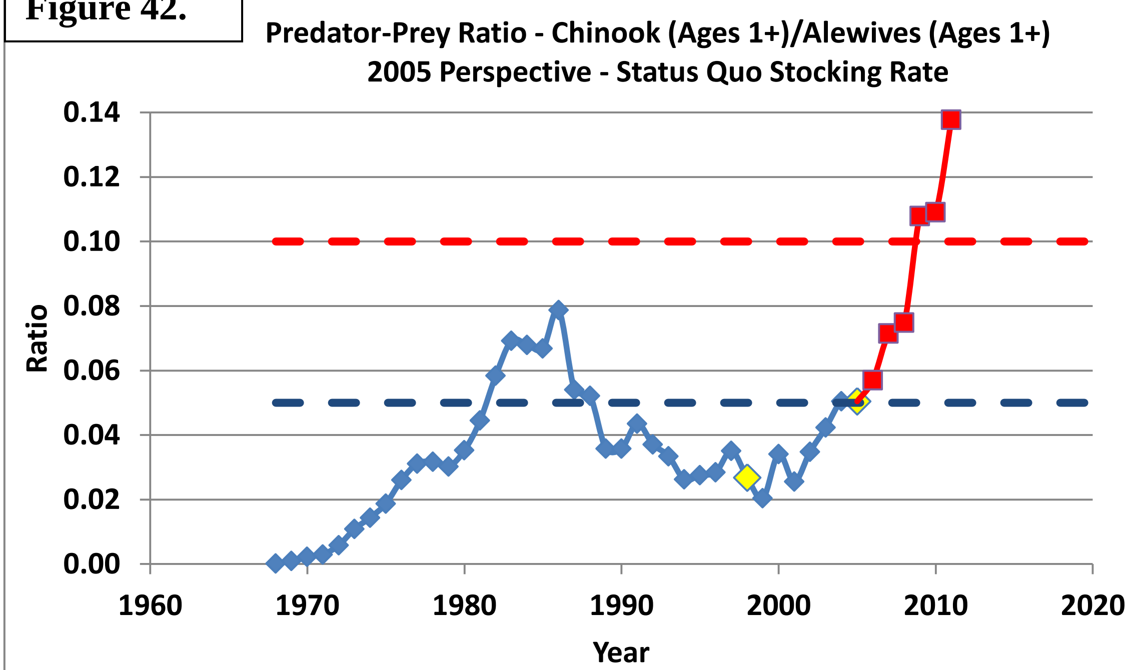


Step 3 – Use results to judge the performance of the stocking policy

A. P-P ratio indicator – The idea behind the Chinook salmon-alewife P-P ratio is that it should be a good measure of trophic balance and that it can be used as a guide for managers to establish and monitor sustainable stocking rates for Chinook salmon. If desired, the deviations between the target and projected ratios (Figure 26) can be used to “fine tune” stocking rates by making small changes to minimize the deviations. The upper limit ratio (Figure 26) can be used as a management “red flag” trigger. If either the estimated historical or projected ratios exceed the upper limit, it indicates a serous imbalance could be occurring now or developing in the near future. Such an outcome should generate immediate and serious discussion regarding reductions in stocking rates.

We conducted a retrospective analysis of the years in which stocking was reduced (1998, 2005, and 2011) to determine if the PPRA, if it had been available in those years, would have supported the previous decisions to reduce stocking rates of Chinook salmon. Results showed that the PPRA would have supported the decisions in every case. The most important finding was that the estimated P-P ratio for the current year of analysis was always within an acceptable range, but that projections of P-P ratios for the near future were predicted to exceed the upper limit of 0.100. For example, Figure 42 shows the results for 2005. The results of the retrospective analysis demonstrate the value of the projection model.

Figure 42.



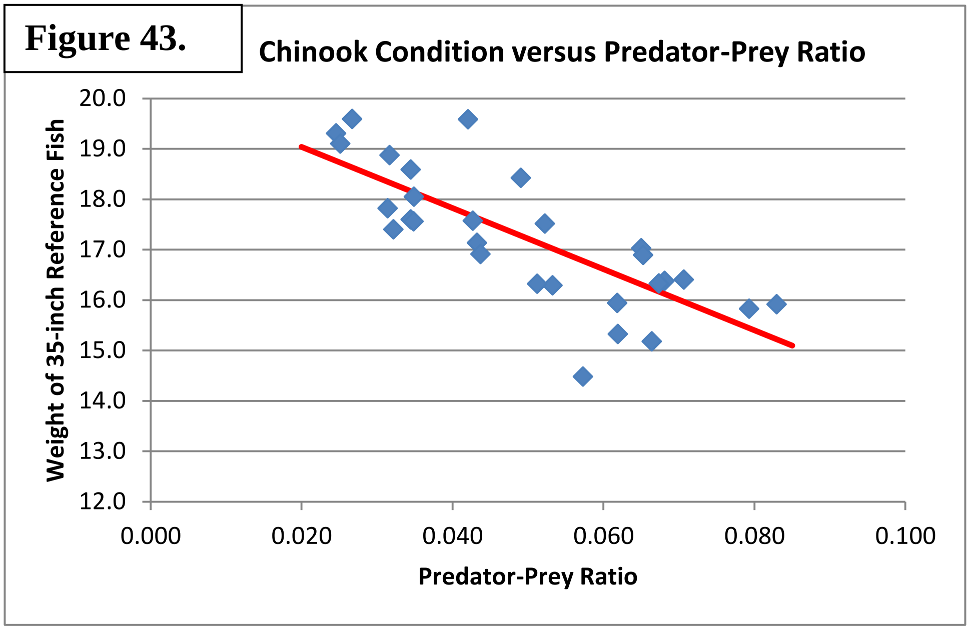
Based on the results of the PPRA through 2013, it appears that the current stocking rate of 1.76 million Chinook salmon smolts is expected to perform well (Figure 26). Of course, this assumes that rates of recruitment, growth, and mortality of predator and prey remain similar to those occurring in recent history. Only continued monitoring of these rates can detect unforeseen changes. For example, recent surveys have suggested that a resurgence of lake trout reproduction could be occurring. If so, additional wild lake trout would likely increase the predation mortality rate on alewives, and it would be necessary to account for this in the analysis.

***B. Auxiliary Indicators* –** Results of the auxiliary indicators should be used to supplement the P-P ratio. For example, if the P-P ratio exceeds the upper limit, calling for serious review of the stocking policy, the auxiliary indictors can be used to help assess the accuracy and reasonableness of that P-P ratio estimate. In addition, several of the auxiliary indicators, such as the average weights of females at weirs and harbors, are direct field measurements in support of the modeling work. Such estimates can be very useful to help explain the status of the predator-prey system and the reasons for stocking decision to stakeholders and the general public. Also, the plots of the historical time series for these indicators help put the current values into context.

Chinook body condition indicator – The relationship between the relative Chinook condition (predicted weight of a 35-inch fish) and the P-P ratio should help biologists evaluate the validity of the estimated P-P ratio for a given year. This is especially true when the P-P ratio estimate approaches the upper limit of 0.100 and suggests management action should be considered.

The weight of predators at a given length should increase as the number of prey per predator (potential ration size) increases. Therefore, the relative condition of predators should be inversely related to the P-P ratio. A plot of Chinook condition versus P-P ratio supports this idea (Figure 43). Also, a regression of Chinook condition versus P-P ratio (solid line in Figure 43) is statistically significant (R^2 = 0.57, $P < 0.01$). Judging from this regression line in Figure 43, when P-P ratios approach the upper limit of 0.100, the predicted weight of a standard 35-inch fish should decline to about 14 pounds. If not, then the estimate of the P-P ratio might be incorrect.

Figure 43.

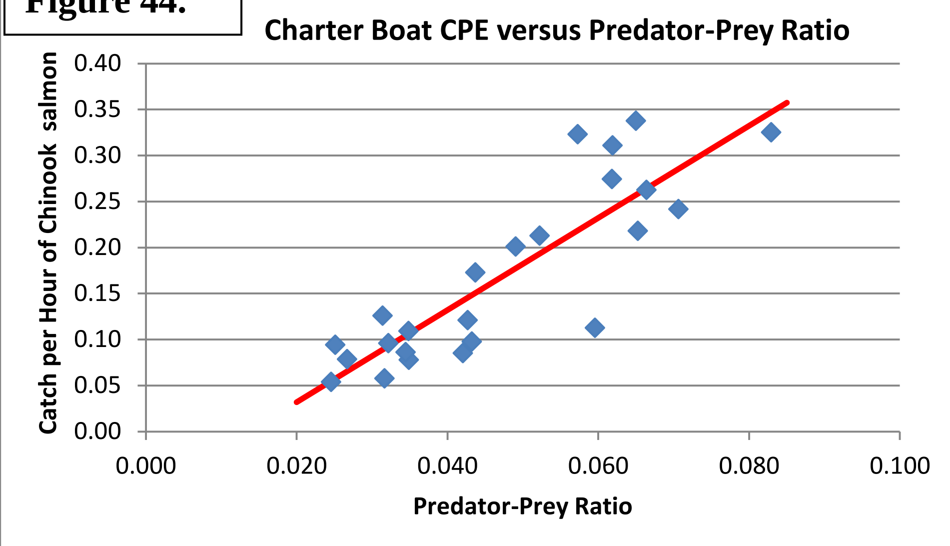


Chinook condition estimates in Lake Huron also support the idea that predator-prey situations leading to predicted weights of 14 pounds for 35-inch fish should be avoided (Figure 28). Predicted weights were below 14 pounds for 4 consecutive years (2004-2007) in Lake Huron.

The problem with the Chinook condition indicator is that by the time the predicted weights reach 14 pounds, it might be too late for managers to take action to prevent a collapse as illustrated by the timing of events in Lake Huron. Alewife populations collapsed in 2003 when the predicted condition of Chinook salmon was 14.9 pounds, a value that had occurred and been approached several times in the past with no apparent problem (Figure 28). It was not until 2004, after the alewife population had already collapsed, that predicted weights dropped to 13.5 pounds and lower (Figure 28). Hopefully, the P-P ratio projection model for Lake Michigan can do a better job of giving advanced warning of these serious problems.

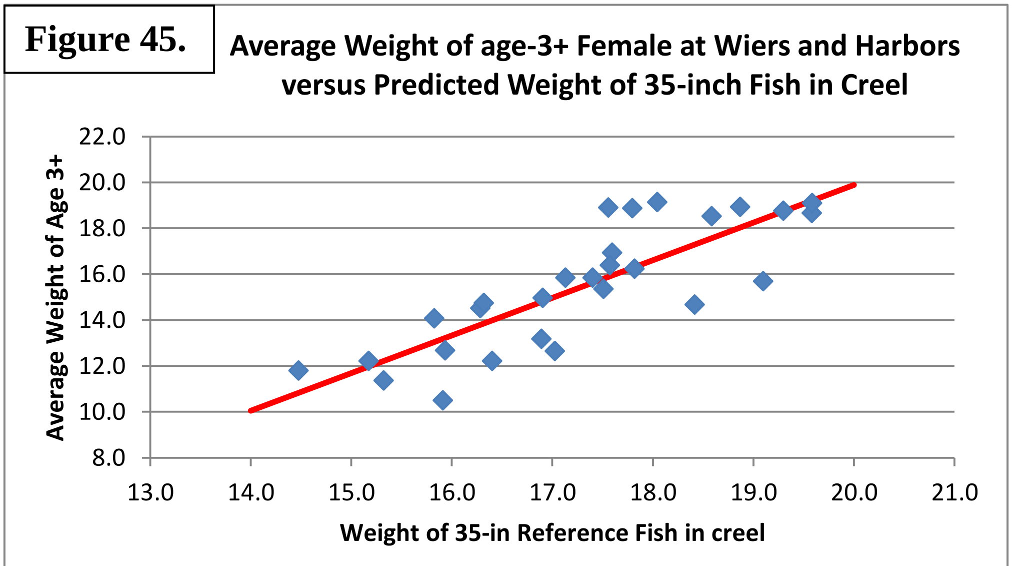
Chinook catch per effort indicator – The catch per hour from the charter fishery is monitored to help judge the relative performance of the fishery from year to year. From the perspective of anglers catch per hour is one of the most important and noticeable performance measures, so anglers usually have a strong interest in the results of this indicator. Although, interpreting and communicating the significance of a given catch rate can be challenging. While high catch rates give anglers the impression that fishing is very good, high catch rates usually occur in years with high P-P ratios and could indicate a problem is developing in the predator-prey balance. Data from this PPRA shows that catch rates are proportional to P-P ratio (Figure 44). The solid line in Figure 44 is a regression ($R^2 = 0.74$, $P < 0.01$). Also, the fish tend to be in relatively poor condition in years with the high P-P ratios (Figure 43). This suggests that attempting to maximize the catch per hour for the Chinook salmon fishery would not be a good management objective unless stakeholders and managers are willing to accept a relatively high risk of collapse of the predator-prey system.

Figure 44.



Female Chinook weights at weirs indicator – The idea behind this indicator is that the average weights of age-3-and-older female Chinook salmon collected at weirs and harbors in fall could be an additional measure of the predator-prey balance in the lake. Ideally, these weights should be correlated with the Chinook condition indicator 1. Data from this PPRA shows this to be true for our data through 2013 (Figure 45). The solid line in Figure 45 is a regression ($R^2 = 0.68$, $P < 0.01$).

Figure 45.



Salmonine harvest composition indicator – Establishing a diverse salmonine community is part of the fish community objectives for Lake Michigan (Eshenroder et al. 1995). The composition in weight of the salmonine harvest has been estimated for many years as one measure of that diversity. The estimate was added to the PPRA to help provide a more complete representation of the salmonine community.

FCO performance indicator – This indicator was added to the PPRA to help judge how successful management practices have been in achieving the yield expectations set forth in the Salmonine Objectives (Eshenroder et al. 1995). The FCO index is one way to measure and communicate the overall performance of the stocking policy and the hypothetical yields from the CONNECT model add species-by-species performance measures.

Alewife age structure indicator – The idea behind this indicator was that the effects of excessive predation on alewives might be revealed by erosion of the number of age groups in the population and/or a reduction in the absolute numbers of older fish. In addition, this indicator could help monitor natural fluctuations in year-class strength of alewives. One way to analyze the age structure would be to compare the numbers by age of alewives for the current year to that of a standard population deemed to have an ideal age structure. For example, the average 2001-2005 population age structure could be used as a standard for comparison because the alewife biomasses (Figure 24) and the P-P ratios (Figure 26) were near target levels in those years. Thus, it seems reasonable to assume that the age structure in these years was close to ideal. Notice that average numbers by age in 2001-2005 were fairly evenly distributed, and included 670,000 fish (5.5%) age 6 or older (Figure 41). On the other hand, numbers by age in 2013 were unevenly distributed, and included only 122,000 fish (0.9%) age 6 or older.

Overall, 94% of the total abundance of alewives in 2013 was within only two age groups (1 and 3). Managers should consider such a skewed age structure as a precarious situation for the alewife population. Thus, the alewife age structure in 2013 should be considered as additional evidence that cutting Chinook salmon stocking in 2013 was a good decision.

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