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Updated herring spawning biomass estimates for German Bank and Scots Bay based on spawning ground turnover rates from tag returns

G.D. Melvin, R. Singh, R. Martin and M.J. Power

Population Ecology Section
Department of Fisheries and Oceans
Biological Station
531 Brandy Cove Road
St. Andrews, N.B.
Canada E5B 2L9

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Foreword

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ABSTRACT

This paper updates the acoustic biomass estimates based on turnover presented at the Herring Assessment meeting in March 2013 and published in Melvin et al. (2014). In addition to updating the acoustic biomass estimates based on turnover to current year (2017), the data calculations used in 2013 were revisited and rechecked for accuracy and the biomass estimates amended where necessary. The acoustic biomass estimates were then analysed and presented in a manner and format as was done in the acoustic summary document (Singh et al. 2016) including the determination of the 3-year moving average and the Limit Reference Point (LRP).

INTRODUCTION

This paper updates the acoustic biomass estimates based on turnover presented at the Herring Assessment meeting in March 2013 and published in Melvin et al. (2014). In addition to updating the acoustic biomass estimates based on turnover to current year (2017), the data calculations used in 2013 were revisited and rechecked for accuracy and the biomass estimates amended where necessary. The acoustic biomass estimates were then analysed and presented in a manner and format as was done in the acoustic summary document (Singh et al. 2016) including the determination of the 3-year moving average and the Limit Reference Point (LRP). The LRP for 4WX herring was defined in 2012 (Clark et al. 2012) as the average acoustic SSB for Scots Bay and German Bank between 2005 and 2010. The 3-year moving average of the two spawning grounds is used to define trends in abundance.

The intention here is not to repeat the entire text presented in Melvin (2014), however, wherever it is deemed necessary some text may be repeated verbatim. Readers are encouraged to refer to Melvin et al. (2014) for further details where necessary.

Currently, the spawning stock biomass (SSB) of Atlantic herring, *Clupea harengus*, for the southwest Nova Scotia/Bay of Fundy (SWNS/BoF) spawning component of the 4WX herring stock utilizes trends in the total annual acoustic estimates. The observed biomass from multiple surveys conducted over the entire spawning season on the two major spawning grounds is summed (Figure 1). The surveys are separated by a period of approximately two weeks to ensure that no double counting occurs between surveys. The assumption is that all spawning herring have left the spawning grounds during this interval and that fish present at the time of a survey are independent of those present during any of the previous surveys.

A multi-year tagging study was implemented in 2009 to investigate residency time of spawning fish on German Bank. Arriving on the spawning ground in waves is a common characteristic occurring among both the Atlantic and Pacific herring (Lambert, 1987). Unlike many of the previous tagging studies conducted in the NAFO Divisions 4VWX, where tagging events were ad hoc and sporadic, this 3-year study was designed to cover the entire spawning period. Some of the previous tagging studies support a residence time for herring in the order of 10–14 days, but there is variability between spawning grounds and it is known that not all herring leave within the assumed window. Unlike the previous tagging studies conducted on the spawning grounds of Scots Bay and German Bank, the 3-year tagging project had a specific focus on turnover issues within a single spawning ground, German Bank. The main objective of the project was to investigate the potential uncertainty of SSB due to double counting or overestimating from survey to survey.

METHOD

During the 3-year study a total of 37 independent tagging events took place on German Bank, between August 19 and October 12 with 15, 10, and 12 events in 2009, 2010 and 2011, respectively (Table 1). Details of the tagging dates, number of events and number of fish tagged from earlier studies (Clark, 2006; Paul, 1999; Maxner et al., 2010) and used in this analysis are also presented in Table 1. The details on tagging method are described in Melvin et al. (2014). Based on tag returns, estimates were made of the proportion of herring remaining on the spawning grounds relative to the elapsed time between marking and recapture. These proportions were used to develop regression analyses specific to the two main spawning grounds (Scots Bay and German Bank) which were then used to adjust the acoustic biomass estimates for all available years (1999–2017). The adjusted biomass numbers were then used

to recalculate the new LRP using the average adjusted acoustic SSB for Scots Bay and German Bank between 2005 and 2010 and to track the trends in the 3-year moving average.

RESULTS

The cumulative percent of tag returns by days at large, or elapsed time, for all years independently in both Scots Bay and on German Bank were determined. Figures 2 and 3 show the raw and landings standardized proportions of tag returns by day and year for German Bank and Scots Bay. The data from each year were used to develop a relationship between the cumulative portion of returns (standardized by landings) and elapsed time. A log linear relationship was used to estimate the proportion of fish remaining on the spawning grounds relative to the (log) days at large for Scots Bay and German Bank (Figure 4). A cut off time for days at large of 31 and 29 days respectively was used to indicate no remaining fish.

The proportional results were applied to the survey data from each spawning ground for each year to estimate the amount of herring biomass remaining on the spawning grounds based on the number of days between surveys. The biomass estimates for the entire time series (1999 to 2017) for Scots Bay are presented in Tables 2–20 and for German Bank (Tables 21–39) for only those surveys that were a minimum of 10 days apart with three exceptions. The first two were on German Bank in 2001 and 2002 when one survey from each year (4 and 9 days apart, respectively) was accepted because there was evidence of turnover. The third time was again on German Bank when the September 17, 2017 survey on German Bank which was 9 days from the previous one was accepted. This survey was included because the exclusion of this one survey would leave a gap of 28 days before the next acceptable survey, at a time when spawning herring are known to be present on the bank. This survey was conducted on the ninth day after the previous survey due to pending bad weather.

Melvin et al. (2014) estimated how well the adjustments preformed for elapsed times of less than the standard 10–14 day by estimating the adjusted biomass for the valid surveys and compared the results with the estimate which included all surveys regardless of the elapsed time. The results of adjusting for fish remaining on the spawning grounds in both cases produced very similar total biomass estimates and thereby provide general support for using the equations to adjust the SSB. The unadjusted biomass estimates are those reported in the annual acoustic survey Research Document and SAR for the 4WX herring stock (DFO 2013, 2015; Singh et al. 2014, 2016).

Overall, applying the regression equations to the elapsed time for other survey year's resulted in a decrease of between 2% and 21% in the annual estimated Scots Bay spawning biomass compared with 10% and 26% decline for German Bank. Figure 5 illustrates the results of these adjustments on the Scots Bay and German Bank SSB estimates for the entire time series (1999–2017). The combined Scots Bay and German Bank total unadjusted and turnover adjusted annual survey SSB for the time series are presented in Figure 6. On both spawning grounds the estimates show the same trends although, the magnitude is different from year to year ranging from 10% to 26% (Figure 6). Most of the variability in difference occurred during the early survey years when timing was more sporadic. In all cases the SSB was reduced from the original estimate due to the presence of fish remaining on the spawning grounds from previous surveys.

Using these turnover equations for both Scots Bay and German Bank, the biomass estimates were adjusted for all the available years (Table 40). The turnover adjusted biomass estimates were then used to provide the 3-year moving average which is used to determine the biomass trends in relation to the Lower Reference Point (LRP) (Figure 7). The LRP based on the

biomass for the years 2005–2010 decreased 17% from 371,067t (unadjusted) to 316,313t with the turnover adjusted biomass estimates.

DISCUSSION

This report brought together all spawning ground tagging results from German Bank and Scots Bay since 1998 to develop equations that estimate the proportion of fish remaining on the spawning grounds over time and to estimate the associated inter-annual error. While one of the limitations of this type of study was the small number of tag returns relative to the number released, this is consistent with what can be expected. Due to the large amounts of bulk handling of herring catches, return rates of <1% are not uncommon. The results on these spawning grounds provide an estimate of the amount and variability of time herring spend on the spawning grounds during several spawning seasons.

Based on the results of this report, the assumption of a complete turnover of fish occurring during the 10–14 day window is invalid. This also means that surveys less than 10 days would also result in double counting, however, the confidence of the adjustment to the biomass would decrease as the number of days decreased. Double counting likely occurs for acoustic surveys on both spawning grounds, thereby resulting in an over estimate of SSB. Both regressions were highly correlated (r = 0.83 and 0.0.97 respectively) and demonstrate that significant amounts (13% in Scots Bay and 18% on German Bank) of biomass remain on the spawning grounds beyond the 10–14 day window and that the percentages can vary from year to year. Comparison of the biomass estimates from all surveys and the valid surveys showed the equation to be fairly robust in determining total biomass estimates. Estimates of percent of fish remaining on the spawning ground at the time of a subsequent survey can be applied to the SSB using the elapsed time between acoustic surveys to obtain a more accurate abundance estimate.

By applying the estimates of the percent of fish remaining on the spawning ground to account for double counting there is a reduction of the SSB. The 3-year moving average using the turnover adjusted biomass estimates indicates that the 2017 data point is at the LRP; however, the confidence interval indicates that this actual value can be higher or lower than the LRP (Figure 7). The 3-year moving average has been basically flat from about 2011 to 2016, however, the 2017 data point decreased to be at the LRP.

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TABLES

Table 1. Summary of tagging events, application dates and the number of herring tagged on German Bank and in Scots Bay from 1998–2011.

Spawning ground tagging location	Year	Tagging dates	Number of tagging days	Number of fish tagged on spawning ground	Number of tags returned from spawning ground	Percent recaptured on spawning ground
German Bank	1998	Aug 20-Sep 22	14	9730	30	0.3
	1999	Sep 21-Sep 22	2	821	1	0.1
	2001	Sep 17-Sep 19	3	9402	47	0.5
	2005	Aug 30-Oct 5	5	8487	43	0.5
	2009	Aug 19-Sep 30	15	10333	94	0.9
	2010	Aug 19-Oct 12	10	6036	22	0.4
	2011	Aug 24-Sep 29	12	6623	36	0.5
Scots Bay	1998	Aug 23-Aug 25	2	2367	21	0.9
	1999	Aug 11-Aug 21	2	2832	0	0.0
	2005	Jul 28-Aug 24	4	5047	150	3.0
	2006	Jul 28-Aug 20	3	3800	45	1.2

Table 2. Scots Bay 1999 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 1999							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
25-Jul-99	1	24,335	3,287	428	0	0	
08-Aug-99	2	14	9,380	1,541	165	0	
20-Aug-99	3	26	12	12,194	2,378	127	
03-Sep-99	4	0	26	14	-	0	45,909
Adjusted total		24,335	6,093	10,224	0	0	**40,652**

Table 3. Scots Bay 2000 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2000							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
01-Aug-00	1	91,816	13,693	324	0	0	
14-Aug-00	2	13	28,999	3,537	0	0	
29-Aug-00	3	28	15	64,683	0	0	185,498
Adjusted total		91,816	15,306	60,821	0	0	**167,943**

Table 4. Scots Bay 2001 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2001							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
16-Jul-01	1	98,923	12,067	0	0	0	
31-Jul-01	2	15	79,250	8,696	0	0	
16-Aug-01	3	0	16	37,842	0	0	216,015
Adjusted total		98,923	67,183	29,146	0	0	**195,252**

Table 5. Scots Bay 2002 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2002							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
28-Jul-02	1	38,856	5,248	1,274	0	0	
11-Aug-02	2	14	15,047	2,993	742	0	
21-Aug-02	3	24	10	72,016	16,592	752	
02-Sep-02	4	0	22	12	3,346	452	129,265
Adjusted total		38,856	9,799	67,749	0	0	**116,403**

Table 6. Scots Bay 2003 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2003							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
31-Jul-03	1	8,759	1,742	287	0	0	
10-Aug-03	2	10	73,331	9,905	765	0	
24-Aug-03	3	24	14	30,351	4,526	0	
06-Sep-03	4	0	27	13	10,564	0	123,005
Adjusted total		8,759	71,589	20,159	5,272	0	**105,779**

Table 7. Scots Bay 2004 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2004							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
19-Jul-04	1	1,042	141	4	0	0	
02-Aug-04	2	14	16,886	2,281	176	0	
16-Aug-04	3	28	14	63,327	9,444	661	
29-Aug-04	4	0	28	13	27,110	3,662	
12-Sep-04	5	0	0	27	14	6,697	115,042
Adjusted total		1,042	16,745	61,042	17,489	2,374	**98,693**

Table 8. Scots Bay 2005 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2005							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
31-Jul-05	1	12,404	721	0	0	0	
21-Aug-05	2	21	7,618	443	0	0	
11-Sep-05	3	0	21	1,206	0	0	21,228
Adjusted total		12,404	6,897	763	0	0	**20,064**

Table 9. Scots Bay 2006 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2006							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
22-Jul-06	1	21,886	2,956	77	0	0	
06-Aug-06	2	15	586	87	0	0	
19-Aug-06	3	28	13	9,144	0	0	
25-Aug-06	4	0	27	13	-	0	31,616
Adjusted total		21,886	0	8,979	0	0	**30,865**

Table 10. Scots Bay 2007 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2007							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
14-Jul-07	1	8,899	1,202	31	0	0	
28-Jul-07	2	14	31,962	4,317	113	0	
11-Aug-07	3	28	14	8,806	1,189	92	
25-Aug-07	4	0	28	14	3,032	410	52,699
Adjusted total		8,899	30,760	4,457	1,730	0	**45,846**

Table 11. Scots Bay 2008 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2008							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
12-Jul-08	1	5,992	809	21	0	0	
26-Jul-08	2	14	14,318	1,934	0	0	
09-Aug-08	3	28	14	3,212	0	0	23,442
Adjusted total		5,992	13,509	1,257	0	0	**20,757**

Table 12. Scots Bay 2009 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2009							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
27-Jun-09	1	7,542	1,019	27	0	0	
11-Jul-09	2	14	45,744	6,179	162	0	
25-Jul-09	3	28	14	19,338	2,612	857	
08-Aug-09	4	0	28	14	14,877	3,154	
21-Aug-09	5	0	0	27	14	256	87,757
Adjusted total		7,542	44,725	13,133	12,103	0	**77,503**

Table 13. Scots Bay 2010 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2010							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
10-Jul-10	1	21,808	2,946	77	0	0	
24-Jul-10	2	14	9,439	1,275	33	0	
07-Aug-10	3	28	14	13,528	1,827	0	
21-Aug-10	4	0	28	14	8,011	977	
05-Sep-10	5	0	0	0	15	1,238	54,024
Adjusted total		21,808	6,493	12,176	6,150	261	**46,888**

Table 14. Scots Bay 2011 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2011							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
02-Jul-11	1	37,706	5,093	133	0	0	
16-Jul-11	2	14	38,600	5,214	136	0	
30-Jul-11	3	28	14	34,576	4,670	361	
13-Aug-11	4	0	28	14	16,898	2,520	
26-Aug-11	5	0	0	27	13	12,933	140,713
Adjusted total		37,706	33,507	29,229	12,091	10,052	**122,585**

Table 15. Scots Bay 2012 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2012							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
30-Jun-12	1	59,795	8,077	211	0	0	
14-Jul-12	2	14	55,787	7,535	197	0	
28-Jul-12	3	28	14	38,756	5,235	137	
11-Aug-12	4	0	28	14	20,939	2,828	
25-Aug-12	5	0	0	28	14	9,550	184,827
Adjusted total		59,795	47,710	31,009	15,507	6,585	**160,606**

Table 16. Scots Bay 2013 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2013									
Survey Date	Survey Number	Surveys							
		1	2	3	4	5	6	7	Totals
22-Jun-13	1	13,245	1,789	0	0	0	0	0	
06-Jul-13	2	14	8,098	988	29	0	0	0	
21-Jul-13	3	0	15	11,949	2,533	125	0	0	
03-Aug-13	4	0	28	13	9,759	1,318	34	0	
17-Aug-13	5	0	0	27	14	15,068	2,035	53	
31-Aug-13	6	0	0	0	28	14	13,917	1.880	
14-Sep-13	7	0	0	0	0	28	14	4,181	76,217
Adjusted total		13,245	6,309	10,961	7,197	13,625	11,847	2,248	**66,184**

Table 17. Scots Bay 2014 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2014								
Survey Date	Survey Number	Surveys						
		1	2	3	4	5	6	Totals
21-Jun-14	1	57,552	5,653	203	0	0	0	
08-Jul-14	2	17	106,927	19,337	2,677	0	0	
19-Jul-14	3	28	11	24,748	3,343	87	0	
02-Aug-14	4	0	25	14	20,565	2,778	73	
16-Aug-14	5	0	0	28	14	7,190	971	
30-Aug-14	6	0	0	0	28	14	9,142	226,124
Adjusted total		57,552	101,274	5,208	14,545	4,325	8,098	191,001

Table 18. Scots Bay 2015 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2015								
Survey Date	Survey Number	Surveys						
		1	2	3	4	5	6	Totals
27-Jun-15	1	82,428	11,134	291	0	0	0	
11-Jul-15	2	14	81,672	11,032	289	0	0	
25-Jul-15	3	28	14	41,192	5,564	146	0	
08-Aug-15	4	0	28	14	34,234	4,624	0	
22-Aug-15	5	0	0	28	14	29,424	2,890	
08-Sep-15	6	0	0	0	0	17	16,245	285,194
Adjusted total		82,428	70,538	29,868	28,382	24,654	13,255	**249,225**

Table 19. Scots Bay 2016 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2016								
Survey Date	Survey Number	Surveys						
		1	2	3	4	5	6	Totals
18-Jun-16	1	23,989	3,240	85	0	0	0	
02-Jul-16	2	14	41,093	5,551	145	0	0	
16-Jul-16	3	28	14	9,423	1,273	33	0	
30-Jul-16	4	0	28	14	11,165	1,508	39	
13-Aug-16	5	0	0	28	14	26,951	3,640	
27-Aug-16	6	0	0	0	28	14	3,047	115,669
Adjusted total		23,989	37,853	3,788	9,747	25,409	0	**100,787**

Table 20. Scots Bay 2017 survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2017										
Survey Date	Survey Number	Surveys								
		1	2	3	4	5	6	7	8	Totals
21-Jun-17	1	75,364	14,992	2,471	0	0	0	0	0	
01-Jul-17	2	10	26,669	3,602	94	0	0	0	0	
15-Jul-17	3	24	14	24,731	3,341	87	0	0	0	
29-Jul-17	4	0	28	14	6,270	847	22	0	0	
12-Aug-17	5	0	0	28	14	17,959	2,426	187	0	
26-Aug-17	6	0	0	0	28	14	11,923	1,778	42	
08-Sep-17	7	0	0	0	0	27	14	8,188	999	
23-Sep-17	8	0	0	0	0	0	28	15	1,751	172,855
Adjusted total		75,364	11,677	18,658	2,385	17,025	9,745	6,222	710	**141,966**

Table 21. German Bank 1999 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 1999							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
27-Aug-99	1	165,085	32,194	4,606	0	0	
10-Sep-99	2	14	240,453	43,085	8,646	0	
25-Sep-99	3	29	15	85,892	18,211	0	
08-Oct-99	4	0	28	13	3,900	0	495,330
Adjusted total		165,085	208,259	38,201	0	0	**411,545**

Table 22. German Bank 2000 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2000							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
29-Aug-00	1	100,250	19,550	2,797	0	0	
12-Sep-00	2	14	132,399	23,724	0	0	
27-Sep-00	3	29	15	80,923	12,176	0	
14-Oct-00	4	0	0	17	20,369	0	333,941
Adjusted total		100,250	112,849	54,402	8,193	0	**275,694**

Table 23. German Bank 2001 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2001							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
27-Aug-01	1	39,160	8,303	5,892	0	0	
09-Sep-01	2	13	36,481	17602	2602	0	
13-Sep-01	3	17	4	123,426	13,968	0	
03-Oct-01	4	0	24	20	58,223	0	257,290
Adjusted total		39,160	28,178	99,332	41,653	0	**208,924**

Table 24. German Bank 2002 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2002								
Survey Date	Survey Number	Surveys						
		1	2	3	4	5	6	Totals
11-Aug-02	1	3,843	689	77	0	0	0	
26-Aug-02	2	15	114,119	20,448	8,140	0	0	
10-Sep-02	3	30	15	108,837	32,260	0	0	
19-Sep-02	4	0	24	9	174,042	47,379	21,744	
29-Sep-02	5	0	0	19	10	4,857	0	
08-Oct-02	6	0	0	28	19	9	10,403	416,101
Adjusted total		3,843	113,430	88,312	133,642	0	0	**339,227**

Table 25. German Bank 2003 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2003							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
29-Aug-03	1	107,204	29,184	12,132	0	0	
08-Sep-03	2	10	101,447	27,616	0	0	
18-Sep-03	3	20	10	52,765	4,817	0	
10-Oct-03	4	0	0	22	66,781	18,179	
20-Oct-03	5	0	0	0	10	20,579	348,776
Adjusted total		107,204	72,263	13,017	61,964	2,400	**256,847**

Table 26. German Bank 2004 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2004							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
02-Sep-04	1	113,333	22,102	4,075	0	0	
16-Sep-04	2	14	167,502	32,665	0	0	
30-Sep-04	3	28	14	111,120	0	0	391,955
Adjusted total		113,333	145,400	74380	0	0	**333,113**

Table 27. German Bank 2005 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2005							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
07-Sep-05	1	91,701	17,883	4,062	0	0	
21-Sep-05	2	14	128,825	27,313	0	0	
04-Oct-05	3	27	13	48,054	0	0	268,580
Adjusted total		91,701	110,942	6,678.1	0	0	**219,321**

Table 28. German Bank 2006 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2006							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
25-Aug-06	1	114,069	11,632	0	0	0	
15-Sep-06	2	21	107,641	17,693	2,166	0	
01-Oct-06	3	0	16	50,893	9,925	0	
15-Oct-06	4	0	30	14	22,787	0	295,390
Adjusted total		114,069	96,009	33,200	10,696	0	**253,974**

Table 29. German Bank 2007 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2007							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
24-Aug-07	1	45,920	8,955	1,651	0	0	
07-Sep-07	2	14	32,769	6,390	1,178	0	
21-Sep-07	3	28	14	191,802	37,404	10,158	
05-Oct-07	4	0	28	14	228,870	52,729	
17-Oct-07	5	0	0	26	12	8,064	507,425
Adjusted total		45,920	23,814	183,761	190,288	0	**443,782**

Table 30. German Bank 2008 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2008							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
22-Aug-08	1	25,445	4,962	915	0	0	
05-Sep-08	2	14	72,300	14,100	0	0	
19-Sep-08	3	28	14	32,159	4,839	0	
06-Oct-08	4	0	31	17	111,046	62,864	
21-Oct-08	5	0	0	0	15	-	240,950
Adjusted total		25,445	67,338	17,145	106,207	0	**216,135**

Table 31. German Bank 2009 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2009							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
12-Aug-09	1	90,118	19,107	0	0	0	
25-Aug-09	2	13	116,084	13,137	2,336	0	
14-Sep-09	3	0	20	70,024	19,062	7,140	
24-Sep-09	4	0	30	10	49,292	12,2340	
05-Oct-09	5	0	0	21	11	71,809	397,327
Adjusted total		90,118	96,977	56,887	27,894	52,328	**324,204**

Table 32. German Bank 2010 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2010							
Survey Date	Survey Number	Surveys					
		1	2	4	6	7	Totals
18-Aug-10	1	85,180	18,060	3,063	0	0	
31-Aug-10	2	13	58,570	10,495	0	0	
15-Sep-10	4	28	15	65,230	7,382	0	
05-Oct-10	6	0	0	20	36,068	7,034	
19-Oct-10	7	0	0	0	14	8,721	253,769
Adjusted total		85,180	40,510	51,673	28,686	1,687	**207,736**

Table 33. German Bank 2011 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2011							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
26-Aug-11	1	30,405	6,446	1,610	0	0	
08-Sep-11	2	13	116,508	24,702	0	0	
21-Sep-11	3	26	13	143,937	17,983	0	
10-Oct-11	4	0	0	19	9,611	0	
23-Oct-11	5	0	0	0	13	-	300,461
Adjusted total		30,405	110,062	117,625	0	0	**258,091**

Table 34. German Bank 2012 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2012								
Survey Date	Survey Number	Surveys						
		1	2	3	4	5	6	Totals
12-Aug-12	1	33,541	6,541	1,206	0	0	0	
26-Aug-12	2	14	107,994	21,060	4,784	0	0	
09-Sep-12	3	28	14	59,917	12,704	2,154	0	
22-Sep-12	4	0	27	13	59,213	10,610	0	
07-Oct-12	5	0	0	28	15	21,475	3,231	
24-Oct-12	6	0	0	0	0	17	6,303	288,443
Adjusted total		33,541	101,453	37,651	41,725	8,711	3,072	**226,153**

Table 35. German Bank 2013 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2013							
Survey Date	Survey Number	Surveys					
		1	2	3	4	6	Totals
19-Aug-13	1	53,509	9,588	1,493	0	0	
03-Sep-13	2	15	118,088	23,029	6,254	0	
17-Sep-13	3	29	14	37,906	8,733	1,679	
29-Sep-13	4	0	26	12	48,419	8,676	
14-Oct-13	5	0	0	27	15	6,606	264,528
Adjusted total		53,509	108,500	13,384	34,432	0	**208,825**

Table 36. German Bank 2014 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2014							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
12-Aug-14	1	51,496	10,918	2,281	0	0	
25-Aug-14	2	13	70,385	13,726	0	0	
08-Sep-14	3	27	14	79,349	10,898	2,853	
26-Sep-14	4	0	0	18	10,510	2861	
06-Oct-14	5	0	0	28	10	21,294	233,034
Adjusted total		51,496	59,467	63,342	0	15,580	**189,884**

Table 37. German Bank 2015 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2015							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
17-Aug-15	1	16,156	2,895	716	0	0	
01-Sep-15	2	15	64,219	14,795	3,401	0	
13-Sep-15	3	27	12	52,782	10,293	1,473	
27-Sep-15	4	0	26	14	39,242	7,031	
12-Oct-15	5	0	0	29	15	3,990	176,389
Adjusted total		16,156	61,324	37,271	25,547	0	**140,298**

Table 38. German Bank 2016 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2016							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
21-Aug-16	1	35,565	8,904	3,247	0	0	
01-Sep-16	2	11	26,914	6,738	1,668	0	
12-Sep-16	3	22	11	90,104	17,572	5,583	
26-Sep-16	4	0	25	14	48,906	12,244	
07-Oct-16	5	0	0	25	11	10,589	212,078
Adjusted total		35,565	18,010	80,119	29,667	0	**163,361**

Table 39. German Bank 2017 survey biomass estimates (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes only those surveys used to estimate total annual biomass.

Year: 2017							
Survey Date	Survey Number	Surveys					
		1	2	3	4	5	Totals
21-Aug-17	1	33,839	4,648	1,499	0	0	
08-Sep-17	2	18	65,393	19,383	2,351	0	
17-Sep-17	3	27	9	62,935	7,863	0	
06-Oct-17	4	0	28	19	5,386	1,241	
18-Oct-17	5	0	0	0	12	30,396	197,949
Adjusted total		33,839	60,745	42,053	0	29,155	**165,793**

Table 40. Summary of the 1999-2017 turnover adjusted SSB for Scots Bay and German Bank spawning grounds in the SWNS/BoF component of the 4WX stock complex. A dash (-) indicates no data.

Location	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Avg. 2005 - 2010	Avg. 1999 - 2017
Scots Bay (inbox)	40,652	167,943	195,253	116,404	105,779	98,692	20,064	30,865	44,536	20,651	72,321	36,567	90,606	122,837	58,521	186,805	228,154	98,201	133,404	37,501	98,329
Scots Bay (outbox)	-	-	-	-	-	-	-	-	1,310	107	5,182	10,321	31,978	37,768	7,662	4,196	21,071	2,585	8,562	4,230	11,886
Scots Bay total	40,652	167,943	195,253	116,404	105,779	98,692	20,064	30,865	45,846	20,758	77,503	46,888	122,584	160,606	66,183	191,002	249,225	100,786	141,966	40,321	105,210
German Bank (inbox)	411,545	275,694	208,923	339,227	256,848	333,113	219,321	249,582	439,828	213,748	322,756	192,201	248,886	219,358	200,314	188,025	140,298	163,361	165,792	272,906	252,043
German Bank (outbox)	-	-	-	-	-	-	-	-	4,392	3,955	2,387	1,448	15,535	9,206	6,795	8,511	1,860	-	-	5,543	6,010
German Bank total	411,545	275,694	208,923	339,227	256,848	333,113	219,321	253,974	443,783	216,135	324,204	207,736	258,092	226,153	208,825	189,885	140,298	163,361	165,792	277,525	254,890
Scots + German	452,197	443,636	404,176	455,631	362,627	431,805	239,385	284,839	489,629	236,893	401,707	254,624	380,676	386,759	275,008	380,887	389,523	264,147	307,758	317,846	360,100
Overall SE (t)	26,848	21,476	6,503	27,957	20,026	21,928	31,004	16,029	33,678	23,314	24,169	9,695	22,279	8,844	15,145	20,131	14,242	9,375	15,643	-	-
Overall SE (%)	6%	5%	2%	6%	6%	5%	13%	6%	7%	10%	6%	4%	6%	2%	6%	5%	4%	4%	5%	-	-

FIGURES

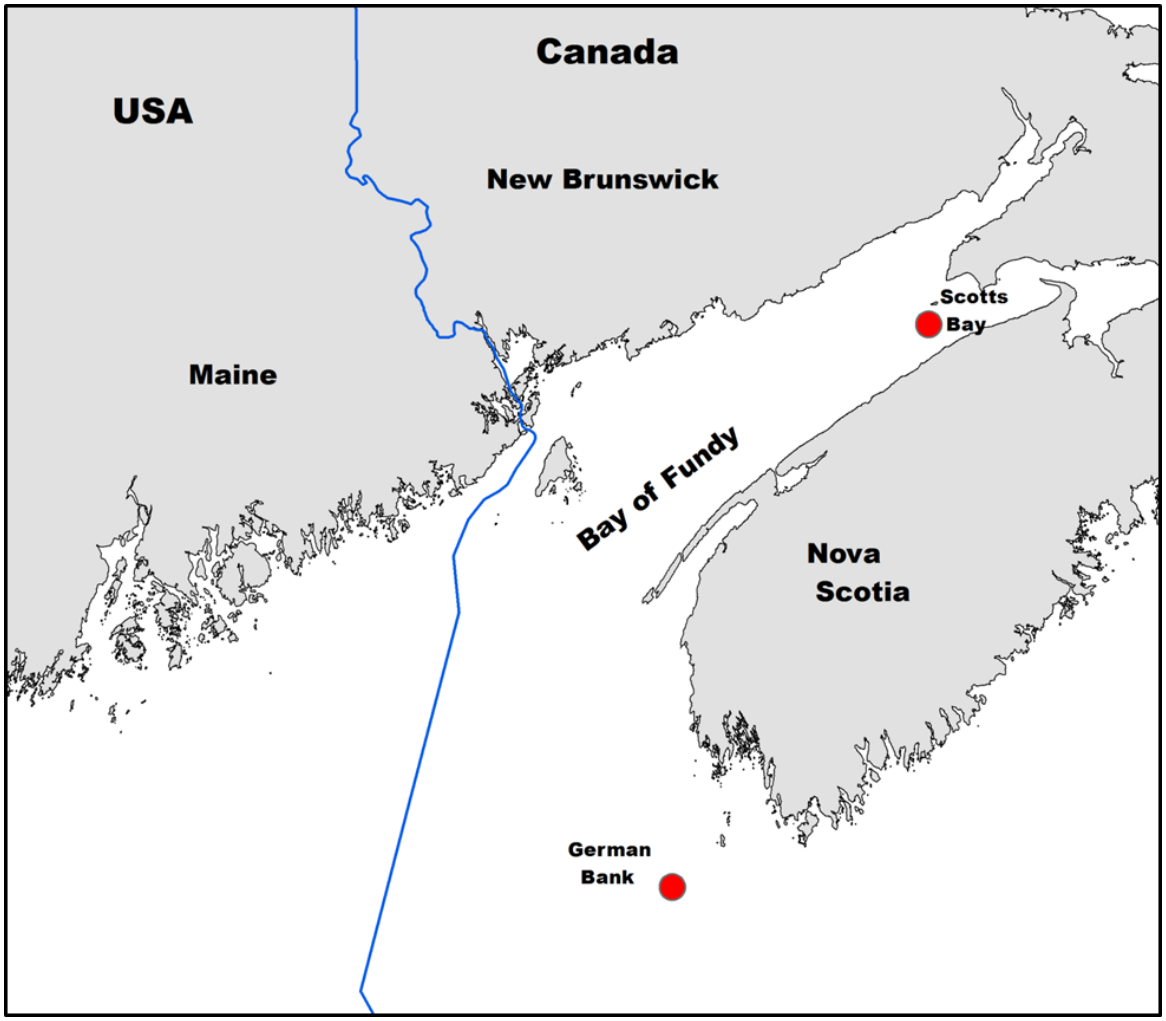

Figure 1. Map of the Bay of Fundy and Southwest Nova Scotia showing the location of Scots Bay and German Bank spawning grounds

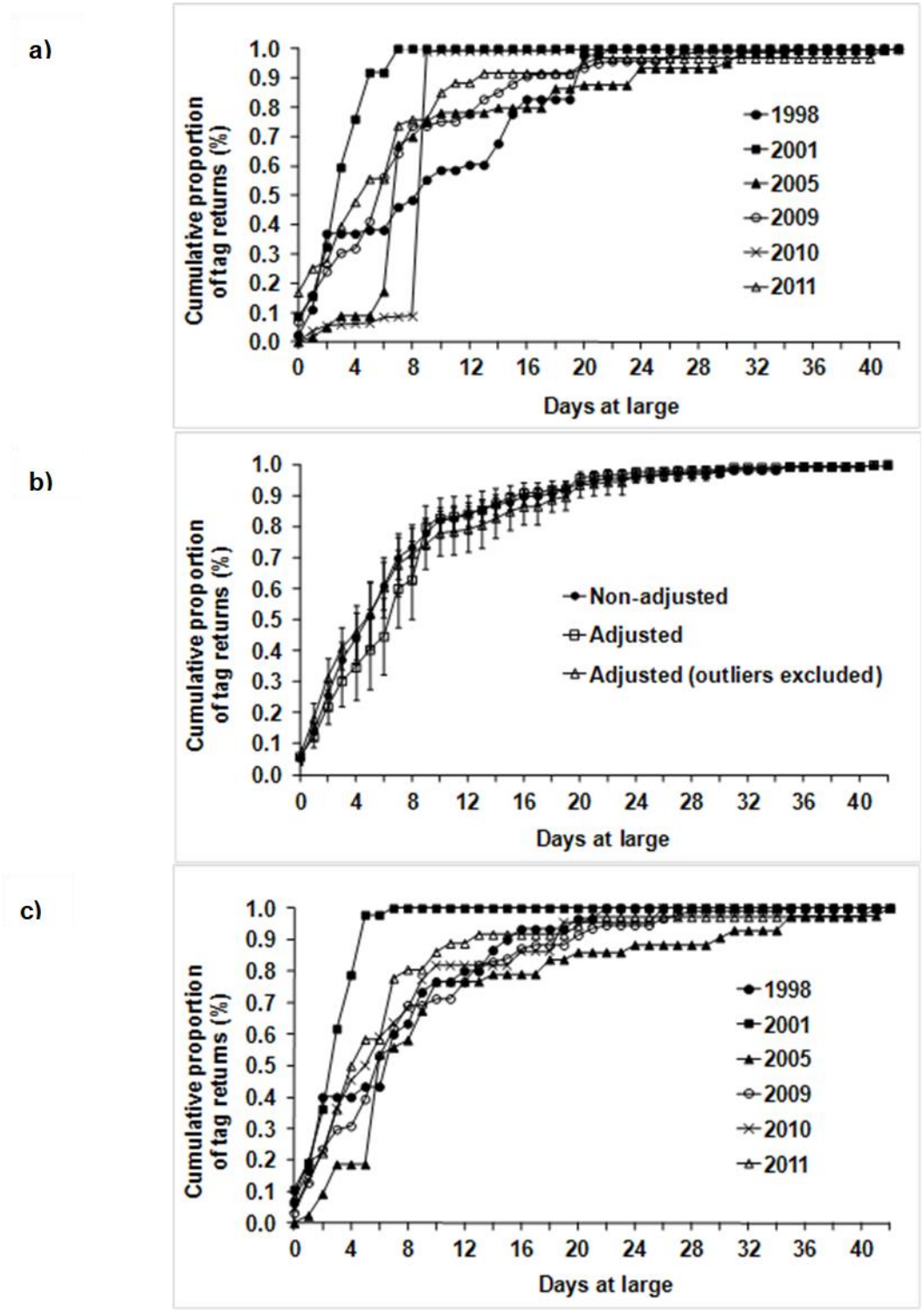

Figure 2. Summary of raw (a) and landings standardized (b) proportions of tag returns by day and year for German Bank. Mean values (all years combined) and associated error bars (SE) for raw, weighted and weighted with outliers removed are in plot (c).

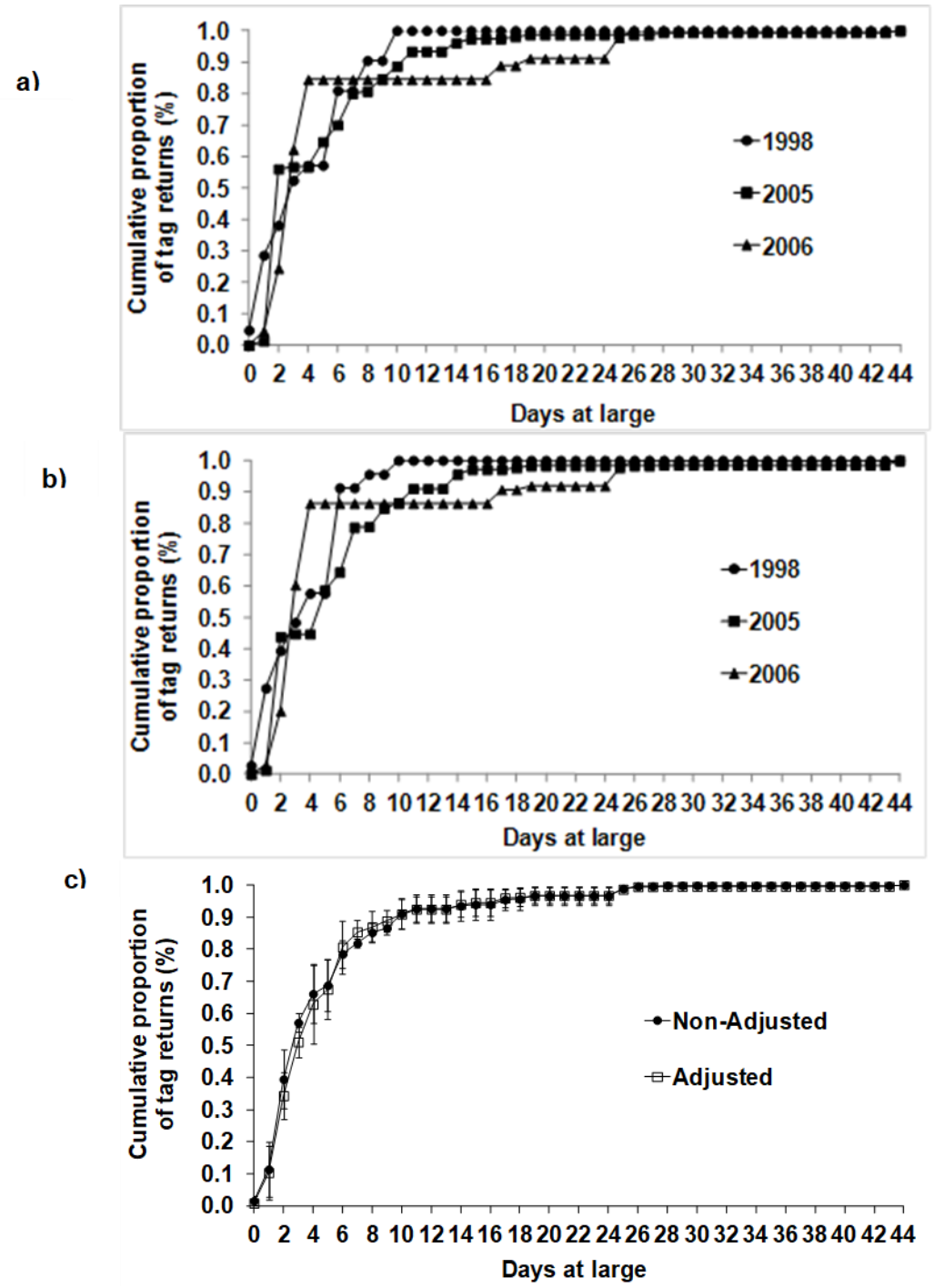

Figure 3. Summary of raw (a) and landings standardized (b) proportions of tag returns by day and year for Berman Bank. Mean values (all years combined) and associated error bars (SE) for raw and landings weighted are plotted in (c).

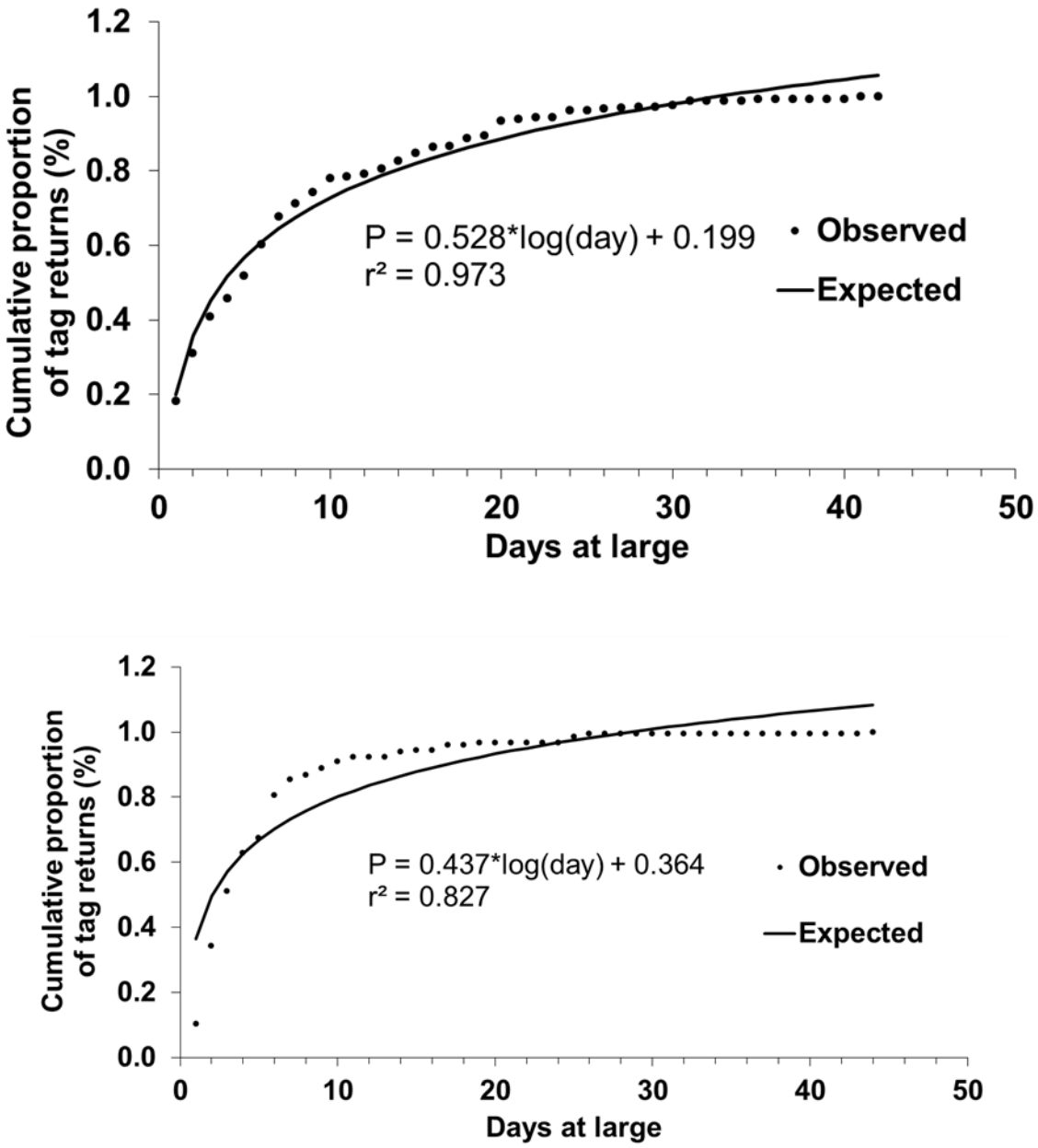

Figure 4. The regression analysis of the expected and observed proportion of tag returns and number of days after tagging for German Bank (above) and Scots Bay (below).

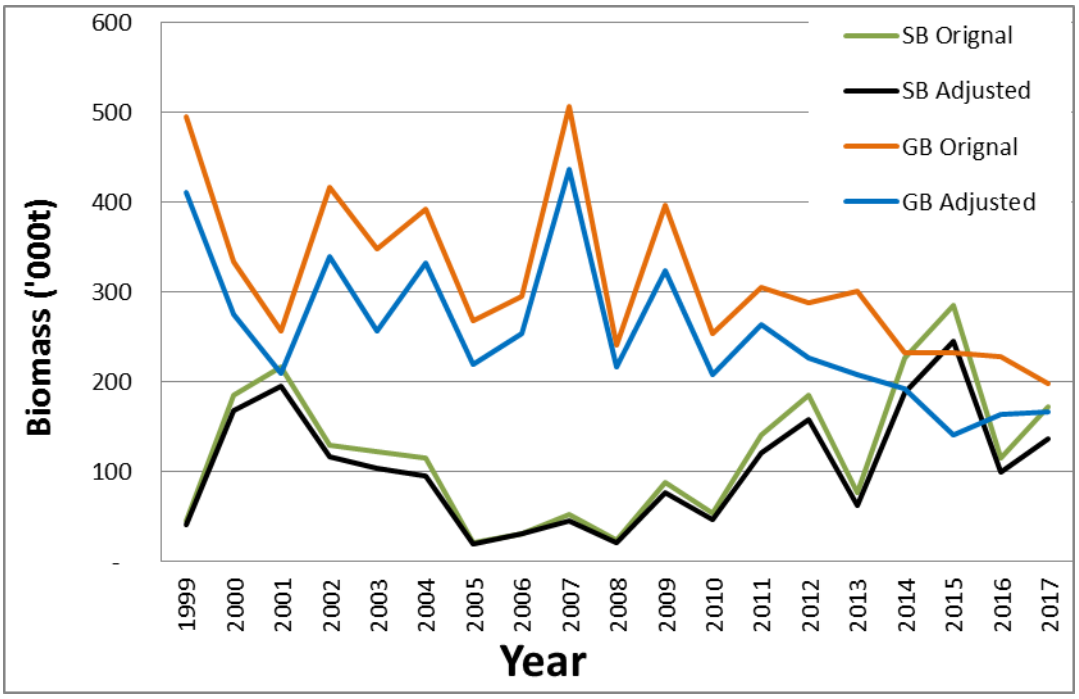

Figure 5. The 1999 to 2017 estimated original and elapsed time adjusted spawning stock biomass for Scot Bay and German Bank herring from acoustic surveys.

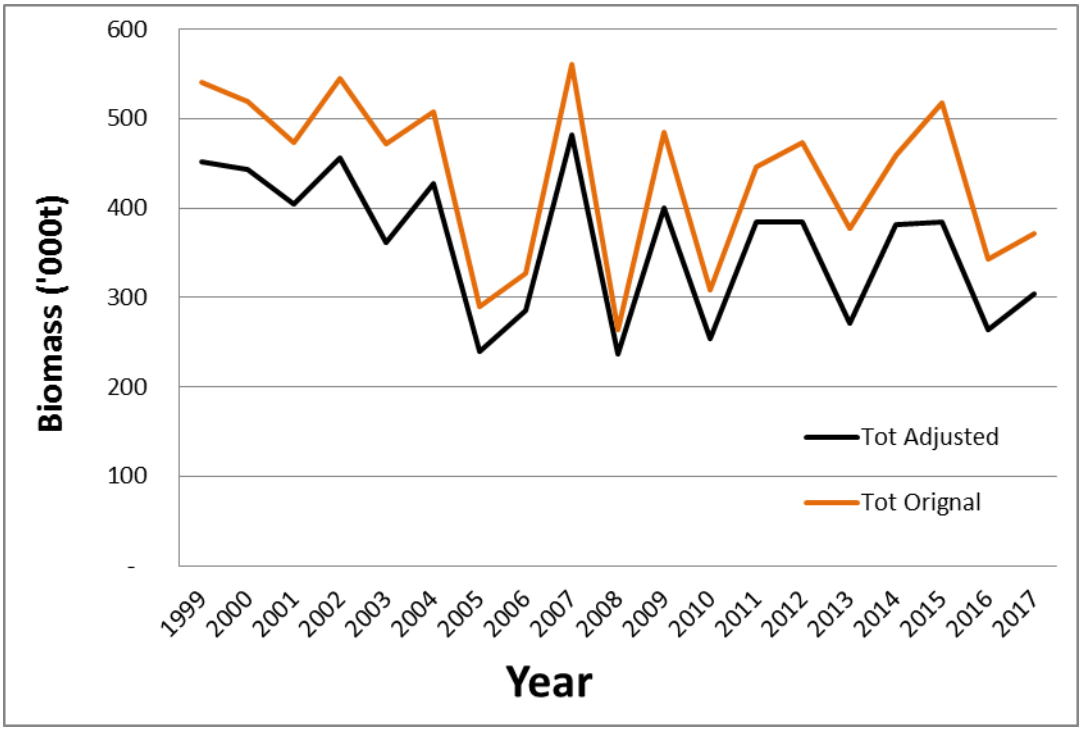

Figure 6. The 1999 to 2017 estimated original and elapsed time adjusted spawning stock biomass for Scot Bay and German Bank combined from acoustic surveys.

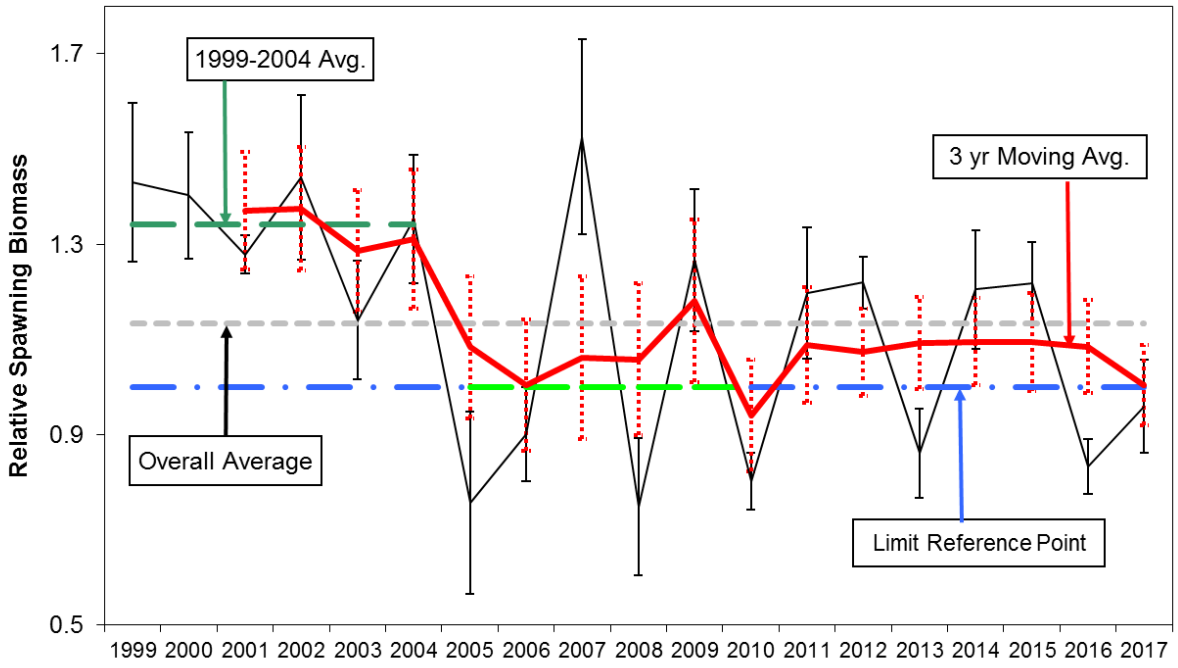

Figure 7. The relative SSB index (with 95% confidence interval), the calculated 3-year moving average, the long-term average and the limit reference point for the SWNS/BoF spawning component (German Bank and Scots Bay). The estimates used here are the turnover adjusted SSB.