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**Maritimes Region**

# Estimating German Bank and Scots Bay Herring Spawning Ground Turnover Rates from Tag Returns

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**Foreword**

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## ABSTRACT

The biomass of herring on individual spawning grounds in the Maritimes Region is determined from the total of multiple acoustic surveys conducted throughout the spawning season. A minimum elapsed time of 14 days between surveys was established to avoid double counting of fish from one survey to another. Data from several tagging studies were combined to estimate the temporal turnover for two of the main spawning grounds in Bay of Fundy/Southwest Nova Scotia area. Between 1998 and 2011, 51,432 herring were released on German Bank and 11,214 in Scots Bay, with a return rate of 0.5% and 1.9%, respectively. A strongly correlated log linear relationship between cumulative proportions of returns and elapsed time was found for both spawning grounds; $r^2 = 0.97$ for German Bank and 0.83 for Scots Bay. Based on a 14 day interval between surveys, approximately 13% in the former and 19% on the latter of herring remained on the spawning grounds between surveys. The equations were then used to adjust individual survey biomass estimates based on the elapsed time between surveys. Estimates of the proportion of spawning herring remaining on both spawning grounds during subsequent surveys were made and the total spawning stock biomass adjusted accordingly for the entire time series (1999-2012).


**Estimation du taux de roulement du hareng dans les frayères de la baie Scots et du banc German à l'aide des données de marquage**


## RÉSUMÉ

La biomasse du hareng dans les frayères de la région des Maritimes est déterminée à partir du nombre du total de plusieurs relevés acoustiques effectués tout au long de la saison du frai. Une période minimale écoulée de 14 jours entre les relevés a été établie pour éviter le double comptage du poisson d'un relevé à l'autre. Les données provenant de plusieurs études de marquage ont été combinées pour estimer le roulement temporel dans deux des principales frayères dans la baie de Fundy et au sud-ouest de la Nouvelle-Écosse. Entre 1998 et 2011, 51 432 harengs ont été remis à l'eau sur le banc German et 11 214 dans la baie Scots, avec un taux de retour de 0,5 % et de 1,9 %, respectivement. Une corrélation log-linéaire étroite entre les proportions cumulatives des retours et le temps écoulé a été constatée pour les deux frayères; $r^2 = 0,97$ pour le banc German et 0,83 pour la baie Scots. Selon un intervalle de 14 jours entre les relevés, environ 13 % du hareng sur le banc German et 19 % du hareng dans la baie Scots sont restés dans la frayère entre les relevés. Les équations ont ensuite servi à ajuster les estimations de la biomasse des relevés individuels fondées sur le temps écoulé entre les relevés. Des estimations de la proportion de hareng frayant qui reste dans les deux frayères pendant les relevés subséquents ont été faites et le total de la biomasse du stock reproducteur a été ajusté en conséquence pour l'intégralité de la série chronologique (de 1999 à 2012).

## INTRODUCTION

The current approach to monitoring spawning stock biomass (SSB) of Atlantic herring, *Clupea harengus,* for the Bay of Fundy/Southwest Nova Scotia spawning component of the Northwest Atlantic Fisheries Organization (NAFO) divisions 4VWX herring stock utilizes trends in the total annual acoustic estimates. The SSB for each spawning grounds is determined by summing the observed biomass from multiple surveys conducted over the entire spawning season. 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. Unfortunately, several studies have suggested that this may not be valid for an unknown portion of spawning fish and that some fish may remain on the spawning grounds for four to five weeks after being tagged (Paul, 1999; Clark, 2006). Conversely, some herring may move on to a spawning ground, spawn, and leave between surveys. These fish would not be counted in total annual SSB.

Information on residency or turnover time of herring, on individual spawning grounds is critical when multiple acoustic surveys are used to estimate the SSB (Melvin and Power, 1999; Power *et al*., 2009). A multi-year tagging study was implemented in 2009 to investigate residency time of spawning fish on German Bank. The study, which ran over a period of three years, was specifically designed to estimate turnover time, to determine inter-annual variability, to minimize double counting during repeat acoustic surveys, and to improve our estimate of the SSB. Data from previous studies on German Bank and in Scots Bay were combined with the current results to improve estimates of turnover times on both German Bank and Scots Bay spawning grounds. This research document provides an overview of the turnover times and estimates the impact or change in SSB assuming the results reflect the portion of double counting occurring on both spawning grounds. Details of the program can be found in Maxner *et al.* (2010) and Martin (2013).

## BACKGROUND

Prior to 2012, the German Bank spawning ground surveys represented the only available index of abundance to monitor trends in biomass for spawning herring in 4VWX. The abundance and distribution of this species in 4VWX has been monitored using commercial fishing vessel deployed acoustic technology since 1997. In the absence of defined reference points, this information was used to evaluate stock status and to recommend catch levels. The limit reference point for 4WX herring was defined in 2012, as the average acoustic SSB of Scots Bay and German Bank between 2005 and 2010, where a three year moving average of the two spawning grounds is used to define trends in abundance. There have, however, always been concerns regarding under or over-estimating of fish biomass due to the assumed complete turnover of herring between surveys.

The turnover time on the spawning ground is defined as the length of time required for herring to aggregate, spawn, exit the spawning area, and for a new wave of herring to arrive (Melvin *et al.*, 2004). This assumption is critical in estimating the total SSB for a specific spawning ground. The current approach is dependent on the summation of multiple surveys of spawning herring to provide an estimate of the annual SSB (Power *et al.*, 2002, 2009). Surveys, which take place on the spawning grounds separated by 10 to 14 days, are assumed to take into account a complete turnover. Based on the acoustic index, the 4WX herring stock declined in the mid-2000s, but has increased somewhat in recent years (Singh *et al*., 2014).

Tagging studies have been conducted intermittently on this stock since the 1930s (Stobo and Fowler, 2009; Mouland *et al*., 2003; Power *et al*., 2009). Recent studies, combined with maturity data, have provided information on the turnover of herring between acoustic surveys and have generally been used to determine spawning events and how long the fish are present on the spawning grounds. Arriving on the spawning ground in waves is a common characteristic occurring among both the Atlantic and Pacific herring (Lambert, 1987). However, to confirm that herring move onto the spawning grounds in large aggregations or waves and then depart promptly after spawning, an increased and focused tagging effort was required (Paul, 1999). Unlike many of the previous tagging studies, where tagging events were *ad hoc* and sporadic, this three year study was designed to cover the entire spawning period.

The evaluation of the herring stock status using acoustic methods relies on turnover time estimated from earlier tagging results (Power *et al*., 2009). Some of these 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. Lambert (1984), studying herring in Bras d'Or Lakes, found three aggregations of spent fish directly following three aggregations of ripe and running fish. Corresponding egg depositions were also noted during a six week study. These results support the current turnover rate and the occurrence of spawning waves. Tagging studies from Paul (1999) and Power *et al*. (2002) released a combined total of 18,766 tags on the spawning grounds of German Bank in 1998 and 2001. Clark (2006) reported that the amount of time a fish resides on the spawning ground fluctuates. In 2005, a total of 8,580 herring were tagged on German Bank with only 56 tags recaptured. The majority of recaptures from the spawning ground occurred within the first two weeks after tagging. However, 16% of the tags were returned after 14 days with some remaining on the spawning ground after five weeks. The number of tags recaptured from the spawning grounds ranged from 28 to 47 and most were recaptured between 8 and 14 days. Because of the variability in the residence time in these studies, there was some uncertainty as to whether all fish moved off the spawning grounds directly after a spawning event. Spent fish were rarely observed in the catches on the spawning grounds, thereby supporting the assumption of a short residency time after spawning.

Following the 2005 Herring Regional Advisory Process meeting, it was recommended that further investigation of the turnover rate be undertaken and an enhanced tagging project was initiated (DFO, 2005; Clark, 2006). In response to the conclusions of tag recaptures from Clark (2006), acoustic surveys were spaced at two week intervals (Power *et al*., 2009). However, it was found that some fish were present on the spawning grounds for up to six weeks after tagging, which suggests that double or even triple counting may be occurring. Unlike the previous projects conducted on the spawning grounds of Scots Bay and German Bank, the current three 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.

## METHODS

The three year collaborative herring tagging program, conducted through the combined efforts of the Herring Science Council (HSC) and Fisheries and Oceans Canada (DFO), St. Andrews Biological Station, began on German Bank in August of 2009. The approach was to undertake continuous tagging throughout the entire German Bank spawning season to monitor the movement, distribution and residence time of herring on the spawning ground. During the three 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). Note the number of events does not include nights each year when the tagging team

was aboard a vessel that was unsuccessful at catching herring or did not proceed to the spawning grounds due to bad weather. 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.

Live herring were removed from the seine by dipnet during normal purse seine fishing operations and retained in an onboard holding tank, with a continuous supply of running sea water, until tagged. Taggers removed individual herring that appeared healthy and characteristic of ripe and running fish from the holding tank, inserted a tag, and immediately released the fish into the ocean. The herring were tagged with an individually numbered FD-94 Anchor tags from Floy Tag and Manufacturing Inc. or with Hallprint T-bar tags. Both tag types were embossed with a return address. A randomly selected length frequency sample of 100-200 herring was collected from each tagging set and a sub-sample of 2 fish per ½ cm interval retained for detailed laboratory processing of total length (mm), weight (gm), maturity, and the excision of otoliths for aging. An annual lottery was established to encourage the returning of tags and capture information.

Tags returns from all years were weighted for daily landings to standardize the returns for variable catches. These data were then used to estimate the proportion of herring remaining on the spawning grounds relative to the elapsed time between marking and recapture. Based on the results of several studies, estimating portions from daily returns provided a better estimate of turnover rates than pooling the data weekly. Estimates followed standard procedures described by Clark (2006), Maxner *et al.* (2009) and Martin (2013).

## RESULTS

During the three year tagging program a total of 22,992 tags were applied on ripe and running herring on the German Bank spawning grounds from August to October (Table 1). The number of tag returns captured on the spawning grounds varied annually from 94 in 2009, 22 in 2010, and 36 in 2011, respectively, representing a return rate of 0.4 to 0.9%. Similar returns rates were observed for the other years, except in Scots Bay in 2005 and 2006 when returns rates were in excess of 1% (1.2 and 3%). This represents a period when the biomass of herring on the Scots Bay spawning ground was at a very low level (Singh *et al.*, 2014).

Three tag return scenarios were investigated; non-landings weighted, landings weighted, and landings weighted with outliers removed for both German Bank (Figure 2) and Scots Bay (Figure 3). In the end, it was decided that landings weighted returns with the outliers removed (on German Bank) provided the best estimate of the proportion of fish remaining on the spawning ground over time. The initial step in the process was to determine 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 (Figure 2). 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. For both spawning grounds the relationships were found to be highly correlated ($r^2$ = 0.973 for German Bank and $r^2$ = 0.827 for Scots Bay) (figures 3 and 4).The relative biomass of the fish remaining on the spawning grounds from survey to survey was estimated as 1-P. A cut off time for days at large (P>1) of 31 and 29 days, respectively, was used to indicate no remaining fish. Instantaneous rates were estimated to be -0.1325 and −0.1584 for German Bank and Scots Bay where $P_{(t)} = e^{-kt}$.

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 2012) for Scots Bay are presented in tables 2-15 and in tables 1-29 for German Bank, for only those surveys that met the standard elapsed time to be considered independent (10-14 days). These biomass estimates are those reported in the annual acoustic survey research document and science advisory report for the 4WX herring stock (DFO, 2013; Singh *et al.*, 2014).

To illustrate the process, on August 12, 2012, the German Bank acoustic survey estimated a total biomass of 33,541t (Table 16). Two weeks later (14 days), survey #2 observed 107,994t; however, based on the above analysis, 6,541t remained on the Bank from the August 12 survey, thus, the SSB for survey #2 (August 26) was reduced to 101,453t to account for fish remaining from the previous survey. In some surveys, herring were estimated to still be present from two previous surveys (e.g. September 22) and the original biomass was reduced accordingly (Table 16).

We examined how the adjustments preformed for elapsed times of less than the standard 10-14 days 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. In 2009, an additional survey was conducted on September 8, but not included in the total SSB, because sufficient time from the previous survey had not elapsed. The next survey on September 14 (11 days later) was included in the total. The results of adjusting for fish remaining on the Bank in both cases produced very similar total biomass estimates (325,375t and 324,389t) and, thereby, provide general support for using the equations to adjust SSB. A similar result was observed for 2010 where the difference was >9%. If the relationship between days elapsed and the proportion remaining on the spawning ground was spurious then the difference corrected for the elapsed time would be expected to be much greater (Table 18).

Overall, applying the regression equations to the elapsed time for other survey year's resulted in a decrease of between 10% and 17% 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 (1999-2012). The combined Scots Bay and German Bank total and adjusted annual survey SSB for the time series are presented in Figure 6. In both spawning grounds the estimates show the same trends although, the magnitude is different from year to year ranging from 10% to 23% (Figure 5). 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 bank from previous surveys.

## DISCUSSION

This report represents the conclusion of the three year tagging program to investigate turnover time on spawning grounds. The data are currently being analyzed as part of a Master degree at the University of New Brunswick to investigate turnover time, migration and population dynamics. In addition to the data collected during this program, all spawning ground tagging results from German Bank and Scots Bay since 1998 were brought together, to develop equations that estimate the proportion of fish remaining on the spawning ground over time and to estimate the associated inter-annual error. One of the limitations of this type of study is the small number of tag returns relative to the number released. Unfortunately, tag return rates for herring are never very high due to large amounts of bulk handling, and return rates of <1% are not uncommon. It is, however, interesting to note that the percent of tag returns increased substantially in 2005 and 2006 in Scots Bay when biomass estimates were extremely low. This may reflect a change in exploitation rate during a period of heavy fishing. The three year study has specifically increased the total number of returns from German Bank, the largest spawning

component of the stock, and provides an estimate of the amount and variability of time herring spend on the spawning grounds during several spawning season.

The tag return rate from earlier tagging studies conducted on German Bank were slightly lower averaging 0.3% for 1998-2001 and 2005, compared with 0.6% for the current program (2009-2011) (Paul, 1999; Waters *et al.*, 2000; Clark, 2006). Scots Bay return rates were generally higher than German Bank rates (Table 1). The majority of tags were recaptured within the first few weeks after tagging; 87% and 81% of tagged fish had left the spawning grounds within two weeks of tagging in Scots Bay and on German Bank, respectively. However, some fish remained on the spawning grounds for up to five to six weeks after being tagged. One fish was recaptured in Scots Bay after 44 days and one on German Bank after 41 days demonstrating the uncertainty associated with the length of spawning activity. On average, all fish were gone after 27 and 31 days, respectively, with Scots Bay fish leaving sooner after spawning. Differences were also observed between the daily and weekly analysis for fish remaining on the bank after 14 days, respectively (Clark 2006). Based on the results of this and previous studies, the assumption of a complete turnover of fish occurring during the 10-14 day window is invalid. Some double counting likely occurs for acoustic surveys on both spawning grounds, thereby resulting in an over-estimate of SSB.

Given the differences in timing and duration of stay, separate regression analysis of elapsed time and returns were undertaken for Scots Bay and German Bank to investigate the relationship between the proportion of recaptures on the spawning grounds and the days at large. Both regressions were highly correlated (r = 0.83 and 0.0.97, respectively) and demonstrate that significant amounts (13% in Scots Bay and 19% 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 (Table 30).

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. This is illustrated by comparing the biomass estimates from all surveys in 2009 with only those that met the elapsed time criteria. The unadjusted biomass was 434,849 versus 397,327t, respectively (Table 30). However, once the surveys were adjusted for elapsed time the estimates were very similar (325,375 versus 342,389t), suggesting that the correction for elapsed time is reasonable. Annual biomass trends for the total and adjusted biomass for the entire time series are shown in Figure 4.

## SUMMARY

Approximately 23,000 spawning herring were marked and released on German Bank during the 2009-2011 spawning seasons with an overall return rate of 0.7%. These data were combined with data from previous Scots Bay and German Bank tagging studies in the analysis. Return data showed that a large proportion of the tagged fish were recaptured within two weeks after tagging; 87% in Scots Bay and 81% on German Bank for all data combined. Current biomass estimates assume that fish remain in the same area for a maximum of two weeks before moving on. Based on these results, double counting of spawning herring occurs in the annual biomass estimates of SSB for both Scots Bay and German Bank. Regression analysis indicates a strong relationship between the days at large and the proportion of fish remaining on the bank. Correcting the 2012 Scots Bay and German Bank spawning biomass for elapsed time reduces the biomass from 397,590t to 308,069t or by 22.5%. A review of this study and its result should be conducted at the next framework review on, if and how, these data should be incorporated

into the assessment. Incorporation will require adjustments also be made to the reference points that utilize acoustic biomass estimates.

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# TABLES

*Table 1. Summary of tagging events, application dates and the number of herring tagged on German Bank during August and September 2009.*

| Tagging Location | Year | Tagging Dates | Tagging Days | Fish Tagged | Tag Returns on grounds | Percent Recaptured |
|---|---|---|---|---|---|---|
| German Bank | 1998 | Aug 20 – Sept 22 | 14 | 9730 | 30 | 0.3 |
| | 1999 | Sept 21-Sept 22 | 2 | 821 | 1 | 0.01 |
| | 2001 | Sept 17-Sept 19 | 3 | 9402 | 47 | 0.5 |
| | 2005 | Aug 30 – Oct 5 | 5 | 8487 | 43 | 0.5 |
| | 2009 | Aug 19 – Sept 30 | 15 | 10333 | 94 | 0.9 |
| | 2010 | Aug 19 – Oct 12 | 10 | 6036 | 22 | 0.4 |
| | 2011 | Aug 24 – Sept 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 | July 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 25-Jul-99 | 1 | 24,335 | 3287 | 428 | 0 | 0 | - |
| 08-Aug-99 | 2 | 14 | 9,380 | 1541 | 165 | 0 | - |
| 20-Aug-99 | 3 | 26 | 12 | 12,194 | 2378 | 127 | - |
| 03-Sep-99 | 4 | 0 | 26 | 14 | 0 | 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 01-Aug-00 | 1 | 91,816 | 12,402 | 324 | 0 | - |
| 14-Aug-00 | 2 | 13 | 28,999 | 3537 | 0 | - |
| 29-Aug-00 | 3 | 28 | 15 | 64,683 | 12,614 | - |
| - | - | - | - | - | - | 185,498 |
| Adjusted total | | 91,816 | 16,597 | 60,821 | 0 | 169,234 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | Totals |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | |
| 16-Jul-01 | 1 | 98,923 | 13362 | 0 | - |
| 31-Jul-01 | 2 | 15 | 79,250 | 8696 | - |
| 16-Aug-01 | 3 | 0 | 16 | 37,842 | - |
| - | - | - | - | - | 216,015 |
| Adjusted total | | 98,923 | 65,888 | 29,146 | 193,957 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 28-Jul-02 | 1 | 38,856 | 5248 | 1274 | 0 | 0 | - |
| 11-Aug-02 | 2 | 14 | 15,047 | 2993 | 742 | 0 | - |
| 21-Aug-02 | 3 | 24 | 10 | 72,016 | 14044 | 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 31-Jul-03 | 1 | 8,759 | 1183 | 287 | 0 | 0 | - |
| 10-Aug-03 | 2 | 10 | 73,331 | 9905 | 765 | 0 | - |
| 24-Aug-03 | 3 | 24 | 14 | 30,351 | 5919 | 317 | - |
| 06-Sep-03 | 4 | 0 | 27 | 13 | 10,564 | 1427 | - |
| - | - | - | - | - | - | - | 123,005 |
| Adjusted total | | 8,759 | 72,148 | 20,159 | 3,880 | 0 | 104,945 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 19-Jul-04 | 1 | 1,042 | 141 | 4 | 0 | 0 | - |
| 02-Aug-04 | 2 | 14 | 16,886 | 2281 | 176 | 0 | - |
| 16-Aug-04 | 3 | 28 | 14 | 63,327 | 12350 | 661 | - |
| 29-Aug-04 | 4 | 0 | 27 | 13 | 27,110 | 3662 | - |
| 12-Sep-04 | 5 | 0 | 0 | 27 | 14 | 6,697 | - |
| - | - | - | - | - | - | - | 115,062 |
| Adjusted total | | 1,042 | 16,745 | 61,042 | 14,584 | 2,374 | 95,788 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | Totals |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | |
| 31-Jul-05 | 1 | 12,404 | 1675 | 0 | - |
| 21-Aug-05 | 2 | 21 | 7,618 | 443 | - |
| 11-Sep-05 | 3 | 0 | 21 | 1,206 | - |
| - | - | - | - | - | 21,228 |
| Adjusted total | | 12,404 | 5,943 | 763 | 19,110 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 22-Jul-06 | 1 | 21,886 | 2956 | 0 | 0 | - |
| 06-Aug-06 | 2 | 15 | 586 | 87 | 45 | - |
| 19-Aug-06 | 3 | 28 | 13 | 9,144 | 0 | - |
| 25-Aug-06 | 4 | 20 | 19 | - | - | - |
| - | - | - | - | - | - | 31,616 |
| Adjusted total | | 21,886 | 2,370 | 9,057 | 0 | 28,572 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 14-Jul-07 | 1 | 8,899 | 1202 | 0 | 0 | - |
| 28-Jul-07 | 2 | 14 | 31,962 | 4317 | 0 | - |
| 11-Aug-07 | 3 | 28 | 14 | 8,806 | 1717 | - |
| 25-Aug-07 | 4 | 0 | 0 | 14 | 3,032 | - |
| - | - | - | - | - | - | 52,699 |
| Adjusted total | | 8,899 | 30,760 | 4489 | 1315 | 45,462 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 12-Jul-08 | 1 | 5,992 | 809 | 0 | 0 | - |
| 26-Jul-08 | 2 | 14 | 14,238 | 1923 | 0 | - |
| 09-Aug-08 | 3 | 0 | 14 | 3,182 | 0 | - |
| - | - | - | - | - | - | 23,412 |
| Adjusted total | | | | | | 20,679 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 27-Jun-09 | 1 | 7,542 | 1019 | 0 | 0 | - |
| 11-Jul-09 | 2 | 14 | 45,744 | 6179 | 0 | - |
| 25-Jul-09 | 3 | 0 | 14 | 19,338 | 3771 | - |
| 08-Aug-09 | 4 | 0 | 0 | 14 | 14,875 | - |
| 05-Sep-10 | 5 | 0 | 0 | 0 | 0 | - |
| - | - | - | - | - | - | 87,499 |
| Adjusted total | | 7,542 | 44,725 | 13,159 | 11,104 | 76,530 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 10-Jul-10 | 1 | 21,808 | 2946 | 0 | 0 | 0 | - |
| 24-Jul-10 | 2 | 14 | 9,439 | 1275 | 0 | 0 | - |
| 07-Aug-10 | 3 | 0 | 14 | 13,528 | 2638 | 0 | - |
| 21-Aug-10 | 4 | 0 | 0 | 14 | 8,011 | 1082 | - |
| 05-Sep-10 | 5 | 0 | 0 | 0 | 15 | 1,238 | - |
| 25-Sep-11 | 6 | 0 | 0 | 0 | 0 | 0 | 54,024 |
| Adjusted total | | 21,808 | 6,493 | 12,253 | 5,373 | 156 | 46,083 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 10-Jul-10 | 1 | 37,706 | 5093 | 0 | 0 | 0 | - |
| 24-Jul-10 | 2 | 14 | 38,600 | 5214 | 0 | 0 | - |
| 07-Aug-10 | 3 | 0 | 14 | 34,576 | 6743 | 361 | - |
| 21-Aug-10 | 4 | 0 | 0 | 14 | 16,898 | 2282 | - |
| 05-Sep-10 | 5 | 0 | 0 | 27 | 13 | 12,933 | - |
| 25-Sep-11 | 6 | 0 | 0 | 0 | 0 | 0 | 140,713 |
| Adjusted total | | 21,808 | 37,706 | 33,507 | 29362 | 10155 | 10290 |

*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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 30-Jun-12 | 1 | 59,795 | 8077 | 0 | 0 | 0 | - |
| 14-Jul-12 | 2 | 14 | 55,787 | 7535 | 0 | 0 | - |
| 28-Jul-12 | 3 | 0 | 14 | 38,756 | 7558 | 0 | - |
| 11-Aug-12 | 4 | 0 | 0 | 14 | 20,939 | 2828 | - |
| 25-Aug-12 | 5 | 0 | 0 | 0 | 14 | 9,550 | - |
| 24-Oct-12 | 6 | 0 | 0 | 0 | 0 | 0 | 184,827 |
| Adjusted total | | 59,795 | 47,710 | 31,221 | 13,381 | 6,722 | 158,829 |

*Table 16. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 27-Aug-99 | 1 | 165,085 | 32194 | 4606 | 0 | - |
| 10-Sep-99 | 2 | 14 | 240,453 | 43085 | 8646 | - |
| 25-Sep-99 | 3 | 29 | 15 | 85,892 | 18211 | - |
| 08-Oct-99 | 4 | 0 | 28 | 13 | 3,900 | - |
| - | - | - | - | - | - | 495,330 |
| Adjusted total | | 165,085 | 208,259 | 38,201 | 0 | 411,545 |

*Table 17. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 29-Aug-00 | 1 | 100,250 | 19550 | 2797 | 0 | - |
| 12-Sep-00 | 2 | 14 | 132,399 | 21763 | 0 | - |
| 27-Sep-00 | 3 | 29 | 16 | 80,923 | 11114 | - |
| 14-Oct-00 | 4 | 0 | 0 | 18 | 20,369 | - |
| - | - | - | - | - | - | 333,941 |
| Adjusted total | | 100,250 | 112,849 | 56,363 | 9,255 | 278,717 |

*Table 18. 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.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 27-Aug-01 | 1 | 39,160 | 8303 | 5892 | 0 | - |
| 09-Sep-01 | 2 | 13 | 36,481 | 17,602 | 2602 | - |
| 13-Sep-01 | 3 | 17 | 4 | 123,426 | 13,968 | - |
| 03-Oct-01 | 4 | 0 | 24 | 20 | 58,223 | - |
| - | - | - | - | - | - | 257,290 |
| Adjusted total | | 39,160 | 28,178 | 99,932 | 41,653 | 208,924 |

*Table 19. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | |
| 11-Aug-02 | 1 | 3,843 | 689 | 0 | 0 | 0 | 0 | - |
| 26-Aug-02 | 2 | 15 | 114,119 | 20,448 | 8140 | 0 | 0 | - |
| 10-Sep-02 | 3 | 0 | 15 | 108,837 | 32,260 | 13,598 | 3,913 | - |
| 19-Sep-02 | 4 | 0 | 24 | 9 | 174,042 | 47,379 | 21,744 | - |
| 29-Sep-02 | 5 | 0 | 0 | 19 | 10 | 4,857 | 1,440 | - |
| 08-Oct-02 | 6 | 0 | 0 | 28 | 19 | 9 | 10,403 | - |
| - | - | - | - | - | - | - | - | 416,101 |
| Adjusted total | | 3,843 | 113,430 | 88,389 | 133,642 | 0 | 0 | 339,305 |

*Table 20. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 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 | 4817 | 0 | - |
| 10-Oct-03 | 4 | 0 | 0 | 22 | 66,781 | 18179 | - |
| 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 21. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 02-Sep-04 | 1 | 113,333 | 22,102 | 4,075 | - | - |
| 16-Sep-04 | 2 | 14 | 167,502 | 32,665 | - | - |
| 30-Sep-04 | 3 | 28 | 14 | 111,120 | - | - |
| - | - | - | - | - | - | 391,955 |
| Adjusted total | | 113,333 | 145,400 | 74,380 | - | 333,113 |

*Table 22. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 07-Sep-05 | 1 | 91,701 | 17,883 | 4,062 | 0 | - |
| 21-Sep-05 | 2 | 14 | 128,825 | 27,313 | 0 | - |
| 04-Oct-05 | 3 | 27 | 13 | 48,054 | 0 | - |
| - | - | - | - | - | - | 268,580 |
| Adjusted total | | 91,701 | 110,942 | 16,678 | 0 | 219,321 |

*Table 23. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | Totals |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 25-Aug-06 | 1 | 114,069 | 11,632 | 0 | 0 | - |
| 15-Sep-06 | 2 | 21 | 107,641 | 17,693 | 0 | - |
| 01-Oct-06 | 3 | 0 | 16 | 50,893 | 9,925 | - |
| 15-Oct-06 | 4 | 0 | 0 | 14 | 22,787 | - |
| - | - | - | - | - | - | 295,390 |
| Adjusted total | | 114,069 | 96,009 | 33,200 | 12,862 | 256,140 |

*Table 24. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 24-Aug-07 | 1 | 45,920 | 8955 | 1,651 | 0 | 0 | - |
| 07-Sep-07 | 2 | 14 | 32,769 | 7,419 | 961 | 0 | - |
| 21-Sep-07 | 3 | 28 | 14 | 191,802 | 43,422 | 9,666 | - |
| 05-Oct-07 | 4 | 0 | 28 | 14 | 228,870 | 61,844 | - |
| 17-Oct-07 | 5 | 0 | 0 | 26 | 12 | 8,064 | - |
| - | - | - | - | - | - | - | 507,425 |
| Adjusted total | | 45,920 | 23,814 | 182,732 | 184,487 | 0 | 436,953 |

*Table 25. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 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 | 0 | 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 26. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 12-Aug-09 | 1 | 90,118 | 17,574 | 0 | 0 | 0 | - |
| 25-Aug-09 | 2 | 14 | 116,084 | 11837 | 0 | 0 | - |
| 14-Sep-09 | 3 | 0 | 21 | 70,024 | 17531 | 6393 | - |
| 24-Sep-09 | 4 | 0 | 0 | 11 | 49,292 | 11356 | - |
| 05-Oct-09 | 5 | 0 | 0 | 22 | 12 | 71,809 | - |
| - | - | - | - | - | - | - | 397,327 |
| Adjusted total | | 90,118 | 98,510 | 58,187 | 31,761 | 54,060 | 332,636 |

*Table 27. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 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 | 3 | 28 | 15 | 65,230 | 7,382 | 0 | - |
| 05-Oct-10 | 4 | 0 | 0 | 20 | 36,068 | 7,034 | - |
| 19-Oct-10 | 5 | 0 | 0 | 0 | 14 | 8,721 | - |
| - | - | - | - | - | - | - | 253,769 |
| Adjusted total | | 85,180 | 40,510 | 51,673 | 28,686 | 1,687 | 207,736 |

*Table 28. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | Totals |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 26-Aug-11 | 1 | 30,405 | 6,446 | 1,347 | 0 | 0 | - |
| 08-Sep-11 | 2 | 13 | 116,508 | 24,702 | 0 | 0 | - |
| 21-Sep-11 | 3 | 27 | 13 | 143,937 | 17,983 | 4,016 | - |
| 10-Oct-11 | 4 | 0 | 0 | 19 | 9,611 | 1,722 | - |
| 23-Oct-11 | 5 | - | - | - | 13 | - | - |
| - | - | - | - | - | - | - | 300,461 |
| Adjusted total | | 30,405 | 110,062 | 117,888 | 0 | 0 | 258,355 |

*Table 29. 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. A "-", indicates no information.*

| Survey Date | Survey Number | Surveys | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | |
| 12-Aug-12 | 1 | 33,541 | 6541 | 1206 | 0 | 0 | 0 | - |
| 26-Aug-12 | 2 | 14 | 107,994 | 21,060 | 3883 | 0 | 0 | - |
| 09-Sep-12 | 3 | 28 | 14 | 59,886 | 12,697 | 1671 | 0 | - |
| 22-Sep-12 | 4 | 0 | 28 | 13 | 59,213 | 10,610 | 0 | - |
| 07-Oct-12 | 5 | 0 | 0 | 29 | 15 | 21,475 | 3231 | - |
| 24-Oct-12 | 6 | 0 | 0 | 0 | 0 | 17 | 6,303 | - |
| - | - | - | - | - | - | - | - | 288,412 |
| Adjusted total | | 33,541 | 101,453 | 37,620 | 42,633 | 9,194 | 3,072 | 227,513 |

## FIGURES

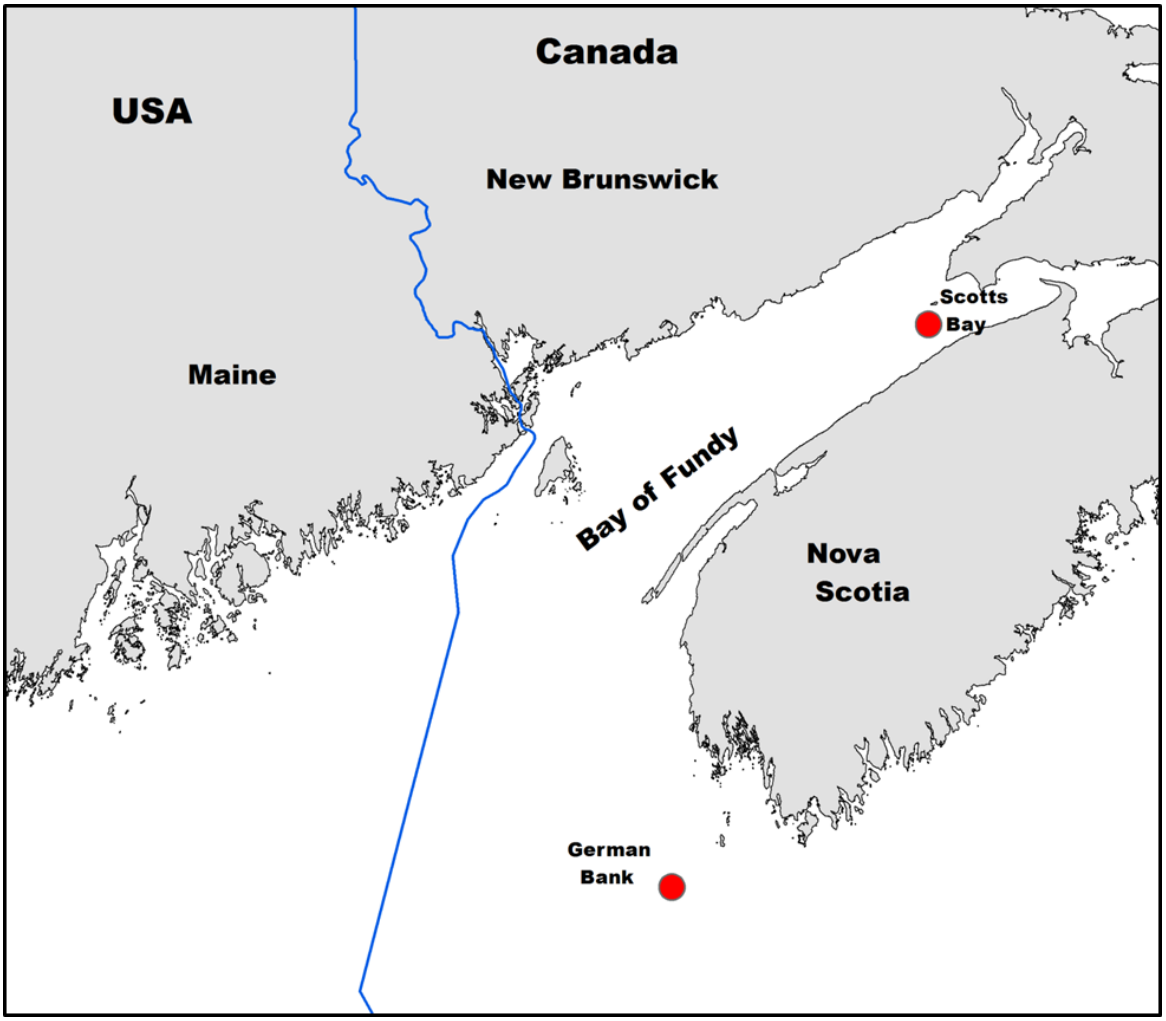


*Figure 1. Map of the Bay of Fundy and Southwest Nova Scotia showing the location of Scots Bay and German Bank spawning grounds.*

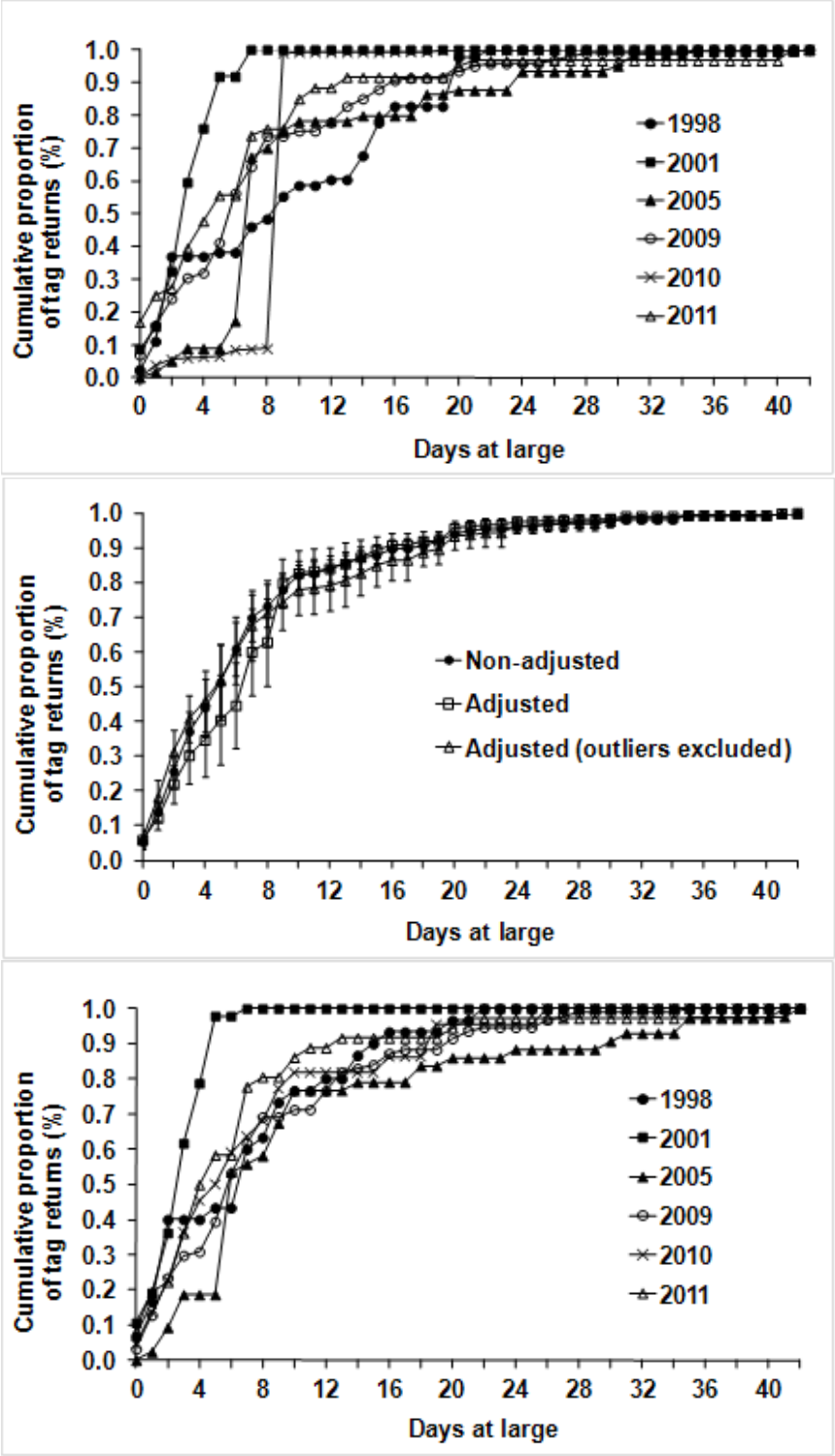


*Figure 2. Summary of raw (upper panel) and landings standardized (middle panel) proportions of tag returns by day and year for German Bank. Mean values (all years combined) and associated error bars (SE) for raw, weighted and weighted with outliers removed are in plot (lower panel).*

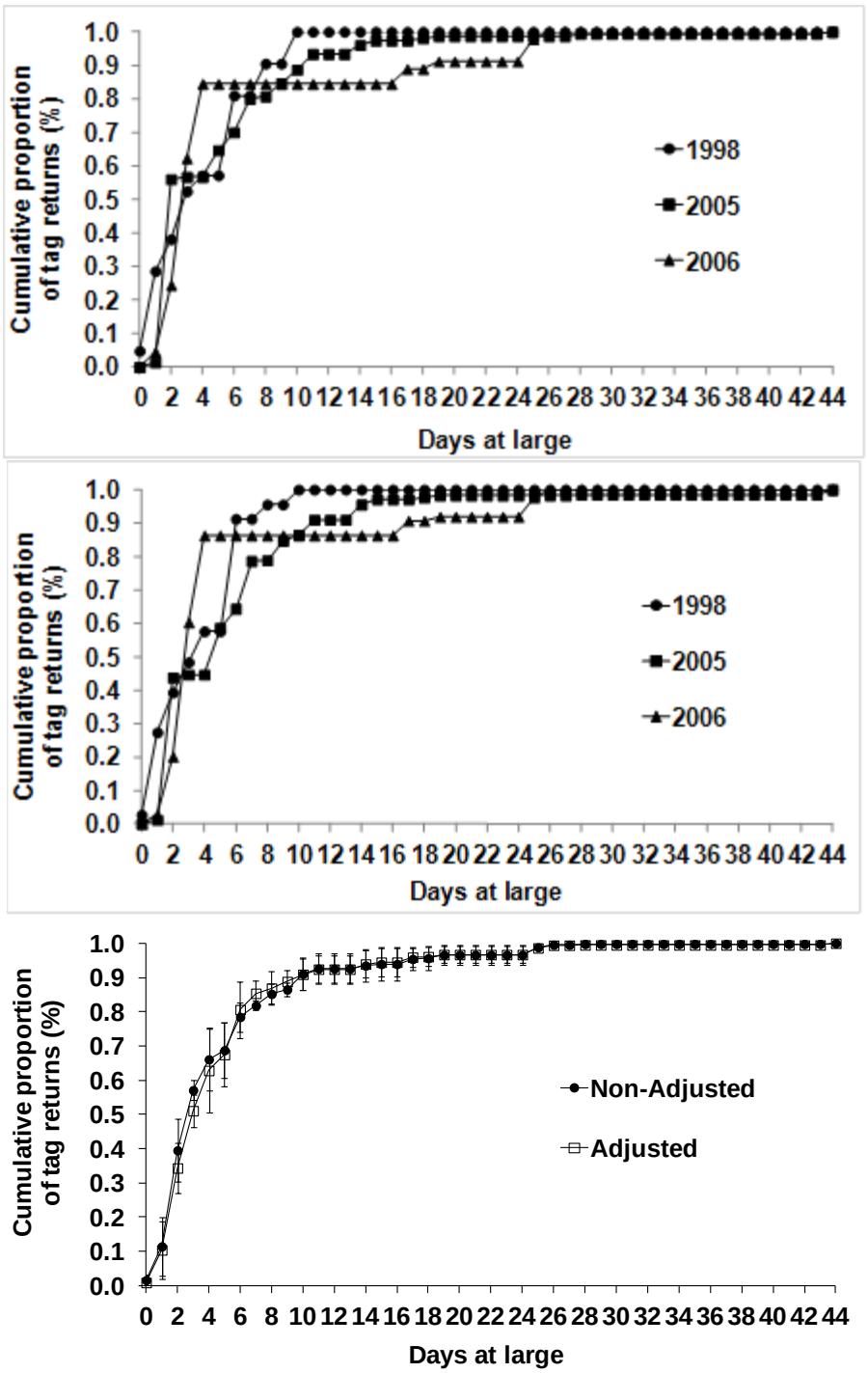


*Figure 3. Summary of raw (a-upper panel) and landings standardized (b-middle panel) proportions of tag returns by day and year for German Bank. Mean values (all years combined) and associated error bars (SE) for raw and landings weighted are plotted in (c-lower panel).*

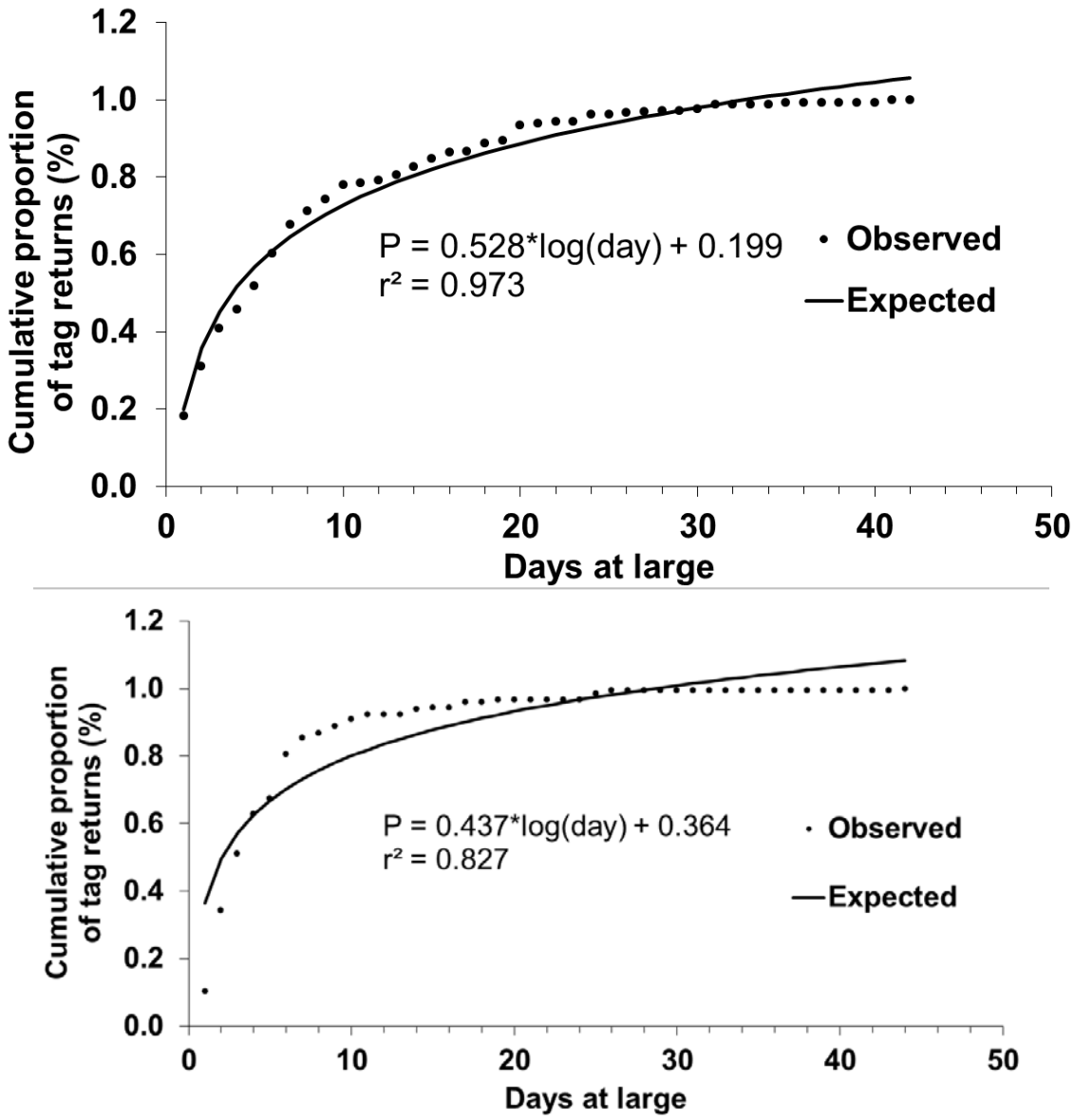


*Figure 4. The regression analysis of the expected and observed proportion of tag returns and number of days after tagging for German Bank (upper panel) and Scots Bay (lower panel).*

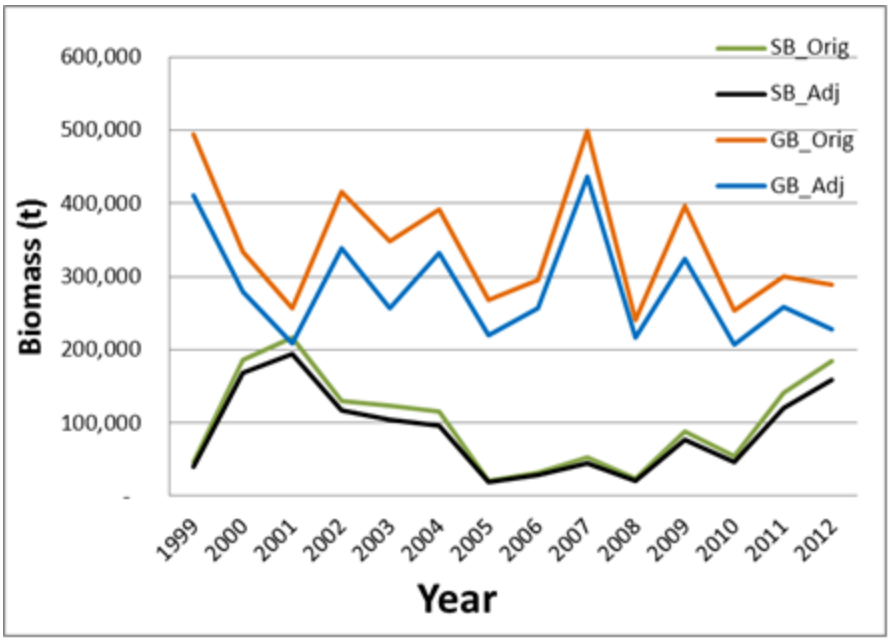


*Figure 5. The 1999 to 2012 estimated original and elapsed time adjusted SSB for Scot Bay and German Bank herring from acoustic surveys.*

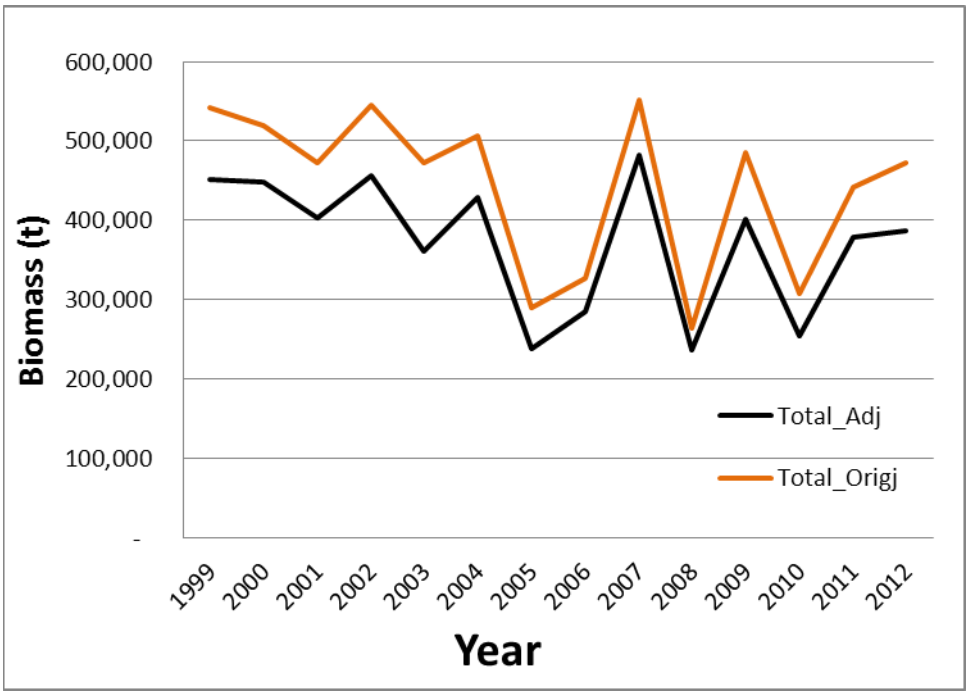


*Figure 6. The 1999 to 2012 estimated original and elapsed time adjusted SSB for Scot Bay and German Bank **combined** from acoustic surveys.*