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The 2009 German Bank Spawning Ground Tagging Turnover Rates

Taux de roulement du hareng dans les frayères du banc German en 2009 d'après une opération de marquage

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ABSTRACT

A tagging study to examine herring turnover rate on the German Bank spawning grounds was conducted during the summer/fall of 2009. The project will continue for the next two years to gain a better understanding of residency time of herring throughout the spawning season. Tagging was conducted whenever possible between August and October with 15 independent tagging events. A total of 10,338 tags were applied with a tag return rate of 0.7% in a 4 month return window. The tag return data were compared to previous turnover studies on German Bank and Scots Bay, which resulted in similar return rates (all under 1%). Tag return and maturity data were used to determine the length of time herring remain on the spawning grounds. Based on daily recoveries from 69 tags recaptured, 52% were recaptured within the first week, 78% by the second week, and 93% by the third week. Although the majority of the tags were returned by the first three weeks after tagging, some fish remained on the spawning grounds for up to five weeks. The relationship between the proportion of fish remaining on the spawning grounds and the days at large was found to be highly correlated (r^2 = 0.972). Turnover information is critical in the estimate of total spawning stock biomass from multiple acoustic surveys. The current assumes a 10 to 14 day resident period.

RÉSUMÉ

Une opération de marquage visant l'étude du taux de roulement du hareng dans les frayères du banc German a eu lieu au cours de l'été et de l'automne de 2009. On poursuivra ce projet sur les deux prochaines années pour mieux comprendre le temps de présence du hareng tout au long de la saison de fraye. Le marquage a été effectué autant que possible en août et en octobre, en 5 opérations indépendantes les unes des autres. Au total, 10 338 étiquettes ont été apposées et le taux de retour de ces étiquettes a été de 0,7 % sur une période de 4 mois. Les données sur les retours d'étiquettes ont été comparées aux résultats des études antérieures sur le roulement du hareng réalisées sur le banc German et dans la baie Scots, et elles ont abouti à des taux de retour semblables (tous inférieurs à 1 %). Les retours d'étiquettes et les données sur la maturité ont servi à déterminer combien de temps le hareng demeure dans les frayères. D'après les données quotidiennes de récupération portant sur un total de 69 étiquettes récupérées, 52 % d'entre elles l'ont été dans la première semaine, 78 % dans la deuxième semaine et 93 % dans la troisième semaine. Quoique la majorité des étiquettes aient été renvoyées dans les trois premières semaines suivant le marquage, certains poissons sont restés dans les frayères pendant cinq semaines. On a établi qu'il existait une forte corrélation entre la proportion de poissons restant dans les frayères et le nombre de jours en mer (r^2 = 0,972). L'information sur le roulement du poisson est essentielle à l'estimation de la biomasse totale du stock de reproducteurs d'après les relevés acoustiques multiples. Selon les données actuelles, le temps de présence est de 10 à 14 jours.

INTRODUCTION

Knowledge of the residency time of herring, *Clupea harengus,* on spawning grounds is important when multiple acoustic surveys in a pre-defined spawning area are used to estimate spawning stock biomass (Melvin and Power, 1999, Power et al., 2009). Currently spawning fish are assumed to move on to a spawning ground in waves with a complete turnover every 10 to 14 days (Power et al., 2002). Annual spawning stock biomass (SSB) is estimated by summing the survey results from all surveys which occur at time intervals greater than the 10 to 14 day window. Determining the length of time that spawning aggregations of herring remain on the spawning grounds will improve our estimate of the spawning stock biomass (SSB) and prevent double counting during repeat acoustic surveys.

A multi-year tagging study is currently underway to investigate turnover rates and stock structure of Atlantic herring, .The study will run over a period of 3 years to determine inter-annual variability. This report provides an overview of the results from the first year of study.

BACKGROUND

German Bank spawning ground surveys represent 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 studied using commercial fishing vessel deployed acoustic technology since 1997. This information is used to evaluate stock status and to recommend catch levels. We define the turnover time on the spawning ground 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 spawning stock biomass (SSB) (Power et al., 2002, Power et al, 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 slightly in recent years (Power et al., 2009).

Tagging studies have been conducted intermittently on this stock since the 1930s (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 exit promptly after spawning, an increased and focused tagging effort is necessary (Paul, 1999). Unlike many of the previous tagging studies, where tagging events were ad hoc and sporadic, this three year study has been 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 O'Dor 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 that spawning

waves do occur. 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. The number of tag 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 move off the spawning grounds directly after a spawning event. Spent fish are rarely observed in the catches on the spawning grounds, thereby supporting a short residency time after spawning. Clark (2006) reported that the amount of time a fish resides on the spawning ground fluctuates. In 2005, she tagged a total of 8,580 fish on German Bank with 56 tag recaptures. The majority of recaptures from the spawning grounds 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 5 weeks.

Following the 2005 Herring Regional Advisory Process (RAP) meeting, it was recommended that further investigation of the turnover rate be undertaken and a enhanced tagging project was initiated (Neilson, 2005, Clark, 2006). In response to the conclusions of tag recaptures from Clark (2006), acoustic surveys were spaced at 2 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 some double or even triple counting may be occurring. Unlike the previous project conducted on the spawning grounds of Scots Bay and German Bank, the current three year tagging project has a specific focus on turnover issues within a single spawning ground, German Bank. The main objective of the project is to investigate the potential uncertainty of SSB due to double counting or overestimating from survey to survey.

METHODS

A three year collaborative herring tagging program commenced on the German Bank spawning grounds in August of 2009. The program is being conducted through the combined efforts of the Herring Science Council (HSC) and Department of Fisheries and Oceans, St Andrews Biological Station. The approach taken is to tag continuously throughout the entire German Bank spawning season to monitor the movement, distribution and residence time of herring on the spawning ground. During the first year a total of 15 independent tagging events took place on German Bank, with 6 events in August and 9 in September (Table 1). Herring were collected during normal purse seine fishing operations. The fish were removed from the seine by dipnet and retained in an onboard holding tank until tagged.   The tank contained a continuous supply of running sea water to aid in the fish's survival. Individual herring were removed from the holding tank, tagged, and immediately released. For the purpose of this study only healthy "ripe and running" fish were selected for tagging.

The herring were tagged with either FD-94 Anchor tags from Floy Tag and Manufacturing Inc. or Hallprint T-Bar tags that were purchased for earlier to herring studies. Floy tags were characterized with an individual identification number and return address as follows:

   ###### DFO/SABS NB E5B 2L9

where the ##### represents a unique number for each tag.

Hallprint tags were marked with a dual Canada/US return address to encourage returns in both countries. A Floy tagging gun was used to insert a tag between the fin rays at the base of the herring's dorsal fin. Following the tagging each fish was immediately released back into the water. A randomly selected length frequency sample of 100-200 herring was collected from

each tagging set and a sample of 2 fish per ½ cm interval was retained for detailed laboratory analysis. Detailed sample analysis included the measurement of total length (mm), weight (gm), determination of sex, maturity, and the excision of otoliths for aging.

As in the previous tagging studies, an annual lottery (i.e., reward) was held as an incentive for returning a tag. Individuals who returned tags with the capture location and date had their name entered in the annual draw of $1,500. The last draw took place in December of 2009 in Yarmouth, Nova Scotia, to acknowledge the 2009 returns. Rewards were presented to three individuals.

The tag returns were initially adjusted by landings for the period of interest (daily or weekly) for German Bank then standardized using the same procedure as Clark (2006) as follows:

n = number of tag returns adjusted by the landings

n_{wi} = the number of tag returns from the tagging event w, where the first week after tagging is i = 1 and the second is i = 2, etc

n_{w1} = the number of tag returns from the first week after tagging for tagging event w. If all the fish are still present on the spawning grounds, this would be the assumed number of tag returns.

N_{wi}/n_{w1} = the proportion of fish in week i from tagging event w still present on the spawning grounds.

$\dfrac{N_{wi}/n_{w1}}{\sum N_{wi}/n_{w1}}$ = to standardize so that proportions from different tagging dates can be compared and averaged

RESULTS

A total of 10,338 tags were applied on the ripe and running herring on the spawning grounds of German Bank throughout August and September, 2009 (Table 1). During this same period 16,182t of fish were caught by the commercial fleet on the spawning grounds. Weekly landings are presented in Table 2 and details of the length sampling in Table 3. Tagging was discontinued after September 30 as the fishery on the spawning grounds slowed due to vessel quotas being filled, weather conditions, and a change in fish market. In October, landings decreased by more than half compared to August and September period (Figure 1, Table 2).

Overall detailed samples were collected and returned to the St. Andrews Biological Station laboratory for processing for 12 of the 15 tagging excursions. Length frequency measurements from the 19 length frequency samples showed nearly all herring measured were between 250 and 300 mm, which suggest mature and spawning herring (Table 3 and Figure 2). Less than 1% of the sampled fish were less than 23cm (the general length used to separate juveniles from adults) (Power et al., 2009). The maturity of herring is characterized by 8 stages specific to each sex (ICES, 2005). The majority of fish sampled on the spawning grounds were stage 6 (ripe and running) herring (Figure 3). Samples collected during the tagging events of August 19 and 31, as well as September 15 and 30 contained high percentages of stage 6 herring, between 79 and 100%. On September 8 and 22, the percentages of stage 6 herring were much lower (29-50%) suggesting a spawning event had occurred. A similar occurrence was observed on September 17. Up to 9% of stage 7 (spent) herring and 28% of stage 8 (recovering) herring

occurred on September 9. The occurrence of stage 8 fish being sampled on September 9 suggests that fish do not leave the grounds immediately after spawning and may stay on the spawning grounds for longer periods of time than previously assumed (Figure 3). Very few immature herring were observed on the spawning ground during the 2009 spawning season.

The majority of herring tagged on German Bank between August and October and returned before the end of 2009 did not travel far from the area where they were released. Only 5 tagged fish were recaptured further than 20km from their tagging site, and 2 had travelled distances greater than 100km (128 and 152 km). There was also a notable southerly movement by the majority of tagged herring after being released on the spawning grounds (Figure 4). A total of 68% of the returned tags had been recaptured on the spawning grounds within 10 days at large. The longest time at large for any tag return used in this study was 35 days. The proportion of herring tags returns by days at large are shown in Figure 5. Tags that were returned <u>after 10 or more</u> days at large within the spawning box area of German Bank are shown in Figure 6. No relationship was found between the distance travelled and the days at large (Figure 7).

In 2009 a total of 69 tags were returned by the end of December 2009 representing a return rate of 0.7% (Table 4). For the initial analysis any tags returned within the first 2 days after tagging were removed to prevent bias from an instant re-catch. Removing tags <3 days after tagging reduced the total number of tag returns to 53 for a return rate of 0.5%. Tags returned from each tagging event are presented in Table 4 and the number of returns summarized by tagging week (Table 5), adjusted by landings (per 1000t landings) for all tag returns (Tables 6) and only for German Bank returns (Table 7). For comparison with previous reports (Clark, 2006) the data are presented as a function of a 7 to 14 day turnover rate (Tables 8 and 9). The majority of tags (38 of 51) on German Bank were recaptured within 14 days at large (Figure 8). The proportion of tags by weeks after tagging for all 2009 tag returns shows that 60% were recovered after two weeks at large and 81% after 3 weeks (Figure 9).

The number of returns by week and tagging event, excluding those recaptured within 2 days of tagging, per 1000t of herring landed are presented in Table 10. Standardization shows that the proportion of spawning fish remaining on the bank declines rapidly during the first 3 weeks with an estimated 19% remaining based on the weekly analysis (Table 11). All fish appear to have moved on after 6 weeks.

Unlike previous studies where the data were analyzed on a weekly basis, we explored the daily returns with all returns from the bank. The same general processing, weighting by landings, and standardization method used for the weekly analysis was used for the daily analysis. The standardized results are presented in Table 12 and show a moderate difference between methods. For 2009 the daily analysis showed a greater portion of herring leaving the Bank within 14 days after tagging than the weekly analysis (78% vs. 60%, respectively) due to a finer time resolution. The daily analysis also showed a smaller portion of spawning fish leaving the grounds within 14 days after tagging than in 2005 (78% vs. 84%) when the 2005 data were analyzed in a similar manner (Table 13, 14, 15). The main difference between the two tagging studies appears to be a large number of returns on day 8 in 2005 (Figure 10). Weekly comparisons for the two years are shown in Figure 11.

The next step in the analysis involved the investigation of the relationship between the cumulative portion of returns (standardized by landings) and elapsed time. A log linear relationship was developed to estimate the proportion of fish remaining on the spawning grounds relative to the (log) days at large (Table 16). The relationship, which was highly correlated (r^2 = 0.972) is shown in Figure 12. The equation was then used to estimate the

relative biomass of the fish remaining on the spawning grounds from survey to survey. The results of this analysis for 2009 are shown in Table 17 for all surveys and Table 18 for only those surveys that met the standard elapsed time to be considered independent (10-14 days). To illustrate the process, for the September 14 survey about 12,928t remained on the Bank from the August 25 and 15,889t from the September 8 survey. The biomass from the survey was reduced from 70,024t to 41,207t (Table 14). Adjusting for fish remaining on the Bank in both cases produced similar total biomass estimates (301,795t and 308,069t), thereby supporting the relationship equation. 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 much greater (Table 18).

Overall applying the regression equation to the elapsed time for other survey years results in a decrease of between 13 and 28% in the annual estimated German Bank spawning biomass. Table 16 illustrates the results of these adjustments for 2004 to 2008 and Table 19 for 1999 to 2003. Figure 20 shows the time series for the total, adjusted, and the maximum annual individual survey SSB. All three estimates show the same trend although the magnitude is different (Figure 11). The biomass declined during the first few years of the time series, increased in 2001, gradually declined until 2007 then dropped sharply in 2008. Spawning stock biomass in 2009 for both the total and the adjusted increased substantially to levels near the beginning of the time series. Excluding 2008, biomass estimates based on the maximum individual survey have remained relatively stable at around 100,000t since 2003 (Tables 19 and 20, Figure 11).

DISCUSSION

This report provides a summary of the results to date from the 2009 German Bank tagging study to investigate spawning ground turnover times. Unfortunately, tag return rates for herring are never very high due to large amounts of bulk handling. The three year study will increase the total number of returns and provide an estimate of the amount and variability in the time herring spend on the spawning grounds during several spawning season. The results from this on going study will be presented annually so they can be incorporated into the analytical assessment.

Compared to earlier tagging studies conducted on German Bank the tag return rate was slightly higher at 0.7% in 2009 than the 0.3% in 1998, 0.5% in 2001 and 0.6% in 2005, but still considered low (Paul, 1999, Waters *et al.*, 2000, Clark, 2006). The majority of tags (93%) were recaptured within the first few weeks after tagging; 78% after 2 weeks and 93% after 3 weeks (Tables 12). However, some fish remain on the spawning grounds for up to 5 weeks after being tagged demonstrating the uncertainty associated with the length of spawning activity (Figure 3). Differences were also observed between the daily and the weekly analysis, 60% and 78% remaining on the bank after 14 days respectively. At present it is assumed that a complete turn over of fish occurs during 10-14 day window. Based on these preliminary results some double counting likely occurs for acoustic surveys conducted following the elapsed time between surveys.

Comparison of estimated turnover rates from this first year and the 2005 German Bank study, analysed in terms of daily returns, show similar results (78% after 14 days vs. 84%). Tables 18, 19, and 20 contain tag return data from 2005 and show that by 14 days at large 84% of the tagged fish were recaptured on German Bank (Clark, 2006). For weekly tag return analysis the rates are far less in 2005 (47%) than in 2009 (60%). In both years, some herring were recaptured on the grounds up to 5 and 6 weeks after being tagged. Figure 10 shows the

comparison by day between 2005 and 2009 tag returns. In 2005 more tags were caught in the first three weeks after tagging than in 2009 (Figure 11).

A regression analysis was undertaken to investigate the relationship between the proportion of recaptures on the spawning grounds and the days at large. The regression, which was highly correlated (r = 0.97) also showed that significant amounts (20%+) of biomass remain on the spawning grounds for several weeks at a time. Comparison of the biomass estimates from all surveys and the valid surveys showed the equation to be fairly accurate in determining total biomass estimates (Tables 14 and 15). 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 435,112t vs 397,590t, respectively (Table 14 and 15). However, once the surveys were adjusted for elapsed time the estimates were very similar (301,795 vs 308,069t), suggesting that the correction for time is reasonable. Annual biomass trends for the total, adjusted and the annual maximum for the entire time series are shown in Figure 13.

Caution is warranted when applying the correction/adjustment to all years. The current data show inter-year variability between 2005 and 2009 of approximately 6%. Other years may show even more, or less, difference in turnover time, which could be miss leading in tracking trends in abundance. That being said, adjusting all SSBs from 1999 to 2009 using the 2009 results produces a similar, but slightly reduced annual SSB. The amount the SSB is reduced is dependent on the elapsed time between surveys.

A major concern with any tagging study is the number of returns. This is particularly true for herring where a large portion of the landings are handled mechanically. In 4WX a significant amount of the landings goes for bait, which is generally processed in bulk, with limited opportunity to visually detect tagged fish. Increasing the amount of tags applied will increase the number of tags returned and help to improve our estimate of turnover rate. However, even with low tag recovery rate, another two years of this project should provide valuable information on the intra and inter-annual variability in turnover times during the spawning season. The southerly movement of tagged herring (Figure 8) is something that needs to be examined further as the tagging program continues over the next couple of years. Tagging effort to date has concentrated on spawning herring only even though juvenile herring are found in the area. Power *et al.* (2009) stated that very small amounts of juvenile herring are caught north of the spawning area, whereas the herring within the area are mostly spawning fish.

Similar tagging efforts on the German Bank spawning grounds will continue for another two years. The final study conclusions will look at both individual and pooled tagging year data to estimate inter and intra-year variability in turnover time. Upon completion of the study recommendations will be made on how to adjust the acoustic biomass for herring moving on and off of the spawning grounds, thereby limiting the amount of double counting among surveys.

SUMMARY

In excess of 10,000 spawning herring were marked and released on German Bank during the 2009 spawning season with a return rate of 0.7%. Return data showed that 78% of tagged fish were recaptured within two weeks after tagging, compared to 84% during the 2005 study. In

both 2005 and 2009 a small proportion tags were returned up to 3-5 weeks after tagging, indicating a broad range in spawning residence time. Current biomass estimates assume that fish remain in the same area for a maximum of 2 weeks before moving on. Some double counting of spawning herring occurs in the annual biomass estimates of SSB for German Bank. Regression analysis, indicates a strong relationship (r^2 = 0.972) between the days at large and the proportion of fish remaining on the bank. Adjusting the 2009 German Bank spawning biomass for elapsed time reduces the biomass from 397,590t to 308,069t or 22.5%.

ACKNOWLEDGEMENTS

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

Tagging Week	Date Tagged	Days Between Tagging	Number Tagged	Week Total
1	18/08/2009		384	
	19/08/2009	1	601	
	20/08/2009	1	1,252	**2,236**
2	24/08/2009	4	500	
	25/08/2009	1	700	**1,200**
3	31/08/2009	6	490	
	02/09/2009	2	1,110	**1,600**
4	08/09/2009	6	575	
	09/09/2009	1	837	
	10/09/2009	1	987	**2,398**
5	15/09/2009	5	701	
	17/09/2009	2	850	**1,551**
6	21/09/2009	4	500	
	22/09/2009	1	450	**950**
7	30/09/2009	8	400	**399**
Total			**10,334**	

Table 2. The 2009 weekly landings from German Bank during the tagging study. These values are used to weight tag returns by catch.

Date	Fishing Nights	Landings (t)
Aug 17 to 23	5	3,913
Aug 24 to 30	5	2,018
Aug 31-Sep 6	5	2,175
Sep 7 to 13	5	2,347
Sep 14 to 20	5	1,270
Sep 21 to 27	6	2,161
Sep 28-Oct 4	4	1,157
Oct 5 to 11	2	967
Oct 12 to 18	1	174
Total		**16,182**

Table 3. Daily length frequency samples and average length measurements of herring collected on the spawning grounds of German Bank during the 2009 tagging study.

Date	Number Samples	Number of Fish Measured	Mean Length (mm)
18/08/2009	1	90	264.9
19/08/2009	1	108	264.4
20/08/2009	2	321	272.1
24/08/2009	1	73	260.4
25/08/2009	1	122	263.4
31/08/2009	1	172	268.5
02/09/2009	2	147	279.5
08/09/2009	1	96	281.0
09/09/2009	1	196	266.6
10/09/2009	2	296	270.5
15/09/2009	1	108	272.6
17/09/2009	2	332	262.1
21/09/2009	1	154	262.5
22/09/2009	1	176	268.2
30/09/2009	1	206	266.7

Table 4. Summary of the 2009 German Bank daily tag returns for each application (release) date. Returns are expressed as the total and those recaptured greater than 2 days at large.

Application Date	Return Location	Number Tags Returned	Tags Returned >2 days at large
18/08/2009	German Bank	3	3
19/08/2009	German Bank	7	6
20/08/2009	German Bank	11	11
24/08/2009	German Bank	1	1
25/08/2009	German Bank	1	1
31/08/2009		0	0
02/09/2009	German Bank	12	5
08/09/2009	German Bank	5	2
09/09/2009	German Bank	10	9
	Grand Manan	1	1
10/09/2009	German Bank	11	7
15/09/2009	German Bank	4	4
17/09/2009		0	0
21/09/2009	German Bank	1	1
22/09/2099		0	0
30/09/2009	Grand Manan	1	1
	German Bank	1	1
Total Number of Returns	**69**		**53**

Table 5. German Bank 2009 tag returns (unadjusted for catch) by week for returns >2 days at large.

Application Date	Number of Tag Returns	Return Location	Aug 17-23	Aug 24-30	Aug 31-Sep 6	Sep 7-13	Sep 14-20	Sep 21-27	Sep 28-Oct 4	Oct 5-11	Total
18/08/2009	384	German Bank	1	1	1						3
19/08/2009	601	German Bank		3	3						6
20/08/2009	1,252	German Bank		7	4						11
24/08/2009	500	German Bank			1						1
25/08/2009	700	German Bank			1						1
31/08/2009	490										0
02/09/2009	1,110	German Bank			1	3				1	5
08/09/2009	575	German Bank				2					2
09/09/2009	837	German Bank				2	2	1	1	3	9
		Grand Manan								1 (Nov 3)	1
10/09/2009	987	German Bank					1	3	2	1	7
15/09/2009	701	German Bank						3	1		4
17/09/2009	850										0
21/09/2009	501	German Bank								1	1
22/09/2009	450										0
30/09/2009	400	Grand Manan								1	1
		German Bank								1	1
Total	**10,338**		1	11	11	7	3	7	4	9	53

Table 6. German Bank 2009 returns (adjusted for landings- number of tags per 1,000t landed) by week for returns >2 days at large.

Application Date	Number of Tag Returns	Return Location	Aug 17-23	Aug 24-30	Aug 31-Sep 6	Sep 7-13	Sep 14-20	Sep 21-27	Sep 28-Oct 4	Oct 5-11	Total
18/08/2009	384	German Bank	0.3	0.5	0.5						**1.3**
19/08/2009	601	German Bank		1.5	1.4						**2.9**
20/08/2009	1,252	German Bank		3.5	1.8						**5.3**
24/08/2009	500	German Bank			0.5						**0.5**
25/08/2009	700	German Bank			0.5						**0.5**
31/08/2009	490										**0**
02/09/2009	1,110	German Bank			0.5	1.3				1	**2.8**
08/09/2009	575	German Bank				0.9					**0.9**
09/09/2009	837	German Bank				0.9	1.6	0.5	0.9	3.1	**7**
		Grand Manan								4.7 (Nov 3)	**4.7**
10/09/2009	987	German Bank					0.8	1.4	1.7	1	**4.9**
15/09/2009	701	German Bank						1.4	0.9		**2.3**
17/09/2009	850										**0**
21/09/2009	501	German Bank								1	**1**
22/09/2009	450										**0**
30/09/2009	400	Grand Manan								4.6	**4.6**
		German Bank								1	**1**
Total	**10,338**		**0.3**	**5.5**	**5.2**	**3.1**	**2.4**	**3.3**	**3.5**	**16.4**	**39.7**

Table 7. German Bank 2009 weekly adjusted tag returns (Number of tags per 1,000t landed) for returns >2 days at large.

Application Date	Number of Tag Returns	Return Location	Aug 17-23	Aug 24-30	Aug 31-Sep 6	Sep 7-13	Sep 14-20	Sep 21-27	Sep 28-Oct 4	Oct 5-11	Total
18/08/2009	384	German Bank	0.3	0.5	0.5						**1.3**
19/08/2009	601	German Bank		1.5	1.4						**2.9**
20/08/2009	1,252	German Bank		3.5	1.8						**5.3**
24/08/2009	500	German Bank			0.5						**0.5**
25/08/2009	700	German Bank			0.5						**0.5**
02/09/2009	1,110	German Bank			0.5	1.3				1	**2.8**
08/09/2009	575	German Bank				0.9					**0.9**
09/09/2009	837	German Bank				0.9	1.6	0.5	0.9	3.1	**7**
10/09/2009	987	German Bank					0.8	1.4	1.7	1	**4.9**
15/09/2009	701	German Bank						1.4	0.9		**2.3**
21/09/2009	501	German Bank								1	**1**
30/09/2009	400	German Bank								1	**1**
Total	**8,548**		**0.3**	**5.5**	**5.2**	**3.1**	**2.4**	**3.3**	**3.5**	**7.1**	**30.4**

Table 8. All 2009 tags applied and returned for selected time intervals that correspond with the 2005 study.

Application Date	Number Tagged	Return Location	Tag Returns <7 days	Tag Returns ≥7 and <10 days	Tag Returns ≥10 and <14 days	Tag Returns ≥14 and <21 days	Tag Returns ≥21 days	Total
18/08/2009	384	German Bank	1	1		1		**3**
19/08/2009	601	German Bank	2		4			**6**
20/08/2009	1,252	German Bank	4	3	3	1		**11**
24/08/2009	500	German Bank		1				**1**
25/08/2009	700	German Bank	1					**1**
31/08/2009	490							**0**
02/09/2009	1,110	German Bank	3	1			1	**5**
08/09/2009	575	German Bank	2					**2**
09/09/2009	837	German Bank	3	1	1		4	**9**
		Grand Manan					1	**1**
10/09/2009	987	German Bank		1	2	2	2	**7**
15/09/2009	701	German Bank		3		1		**4**
17/09/2009	850							**0**
21/09/2009	501	German Bank				1		**1**
22/09/2009	450							**0**
30/09/2009	400	Grand Manan	1					**1**
		German Bank	1					**1**
Total	**10,338**		**18**	**11**	**10**	**6**	**8**	**53**

Table 9. Summary of 2009 German Bank tags applied and returned after more than 2 days at large for selected time intervals that correspond with the 2005 study.

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Application Date	Number Tagged	Return Location	Tag Returns <7 days	Tag Returns >7 and <10 days	Tag Returns >10 and <14 days	Tag Returns >14 and <21 days	Tag Returns >21 days	Total
18/08/2009	384	German Bank	2			1		3
19/08/2009	601	German Bank	2		4			6
20/08/2009	1,252	German Bank	4	3	3	1		11
24/08/2009	500	German Bank		1				1
25/08/2009	700	German Bank	1					1
02/09/2009	1,110	German Bank	3	1			1	5
08/09/2009	575	German Bank	2					2
09/09/2009	837	German Bank	3	1	1		4	9
10/09/2009	987	German Bank		1	2	2	2	7
15/09/2009	701	German Bank	1	2		1		4
21/09/2009	501	German Bank				1		1
30/09/2009	400	German Bank	1					1
Total	8,548		19	9	10	6	7	51

Table 10. The number of German Bank tag returns per 1,000t landed by tagging event and tagging week after the program began in 2009.

Tagging Event (w	Number of Weeks after Tagging (i)								Total
	1	2	3	4	5	6	7	8	
17/08/2009	2.72	5.45	4.66						**12.83**
24/08/2009			1.69						**1.69**
02/09/2009			4.82	2.53				3.03	**10.38**
08/09/2009				6.69	4.14	1.70	3.24	4.14	**19.90**
15/09/2009						3.00	2.05		**5.05**
21/09/2009								3.03	**3.03**
30/09/2009								1.57	**1.57**
Total	**2.72**	**5.45**	**11.17**	**9.22**	**4.14**	**4.69**	**5.29**	**11.77**	**54.45**

Table 11.Total number of tag returns from German Bank standardized by the weekly totals $[(n_{wi}/n_{w1})/(\sum(n_{wi}/n_{w1})]$ for 2009.

Tagging Event	Number of Weeks after Tagging (i)						Total
	1	2	3	4	5	6	
17/08/2009	0.05	0.10	0.09				0.24
24/08/2009		0.03					0.03
02/09/2009	0.09	0.05				0.06	0.19
08/09/2009	0.12	0.08	0.03	0.06	0.08		0.37
15/09/2009		0.06	0.04				0.09
21/09/2009			0.06				0.06
30/09/2009		0.03					0.03
Total	0.26	0.34	0.21	0.06	0.08	0.06	1.00
Average	0.087	0.056	0.05	0.06	0.08	0.06	0.387
SD	0.04	0.03	0.02				
Percent	22.50	14.54	13.58	15.38	19.63	14.38	
Cumulative	0.26	0.60	0.81	0.87	0.94	1.00	

Table 12. The 2009 German Bank tag returns standardized by daily landings $[(n_{wi}/n_{w1})/(\sum(n_{wi}/n_{w1}))]$ for each day at large.

Tagging Event	Days at Large 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
18/08/2009				0.01					0.07						
19/08/2009		0.01					0.02				0.01			0.02	0.04
20/08/2009						0.03		0.02	0.02				0.02		
24/08/2009											0.01				
25/08/2009								0.01							
02/09/2009	0.04	0.04	0.04				0.02		0.01						
08/09/2009		0.02	0.02	0.01	0.02										
09/09/2009			0.01	0.05		0.03		0.03					0.01	0.01	
10/09/2009		0.02	0.05						0.02						
15/09/2009								0.01	0.02						
21/09/2009															
30/09/2009						0.01									
Total	0.04	0.08	0.12	0.07	0.02	0.08	0.04	0.07	0.14		0.03		0.03	0.03	0.04
Average	0.04	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.03		0.01		0.02	0.01	0.04
SD		0.011281	0.017816	0.023235		0.013844	0.004424	0.009347	0.024936		0.000119		0.010731	0.003106	
Percent	0.079094	0.053296	0.050604	0.047867	0.051715	0.052006	0.0423	0.036249	0.059247		0.026539		0.034522	0.02896	0.079094
Clumulative	0.04	0.12	0.24	0.31	0.33	0.41	0.45	0.52	0.66	0.66	0.68	0.68	0.72	0.75	0.78

Tagging Event	Days at Large 15	16	17	18	19	20	21	22	23	24	25	26	27	28
18/08/2009			0.01											
19/08/2009														
20/08/2009		0.02												
24/08/2009														
25/08/2009														
02/09/2009														
08/09/2009														
09/09/2009							0.01					0.02		0.02
10/09/2009	0.05					0.01	0.01						0.02	
15/09/2009		0.01												
21/09/2009		0.02												
30/09/2009														
Total	0.05	0.05	0.01			0.01	0.03					0.02	0.02	0.02
Average	0.05	0.02	0.01			0.01	0.01					0.02	0.02	0.02
SD		0.003019					0.000925							
Percent	0.100012	0.031966	0.024747			0.027566	0.026207					0.037995	0.036671	0.036671
Clumulative	0.83	0.88	0.89	0.89	0.89	0.90	0.93	0.93	0.93	0.93	0.93	0.95	0.96	0.98

Table 12. (cont.) The 2009 German Bank tag returns standardized by daily landings $[(n_{wi}/n_{w1})/(\sum(n_{wi}/n_{w1})]$ for each day at large..

| Tagging Event | Days at Large | | | | | | | | | | | | | Total |
	29	30	31	32	33	34	35	36	37	38	39	40	41	
18/08/2009														0.09
19/08/2009														0.09
20/08/2009														0.12
24/08/2009														0.01
25/08/2009														0.01
02/09/2009							0.02							0.16
08/09/2009														0.07
09/09/2009														0.19
10/09/2009														0.18
15/09/2009														0.05
21/09/2009														0.02
30/09/2009														0.01
Total							0.02							1.00
Average							0.02							0.48
SD														
Percent							0.036671							
Clumulative	0.98	0.98	0.98	0.98	0.98	0.98	1.00							

Table 13. German Bank standardized (daily landings) tag returns from 2005 for each tagging event and the days at large. (Data Source: Clark, 2006).

Section 1 — Days at Large and Return Days (0–14)

Tagging Event	0 30/08/2005	1 31/08/2005	2 01/09/2005	3 02/09/2005	4 03/09/2005	5 04/09/2005	6 05/09/2005	7 06/09/2005	8 07/09/2005	9 08/09/2005	10 09/09/2005	11 10/09/2005	12 11/09/2005	13 12/09/2005	14 13/09/2005
30/08/2005											0.01				
06/09/2005			0.01	0.04					0.03	0.05	0.02				0.02
13/09/2005			0.03				0.01								
21/09/2005															
05/10/2005		0.02					0.06	0.53							
Total		**0.02**	**0.04**	**0.04**			**0.08**	**0.53**	**0.03**	**0.05**	**0.03**				**0.02**
Average		0.02	0.02	0.04			0.04	0.53	0.03	0.05	0.02				0.02
SD			0.01				0.04				0.01				
Percent		0.02	0.02	0.05			0.04	0.60	0.03	0.06	0.02				0.02
Clumulative		0.02	0.05	0.10	0.10	0.10	0.17	0.70	0.73	0.79	0.82	0.82	0.82	0.82	0.84

Section 2 — Days at Large (15–28)

15 14/09/2005	16 15/09/2005	17 16/09/2005	18 17/09/2005	19 18/09/2005	20 19/09/2005	21 20/09/2005	22 21/09/2005	23 22/09/2005	24 23/09/2005	25 24/09/2005	26 25/09/2005	27 26/09/2005	28 27/09/2005
			0.01		0.01			0.01					
			0.06										
			0.07		**0.01**			**0.01**					
			0.03		0.01			0.01					
			0.04										
			0.04		0.01			0.01					
0.84	0.84	0.84	0.91	0.91	0.92	0.92	0.92	0.93	0.93	0.93	0.93	0.93	0.93

Section 3 — Days at Large (29–42) and Total

29 28/09/2005	30 29/09/2005	31 30/09/2005	32 01/10/2005	33 02/10/2005	34 03/10/2005	35 04/10/2005	36 05/10/2005	37 06/10/2005	38 07/10/2005	39 08/10/2005	40 09/10/2005	41 10/10/2005	42 11/10/2005	Total
													0.01	**0.05**
	0.02	0.04				0.01								**0.30**
														0.04
														0.00
														0.61
	0.02	**0.04**				**0.01**							**0.01**	**1.00**
	0.02	0.04				0.01							0.01	**0.89**
	0.02	0.04				0.01							0.01	
0.93	0.95	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	

Table 14. The number of German Bank 2005 tag returns per 1,000t landed by tagging event (w) and by the number of weeks after tagging. (Source: Clark, 2006)

Tagging Event (w)	Number of Weeks After Tagging (i)						Total
	Sep 5 to 11	Sep 12 to 18	Sep 19 to 25	Sep 26 to Oct 2	Oct 3 to 9	Oct 10 to 16	
30/08/2005	1.81	1.43	1.94			0.92	**6.10**
06/09/2005	3.97	5.67	4.78		4.08	1.84	**20.35**
13/09/2005		4.58	2.12				**6.70**
21/09/2005							**0.00**
05/10/2005					3.05	11.84	**14.89**
Total	**5.78**	**11.67**	**8.85**	**0.00**	**7.13**	**14.60**	**48.03**

Table 15. Total number of German Bank 2005 tag returns standardized by weekly totals $[(n_{wi}/n_{w1})/(\sum(n_{wi}/n_{w1})]$. (Source: Clark, 2006)

Tagging Event (w)	Number of Weeks After Tagging (i)						Total
	Sep 5 to 11	Sep 12 to 18	Sep 19 to 25	Sep 26 to Oct 2	Oct 3 to 9	Oct 10 to 16	
30/08/2005	0.03	0.03	0.04			0.02	**0.12**
06/09/2005	0.08	0.12	0.10		0.09	0.04	**0.43**
13/09/2005	0.10	0.04					**0.14**
21/09/2005							**0.00**
05/10/2005		0.06	0.25				**0.31**
Total	**0.21**	**0.26**	**0.39**		**0.09**	**0.06**	**1.00**
Average	0.07	0.06	0.13		0.09	0.03	**0.38**
SD	0.03507049	0.0389576	0.1069517			0.0136521	
Percent	0.1843775	0.1699022	0.343011		0.2262255	0.0764838	
Clumulative	0.21	0.47	0.86	0.86	0.94	1.00	

Table 16. Proportions and days at large from German Bank, 2009 and used to estimate the amount of herring remaining on the bank. The observed and the expected values are plotted in Figure 9.

Days at Large	Cumulative Portion	Log Days	Estimated Portion
0	0.038081883		
1	0.115063943	0	0.0233
2	0.236887521	0.301029996	0.2204
3	0.306027944	0.477121255	0.3357
4	0.330927633	0.602059991	0.4174
5	0.406045713	0.698970004	0.4809
6	0.446778031	0.77815125	0.5327
7	0.516589201	0.84509804	0.5765
8	0.659219729	0.903089987	0.6145
9	0.659219729	0.954242509	0.6480
10	0.684775783	1	0.6779
12	0.718019113	1.079181246	0.7298
13	0.745906115	1.113943352	0.7585
14	0.783987997	1.146128036	0.7736
15	0.832141117	1.176091259	0.7932
16	0.878314029	1.204119983	0.8116
17	0.890229219	1.230448921	0.8288
20	0.903501497	1.301029996	0.8750
21	0.928737899	1.322219295	0.8889
22	0.928737899	1.342422681	0.9021
26	0.947031552	1.414973348	0.9496
27	0.964687701	1.431363764	0.9603
28	0.982343851	1.447158031	0.9707
35	1	1.544068044	1.0341
31		1.491361694	0.9996
33		1.51851394	1.0174
32		1.505149978	1.0086

Table 17. Survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey. Table includes all surveys.

Survey Date	Survey	1	2	3	4	5	6	Total
12-Aug-09	1	90,118	20,402	2,643	0	0	0	
25-Aug-09	2	14	116,347	24,058	12,928	46	0	
08-Sep-09	3	28	15	37,522	15,889	6,423	1,100	
14-Sep-09	4	0	21	7	70,024	20,654	6,855	
24-Sep-09	5	0	31	17	11	49,292	13,320	
05-Oct-09	6	0	0	28	22	12	71,809	435,112
Adjusted total		90,118	95,945	10,821	41,207	22,169	50,534	310,795

Table 18. 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 valid surveys.

Survey Date	Survey	1	2	3	4	5	6	Total
12-Aug-09	1	90,118	20402	0	0	0		
25-Aug-09	2	14	116,347	12,928	46	0		
14-Sep-09	3	0	21	70,024	29,652	11,988		
24-Sep-09	4	0	31	11	49,292	14,539		
05-Oct-09	5	0	0	22	12	71,809		397,590
Adjusted total		90,118	95,945	57,096	19,594	45,283		308,036

Table 19. Survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey for 2004-2008. Table includes only valid surveys.

Survey Date	Survey	1	2	3	4	5	6	Total
22-Aug-08	1	22,400	4,632	433	-	-		
05-Sep-08	2	15	58,600	12,117	-	-		
19-Sep-08	3	29	15	28,900	4,478	-		
06-Oct-08	4	-	-	18	11,480	2,163		
21-Oct-08	5	-	-	-	16	1,000		122,380
Adjusted total		22,400	53,968	16,349	7,002	-		99,720
24-Aug-07	1	29,700	6,141	575	-	-		
07-Sep-07	2	15	21,600	4,466	418	-		
21-Sep-07	3	29	15	133,800	27,667	5,308		
05-Oct-07	4	-	29	15	154,000	38,109		
17-Oct-07	5	-	-	27	13	5,800		344,900
Adjusted total		29,700	15,459	128,759	125,915	-		299,833
25-Aug-06	1	94,650	9,265	-	-	-		
15-Sep-06	2	22	88,144	15,090	35	-		
01-Oct-06	3	-	17	44,486	9,199	-		
15-Oct-06	4	-	31	15	18,100	-		245,380
Adjusted total		94,650	78,879	29,396	8,867	-		211,792
07-Sep-05	1	74,924	15,493	2,197	-	-		
21-Sep-05	2	15	99,520	22,530	-	-		
04-Oct-05	3	28	14	36,515	-	-		
15-Oct-06	4	-	-	-	-	-		210,959
Adjusted total		74,924	84,027	11,787	-	-		170,739
02-Sep-04	1	109,775	22,699	2,124	-	-		
16-Sep-04	2	15	155,348	32,122	19,417	-		
30-Sep-04	3	29	15	102,560	47,924	-		
05-Oct-04	4	-	20	6	-	-		367,683
Adjusted total			109,775	132,649	68,313	-	-	310,737

Table 20. Survey biomass (diagonal), elapsed time between surveys (below diagonal), and estimated tonnes remaining (above diagonal) at the time of a subsequent survey for 1999-2003. Table includes only valid surveys.

| Survey Date	Survey	1	2	3	4	5	6	Total
29-Aug-03	1	101,182	29844	11243	-	-		
08-Sep-03	2	11	97,926	28884	-	-		
18-Sep-03	3	21	11	52,599	4484	-		
10-Oct-03	4	-	-	23	70,011	20650		
20-Oct-03	5	-	-	-	11	21,768		343,486
Adjusted total		101,182	68,082	12472	65527	1118		248,381
11-Aug-02	1	2,866	540	1	-	-	-	
26-Aug-02	2	16	117,673	22173	7243	-	-	
10-Sep-02	3	31	16	79,410	25574	9925	1537	
19-Sep-02	4	-	25	10	181,264	53464	22656	
29-Sep-02	5	-	-	20	11	3,623	1167	
08-Oct-02	6	-	-	29	20	10	8,285	393,121
Adjusted total		2,866	117,133	57236	148447	-	-	325,682
27-Aug-01	1	33,021	7476	5116	-	-		
09-Sep-01	2	14	31,026	16106	1910	-		
13-Sep-01	3	18	5	80,487	8943	-		
03-Oct-01	4	-	25	21	45,600	-		
20-Oct-03	5	-	-	-	-	-		190,134
Adjusted total		33,021	23,550	59265	34747	-		150,583
29-Aug-00	1	74,808	15469	727	-	-		
12-Sep-00	2	15	121,783	22947	-	-		
27-Sep-00	3	30	16	145,273	22509	-		
14-Oct-00	4	-	-	18	14,508	-		
20-Oct-03	5	-	-	-	-	-		356,372
Adjusted total		74,808	106,314	121599	-	-		302,721
27-Aug-99	1	191,496	39597	1860	-	-		
10-Sep-99	2	15	182,637	34414	3534	-		
25-Sep-99	3	30	16	82,790	18743	-		
08-Oct-99	4	-	29	14	3,900	-		
20-Oct-03	5	-	-	-	-	-		460,823
Adjusted total		191,496	143,040	46516	-	-		381,052
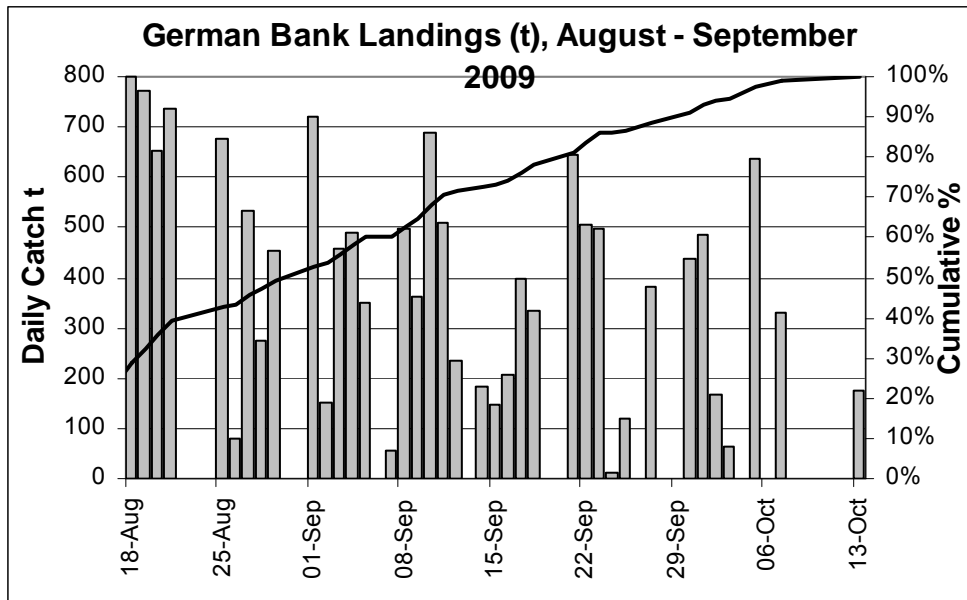
Figure 1. Daily landings and cumulative tag returns during the 2009 German Bank tagging.
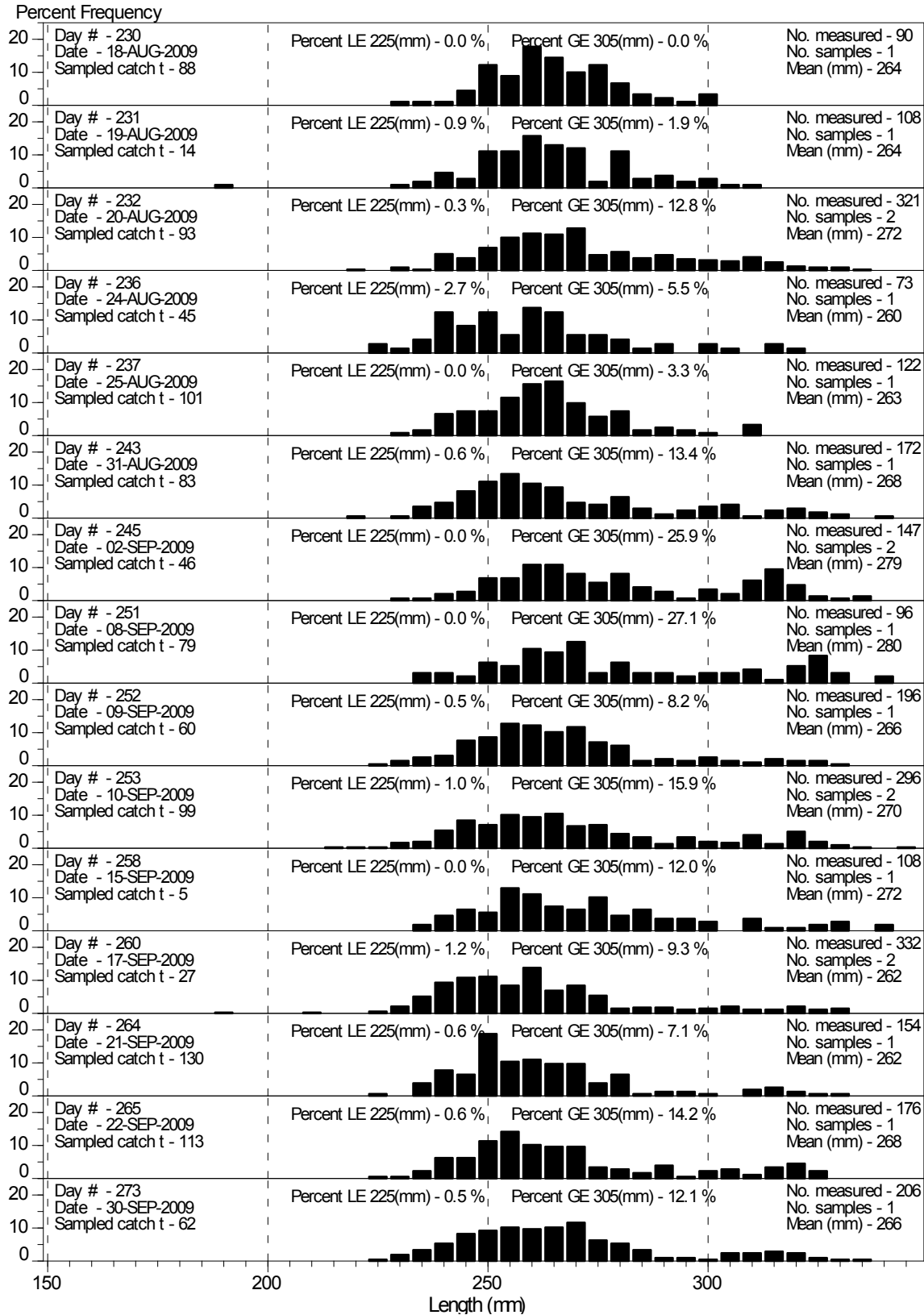
Figure 2. Daily length frequencies of the samples collected in August to September, 2009, on German Bank.
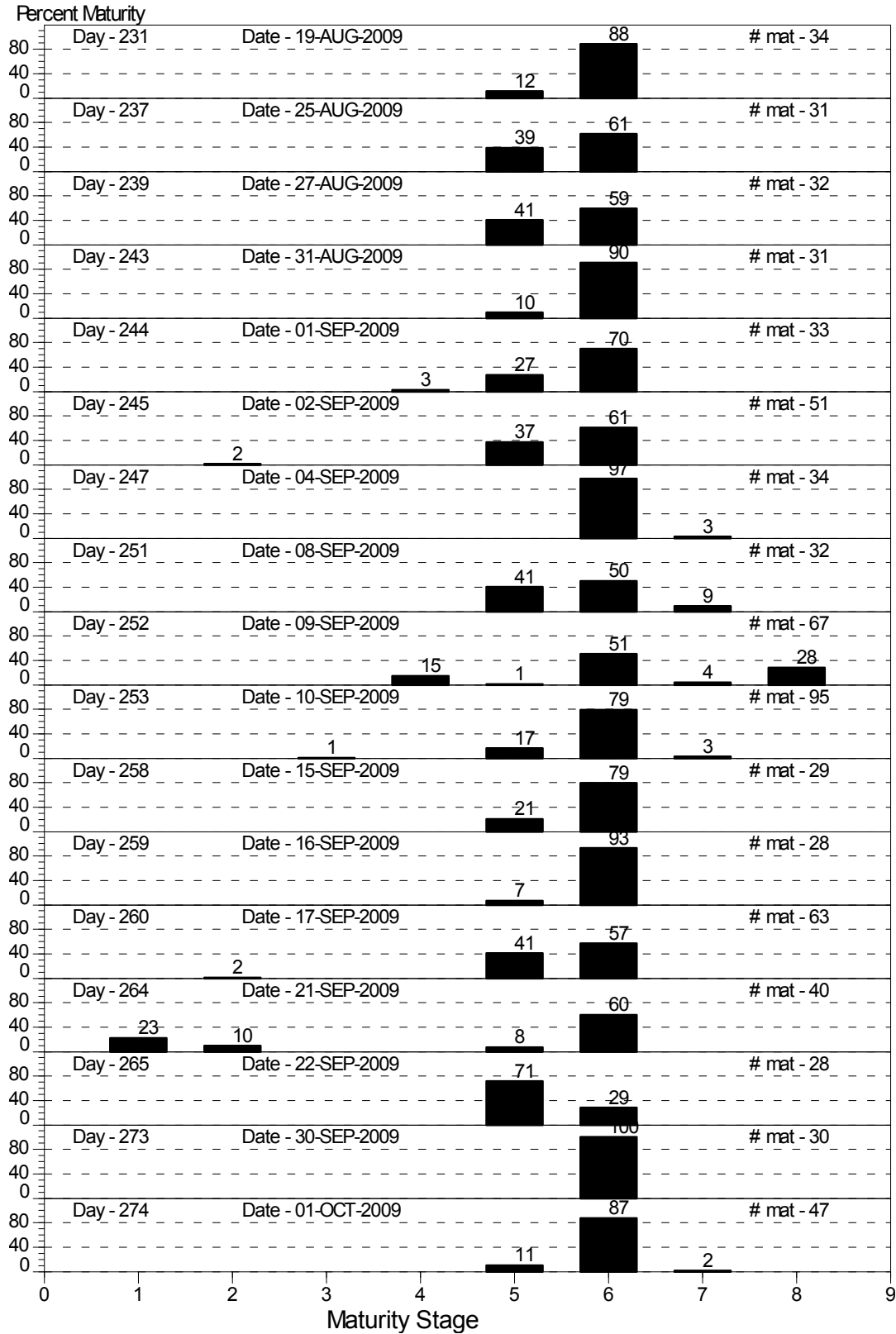
Percent Maturity

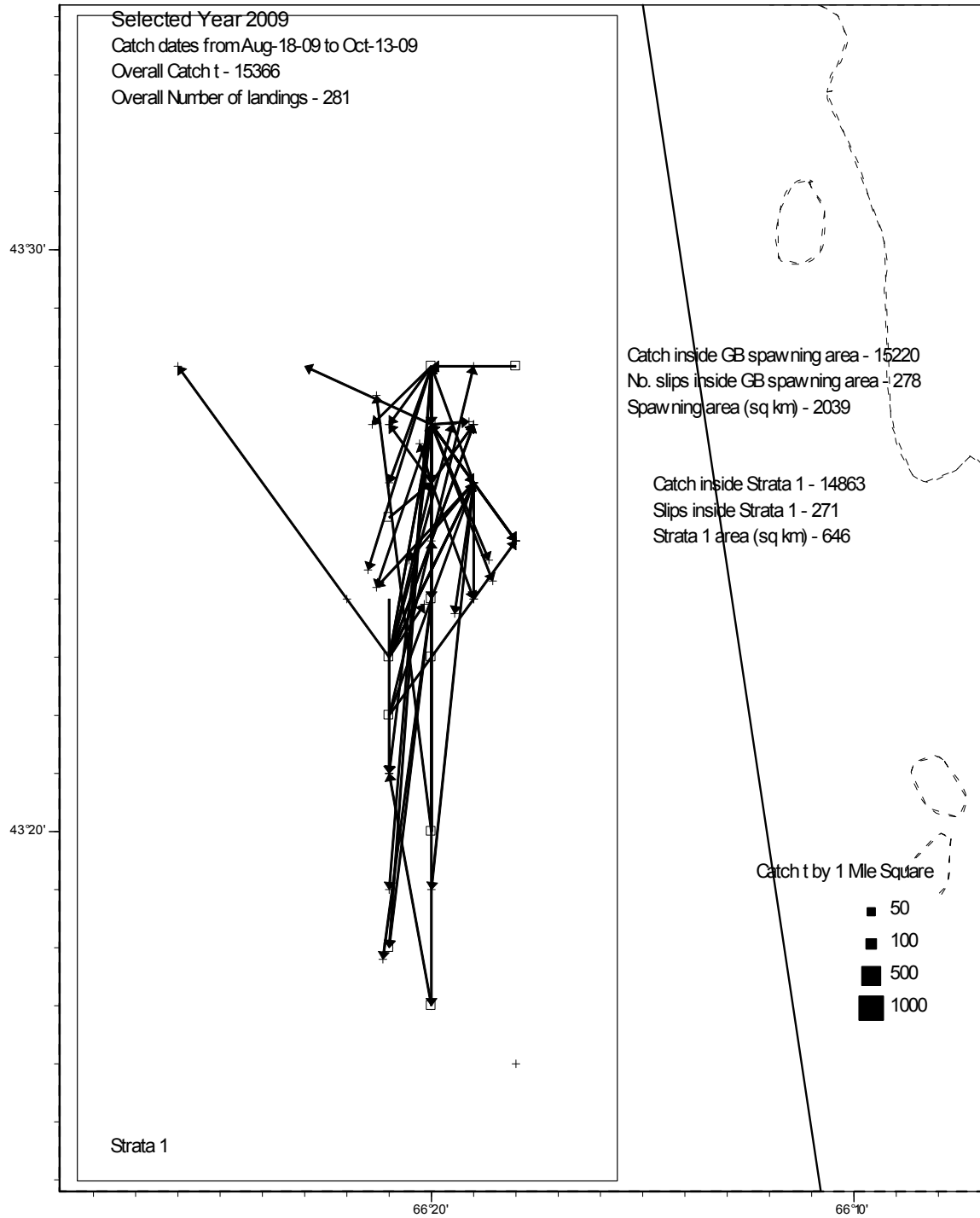Figure 3. Daily percent composition of maturity stages from samples taken in August to September, 2009, on German Bank.

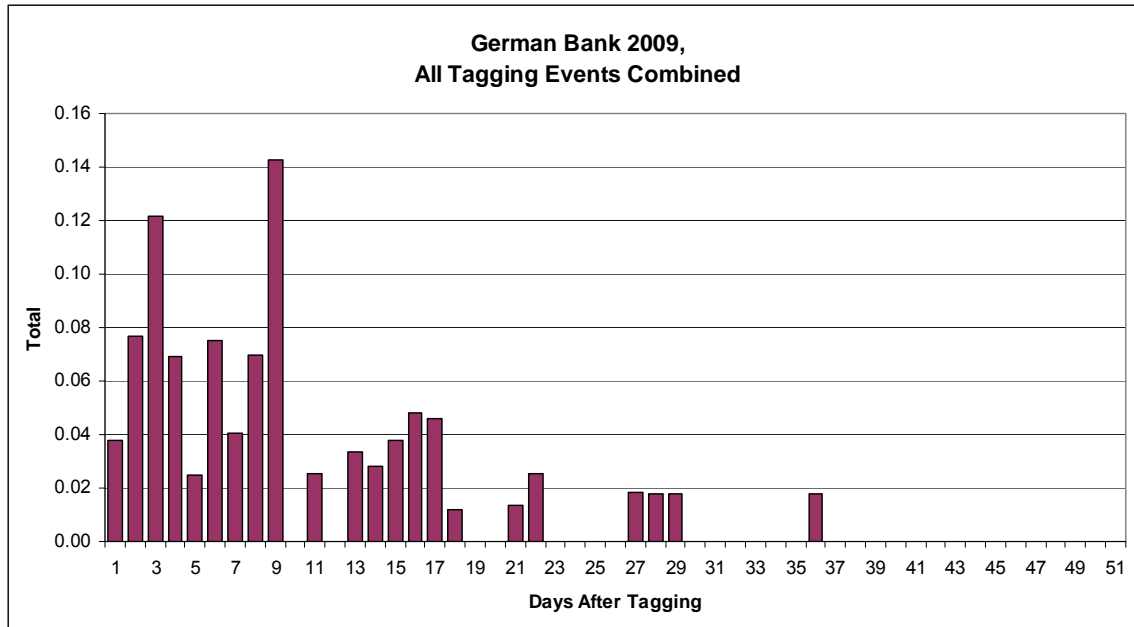Figure 4. All 2009 German Bank tag releases and recaptures between August 18 and November 3 within the spawning box.

**German Bank 2009,
All Tagging Events Combined**

Figure 5. German Bank 2009 total tag returns as a proportion of returns from week 1 for all tagging events displayed by days at large.
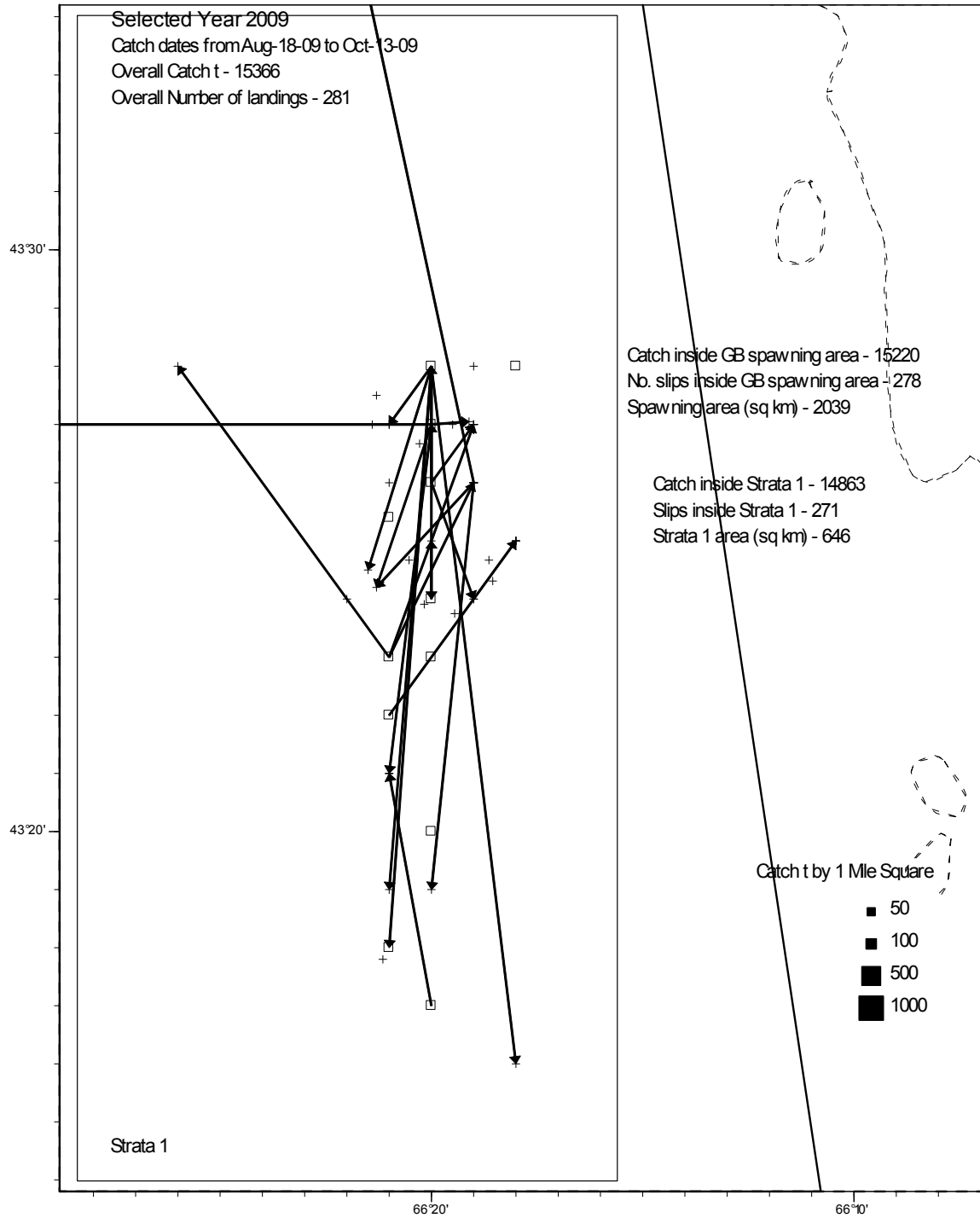
Figure 6. German Bank 2009 tag returns for $\geq$10 days at large, August 18 to November 3.
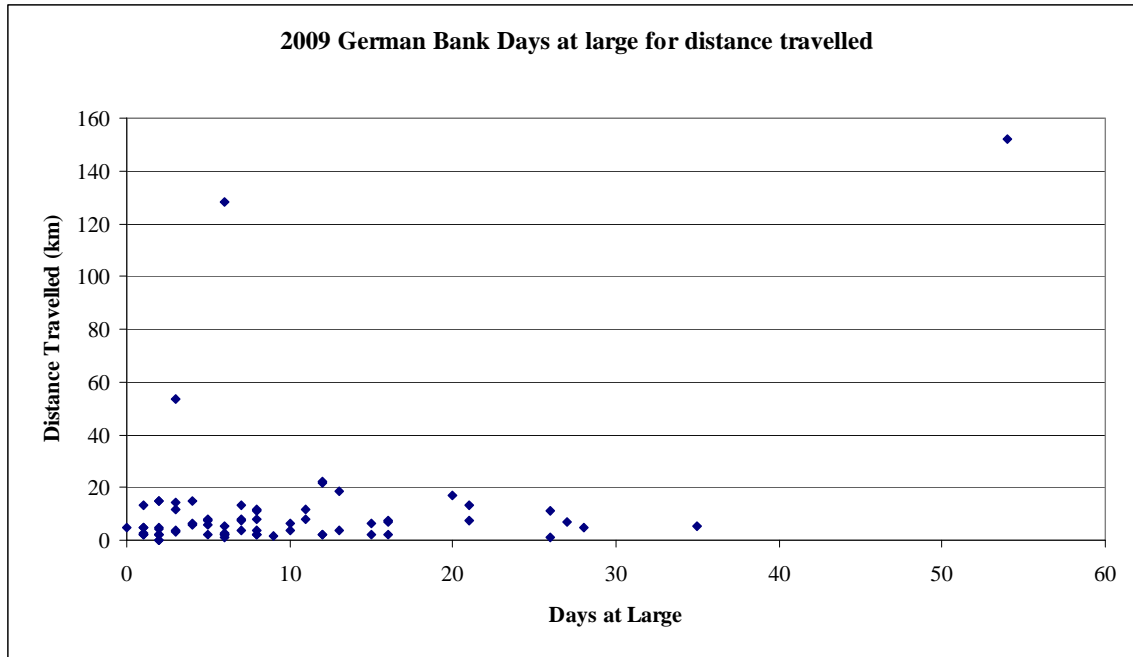
Figure 7. German Bank 2009 distance travelled in comparison to days at large for each tag return.

Figure 8. Tag recaptures from German Bank 2009 for <3 days at large.

**German Bank 2009,
All Tagging Events Combined**
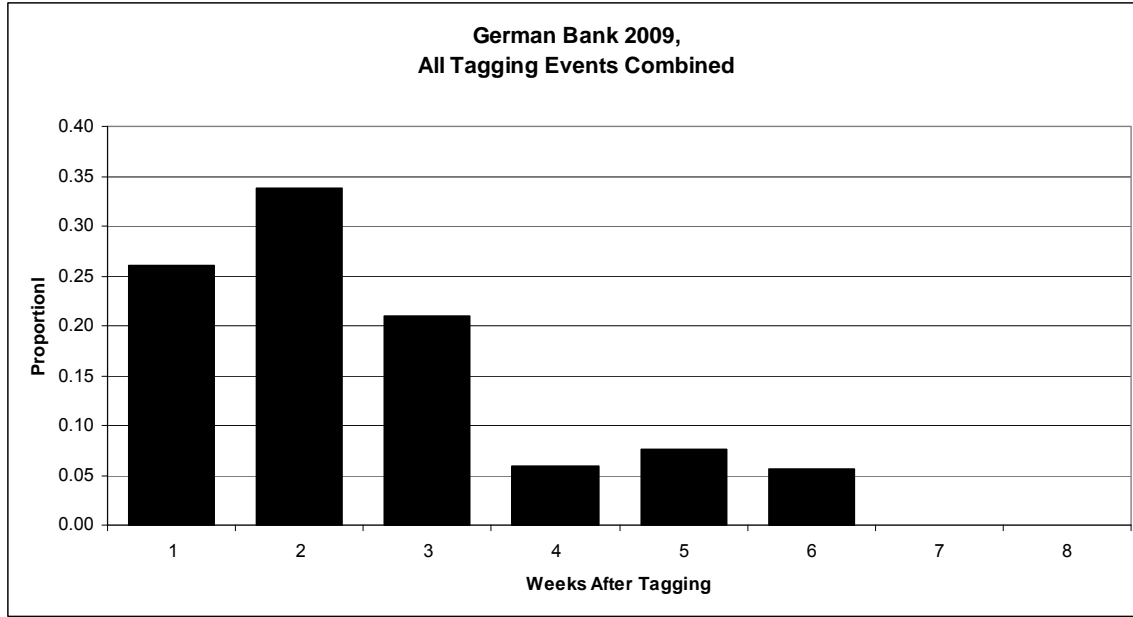
Figure 9. The 2009 German Bank total tag returns expressed as a proportion of returns for all tagging evens displayed by weeks after tagging.

**German Bank 2005 and 2009 Comparison
All Tagging Events Combined**
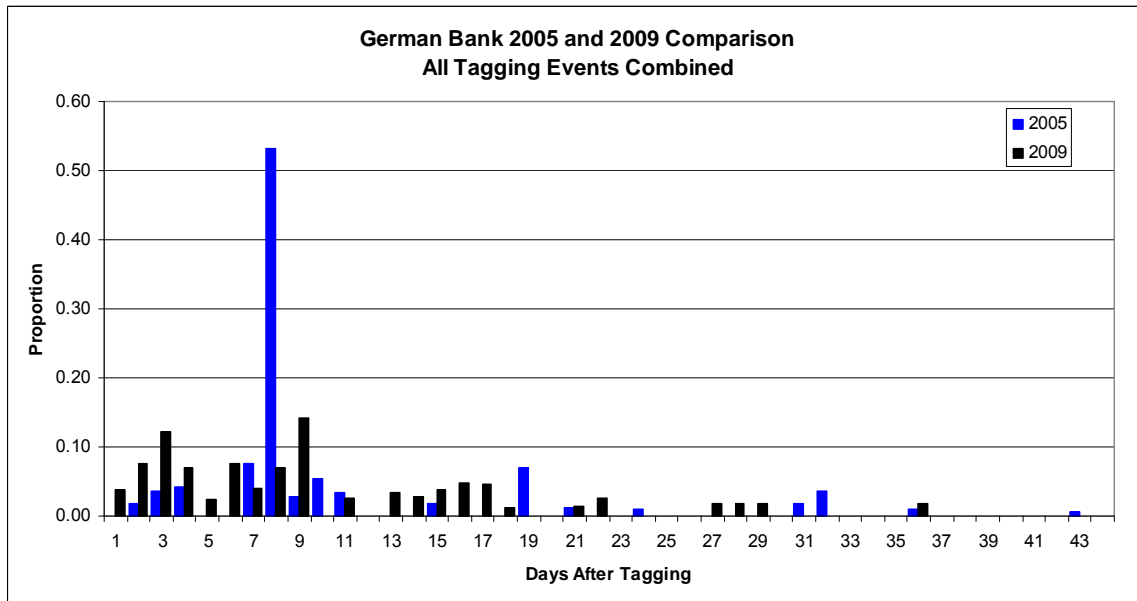
Figure 10. Comparison of 2005 and 2009 German Bank 2005 total tag returns expressed as a proportion of returns for each day at large.
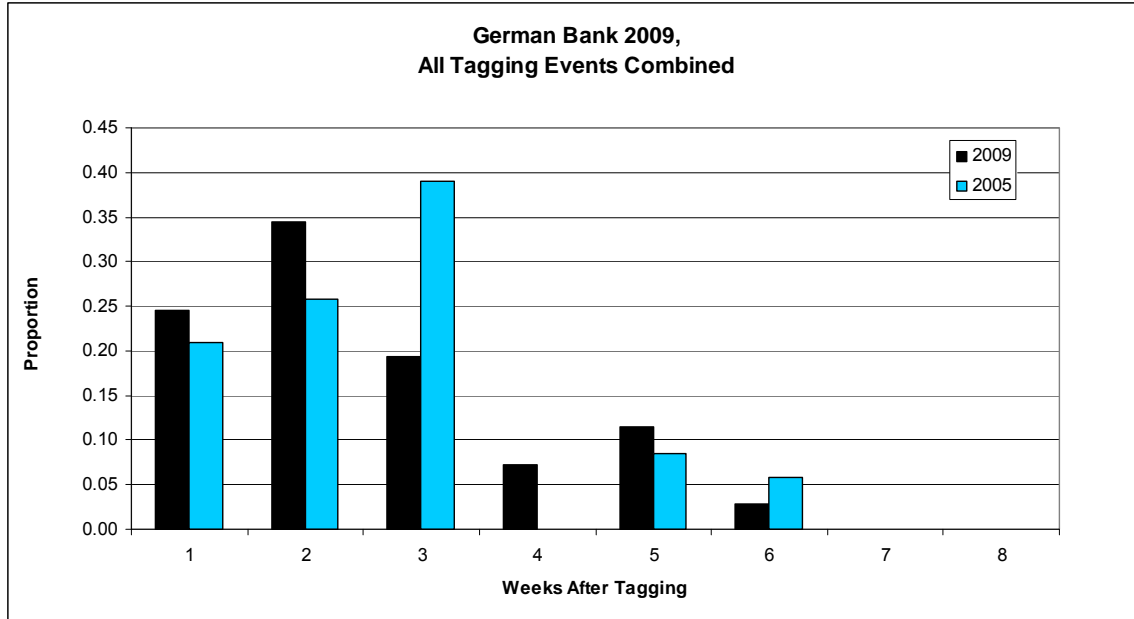
Figure 11. Comparison of German Bank 2005 and 2009 weekly tag returns expressed as a proportion of total returns.
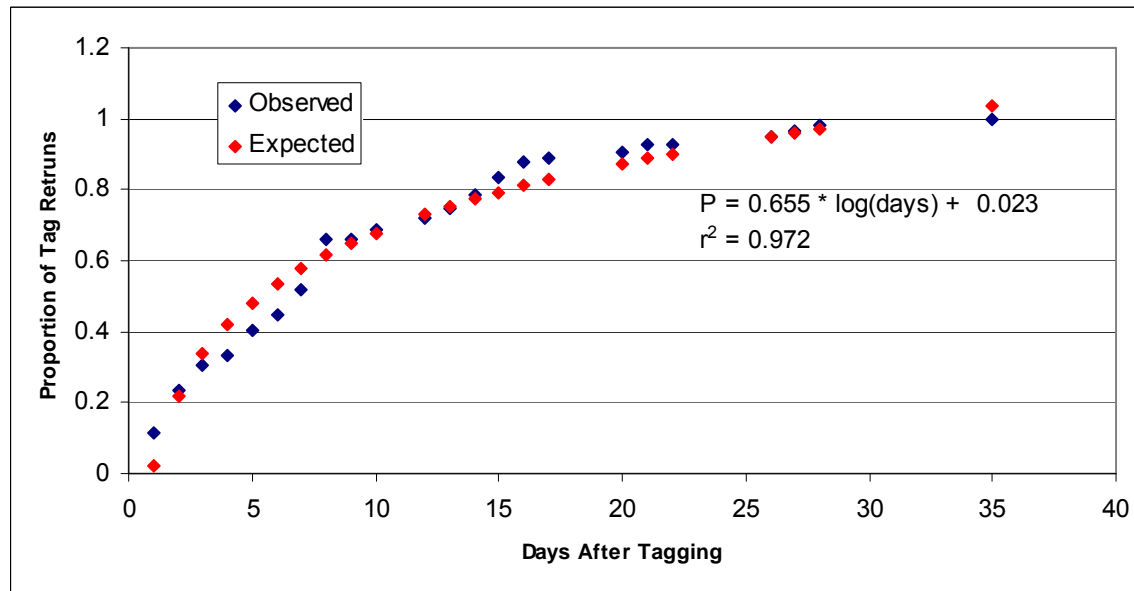

Figure 12. The regression analysis of the expected and observed proportion of tag returns and number of days after tagging in 2009.
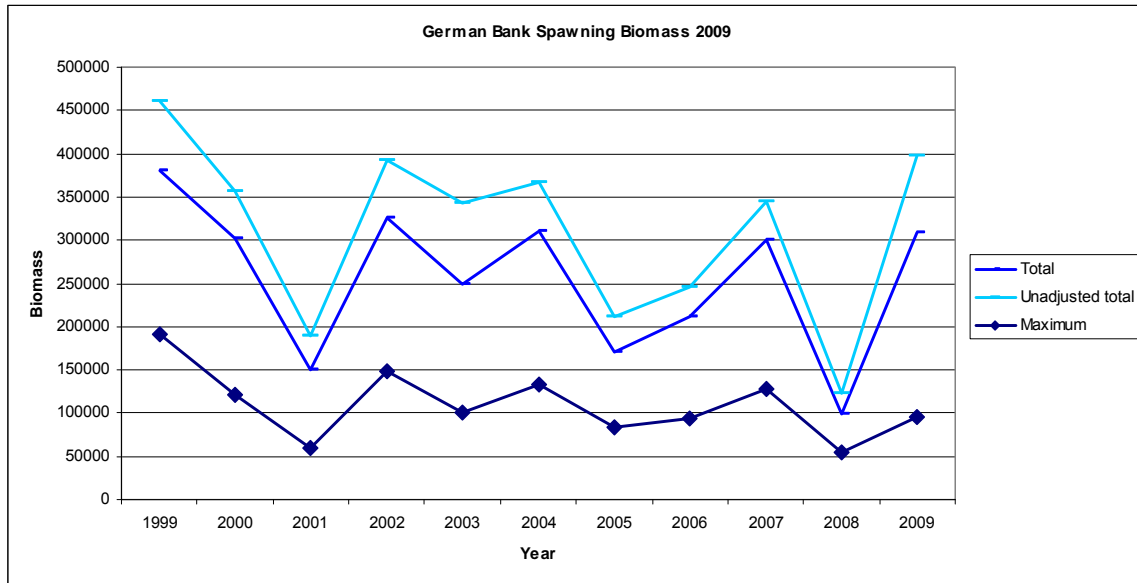
Figure 13. The 1999 to 2009 estimated spawning stock biomass of German Bank herring from acoustic surveys, surveys adjusted for turnover time, and the maximum annual survey.