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Tag Loss and Reporting Rates for 1997 and 1998 Cod Tagging Experiments in 3Psc and 3KL

by

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Abstract

Estimation of …shery exploitation rates from tagging studies requires information on tag-shedding rates and tagging-induced mortality rates, as well as tag reporting rates. In this paper we present statistical analyses of tag reporting and tag loss rates for tag-return data from the 1997 and 1998 cod …sheries o¤ the south coast of Newfoundland in Placentia Bay (3Psc) and o¤ the northeast coast of Newfoundland (3KL). Tag loss is especially important when the time at liberty for tagged …sh is relatively long, and this is the case for the data we examine. Inference about tag loss and tag reporting rates are based on the di¤erential recaptures from simultaneous releases of cod tagged with three types of tags: low reward tags, high reward tags, and those from double tagged …sh. We use robust and e¢cient inference methods to estimate the rate at which …sh lose tags, and the regional reporting rates for the various tag types.

Our results suggest that the reporting rate for single low-reward tags in Placentia Bay is 63%, and 68% for double low-reward tags. These reporting rates appear the same in 1997 and 1998. In 3KL the reporting rates are slightly higher. Tag loss appears to be higher within the …rst 15 weeks following release. Approximately 80% of tags are retained after two years.

Résumé

L'estimation des taux d'exploitation des pêches par études de marquage exige de connaître le taux de perte d'étiquettes et la mortalité due au marquage, en plus du taux de signalement des étiquettes. Nous présentons ici des analyses statistiques des taux de signalement et de perte d'étiquettes portant sur les données sur les étiquettes retournées des pêches de la morue de 1997 et 1998 e¤ectuées au large de la côte sud de Terre-Neuve, dans la baie Placentia (3Psc), et au large de la côte nord-est de Terre-Neuve (3KL). La perte d'étiquettes est particulièrement importante lorsque le temps séparant la pose de l'étiquette et la capture du poisson est relativement long, comme c'est le cas des données que nous avons examinées. Les déductions faites relativement aux taux de perte d'étiquettes et de signalement reposent sur les recaptures di¤érentielles après remises à l'eau simultanées de morues marquées par trois types d'étiquettes : étiquettes donnant une faible récompense, étiquettes à récompense importante et étiquettes doubles sur un même poisson. Nous avons utilisé des méthodes de déduction robustes et e¢caces pour estimer le taux de perte d'étiquettes par les poissons et les taux de signalement régionaux pour les divers types d'étiquettes.

Nos résultats indiquent que le taux de signalement des étiquettes à faible récompense de la baie Placentia est de 63% pour les étiquettes simples et de 68% pour les étiquettes doubles. Ces taux semblent être les mêmes en 1997 et 1998. Ils sont légèrement supérieurs en 3KL. La perte d'étiquettes semble être plus élevée au cours des 15 semaines suivant la remise à l'eau. Environ 80% des étiquettes sont encore présentes après deux ans.

1 Introduction

Estimation of the abundance of inshore cod around Newfoundland is difficult because the near-shore topography causes problems when using common survey methods, e.g. trawl and acoustic surveys. Tag returns from commercially exploited stocks can be used to estimate the abundance of fish exploited by the fishery, even in difficult near-shore regions. This is because the return of tags from a commercial fishery is related to the exploitation rate of the fishery. Fishermen are encouraged, using rewards, to return tags. However, tag returns also depend on the rate at which fish lose tags, and on the number of tags removed by the fishery but not reported. These are critical parameters to understand when estimating exploitation rates.

When the rewards for some tag types are high enough to ensure complete reporting then it is possible to estimate the reporting rates for lower reward tags. Also, when some fish are released with two tags attached then it is possible to estimate tag loss rates. Barrowman and Myers (1996) describe a method for estimating reporting and loss rates based on returns of multiple types of tags. In this paper we modify these methods and apply them to the tag returns from the 1997 and 1998 fisheries in Placentia Bay (3Psc) and off the northeast coast of Newfoundland (3KL). The tagging experiments in these regions involved the simultaneous release of cod with single or double low reward tags, or single high reward tags (Floy t-bar anchor tags FD-68BC). Further details of the tagging experiments are given elsewhere (Brattey et al., 1999; Cadigan and Brattey, 1999). These different types of tags allow reporting rate and tag loss to be estimates (see Section 2). Tag loss is very important for the estimation of 1998 exploitation rates because the time at liberty is large for many of the tagged fish in 3Psc and 3KL. Since total tag loss increases as time at liberty increases, understanding tag loss for multi-year tagging experiments such as ours is critical.

2 The model

Let R^i_{xglt} be the number of type i tag returns from experiment x, gear type g, time t, and length l. Each tag-release experiment involves releasing specific numbers of single, double, and high-reward tagged fish, which we denote as M^s_{xl}; M^d_{xl} and M^h_{xl}. The number of tags returned depends primarily on the exploitation rate of the fishery, but also depends on the natural mortality rate of cod, the tag loss rate before capture, the handling loss rate, and the reporting rate. To estimate tag loss and reporting rates we analyze four types of tag returns:

$$i = \begin{cases} 1, & \text{for a single low-reward (SLR) return from a SLR release,} \\ 2; & \text{for a SLR from a double release} \\ 3; & \text{for a double return,} \\ 4; & \text{a high-reward return.} \end{cases}$$

For now we assume there is no handling loss. We assume that tag-returns are distributed as over-dispersed Poisson random variables, with expectation

$$E(R^i_{xglt}) = \lambda^i \mu_{glt} M^i_{xlt}, \tag{1}$$

where

1. λ^i is the reporting rate,
2. μ_{glt} is the exploitation rate of the fishery for gear type g and length l fish at time t, and
3. M^i_{xlt} is the number of type i tagged fish from experiment x that have survived and still retain their tag(s) at time t.

We do not know exactly how many tagged fish (M^i_{xlt}) remain in the population at any time; however, we can estimate this because M^i_{xlt} is a function of the known number of releases, and other factors we can estimate. These factors include the tag loss rate and the survival rate of tagged fish. To estimate tag loss rates we need to express M^i_{xlt} in terms of the known releases. We use a simple exponential decay model for this purpose. Let t_x denote the release time for experiment x, and let ξ_{xlt} denote the cumulative total survival at time t for the fished tagged in experiment x; that is

$$\xi_{xlt} = \prod_{j=t_x}^{t-1} (1 - \mu_{lj}), \tag{2}$$

where a missing subscript denotes summation over the subscript ($\mu_{lj} = \sum_g \mu_{glj}$). The model for M^i_{xlt} is

$$M^i_{xlt} = e^{-(m+\phi)(t-t_x)} \xi_{xlt} \begin{cases} \times M^s_{xl}, & i = 1; \\ 2\left\{1 - e^{-\phi(t-t_x)}\right\} \times M^d_{xl}, & i = 2; \\ e^{-\phi(t-t_x)} \times M^d_{xl}, & i = 3; \\ \times M^h_{xl}, & i = 4; \end{cases} \tag{3}$$

where m is the natural mortality rate and ϕ is the tag loss rate. We have assumed that the handling loss rate of low-reward and high-reward tags is the same, and that tags are lost independently of each other.

For single tagged fish, M^1_{xlt} is equal to the number released (M^s_{xl}), times the fraction not removed by the fishery (ξ_{xlt}), times the fraction that do not lose their tags ($e^{-\phi(t-t_x)}$), times the fraction that do not die "naturally" ($e^{-m(t-t_x)}$). The model for M^4_{xlt} is identical. The model for double tag returns is similar, except that $e^{-\phi(t-t_x)}$ is replaced by $e^{-\phi(t-t_x)} \times e^{-\phi(t-t_x)}$, which is the fraction than do not lose both tags. For single tag returns from double releases, the fraction that lose only one tag is $2e^{-\phi(t-t_x)}\{1 - e^{-\phi(t-t_x)}\}$.

Most of the information the tag returns supply about λ^i's and ϕ is contained in the distribution of $R^i_{xglt} | R_{xglt}$, where $R_{xglt} = \sum_i R^i_{xglt}$ as usual. The total number of tag returns at time t for each gear type g and length class l has expectation

$$E(R_{xglt}) = \mu_{glt} \sum_i \lambda^i M^i_{xlt}.$$

Tag returns at each time and for each gear type and length class are very sparse, and we feel that R_{xglt} gives negligible information about θ^i's and ϕ in the absence of further information about μ_{glt}'s. The distribution of $R^i_{xglt}|R_{xglt}$ is Multinomial under a Poisson assumption for tag returns, and we use the multinomial distribution to model $R^i_{xglt}|R_{xglt}$. This distribution does not depend on the μ_{glt}'s. For inferences about θ^i's and ϕ we use the Multinomial likelihood function

$$L(\theta^i;\phi) = \prod_t \prod_g \prod_l \prod_x M(R^i_{xglt}|R_{xglt}); \tag{4}$$

where $M(\cdot)$ is the relevant part of the Multinomial probability density function. This is developed in detail in the next paragraph. This is the same approach taken by Barrowman and Myers (1996), although they did not consider within-year variations in exploitation rates by gear type, the effects of length selection for different fishing gears, or multiple tagging experiments.

Another type of tag loss that we have not included in our model so far is handling loss, which we denote as $1-\gamma_g$. Occasionally tags are lost during the fish capture process. We feel that handling tag loss is only a problem for gillnets, because only gillnet fisherman reported finding tags on the decks of their fishing vessels after the catch was removed from the nets. This was also observed by Fabrizio et al. (1996). For gear types other than gillnets we assume that $\gamma_g = 1$. Handling loss can be accommodated as an intercept in the model for the tag loss rate. We also assume that the reporting rate for high-reward tags is one. This is the reason for releasing this type of tag. Hence,

$$\theta^i = \begin{cases} \theta_1; & i = 1;2 \\ \theta_2; & i = 3; \\ 1; & i = 4. \end{cases}$$

Let the Multinomial tag type probabilities be denoted as $p^i_{xglt} = \Pr(R^i_{xglt}|R_{xglt})$. These are

$$p^i_{xglt} \propto \begin{cases} \theta_1 M^s_{xl}; & i = 1; \\ 2\theta_1 \left\{1-\gamma_g e^{-\phi(t-t_x)}\right\} M^d_{xl}; & i = 2; \\ \theta_2 \gamma_g e^{-\phi(t-t_x)} M^d_{xl}; & i = 3; \\ M^h_{xl}; & i = 4. \end{cases} \tag{5}$$

The proportionality $\propto$ is such that $\sum_i p^i_{xglt} = 1$. Note that $\gamma_g < 1$ only for gillnets.

Inferences based on (4) are completely free from assumptions about natural mortality or exploitation rates. This is an important robust property. This approach is efficient in that all of the information is used for inferences, rather than estimating particular parameters from only some of the data. For example, estimating tag loss from only type 1 and 2 returns is common.

3 Results and Discussion

We analyze the 944 returns from tagging experiments in 3Psc and 3KL during 1997 and 1998. Release and return times were grouped by weeks. Within-week variations in exploitation, tag loss, and natural mortality rates are assumed to be negligible; we feel this is reasonable.

3.1 Estimates, I

Estimates of reporting rates and tag loss rates are presented in Table 1. Standard errors

Table 1. Estimates of reporting rates (λ), handling loss (γ), and tag loss rate (ϕ). Handling loss is for gillnets only.

Region		Estimate	Std. Err.
3Psc	λ_1	0.62091	0.06436
3Psc	λ_2	0.67643	0.07261
3KL	λ_1	0.63425	0.15109
3KL	λ_2	0.80301	0.20268
Both	γ	0.95078	0.02102
Both	ϕ	0.00304	0.00062

are based on asymptotic linear-approximation theory, and are computed using the inverse of the Hessian matrix for the maximization of (4). The reporting rate in Placentia Bay for double tags is about 5% higher than for single low-reward tags. This is probably caused by the higher reward for two tags ($20) compared to one tag ($10). The reporting rates in 3KL are slightly higher than in 3Psc. Gillnet handling loss is 5%. The estimates are reasonably precise. The standard errors for the 3Psc reporting rate estimates are lower than for the 3KL estimates because of the larger fishery and consequently larger number of tag returns. Also, more fish were tagged in 3Psc.

The tag loss rate is weekly. It indicates that within one year 15% of single tagged fish have lost their tag. The percentage of single tagged fish still retaining their tag is presented in Table 2 for times at liberty ranging up to five years. We emphasize that

Table 2. Percentage of tags retained at week intervals.

Week	12	13	14	15	20	52	104	156	260
% retained	0.96	0.96	0.96	0.96	0.94	0.85	0.73	0.62	0.45

estimates of tag retention beyond two years are extrapolations beyond the time scale of our data.

3.2 Diagnostics, I

In this section we present graphical diagnostic analyses to assess the validity of our assumptions about reporting rates and tag loss rates. We also present the results of an analytic lack-of-fit test for the tag loss model.

3.2.1 Single tag reporting rates, λ_1

The diagnostic we examine to focus on the single tag reporting rate (λ_1) is the number of single low-reward returns compared to the number of single low-reward and high-reward returns. The expected value of this quantity is, conditionally,

$$E\left(\frac{R^1_{xglt}}{R^1_{xglt}+R^4_{xglt}}\,\middle|\,\text{given } R^1_{xglt}+R^4_{xglt}\right)=\left(\frac{\lambda_1 M^s_{xl}}{\lambda_1 M^s_{xl}+M^h_{xl}}\right).$$

We examine standardized residuals based on this relationship. If

$$\begin{aligned} p^1_{xglt} &= R^1_{xglt}/(R^1_{xglt}+R^4_{xglt}) \text{ and} \\ \hat{p}^1_{xglt} &= \hat{\lambda}_1 M^s_{xl}/(\hat{\lambda}_1 M^s_{xl}+M^h_{xl}); \end{aligned}$$

then the single tag reporting rate residual is

$$e^1_{xglt}=\frac{p^1_{xglt}-\hat{p}^1_{xglt}}{\left\{(R^1_{xglt}+R^4_{xglt})\hat{p}^1_{xglt}(1-\hat{p}^1_{xglt})\right\}^{1/2}}.$$

These residuals should have approximately standard-normal distributions. These residuals are examined for Placentia Bay and 3KL returns. The results are plotted in Figures 1 and 2 in the Appendix. These plots do not suggest any serious problems with our assumptions about the reporting rates of single low-reward tags compared to high-reward tags.

3.2.2 Double tag reporting rates (λ_2) and tag loss (ϕ) diagnostics

We have not been able to construct diagnostics that focus specifically on double tag reporting rates or tag loss. The diagnostics we consider are functions of both these parameters, and also single tag reporting rates. The first diagnostic is based on the ratio of double tag returns compared to single low-reward, single high-reward, and double tag returns. The expected value of this quantity is, conditionally

$$E\left(\frac{R^3_{xglt}}{R^{1+3+4}_{xglt}}\,\middle|\,R^{1+3+4}_{xglt}\right)=\exp\{-\phi(t-t_x)\}\left(\frac{\lambda_2\gamma M^d_{xl}}{\lambda_1 M^s_{xl}+\lambda_2\gamma M^d_{xl}+M^h_{xl}}\right).$$

We examine standardized residuals based on this relationship. If

$$\begin{aligned} p^3_{xglt} &= R^3_{xglt}/(R^{1+3+4}_{xglt}) \text{ and} \\ \hat{p}^3_{xglt} &= \exp\left\{-\hat{\phi}(t-t_x)\right\}\hat{\lambda}_2\hat{\gamma} M^d_{xl}/(\hat{\lambda}_1 M^s_{xl}+\hat{\lambda}_2\hat{\gamma} M^d_{xl}+M^h_{xl}); \end{aligned}$$

then the double tag reporting rate and tag loss rate residual is

$$e^3_{xglt} = \frac{p^3_{xglt} - \hat{p}^3_{xglt}}{\left\{R^{1+3+4}_{xglt}\hat{p}^3_{xglt}(1 - \hat{p}^3_{xglt})\right\}^{1/2}}:$$

The results are plotted in Figures 3 and 4. Some systematic departures in the residuals are apparent in terms of time at liberty and length. The first departure is likely related to a mis-specification of the tag loss model. We use a lack-of-fit test for the tag loss model (see below) to assess if the discrepancies in Figure 3 account for substantial amounts of variation in the returns.

Another piece of information we use to estimate tag loss rate is the returns of single tags from double tag releases. These returns, while minor in number, contain much of the information about tag loss rates. The second diagnostic we examine is based on the ratio of type 2 returns compared to type 1 + type 2 + type 4 returns. The expected value of this quantity is, conditionally

$$E\left(\frac{R^2_{xglt}}{R^{1+2+4}_{xglt}}\Bigg| R^{1+2+4}_{xglt}\right) = \left(\frac{2\lambda_1\gamma\,[1 - \exp\{-\phi(t - t_x)\}]\,M^d_{xl}}{\lambda_1 M^s_{xl} + 2\lambda_1\gamma\,[1 - \exp\{-\phi(t - t_x)\}]\,M^d_{xl} + M^h_{xl}}\right):$$

We examine

$$e^2_{xglt} = \frac{p^2_{xglt} - \hat{p}^2_{xglt}}{\left\{R^{1+2+4}_{xglt}\hat{p}^2_{xglt}(1 - \hat{p}^2_{xglt})\right\}^{1/2}};$$

where p^2 is defined in a similar manner as p^3. The results are plotted in Figures 5 and 6. Most notable in these figures is the size of the residuals. This is to be expected. Rare events such as the return of a single tag from a double release should appear extreme. What is of concern in these figures is the trend in residuals observed when times at liberty are less than about 15 weeks (see top panel in Figures 5,6). This suggest that tag loss may initially be high, but then decline after 15 weeks

3.2.3 Tag loss lack-of-fit test

The usual approach when testing for lack-of-fit in regression with repeated observations at each covariate level is to compare the regression sum of squares with the pure error sum of squares that can be obtained using a one-way ANOVA with the covariates treated as factors. Unfortunately we rarely have repeated observations of time at liberty for each tag type, experiment, return week, gear type, and length class. An approach for this situation is to compare the parametric tag loss estimates with smooth nonparametric estimates. A reasonably simple procedure, and the one we use, is to compare the tag loss estimates with those obtained by estimating tag loss separately for many "bins" of time at liberty. We compared estimates using a likelihood ratio test, which should have approximately a chi-square distribution with degrees of freedom equal to the number of bins minus one. We performed this procedure for different choices of bin numbers, ranging from 3 to 15.

We present the results for the lack-of-fit test using five bins. The chi-square lack-of-fit statistic is 17.43. With four degrees of freedom the p-value for the lack-of-fit test is 0.008.

This indicates some evidence in the data against the null hypothesis that the tag loss rate is constant over time at liberty. The tag loss estimates for each time bin are presented in Table 3. These estimates suggest that tag loss is higher when …sh are …rst released.

Table 3. Tag loss estimates at …ve time intervals.

Interval end point (week)	$\hat{Â}$
18	0.0080633
35	0.0061432
52	0.0012557
69	0.0015719
86	0.0035963

This is consistent with …eld observations where the tissue around the tag is often soft and swollen for several weeks after implantation. During this stage tags may be more easily dislodged, whereas after several weeks tough scar tissue forms which holds the tags more …rmly.

3.3 Estimates, II - Two-stage tag loss model

The diagnostic analyses suggest that a modi…cation to our tag loss model is required. We decided to estimate the tag loss rate separately for times at liberty less than and greater than 15 weeks. The results are presented in Table 4. The estimates of reporting

Table 4. Estimates of reporting rates (¸), handling loss (°), and tag loss rate (Á). Handling loss is for gillnets only.

Region		Estimate	Std. Err.
3Psc	$¸_1$	0.61801	0.06407
3Psc	$¸_2$	0.67677	0.07275
3KL	$¸_1$	0.63586	0.15126
3KL	$¸_2$	0.79699	0.20147
Both	°	0.97613	0.02769
Both, short-term	$Á_1$	0.00622	0.00258
Both, long-term	$Á_2$	0.00108	0.00081

rates are similar to those in Table 1. The estimate of the initial tag loss rate is much higher than the tag loss rate in Table 1. The percentage of single tagged fish that still have their tag are presented in Table 5 for times at liberty ranging up to 5 years. The

Table 5. Percentage of tags retained at week intervals.

Week	12	13	14	15	20	52	104	156	260
% retained	0.92	0.91	0.90	0.90	0.89	0.86	0.81	0.77	0.69

two-stage tag loss model suggests that at 5 years, 70% of the surviving tagged fish still have their tags, whereas the simple tag loss model suggests that only 45% (see Table 2) of the surviving tagged fish still have their tags after 5 years. The comparison illustrates the magnitude of the differences that could occur when times at liberty are long. This type of mis-specification could have a serious effect on exploitation estimates.

3.4 Diagnostics, II

The single tag reporting rate diagnostics are unchanged with the two-stage tag loss model. This is because their distribution does not depend on tag loss. The type 3 double tag reporting rate and tag loss rate diagnostics are presented in Figure 6 and 7. The type 2 diagnostics are presented in Figures 8 and 9. The diagnostics in Figures 8 and 9 show that the two-stage model has explained a substantial amount of variability in tag returns, as evidenced by the smaller magnitude of the residuals compared to Figures 5 and 6. Some systematic residual variation in terms of time at liberty is still apparent. This suggests that further improvements in our tagging model are still possible, although we feel that the two-stage estimate of the percentage of surviving tags that still have their tags at two years will not change much with further refinements to the tag loss model.

4 Conclusions

Our results suggest that the reporting rate for single low-reward tags in Placentia Bay is 63%, and the reporting rate is 68% for double low-reward tags. These reporting rates appear the same in 1997 and 1998. In 3KL the reporting rates are slightly higher. We have insufficient data to test whether the 3KL reporting rates have changed between 1997 and 1998. We assume that the tag loss rate is the same in 3Psc and 3KL. Tag loss appears to be higher within the first 15 weeks following release. Approximately 80% of tags are retained after two years. The estimates of reporting rates and tag loss are used in Cadigan and Brattey (1999) to estimate exploitation and migration rates.

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5 Appendix: Figures

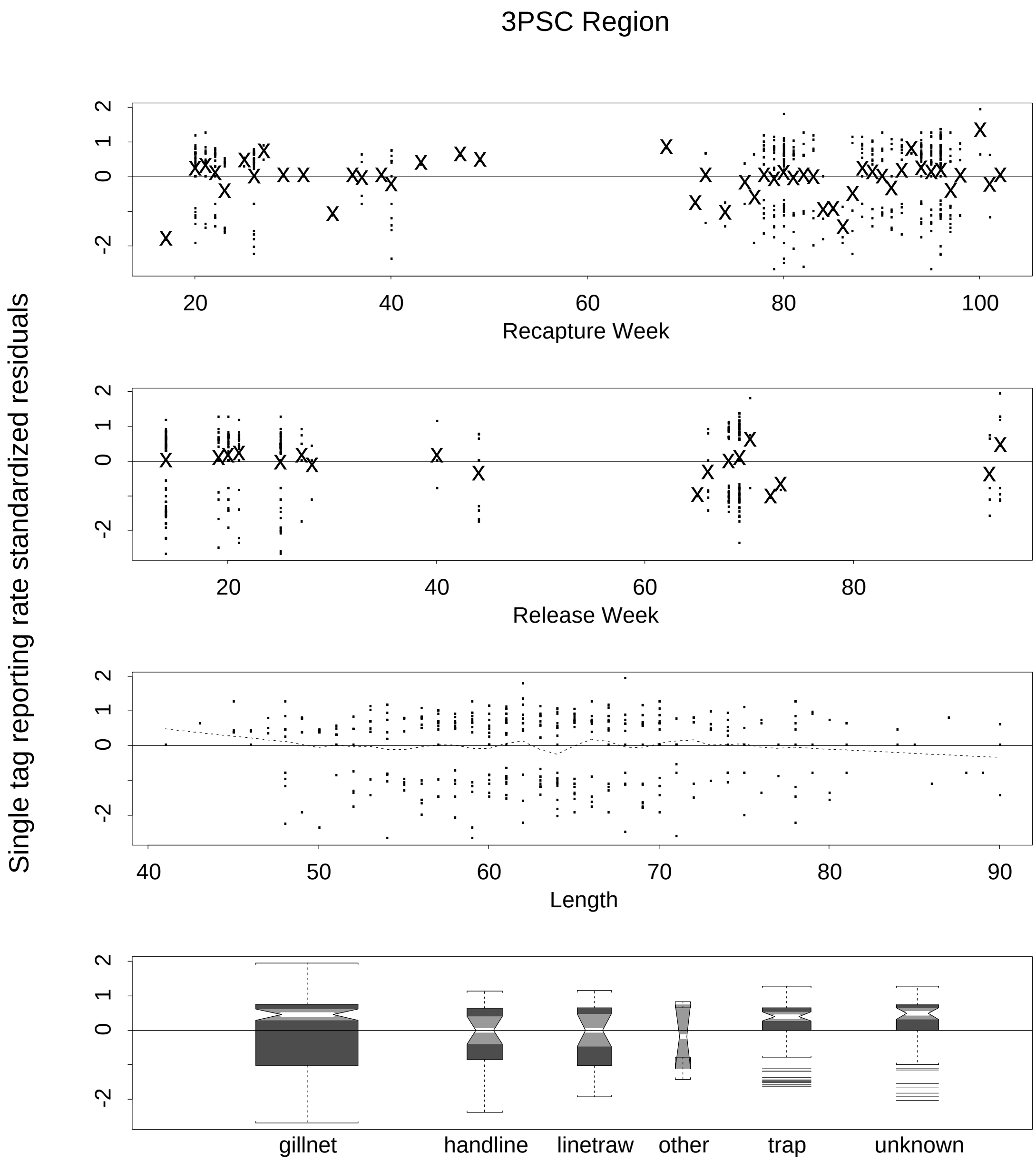

Figure 1: Single tag reporting rate standardized residuals for returns in 3Psc - Placentia Bay. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.

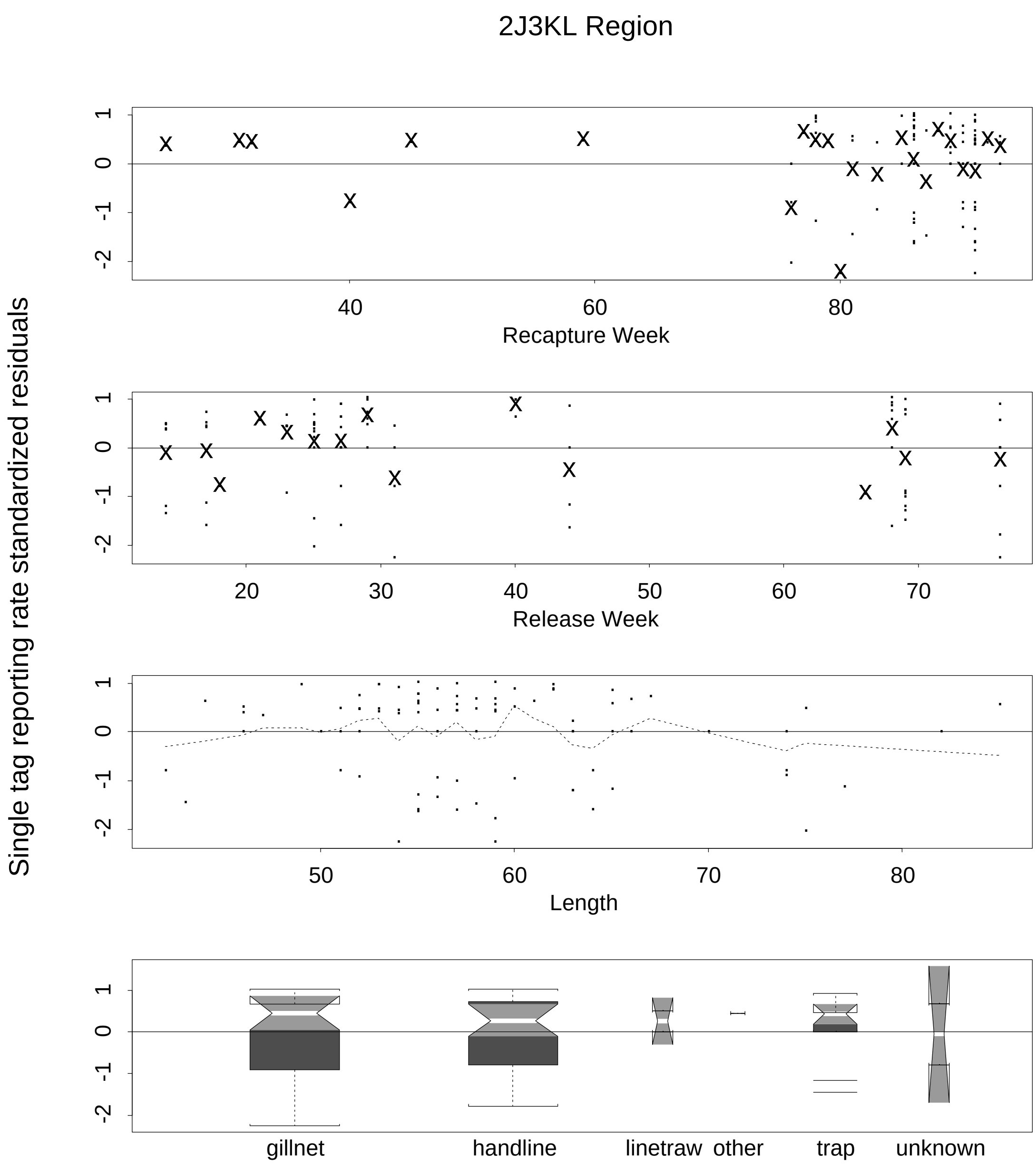

Figure 2: Single tag reporting rate standardized residuals for returns in 3KL. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.

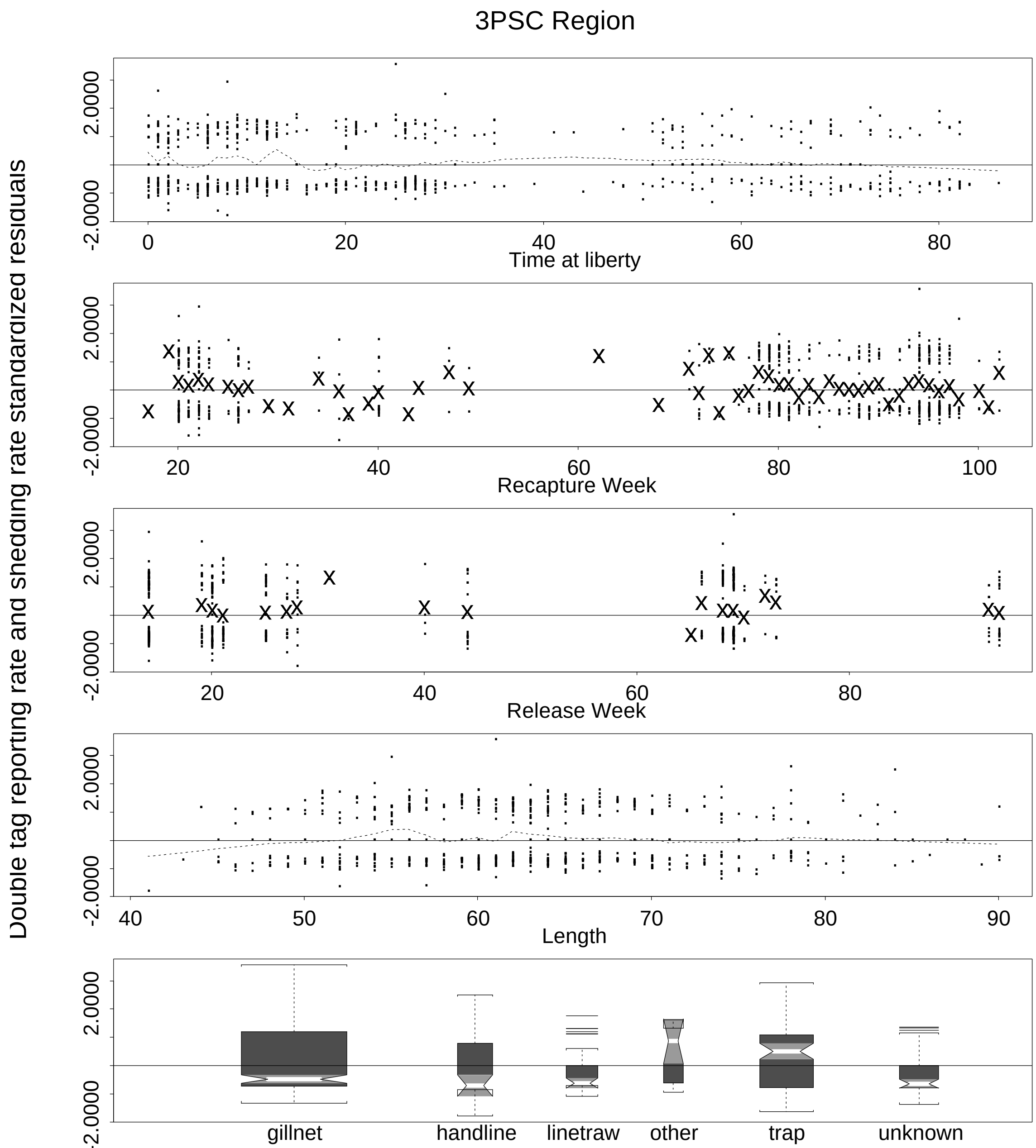

Figure 3: Double tag reporting rate and tag loss rate standardized residuals based on type 3 returns (p^3) in 3Psc - Placentia Bay. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.

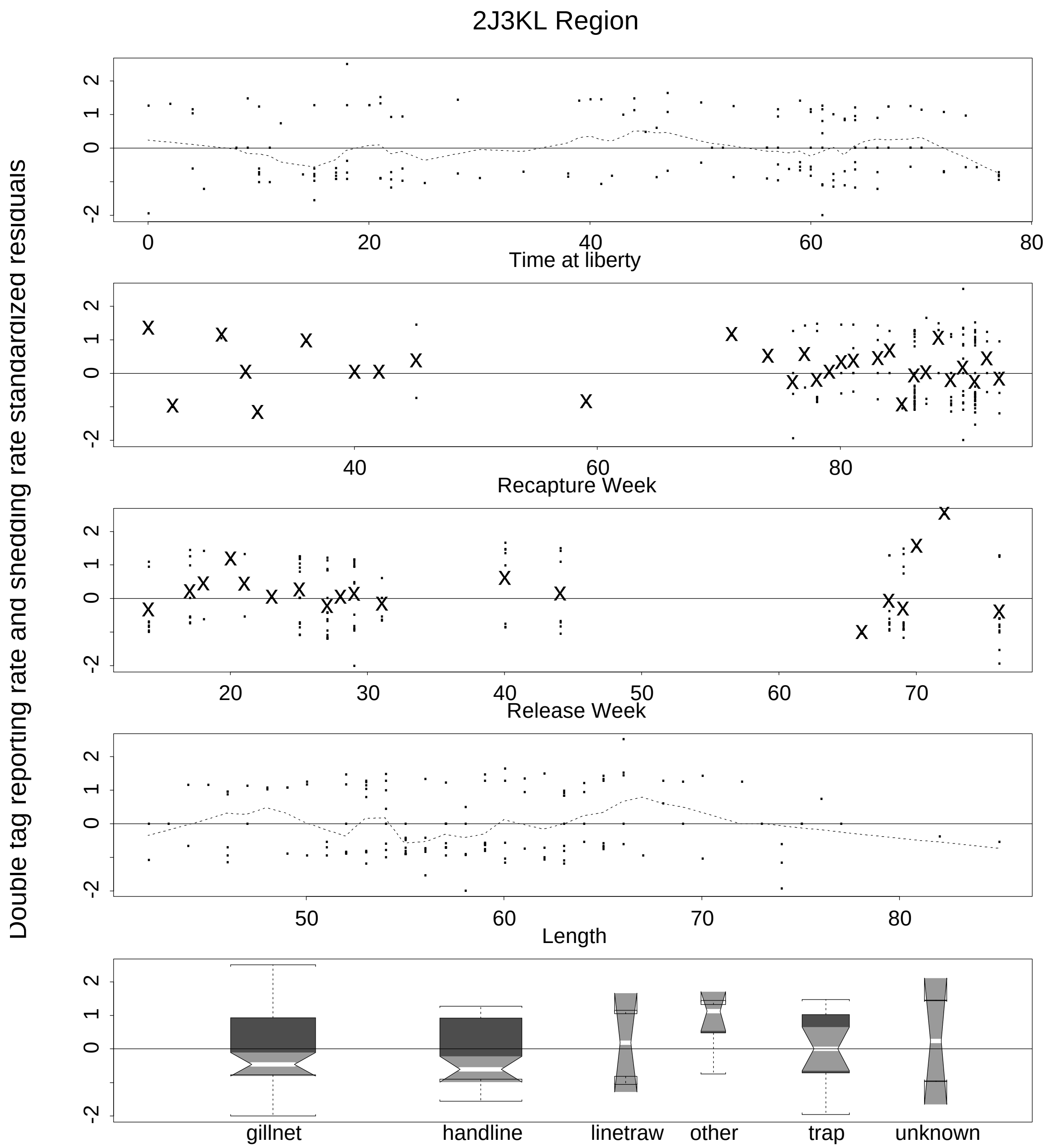

Figure 4: Double tag reporting rate and tag loss rate standardized residuals based on type 3 returns (p^3) in 3KL. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.

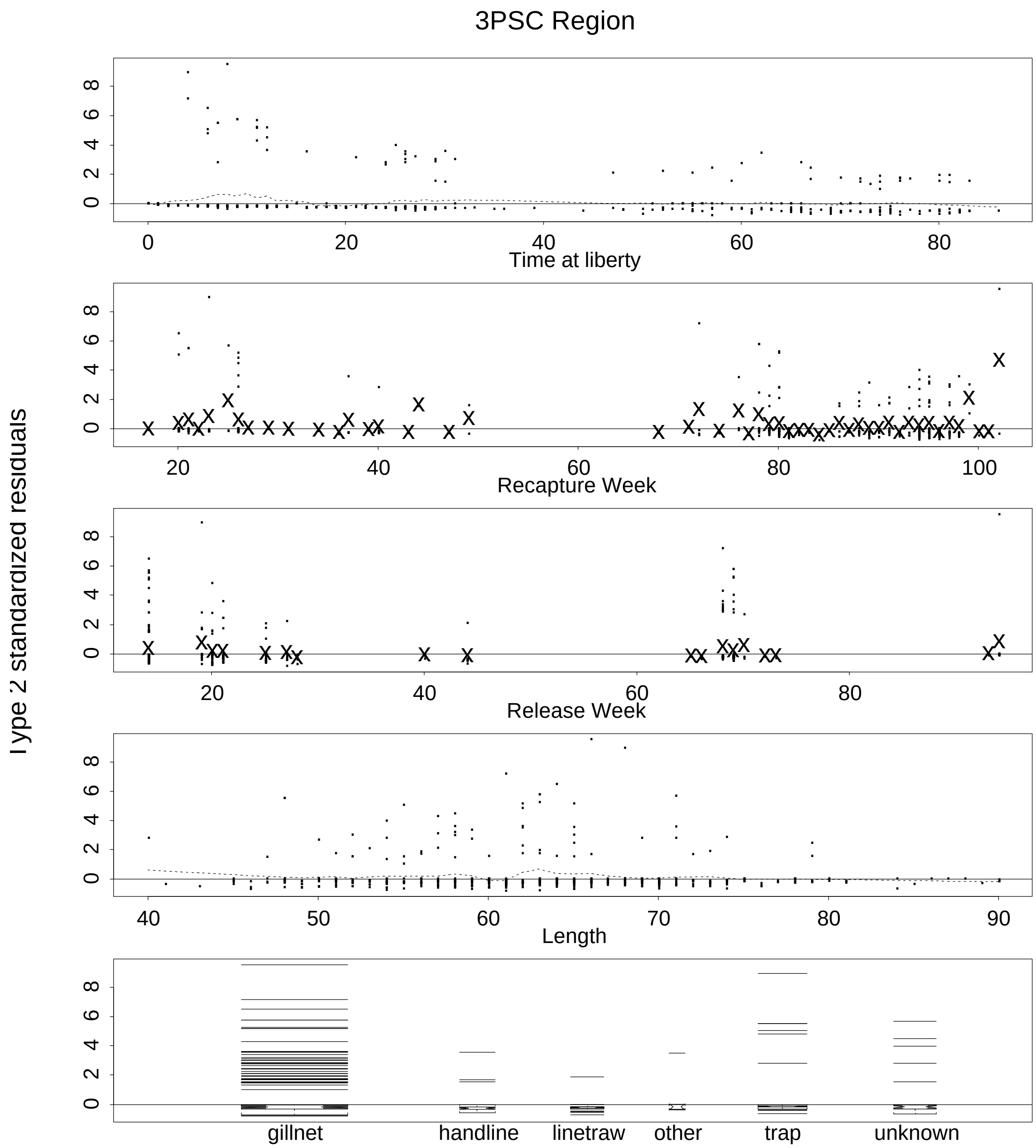

Figure 5: Double tag reporting rate and tag loss rate standardized residuals based on type 2 returns (p^2) in 3Psc - Placentia Bay. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.

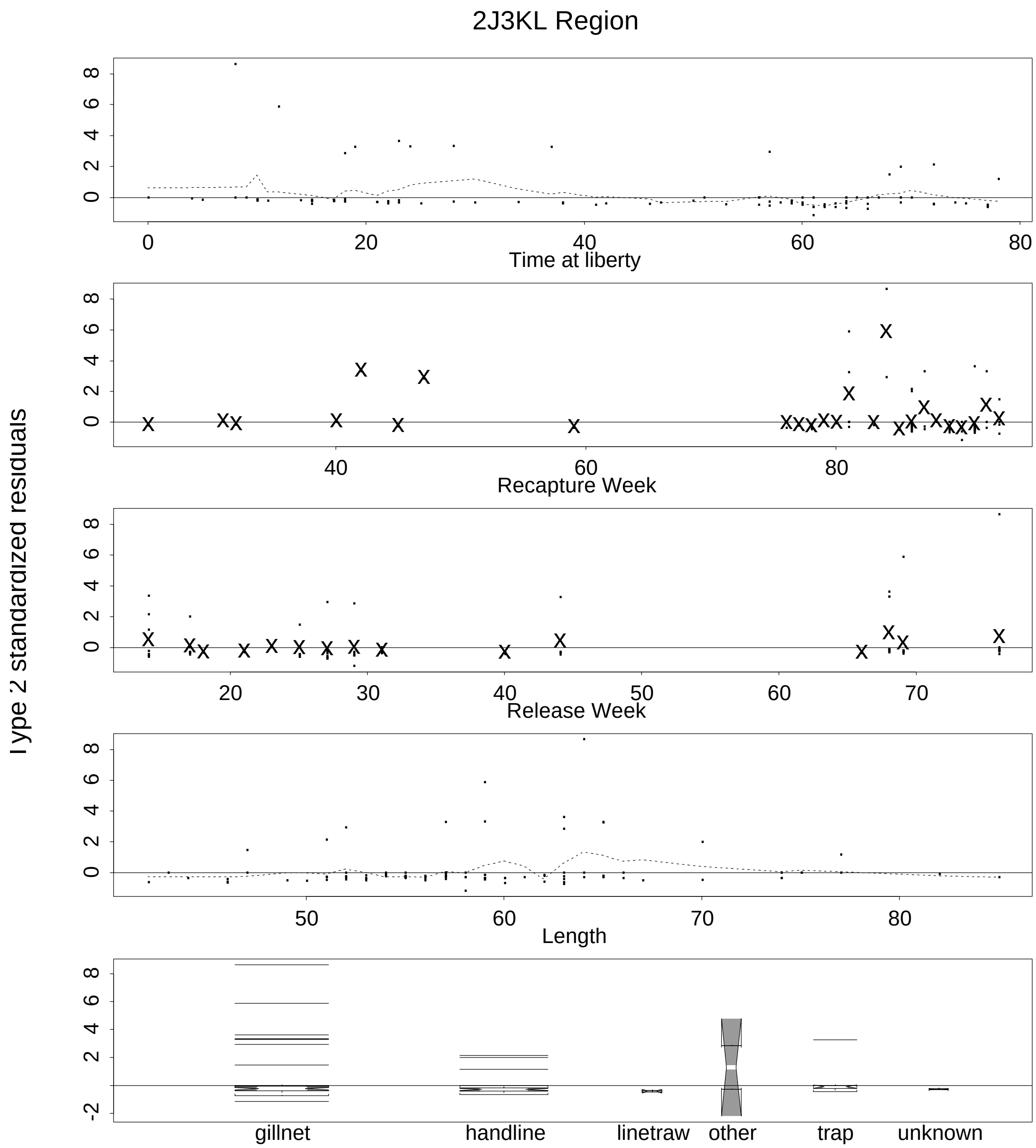

Figure 6: Double tag reporting rate and tag loss rate standardized residuals based on type 2 returns (p^2) in 3KL. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.

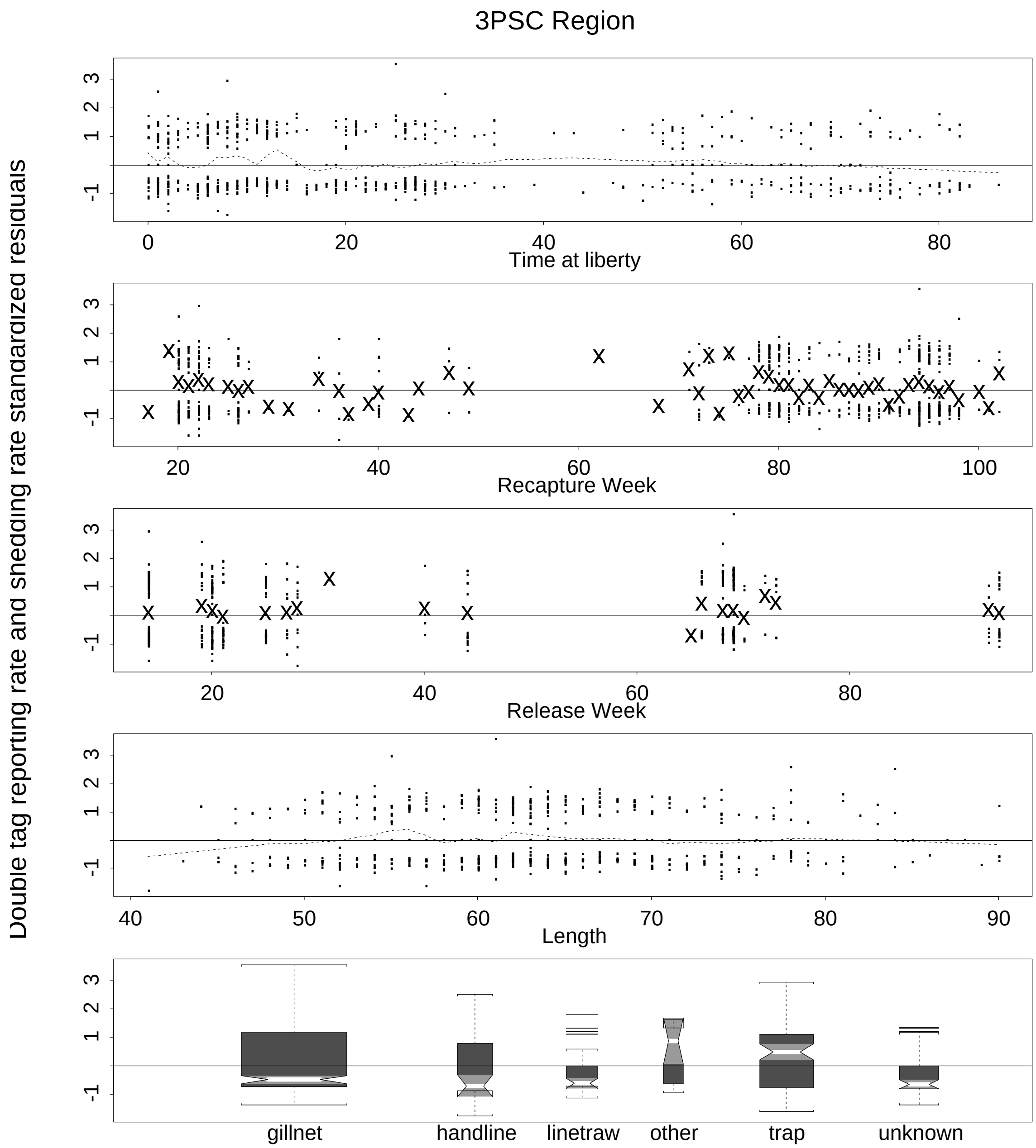

Figure 7: Double tag reporting rate and tag loss rate standardized residuals based on type 3 returns (p^3) in 3Psc - Placentia Bay, for the two-stage tag loss model. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.

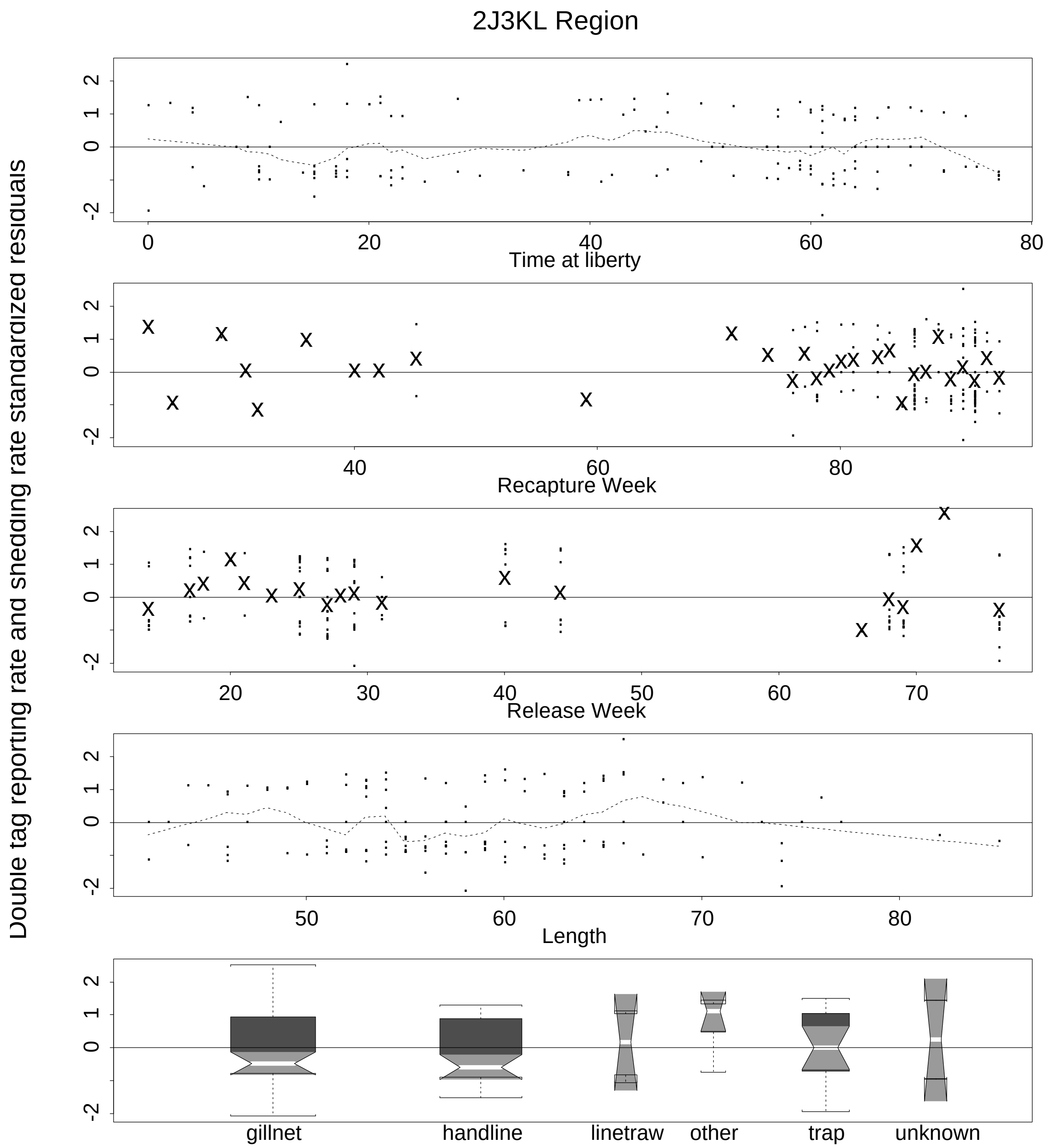

Figure 8: Double tag reporting rate and tag loss rate standardized residuals based on type 3 returns (p^3) in 3KL, for the two-stage tag loss model. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.

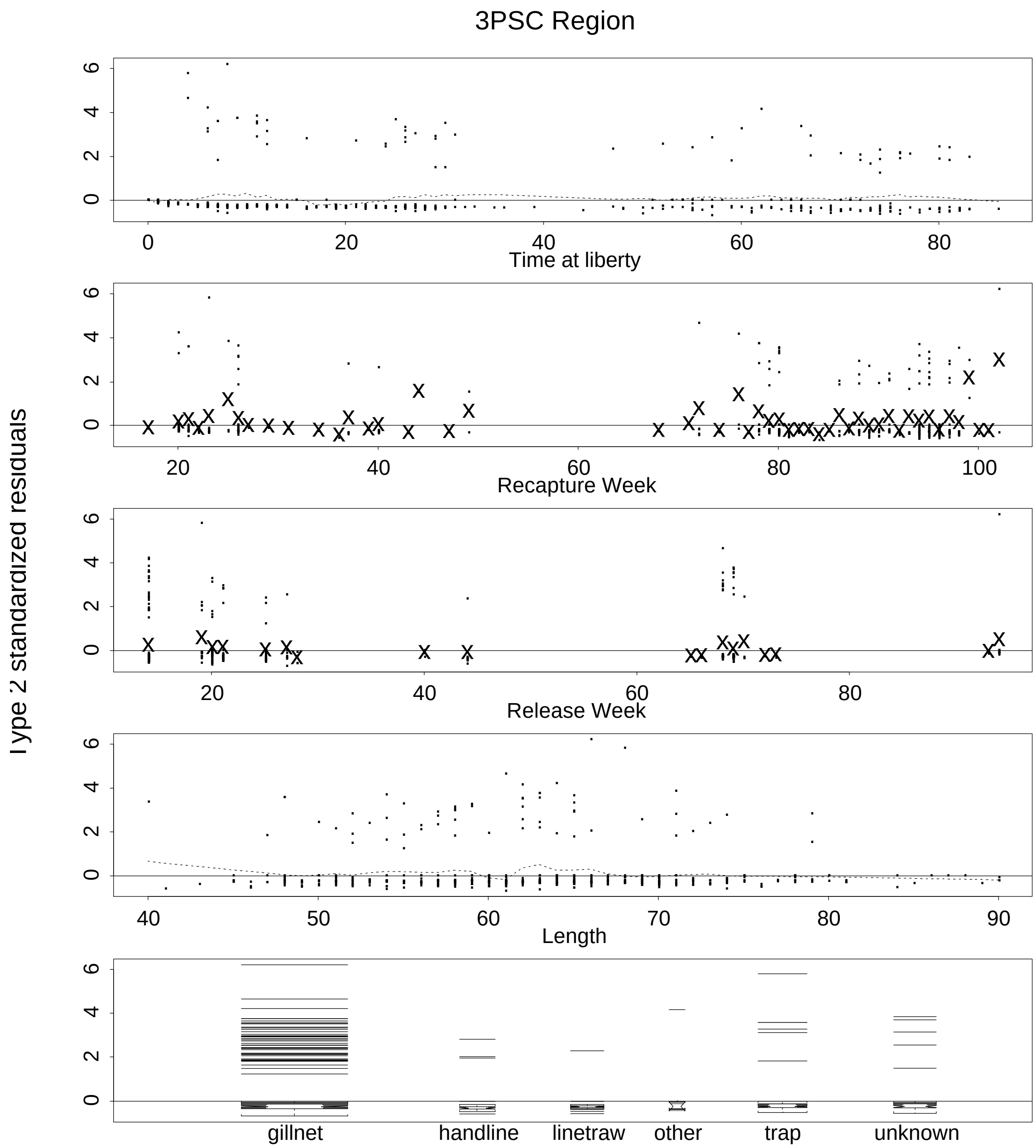

Figure 9: Double tag reporting rate and tag loss rate standardized residuals based on type 2 returns (p^2) in 3Psc - Placentia Bay, for the two-stage tag loss model. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.

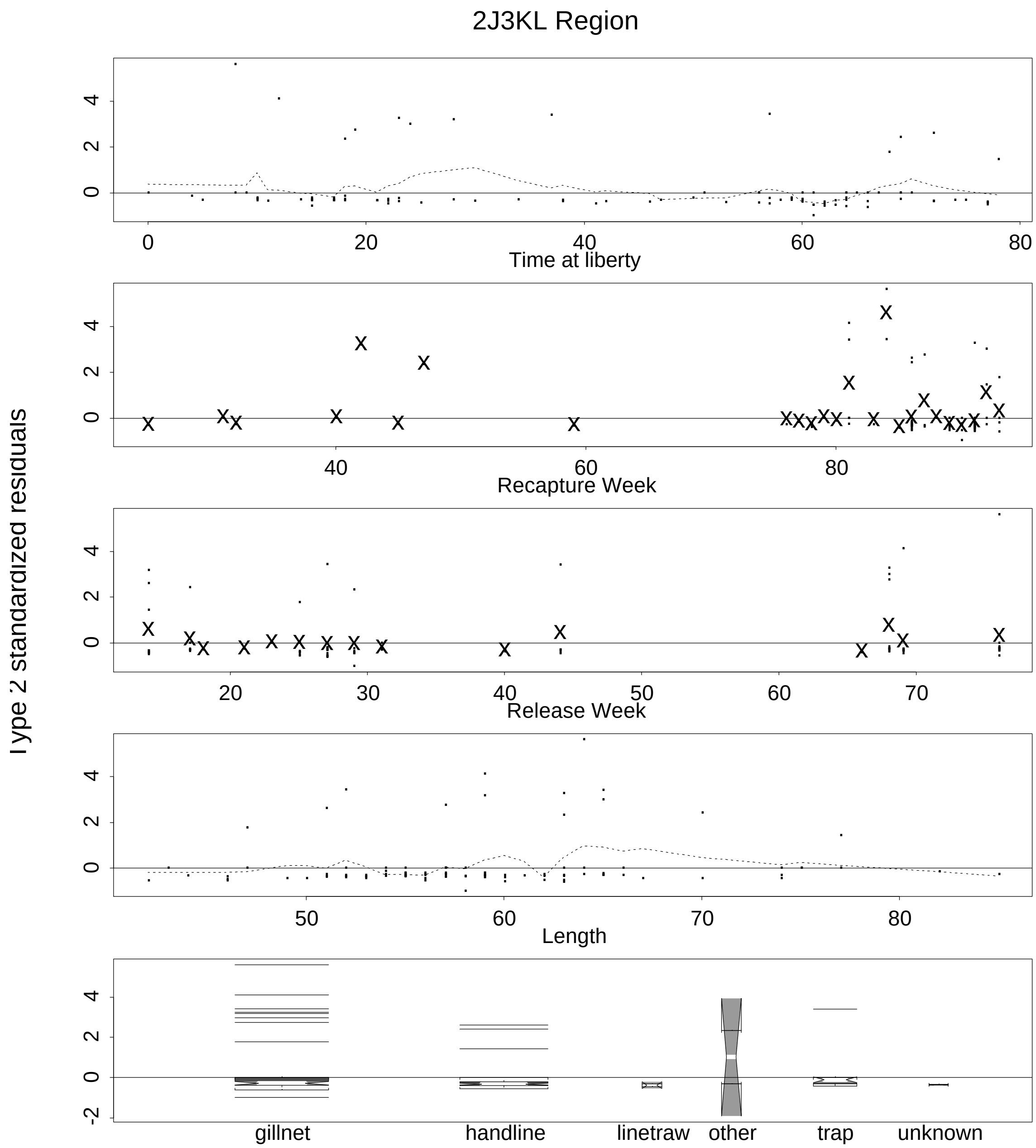

Figure 10: Double tag reporting rate and tag loss rate standardized residuals based on type 2 returns (p^2) in 3KL, for the two-stage tag loss model. The dotted line represents a smoothed …t to the residuals. The X's represent the average residual.