Fisheries and Oceans Canada Pêches et Océans Canada
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Research Document 2011/079 **Document de recherche 2011/079**

Maritimes Region **Région des Maritimes**

Lobster Size at Maturity Estimates in Eastern Cape Breton, Nova Scotia

Estimations de la taille du homard à la maturité dans l'est du Cap-Breton, en Nouvelle-Écosse

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

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Correct citation for this publication:
La présente publication doit être citée comme suit :

Reeves, A., J. Choi, and J. Tremblay. 2011. Lobster Size at Maturity Estimates in Eastern Cape Breton, Nova Scotia. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/079: vi + 18 p.

ABSTRACT

This study describes spatio-temporal variability in female size at maturity for three areas in eastern Cape Breton, Nova Scotia, Canada. Cement gland staging techniques were used to assess sexual maturity and were confirmed as required by ovary examination. Sampling took place from April to November (2005-2008). Generalized Linear Models (GLMs) were constructed to explore the relationship between maturity and carapace length using a binomial distribution for the dependant variable with a log odds (logit) link. Preliminary regressions of individual samples suggested that the estimates of size at maturity (SOM50) were variable across the three sites, variable across years from 2005 to 2007, and variable across weeks with years. Further investigation using two separate models, one incorporating terms for annual and seasonal components, and another incorporating spatial and seasonal components verified that size at maturity was annually, spatially and seasonally variable. These models indicated reduced size at maturity for the most northern site and the most recent year (2007), while indicating an increased size at maturity as the sampling season progressed. The results suggest that monitoring size at maturity over time may represent a valuable non-fishery based indicator of stock status and health. Furthermore, the need for standardized, replicated seasonal sampling over the period prior to extrusion and hatching is clearly necessary for accurate estimates of SOM50.

RÉSUMÉ

La présente étude décrit la variabilité spatiotemporelle de la taille des homards femelles à la maturité dans trois zones de l'est du Cap-Breton (Nouvelle-Écosse), au Canada. Des techniques de détermination du stade des glandes cémentaires ont été utilisées pour évaluer la maturité sexuelle, leurs résultats étant confirmés au besoin par un examen des ovaires. L'échantillonnage a eu lieu d'avril à novembre (de 2005 à 2008). Des modèles linéaires généralisés ont été établis pour étudier la relation entre la maturité et la longueur de la carapace; ils faisaient appel à une distribution binomiale pour la variable dépendante, avec un lien au logarithme du rapport de cotes (logit). Les régressions préliminaires d'échantillons laissaient croire que les estimations de la taille à laquelle 50 % des homards atteignent la maturité (SOM50) variaient de l'une à l'autre de ces trois zones, d'une année sur l'autre de 2005 à 2007 et également d'une semaine à une autre au cours des années considérées. De plus amples études fondées sur deux modèles distincts, intégrant l'un les paramètres des composantes annuelles et saisonnières et l'autres les paramètres des composantes spatiales et saisonnières, ont permis de vérifier que la taille à la maturité variait selon l'année, l'endroit et la saison. Les modèles reflétaient une taille à la maturité plus petite dans la zone située le plus au nord et pour l'année la plus récente (2007), avec augmentation de cette taille au fur et à mesure de l'avancement de la saison d'échantillonnage. Les résultats révèlent que la surveillance de la taille à la maturité au fil du temps peut représenter un indicateur utile et indépendant de la pêche de l'état et de la santé d'un stock. De plus, il apparaît clairement nécessaire de procéder à un échantillonnage saisonnier répété et standardisé dans la période qui précède la ponte et l'éclosion pour obtenir des estimations précises de la SOM50.

INTRODUCTION

Maturity ogives are key inputs to lobster population models and the determination of management measures such as the minimum legal size (MLS). It is generally assumed that when a female American lobster's ovaries mature, extrusion will occur. Thus, physiological and functional maturity are considered to be the same (Waddy and Aiken, 2005). Ovary resorption could confound this assumption. The incidence of this event has not been assessed in coastal Cape Breton and Nova Scotia. However, ambient temperatures have been shown to influence ovary resorption in the laboratory (Waddy and Aiken, 1995). Fahy (2003) and Laurans *et al*. (2009) suggest reserving the term functional maturity (or "expressed maturity") for maturity based on the presence of eggs. Here, we assume that female lobsters are mature when their ovaries mature (prior to first egg extrusion or "spawning").

In the literature, the maturity of female lobsters has been assessed with a number of different methods. These include: (1) direct observation of the presence/absence of eggs under the abdomen (2) morphometric measurements of the abdominal width and (3) observation of the ovarian condition (Comeau, 2003). Morphometric maturity based on the relative growth of abdomen and crusher claw occurs prior to functional maturity in females (Emond *et al*., 2010). Ovary condition can be considered the "gold standard" for establishing sexual maturity, but the cement gland development staging technique compares very well with assessment of ovary condition (Comeau, 2003; Gendron, 2003). This technique provides a non-lethal, reliable, and relatively rapid method of female maturity assessment (Waddy and Aiken, 2005).

Characterizing the size at which individuals reach maturity is typically done by modeling the relationship between the proportion mature and carapace length with a logistic regression (Campbell and Robinson, 1983; Comeau and Savoie, 2002; Little and Watson, 2005; Laurans *et al*., 2009). The resulting sigmoid curve is referred to as an ogive. The size at 50% maturity (SOM50) is generally used for comparison of maturity ogives. The first published evaluation of female sexual maturity for lobsters from coastal Nova Scotia was Campbell and Robinson (1983). They staged cement glands from lobsters sampled in the late 1970s from Nova Scotia's eastern shore (combined samples from Gabarus, Fourchu and New Harbour (LFA 31a)). Their estimate for SOM50 was 92.5 mm CL. Watson (1988, unpublished) and Miller and Watson (1991) used cement glands to provide estimates for SOM50 for eastern Cape Breton as follows: 73 mm (Ingonish and Glace Bay), 78 mm (Fourchu) and 84 mm (Petit de Grat). Miller and Watson (1991) remarked on some of the annual and spatial variability. Ugarte (1994, unpublished) examined female sexual maturity in lobsters from the Canso fishing grounds. His estimate for the fishing grounds as a whole was 83 mm CL but he also provided separate estimates for the "inner" area (shallow and protected, average depth 8 m) and the "outer" area (exposed, several km off any headlands with a depth of 22 m). The estimate for the inner ground was 76 mm CL, substantially less than the estimate of 99 mm CL for the outer grounds. Ugarte also estimated a SOM50 of 98 mm CL for Jeddore on the eastern shore (LFA 32). It is important to note that there are slight variations in the sampling and assessment techniques in the studies mentioned above.

The current paper describes the spatio-temporal variability in estimates of female lobster maturity for three areas in eastern Cape Breton, Nova Scotia, Canada (Fig. 1). Two of the sites, Dingwall (northern) and False Bay (central), are in Lobster Fishing Area (LFA) 27. The southern site, Petit de Grat, is located on Isle Madame in LFA 29. LFA 27 has traditionally had a somewhat different management regime when compared to LFA 29, including a lower minimum legal size (MLS) ("canner fishery") and slightly different seasons and trap limits. Furthermore, the management regimes have changed for these LFAs in the recent past, the most important of these being the increases in MLS in LFA 27 (70-76 mm CL -1997 to 2002, 76-81 mm CL –

2006 to 2009). There are clear differences between the sites in terms of lobster catches, as well as within the sites in recent years (Tremblay *et al.* 2011). The most obvious change is seen in the dramatic increases in landings and catch rates for the southern most port (Petit de Grat, LFA 29) since 2004. There are also large variations in available fishing ground and effort density from port to port, both within and between LFAs.

Thus, to investigate potential factors influencing maturity, it is essential to determine the variation in maturity estimates over time and space. In addition, maturity ogives may be influenced by environmental variables (temperature, primary productivity, water chemistry and others) and population variables such as size structure, abundance, prey availability, disease, predation and fishery exploitation. We describe the spatio-temporal variability in estimates of female lobster maturity for three areas in eastern Cape Breton, Nova Scotia, Canada (Fig. 1) and highlight some of the management implications of these influences.

METHODS

Three approximately equidistant ports were selected on the eastern coast of Cape Breton Island. Two of the sites, Dingwall (northern) and False Bay (central), are in Lobster Fishing Area (LFA) 27 (Fig. 1). The southern site, Petit de Grat, is located on Isle Madame in LFA 29. These areas were chosen because LFA 27 has traditionally had a somewhat different management regime when compared to LFA 29, including a lower minimum legal size (MLS) ("canner fishery"). Further, the MLS in LFA 27 changed from 70-76 mm CL from 1997 to 2002, and from 76-81 mm CL from 2006 to 2009). There are also clear differences between the sites in terms of lobster catches, as well as within the sites in recent years. The most obvious change is seen in the dramatic increases in landings and catch rates for the southern most port (Petit de Grat, LFA 29) since 2004 (Tremblay *et al*., 2011). There are also large variations in available fishing grounds and effort from port to port, both within and between LFAs.

A total of 2263 female lobster were collected by trapping during 28 sampling events from 2005 to 2008 at these three sites. All samples included the majority of the female catch (whenever possible the largest reasonable range of sizes were sampled from a single fisherman's catch at each site; data on ovigerous females were collected for some samples but were excluded from this analysis). Table 1 provides a breakdown of the sampling weeks and number of animals for each site by year (note that not all samples were used in the final model, see below).

Cement gland staging is used to infer ovary maturation. Carapace length (CL) was measured to 0.1 mm for each female. Molt stage of the second right pleopod endopodite was then determined using the molt stages (MS) described in Aiken and Waddy (1982). Pleopod stage 2.5 and greater are considered to represent imminent, irreversible molt (Aiken, 1980). All pleopods were then assigned a cement gland stage (CGS) as described in Aiken and Waddy, 1982. Initially and periodically maturity levels based on cement gland stages were verified through visual determination of ovary stage based on color, relative size and oocyte size as described in Aiken and Waddy (1982) and Comeau and Savoie (2002). Animals with a cement gland stage of 2 were considered mature, as per Watson (1988), Comeau and Savoie (2002), and Aiken and Waddy (1982) (also see Gendron *et al*., 2004, for discussion).

All statistical analyses were completed using the statistical computing language and environment R (The R Foundation for Statistical Computing, 2010). Preliminary ogives, using a Generalized Linear Model (GLM) with maturity as the dependant variable and the single continuous covariate of CL were created for each sample set to assess whether the sample size and CL ranges were adequate and to provide an initial visual comparison of the areas and sampling periods. A binomial distribution (0 = immature, 1 = mature) with log odds (logit) link was used for all GLMs. Sample sets with poor fit caused by inadequate sample size and/or range were removed from further analyses.

To determine the temporal and spatial influence of sampling on the maturity estimates, more complex GLMs were constructed using terms for area (co-factor), week of year (co-variate) and year (co-factor) and associated first order interactions. (Week of year was predetermined (using the methods given below) to be the best choice to relate seasonality for the dataset when compared to day of year, month or season). Comparisons of anova residual deviance and of the Akaike Information Criteria (AIC) values were used as the model selection criteria. All terms were tested for statistical significance (anova) in the resulting GLM to determine their effect on the response variable (maturity).

The R package “effects” was used to visualize the significant main effects (intercepts) and first order interaction terms (slopes) of the fitted models. It provides the proportion (and associated 95% confidence intervals) of females that are mature at the adjusted (across all levels of other terms) mean carapace length. The effect plots demonstrate the effect on maturity by the selected model term (i.e. year, week of year, etc) across all levels of the chosen term. This simplifies interpretation of various effects on maturity.

RESULTS AND DISCUSSION

Preliminary Size at Maturity Estimates

Single covariate (CL) GLM regressions for each sample set were used as a baseline for selecting samples with adequate ranges of CL and sufficient sample size (samples removed- Dingwall-week 21-2005, Petit de Grat- week 21-2005, False Bay- week 17- 2007, Petit de Grat- week 22-2007). Figure 2 provides examples of regressions of individual samples from each area based on best fit and lowest CI around the SOM50 estimates (Note: raw data points are not included in these plots due to the use of individual CL as the covariate at 0.1mm, not binned groups which would provide a percent per ‘size bin’). Table 2 provides a summary of the SOM50 for these samples, as well as the intercepts at 25% and 75% mature (SOM25 and SOM75 respectively). The estimated percentage mature at the current MLS is also provided in Table 2. These estimates are from the early June to mid July period which is expected to be the best period to capture females that are getting ready to extrude eggs or have yet to hatch eggs (Comeau 2003). The 95% confidence intervals around the SOM50 estimates for these samples are quite narrow, 1.8 to 5.2 mm CL. They indicate best estimates for SOM50 of 71.5-72.4 mm CL for Dingwall, 75.6-75.8 mm CL for False Bay and 74.7-75.8 mm CL for Petit de Grat. The values for Dingwall and False Bay are very similar to the estimates by Watson and Miller from samples in the mid-1980s, whereas the estimate for Petit de Grat is approximately 9 mm lower than Watson and Miller. Also shown are the estimates for SOM25 and SOM75, which show the potential for seasonal, annual and spatial changes in the shape of the ogives.

These results suggested geographic, annual, and seasonal differences in maturity estimates. Further investigation of these differences was accomplished with GLM models incorporating seasonal (week of sampling), annual and spatial effects. Due to the lack of multiple week samples in each area and year, 2 models were developed to separately test spatial and annual influences, with a seasonal component (week of year) in both.

Annual Differences

The years 2005 to 2007 from the two sites in LFA 27, Dingwall and False Bay, were used to examine annual differences in the relationship between maturity and size.

The following model was selected by AIC comparison (see Appendix A) and anova:

Maturity ~ CL + Week of Year + Year + CL:Year

(where continuous covariate=CL; main effects=Week of Year, Year; interactions= CL:Year).

Anova (type II, likelihood ratio) results suggested the first order interaction term CL:Week of Year (p-value high) to be dropped from the model, indicating that the slope of the logit regressions for each week were not significantly different. The interaction between Week of Year and Year was also not significant. The terms Year and Week of Year were significant, indicating the intercept or elevation are variable across years, and across weeks within years. The significant first order CL–Year interaction suggests the slopes of the regressions are changing across years (the shape of the ogives are significantly different). Table 3 provides the results of type II anova for GLM regression analysis for the above model, which indicated significance at 95% confidence level or higher for all terms. Appendix A provides the final model summary, residual plot and AIC table for model selection.

The Year main effect plots show increased percent maturity at adjusted mean CL from 2005 to 2007 (Fig. 3, variance indicated by dotted lines). This indicates the SOM50 estimates decreased over this time period (the maturity ogives are left shifted). Further exploration as to the cause of this trend is required. The effects plots for the CL–Year interaction show increasing slopes with year (the range of carapace lengths for mature individuals decreased from 2005-2007; Fig. 4 and 5).

The annual variations in maturity suggest the need to monitor this relationship over time, and that estimates of maturity at size may provide important information for the evaluation of stock status in a given area. This monitoring could provide a useful tool for a flexible management regime by providing rationale for minimum legal size and season modifications.

Spatial Differences

A model was also constructed to explore geographic variations in maturity estimates. Data from the three aforementioned sites were used from a single year (2006) with comparable datasets across all areas. The resulting best fit model had the form:

Maturity ~ CL + Week of Year + Area + CL:Week of Year

Interaction terms for CL-Area and Week of Year-Area were not significant and thus dropped from the model. The significant terms Area and Week of Year indicate the intercept (elevation) are variable across areas, and across weeks within areas. Table 4 provides the results of type II anova for GLM regression analysis for the above model, which indicated significance at 95% confidence level or higher for all terms. Appendix B provides the final model summary, residual plot and AIC table for model selection.

The Area main effect plots show a higher percent maturity at adjusted mean CL for Dingwall (smaller SOM50) compared to the other sites for 2006 (Fig. 6). The percent maturity for False Bay and Petit de Grat are similar, which is consistent with the results of the SOM50 estimates from the preliminary ogives give in Table 2. The lack of significance for the CL-Area interaction suggests that, for 2006, the slopes are similar across areas.

These spatial variations suggest the need for additional sampling at other sites to determine where the transition zones occur and to allow possible determination of the causes of these maturity differences across areas, such as environmental effects or exploitation. Again we see that using fixed maturity estimates (across areas in this case) in management strategies could be problematic.

Seasonal Differences

The main effect of Week of Season was significant for both the annual and spatial models, indicating seasonal variations in maturity estimates. The effects plot for the main effect of 'Week of year' (for both models) indicated reduced percent maturity with increasing weeks (Fig. 7 and 8). This is also demonstrated in increased SOM50 estimates as the season progresses (ogives are right-shifted). The significant first order CL-Week of Year interaction for the spatial model indicates the slopes of the regressions are changing across weeks in the three sites (the shape of the ogives are significantly different; Fig. 9 and 10).

These seasonal differences are due to cement gland development, as well as the events of egg extrusion (ovigerous females are not currently included in analyses) and spawning (post hatch animals no longer show advanced cement gland development but are clearly mature). The model indicates the best period for sampling is between weeks 25 to 30 (lowest CI, mid June to late July), which is consistent with recommendations by other investigators (Comeau and Savoie, 2002; Waddy and Aiken, 2005).

SUMMARY

- Size at maturity estimates differ significantly by year, indicating decreases from 2005 to 2007.
- Size at maturity estimates differ significantly by area, with the northern port having the lowest SOM50 estimate.
- Size at maturity estimates differ significantly by week of year, indicating increased estimates with increased weeks.

ACKNOWLEDGEMENTS

This project would not have been possible without the investment of time, energy, space and interest of three fishermen: David Ferguson, Guy Landry and David Podanovich. DFO staff that provided technical support during the sampling included Ben Zisserson, Cheryl Denton, and the late Stephen Nolan. Extra thanks to Ben Zisserson for review of the various incarnations of this document and for the lengthy but productive discussions. Fishermen and Scientist Research Society (FSRS) provided various staff for assistance with sample collection. Special thanks to Michelle Theriault from Université Sainte-Anne - Collège de l'Acadie for assistance with data collection and staging. Thanks to Stephen Smith (DFO) for guidance with the modeling techniques and to Nell den Heyer for providing comments on the manuscript.

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Table 1 Summary of sample sites in eastern Cape Breton, 2005-2008.

Year	**Port**	**Sample Week in Year**	**No. Fem.**
2005	Dingwall (LFA 27 North)	21, 26, 27, 29	170
2005	False Bay (LFA 27 South)	26, 27, 29, 35	138
2005	Petit de Grat (LFA 29)	21	59
2006	Dingwall (LFA 27 North)	26, 45	181
2006	False Bay (LFA 27 South)	26, 28, 34, 43	431
2006	Petit de Grat (LFA 29)	24, 33, 42	271
2007	Dingwall (LFA 27 North)	23, 25, 27	363
2007	False Bay (LFA 27 South)	17, 23, 25	274
2007	Petit de Grat (LFA 29)	22	98
2008	Petit de Grat (LFA 29)	23, 25	278

Table 2 Estimates for SOM50, SOM25 and SOM75 for ports in Cape Breton.

Year	**Period**	**Port**	**SOM50 (mm CL)**	**CI (± mm)**	**SOM25 (mm CL)**	**SOM75 (mm CL)**	**Range SOM25-75**	**Pct mature at MLS**
2006	Late June	Dingwall	71.5	1.8	72.4	77.1	4.7	88.2
2007	Early July	Dingwall	72.4	1.2	70.6	74.1	3.5	99.6
2006	Mid July	False Bay	75.8	1.8	71.2	80.5	9.3	77.2
2007	Early June	False Bay	75.6	0.9	73.4	77.9	4.5	93.3
2006	Mid June	Petit de Grat	74.7	2.6	71.7	77.7	6.0	90.9
2008	Late June	Petit de Grat	74.8	1.7	72.4	77.1	4.7	94.7

Table 3. Anova Type II results for best fit model logistic regression for Annual variability.

	LR Chisq	Df	Pr(>Chisq)
CARLENGTH	409.02	1	< 2.2e-16 ***
WEEKOFY	4.63	1	0.0314449 *
YEAR	11.71	2	0.0028643 **
CARLENGTH:YEAR	15.64	2	0.0004017 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 4. Anova Type II results for best fit model logistic regression for Spatial variability.

	LR Chisq	Df	Pr(>Chisq)
CARLENGTH	300.148	1	< 2.2e-16 ***
WEEKOFY	13.693	1	0.0002153 ***
AREA	9.101	2	0.0105636 *
CARLENGTH:WEEKOFY	10.604	1	0.0011285 **

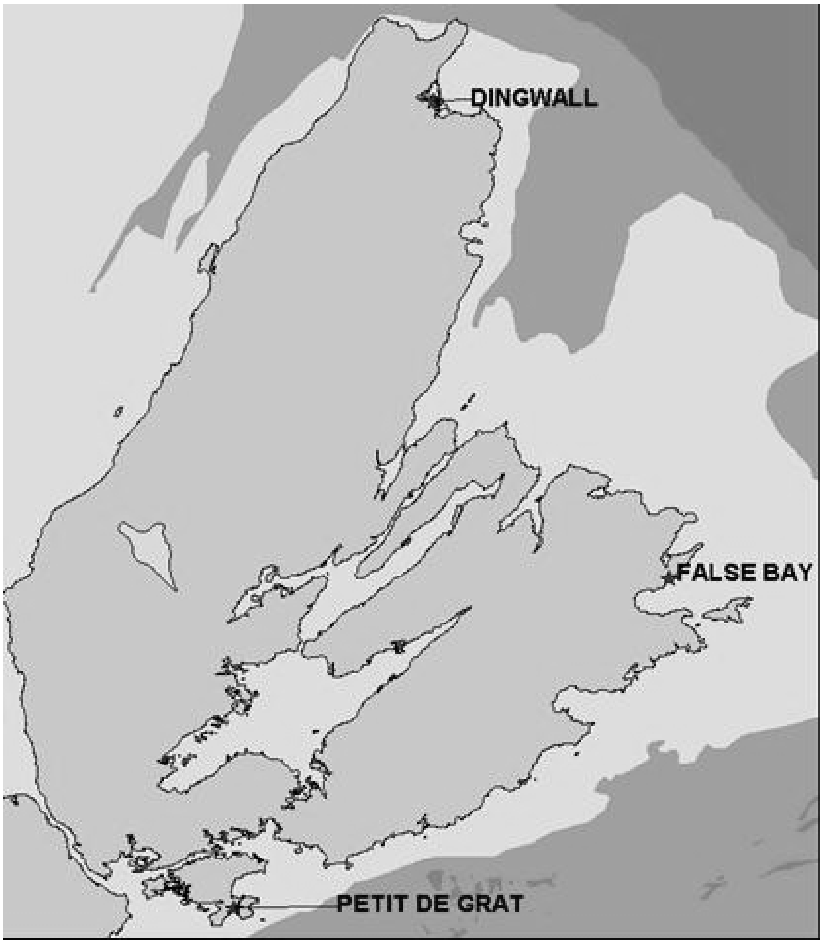


Figure 1. Size at maturity sampling sites in Cape Breton, 2005-2008.

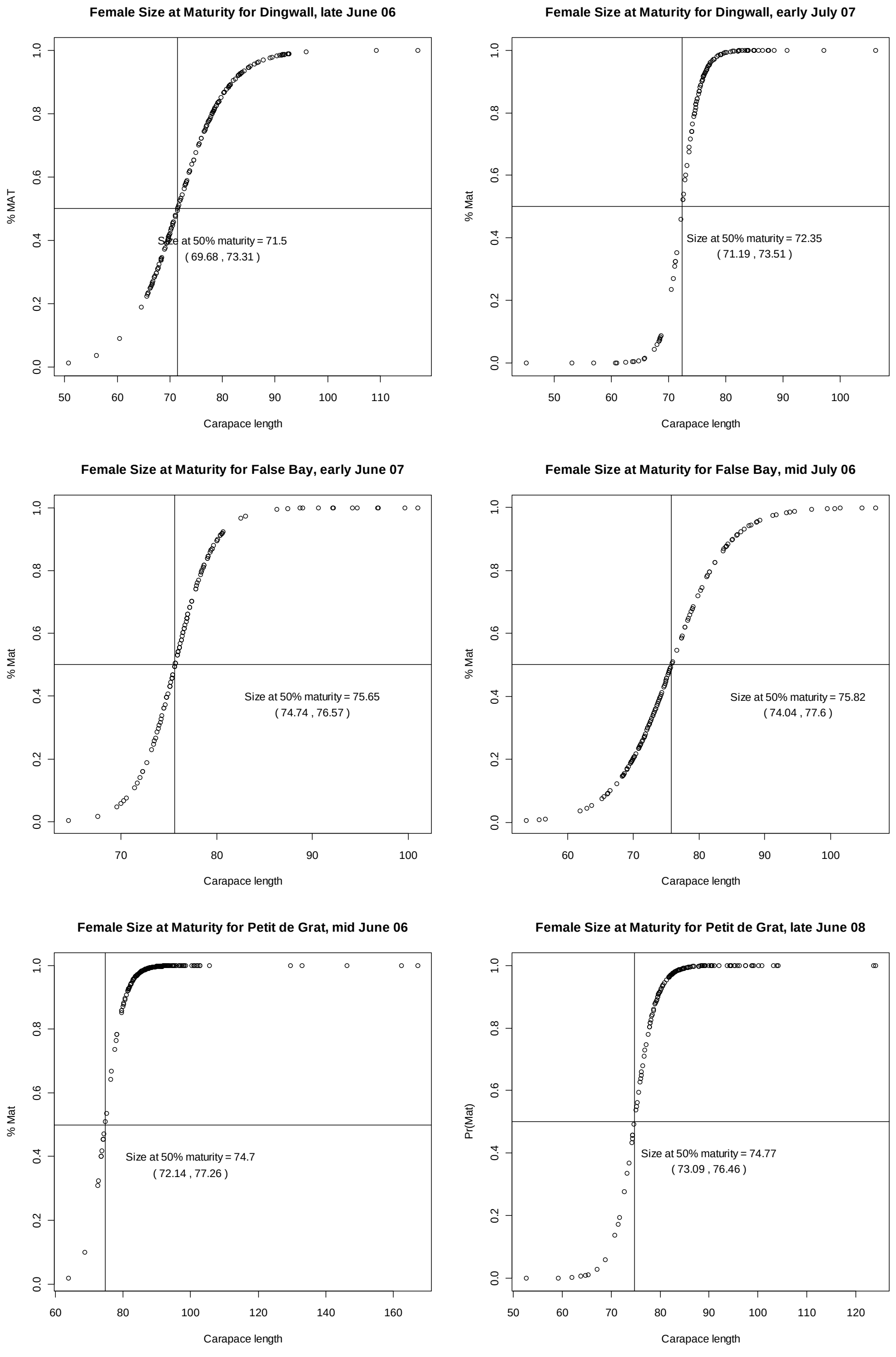


Figure 2. Initial best fit plots of percent mature versus carapace length for Dingwall (LFA 27 North), False Bay (LFA 27 South) and Petit de Grat (LFA 29). The 0.5 y-intercept and associated CI is provided for each.

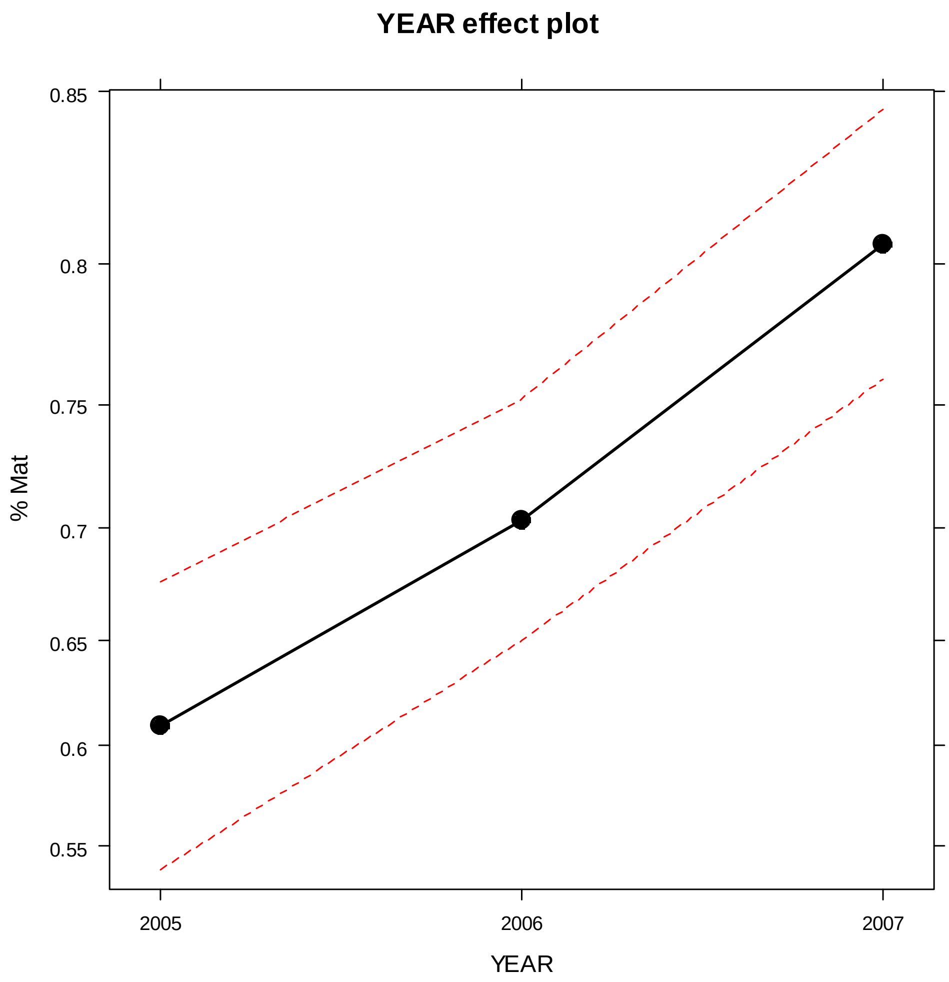


Figure 3. Effects plot for main effect "Year" (year versus percent mature at adjusted mean size).

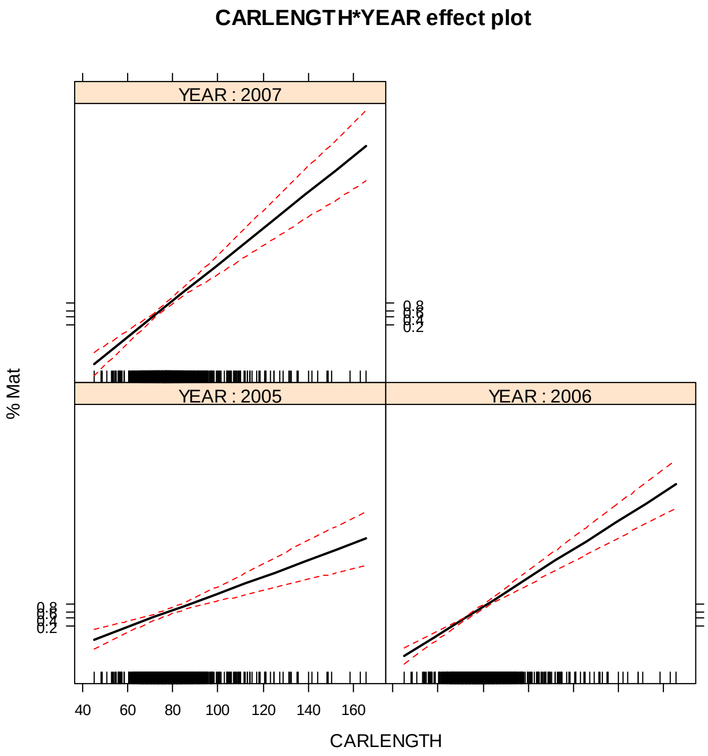


Figure 4. Effects plot for interaction effect cl:year (logit scale).

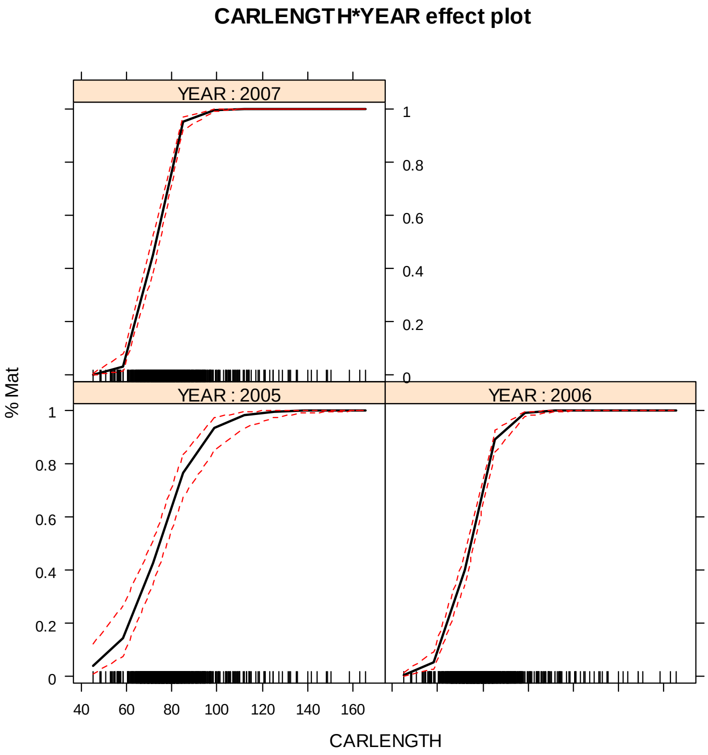


Figure 5. Effects plot for interaction effect cl:year (response scale).

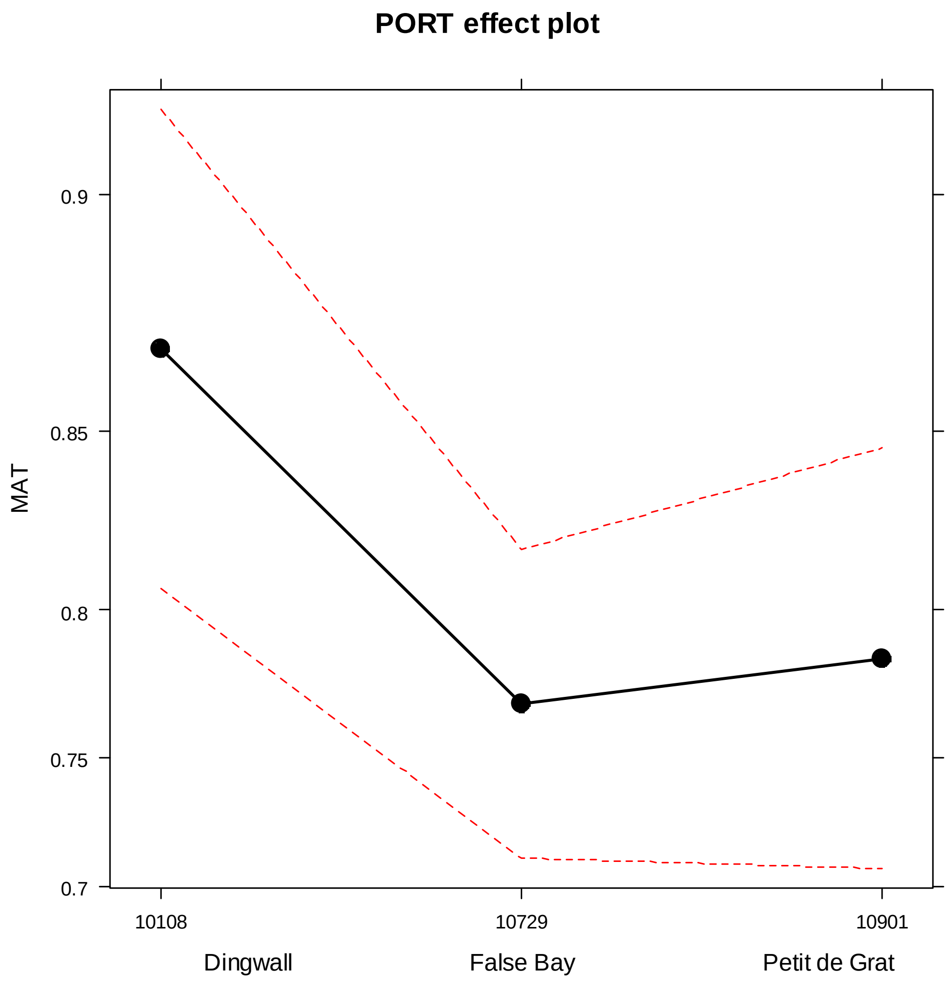


Figure 6. Effects plot for main effect “Area” (area versus percent mature at adjusted mean size).

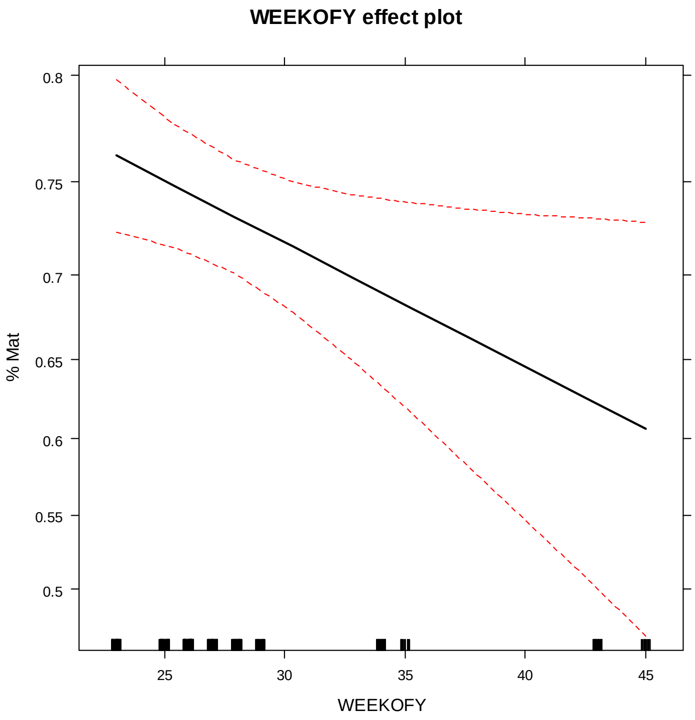


Figure 7. Effects plot main effect “Week of Year” (annual model; week of year versus percent mature at adjusted mean size).

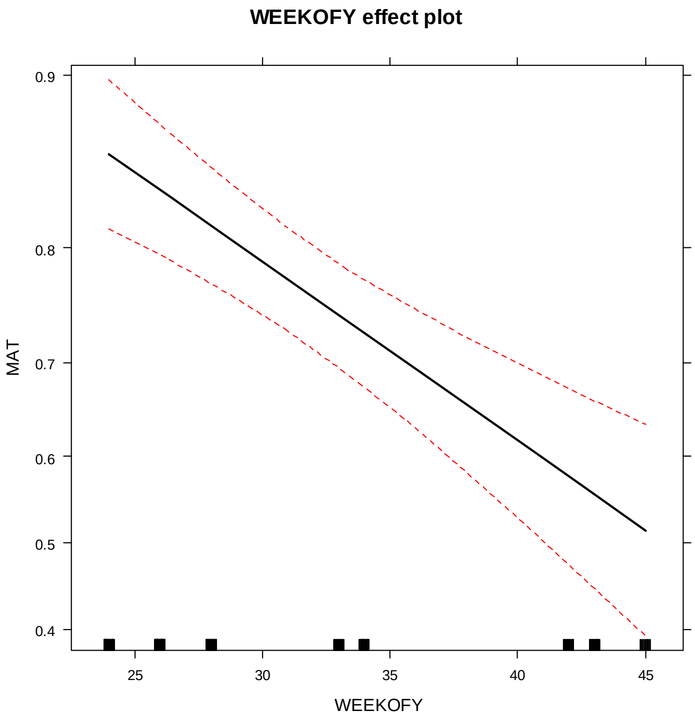


Figure 8. Effects plot main effect "Week of Year" (annual model; week of year versus percent mature at adjusted mean size).

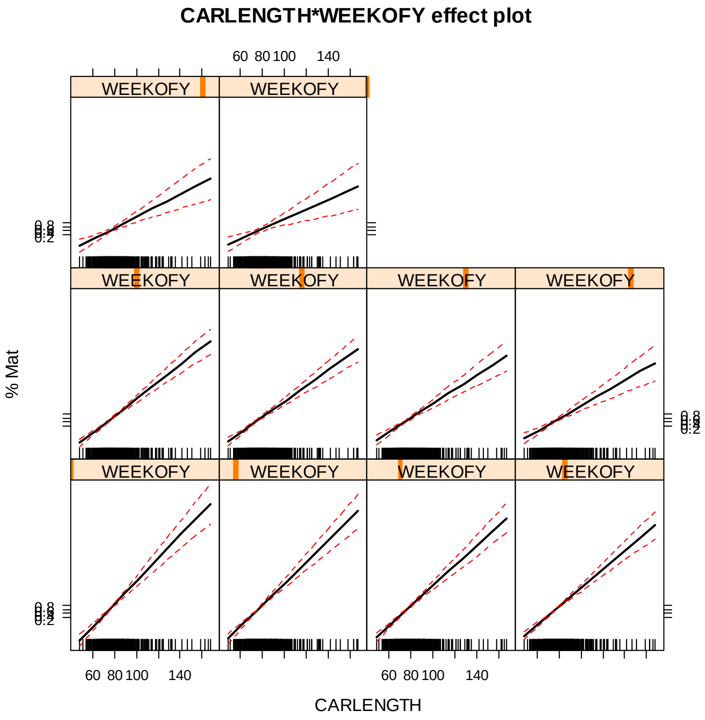


Figure 9. Effects plot for interaction of carapace length and week of year (weeks increasing from bottom right panel).

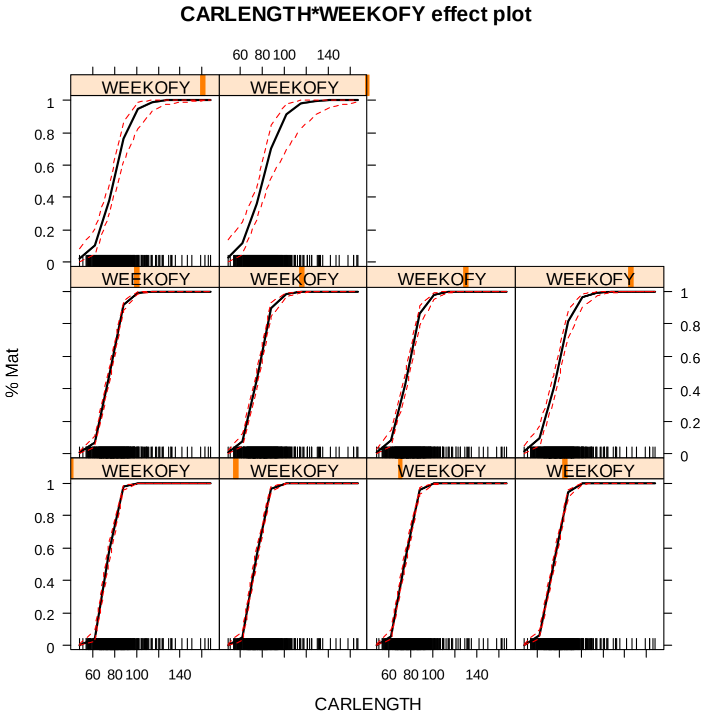
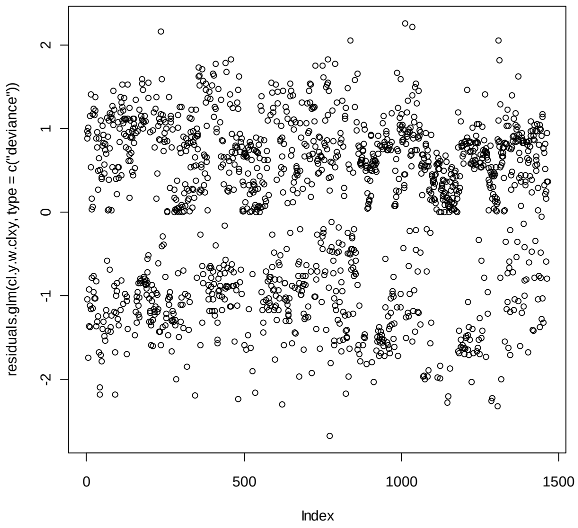


Figure 10. Effects plot for interaction of carapace length and week of year (weeks increasing from bottom right panel; response scale).

Appendix A. Spatial Model Summary

```
lmat.model = as.formula( "MAT ~ CARLENGTH+WEEKOFY+YEAR+CARLENGTH:YEAR" )

Call:
glm(formula = lmat.model, family = binomial(link = "logit"),
    data = f3, na.action = "na.omit")

Deviance Residuals:
    Min       1Q       Median     3Q       Max
-2.6796  -0.8812   0.3664   0.8339   2.2641

Coefficients:
                              Estimate         Std. Error        z value    Pr(>|z|)
(Intercept)                   -7.26778         1.61444           -4.502      6.74e-06 ***
CARLENGTH                       0.10976        0.02030            5.408      6.38e-08 ***
WEEKOFY                       -0.03354         0.01566           -2.142      0.032194 *
YEAR2006                      -5.69669         2.04585           -2.785      0.005361 **
YEAR2007                       -9.10599        2.51023            -3.628     0.000286 ***
CARLENGTH:YEAR2006             0.07778         0.02696           2.885       0.003911 **
CARLENGTH:YEAR2007             0.12826         0.03306           3.879       0.000105 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1923.3  on 1463  degrees of freedom
Residual deviance: 1452.0  on 1457  degrees of freedom
AIC: 1466.0
```

Residual Plot



AIC Table

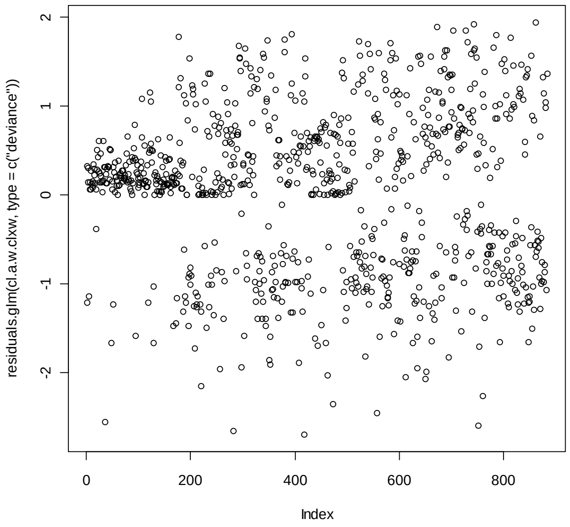
Model Terms	AIC
CL	1500.3
CL + WeekofY	1485.4
CL + Year	1480.3
CL + WeekofY + Year	1477.7
CL + WeekofY + Year + CL:WeekofY*	1476.6
CL + WeekofY + Year + CL:Year	**1466.0**
CL + WeekofY + Year +WeekofY:Year*	1462.0

* - non-significant term at 0.05; best model in bold

Appendix B. Annual Model Summary

```
lmat.model = as.formula( "MAT ~ CARLENGTH+WEEKOFY+PORT+CARLENGTH:WEEKOFY" )

Call:
glm(formula = lmat.model, family = binomial(link = "logit"),
    data = f4, na.action = "na.omit")

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.6953  -0.7407   0.1633   0.6626   1.9457

Coefficients:
                        Estimate        Std. Error      z value    Pr(>|z|)
(Intercept)             -30.009557      5.328402        -5.632     1.78e-08 ***
CARLENGTH                 0.425769      0.070339         6.053     1.42e-09 ***
WEEKOFY                   0.482955      0.157878         3.059     0.002220 **
PORT10729                -0.693187       0.233020       -2.975     0.002932 **
PORT10901                -0.603766       0.301179       -2.005     0.044998 *
CARLENGTH:WEEKOFY       -0.007023        0.002064       -3.403      0.000667 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 1152.92  on 882  degrees of freedom
Residual deviance:  739.94  on 877  degrees of freedom
AIC: 751.94
```

Residual Plot



AIC Table

Model Terms	AIC
CL	781.8
CL + Area	772.2
CL + WeekofY	764.2
CL + Area + WeekofY	760.5
CL + Area + WeekofY + CL: Area *	764.14
CL + Area + WeekofY + CL: WeekofY	**751.94**
CL + Area + WeekofY + WeekofY: Area *	753.3

* - non-significant term at 0.05; best model in bold