S E D A R

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Red snapper: Regression and Chapman–Robson estimators of total mortality from catch curve data

Prepared by
Sustainable Fisheries Branch
Southeast Fisheries Science Center
Beaufort, NC

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SEDAR Headquarters
The South Atlantic Fishery Management Council
4055 Faber Place #201
North Charleston, SC 29405
(843) 571-4366

Introduction

The plot of catch (or abundance or proportion) at age is termed a catch curve. Analysis of catch curves provides a simple means of estimating total mortality rate (Z). Rarely is catch curve analysis alone used for management measures, as its simplifying assumptions are quite strong and rarely if ever met, but instead it serves as a method to understand results from more detailed models. Because catch curves rely on age data, they can reveal issues surrounding the observed age samples. The application of catch curve analysis in this report is primarily for diagnostic purposes.

The two most popular methods for estimating Z from catch curves are regression-based estimators (Quinn and Deriso, 1999) and the Chapman–Robson estimator (Chapman and Robson, 1960; Robson and Chapman, 1961). Perhaps the strongest assumption behind these methods is that the population is in steady state, i.e., that the age structure is stable through time as a consequence of constant recruitment and constant mortality. Both methods also assume that ageing error is negligible and that fish older than some known age are equally vulnerable to sampling. Performance of the two methods will vary across data sets, but the Chapman–Robson estimator has been found in some cases to be more robust to violations of assumptions (Murphy, 1997; Dunn et al., 2002).

Methods

Regression estimator

Regression estimators use linear regression to fit the log-transformed numbers or proportions-at-age, under the common assumption of exponential population decay. Thus, the estimated slope from this regression gives an estimate of Z. The regression can be performed by either tracking a cohort through time or to a single year of data (i.e., a synthetic cohort). In this report, regression estimators rely mostly on synthetic cohorts, constructed from proportions of catch at age (although results are identical if based on absolute numbers rather than proportions). Regression estimators were also applied to several true cohorts; however data on cohorts were generally incomplete.

One issue that arises with limited sampling data is the presence of zeros. Because the regression analysis involves log-transformed data, zeros must either be removed prior to fitting the linear model or treated with a small, additive constant. Both approaches were examined in this study. In cases where a constant was added to zero data, the constant was assumed to be $\delta = 0.001$.

Chapman–Robson estimator

The Chapman–Robson estimator is based on mean age ($\bar{a}$) above the recruitment age and the sample size (n),

$$Z = \log\left([1 + \bar{a} - 1/n]/\bar{a}\right)$$

This estimator is considered a minimum variance unbiased estimator (Chapman and Robson, 1960), with variance approximated by,

$$var(Z) \approx \frac{\left(1-e^{-Z}\right)^2}{ne^{-Z}}$$

Additional details

Both estimators were applied to landings at age data from the for-hire (i.e., headboats and charterboats), commercial handline, and commercial diving fleets (although few years were available for diving). The private recreational fleet was not included because data were limited, both in terms of sample size and number of ages represented. Synthetic cohorts were included if they met a minimum sample size criterion of 50 fish and had at least two ages represented (this latter criterion excluded only one synthetic cohort, namely 2001 from the for-hire fleet). Sample sizes are reported in Table 1.

Both estimators require specifying the age at which all fish are vulnerable to capture. Although this age is typically unknown *a priori*, examination of the data can indicate an appropriate starting age for the analyses, typically the modal age or the modal age plus one. After visual inspection of age compositions, age four was chosen as the starting age, and age 12 as the terminal age (generally, less than 1% of sampled fish were ages 13+). As these analyses rely only on landings data, vulnerable but discarded fish were not included here. Thus for each data set, four different analyses were applied using synthetic cohorts: regression estimator with zeros replaced by $\delta = 0.001$, Chapman−Robson estimator with zeros replaced by $\delta = 0.001$, regression estimator on original data (observed zeros removed to avoid undefined logarithms), and Chapman−Robson estimator on original data (zeros unaltered). In addition, regression estimators were applied to limited data on true cohorts from the for-hire and commercial handline fleets (cohorts defined in Table 2). Analyses were performed using the R statistical software package (R Development Core Team, 2010).

Results and discussion

Point estimates of total mortality rates suggest that Z generally ranges between 0.4 and 1.0, but with wide confidence intervals and with some point estimates well above or below that range (Figures 1−3, residuals from regression estimators in the Appendix). Assuming a constant natural mortality of $M \approx 0.08$, which corresponds to the point estimate recommended by the Data Workshop's Life History Working Group, fully selected fishing mortality rates could be expected on the range of [0.32, 0.92]. As this approximation is only a rough guideline, annual values outside that range should not be surprising.

Estimates of Z from the for-hire and commercial handline fleets were plotted side by side (Figures 4−6), in part to examine potential differences in vulnerability. That is, higher estimates from one fleet could indicate that vulnerability to that fleet drops off more quickly with age than it does with the other fleet. Results on this topic were equivocal. On one hand, there does appear to be more fish older than the modal age in the commercial data, particularly between ages 5 and 9. On the other hand, in years when data overlapped (1996, 2003, 2004, 2007, 2009), the estimates of Z from the two fleets were in most cases indistinguishable. The exception was near the end of the time series, when estimates of Z from the for-hire fleet appeared higher, although not always statistically different. These estimates are likely affected by a large cohort or multiple cohorts believed to be entering the fishery in the last several years, which violates assumptions of the analyses and may bias estimates from the two fleets to different degrees.

Acknowledgments

Mike Murphy provided helpful comments.

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Table 1. Sample sizes of age composition data.

Headboat&Charterboat

Year	N (fish)	N (trips)
1977	72	22
1978	279	83
1979	47	32
1980	94	36
1981	415	145
1982	134	56
1983	754	173
1984	619	178
1985	511	161
1986	192	100
1987	93	64
1988	23	20
1989	57	32
1990	37	23
1991	28	20
1992	13	10
1993	20	14
1994	25	11
1995	19	11
1996	124	58
1997	13	12
1998	7	6
2000	4	3
2001	75	27
2002	421	105
2003	486	108
2004	378	98
2005	461	130
2006	355	123
2007	112	51
2008	160	52
2009	1909	359

Private Recreational

Year	N (fish)	N (trips)
2002	10	2
2003	2	2
2004	4	2
2007	2	1
2009	78	11

Commercial handline

Year	N (fish)	N (trips)
1992	33	18
1995	28	13
1996	171	58
1997	191	144
1998	75	37
1999	164	156
2000	294	257
2001	151	28
2002	38	10
2003	51	10
2004	103	30
2007	292	138
2009	2624	294

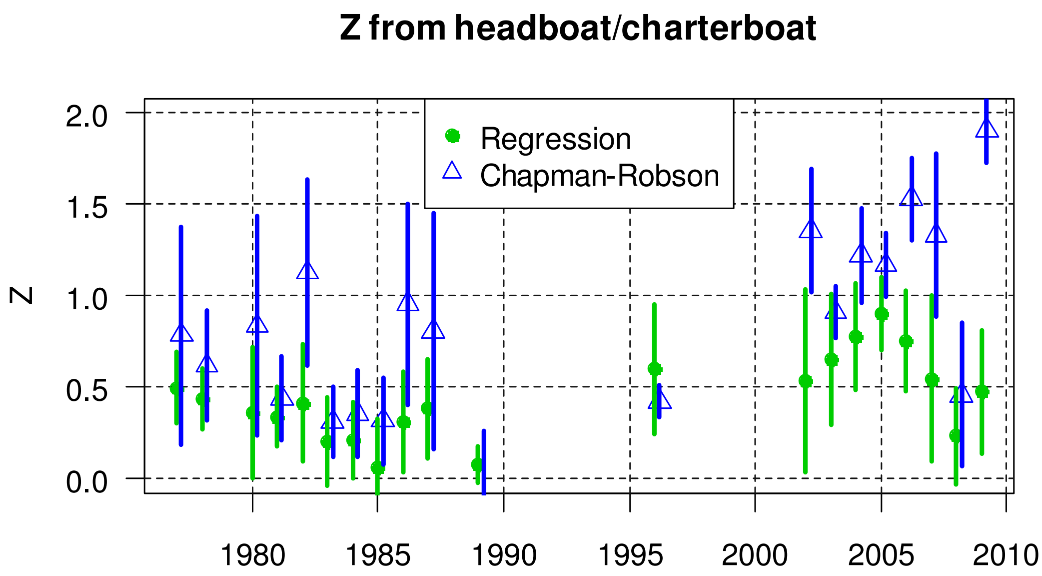
Commercial diving

Year	N (fish)	N (trips)
2000	124	124
2001	30	30
2009	58	17

Table 2. Definition of cohorts and data used for regression estimators applied to true cohorts. Note that commercial handline data were sparse in 2002 and 2003, and were not available for 2005, 2006, and 2008 (see Table 1).

Fleet	Cohort (age 0)	Years of data	Regression ages
Headboat&Charterboat	1998	2001-2009	3-11
	1999	2002-2009	3-10
	2000	2003-2009	3-9
	2001	2004-2009	3-8
Commercial handline	1993	1997-2004	4-11
	1994	1998-2005	4-11
	1995	1999-2006	4-11
	1996	2000-2007	4-11
	1997	2001-2008	4-11
	1998	2002-2009	4-10
	1999	2003-2009	4-9

Figure 1. Red snapper: Total mortality estimates (Z) from catch curve data from the for-hire fleet. Analyses were conducted by year (i.e. using synthetic cohorts). Vertical lines represent 95% confidence intervals. Top panel: observed zeros replaced by $\delta = 0.001$. Bottom panel: observed zeros removed for the regression estimator, unmodified for the Chapman-Robson estimator.



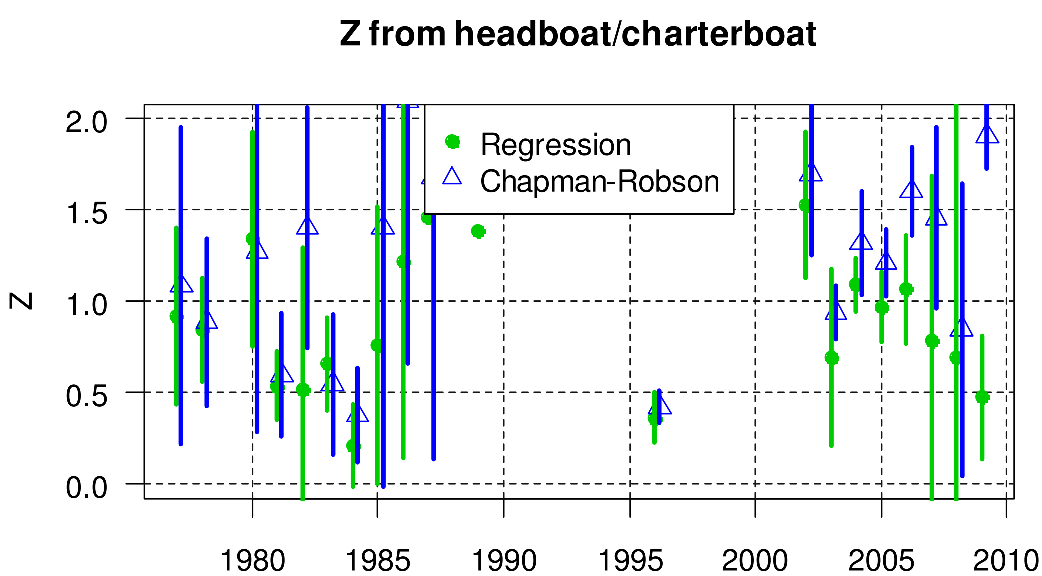
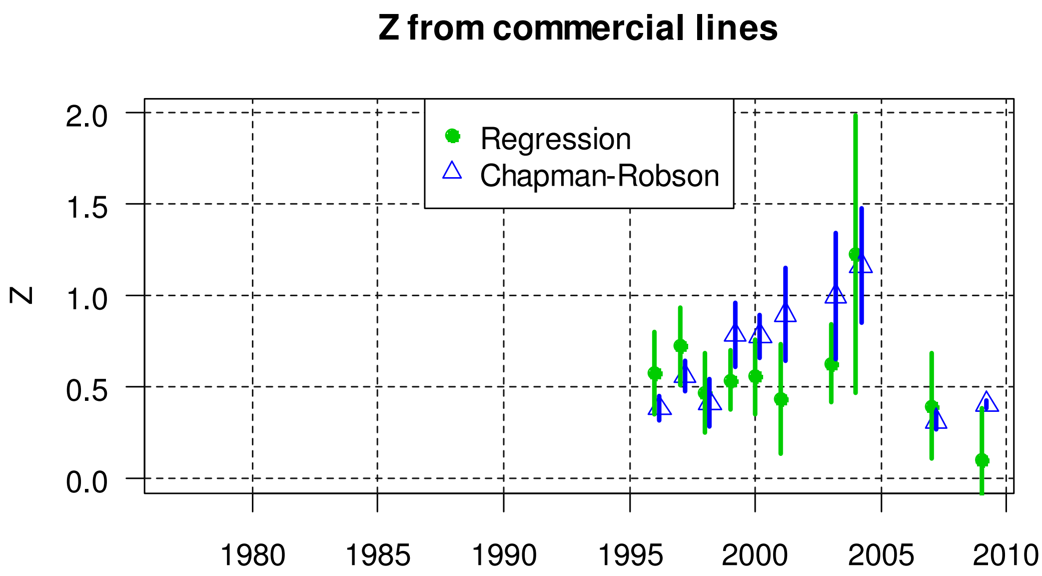


Figure 2. Red snapper: Total mortality estimates (Z) from catch curve data from the commercial handline fleet. Analyses were conducted by year (i.e. using synthetic cohorts). Vertical lines represent 95% confidence intervals. Top panel: observed zeros replaced by $\delta = 0.001$. Bottom panel: observed zeros removed for the regression estimator, unmodified for the Chapman-Robson estimator.



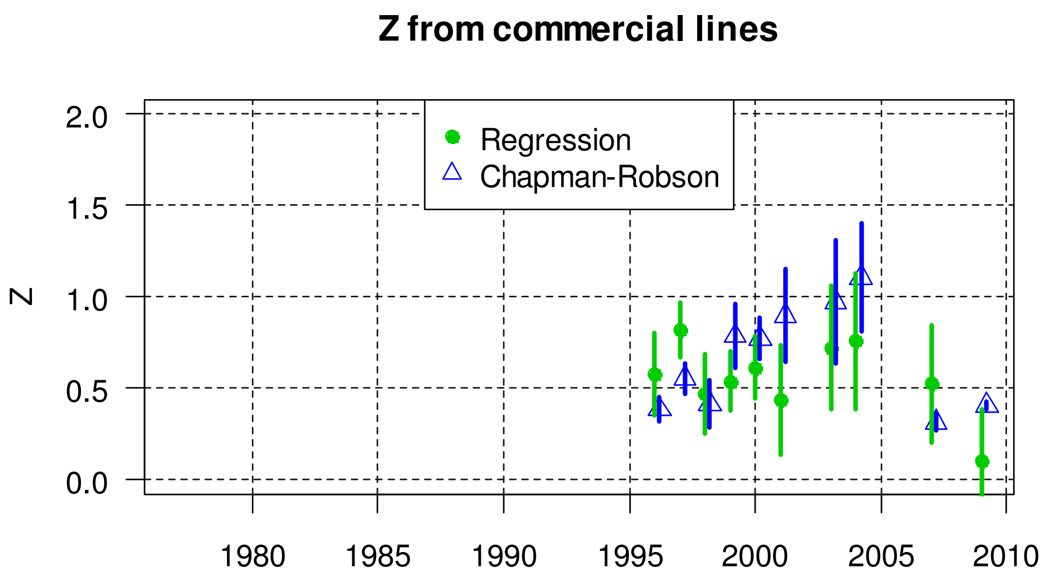
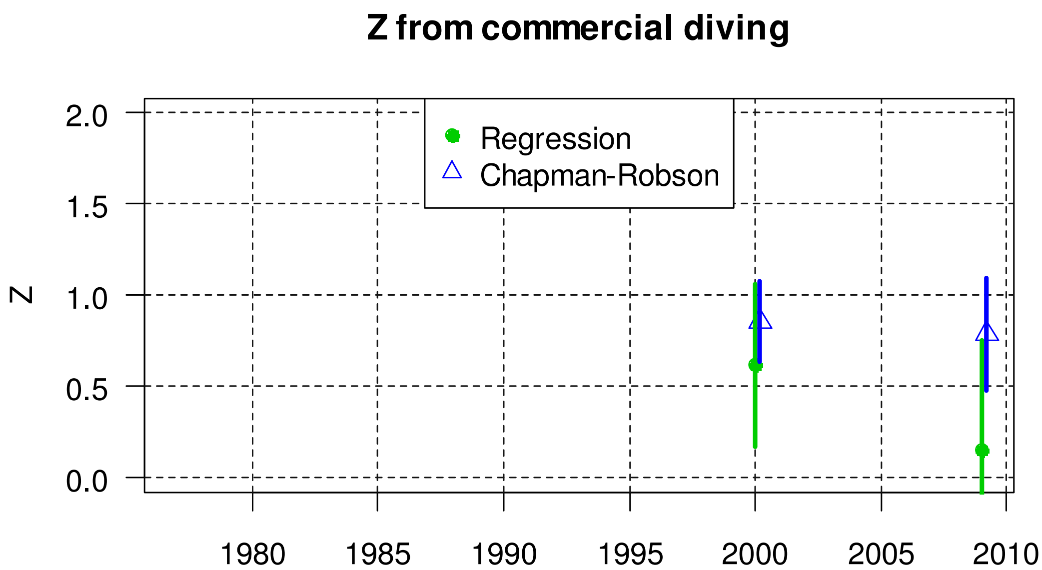


Figure 3. Red snapper: Total mortality estimates (Z) from catch curve data from the commercial diving fleet. Analyses were conducted by year (i.e. using synthetic cohorts). Vertical lines represent 95% confidence intervals. Top panel: observed zeros replaced by $\delta = 0.001$. Bottom panel: observed zeros removed for the regression estimator, unmodified for the Chapman-Robson estimator.



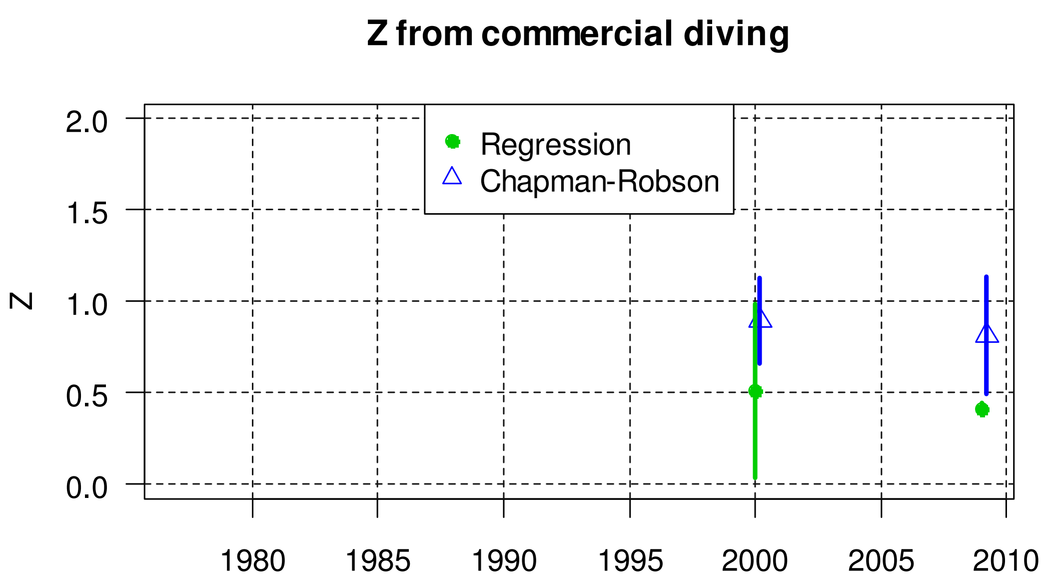


Figure 4. Red snapper: Total mortality estimates (Z) using the regression estimators applied to catch curve data from the for-hire (circles) and commercial handline (triangles) fleets. Analyses were conducted by year (i.e. using synthetic cohorts). Vertical lines represent 95% confidence intervals. Top panel: observed zeros replaced by $\delta = 0.001$. Bottom panel: observed zeros removed.

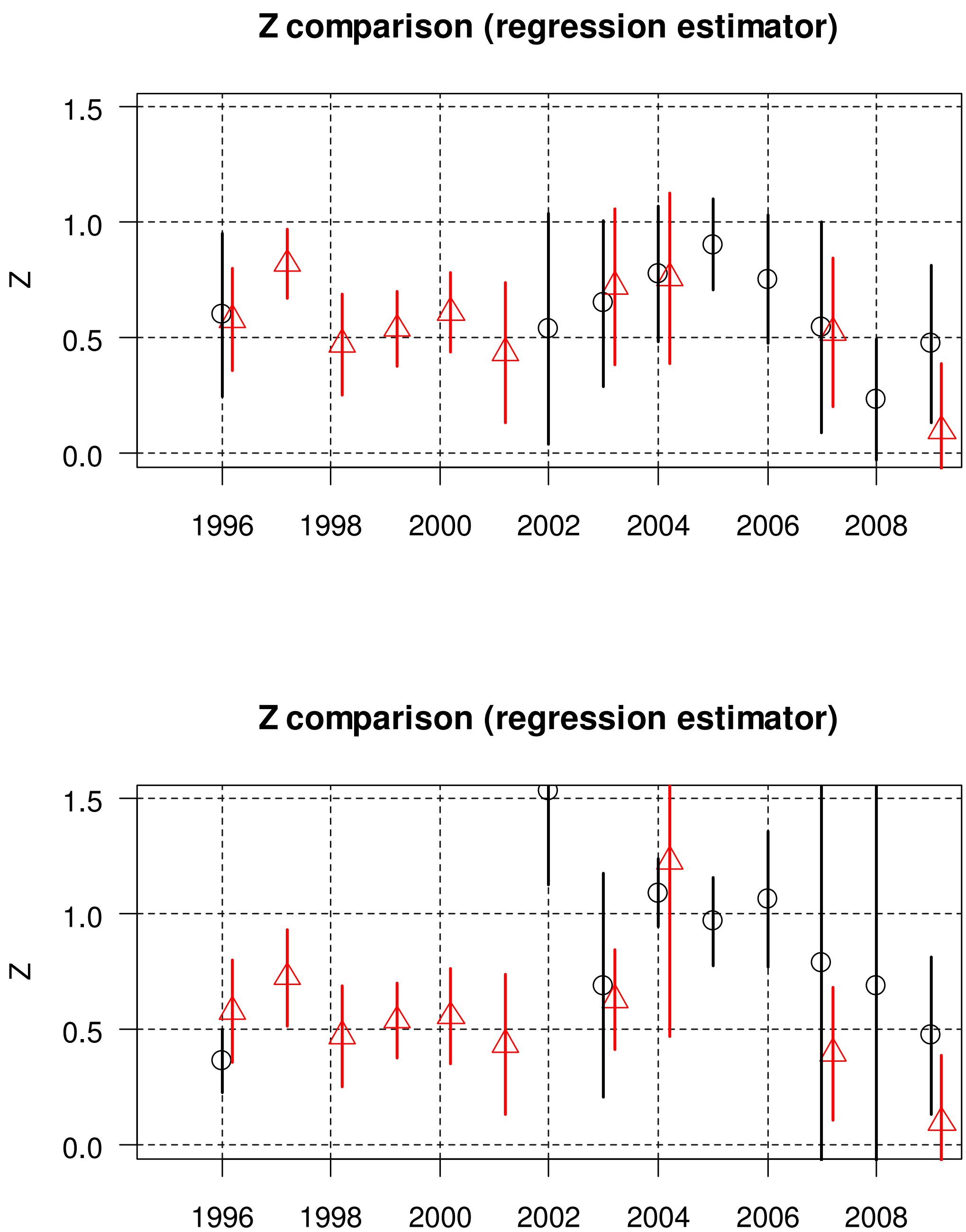
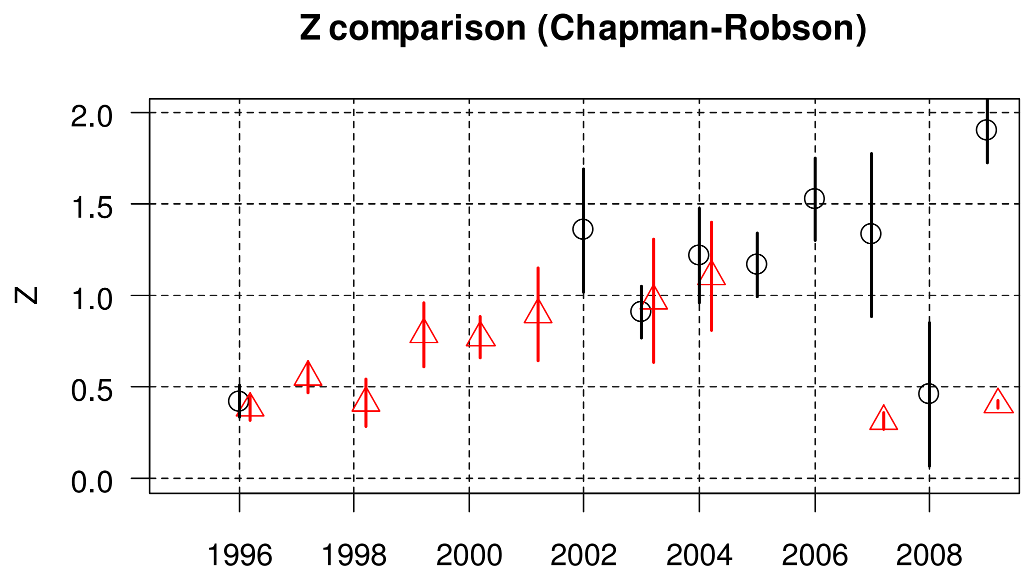


Figure 5. Red snapper: Total mortality estimates (Z) using the Chapman-Robson estimator applied to catch curve data from the for-hire (circles) and commercial handline (triangles) fleets. Analyses were conducted by year (i.e. using synthetic cohorts). Vertical lines represent 95% confidence intervals. Top panel: observed zeros replaced by $\delta = 0.001$. Bottom panel: observed zeros unmodified.



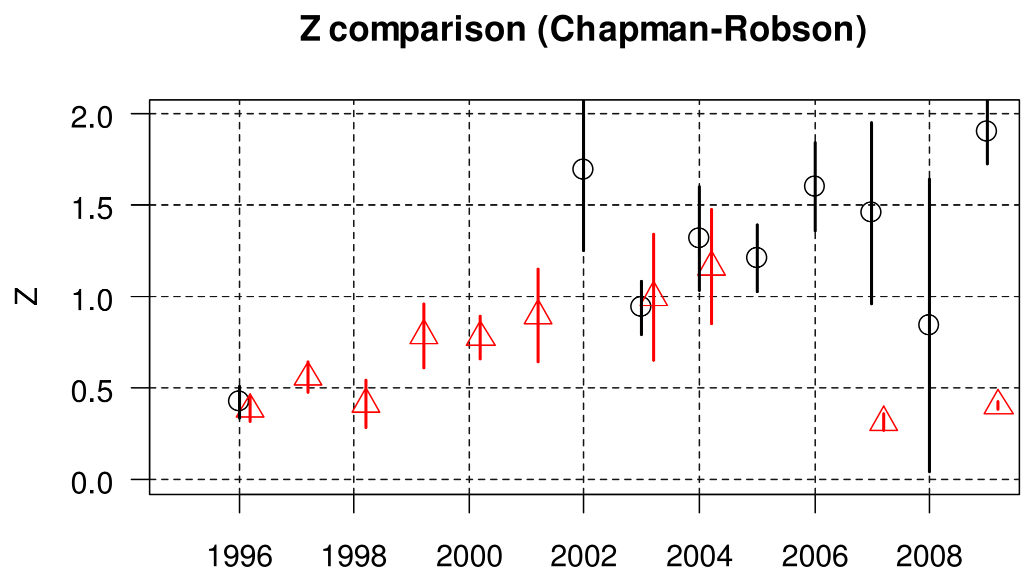
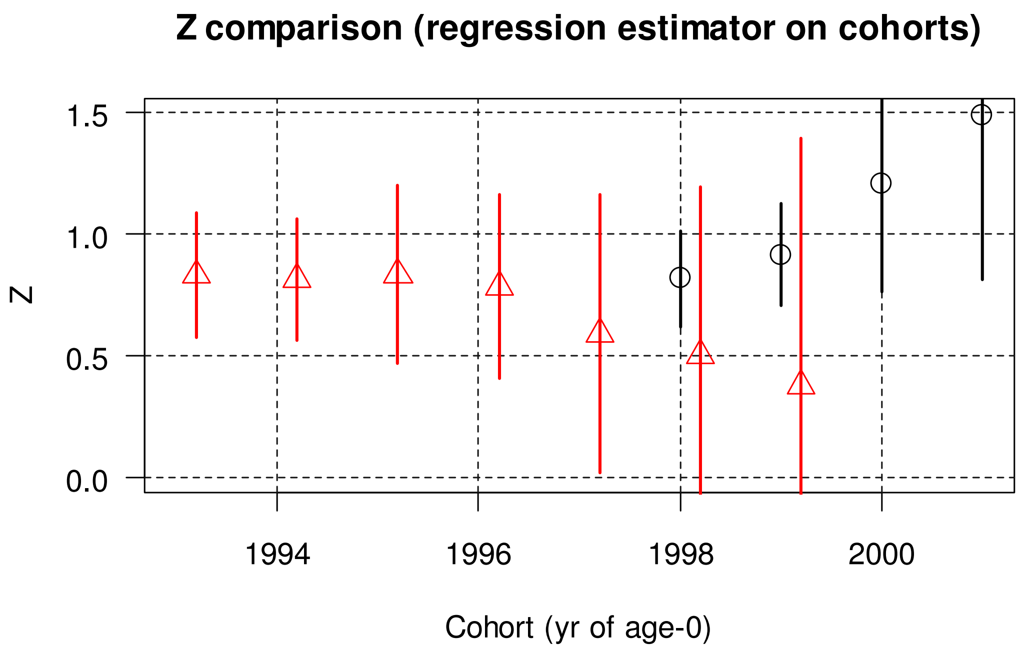
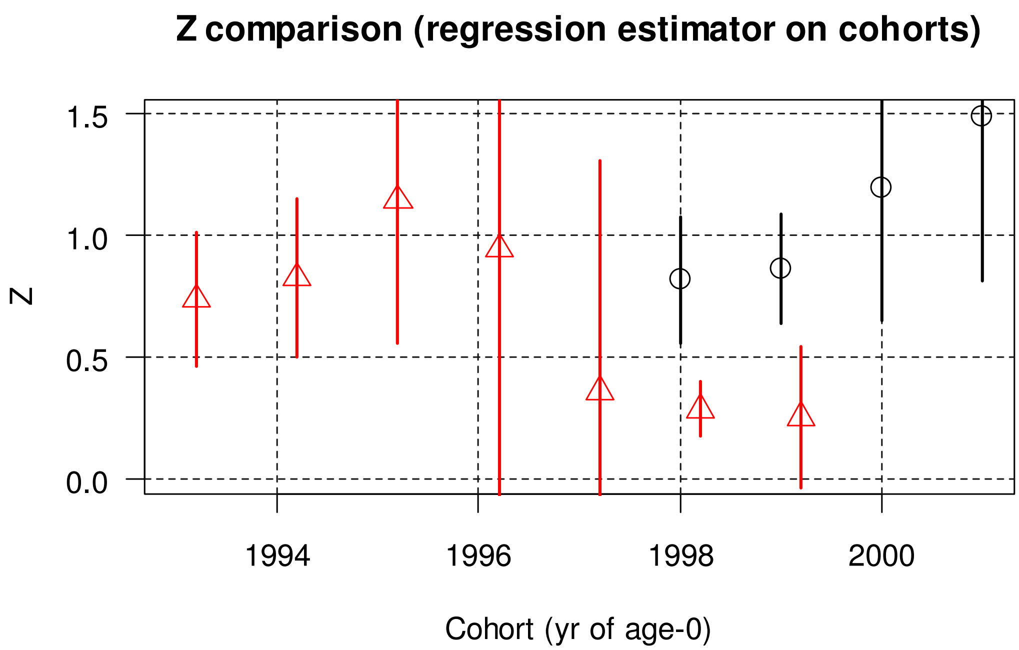
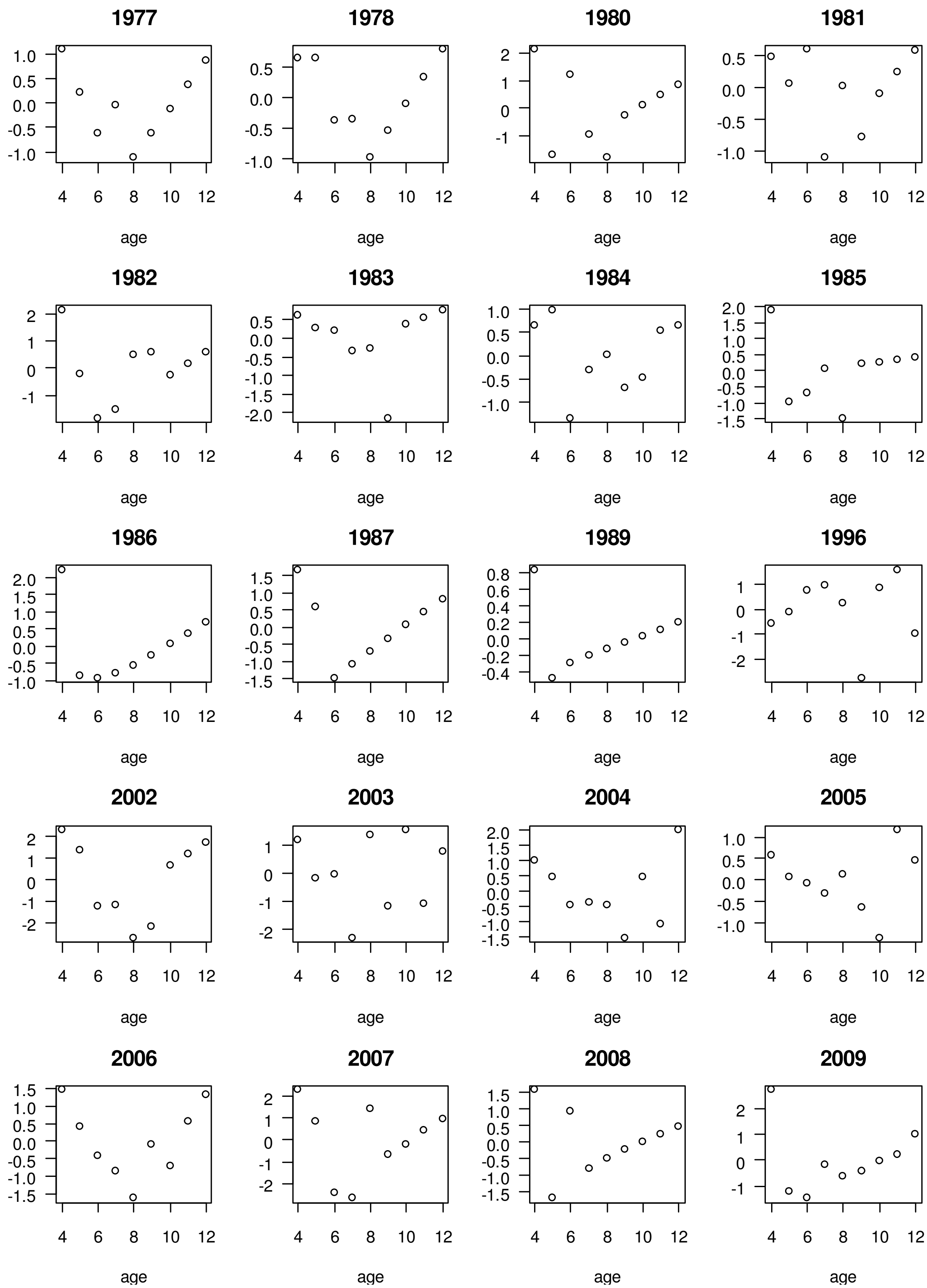


Figure 6. Red snapper: Total mortality estimates (Z) using the regression estimators applied to catch curve data from the for-hire (circles) and commercial handline (triangles) fleets. Analyses were applied to true cohorts. Vertical lines represent 95% confidence intervals. Top panel: observed zeros replaced by $\delta = 0.001$. Bottom panel: observed zeros removed. Cohorts and data used in these analyses are defined in Table 2.

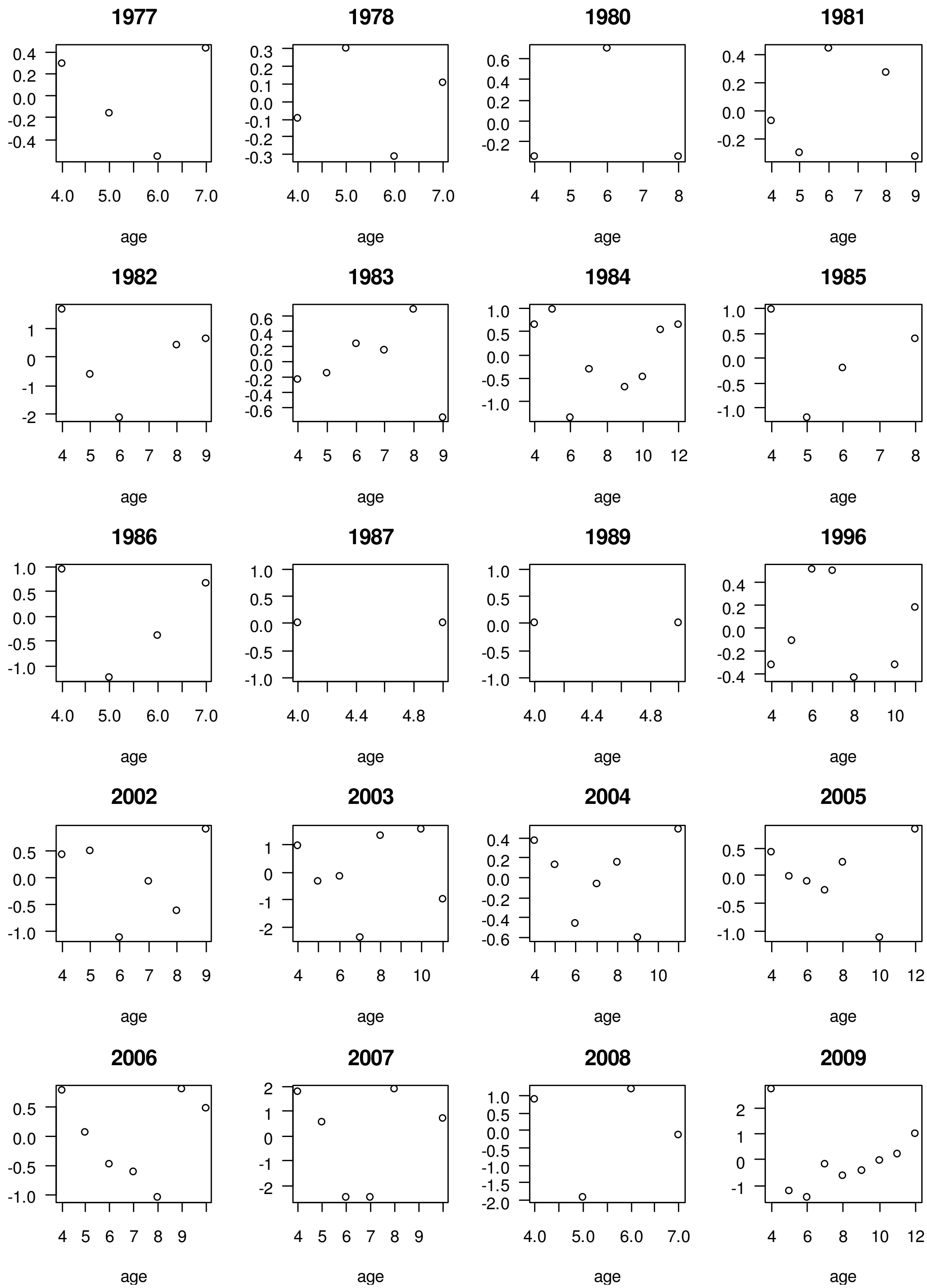




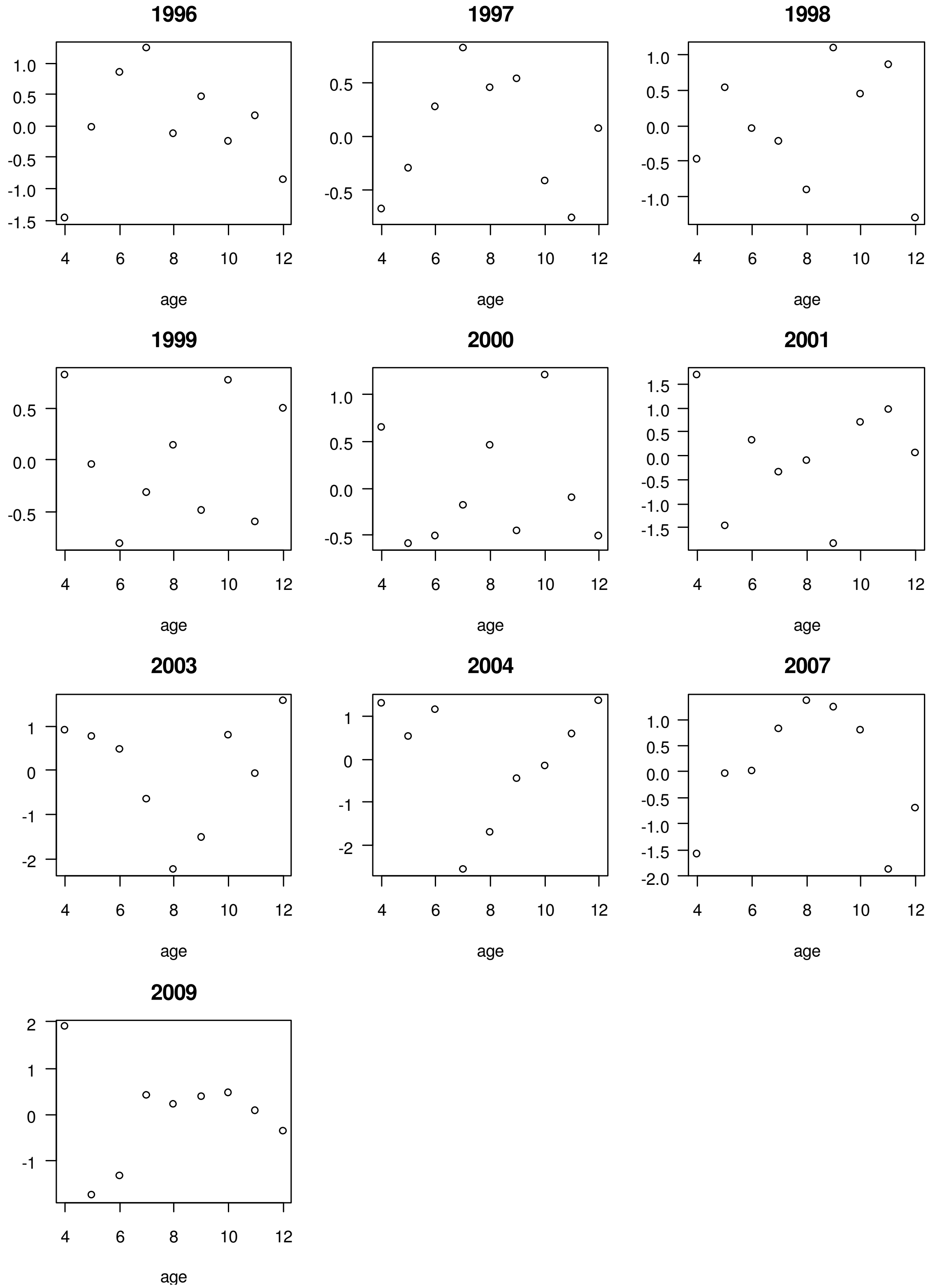
Appendix Figure 1A. Residuals from the regression estimator applied to the for-hire fleet. Analyses were conducted by year (i.e. using synthetic cohorts), with observed zeros replaced by $\delta = 0.001$.



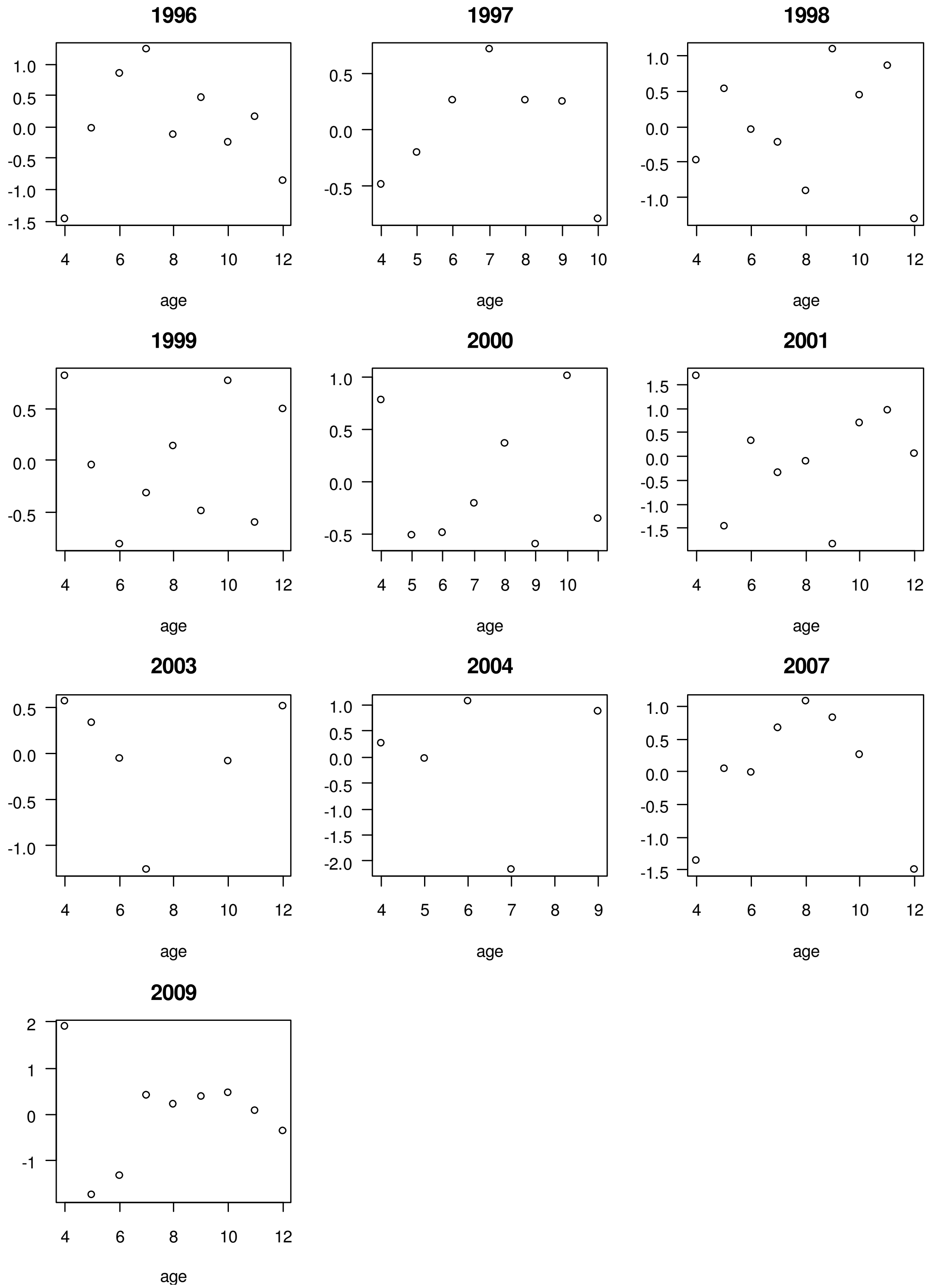
Appendix Figure 1B. Residuals from the regression estimator applied to the for-hire fleet. Analyses were conducted by year (i.e. using synthetic cohorts), with observed zeros removed.



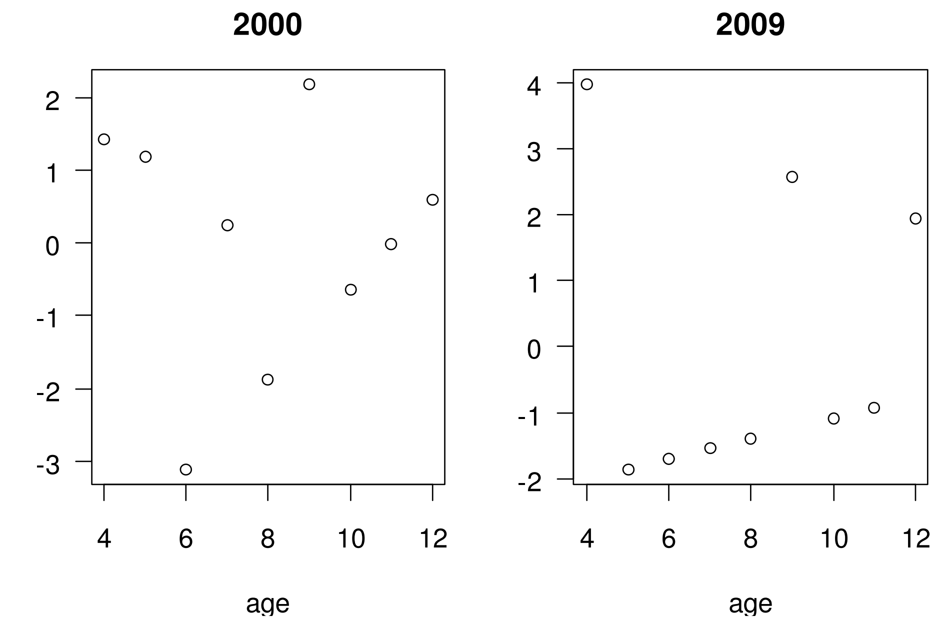
Appendix Figure 2A. Residuals from the regression estimator applied to the commercial handline fleet. Analyses were conducted by year (i.e. using synthetic cohorts), with observed zeros replaced by $\delta = 0.001$.



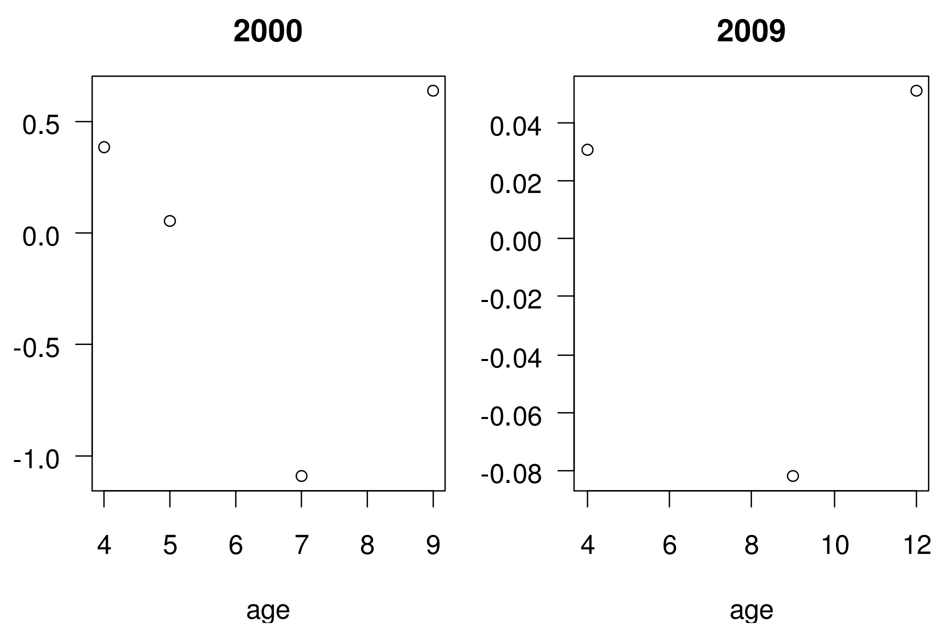
Appendix Figure 2B. Residuals from the regression estimator applied to the commercial handline fleet. Analyses were conducted by year (i.e. using synthetic cohorts), with observed zeros removed.



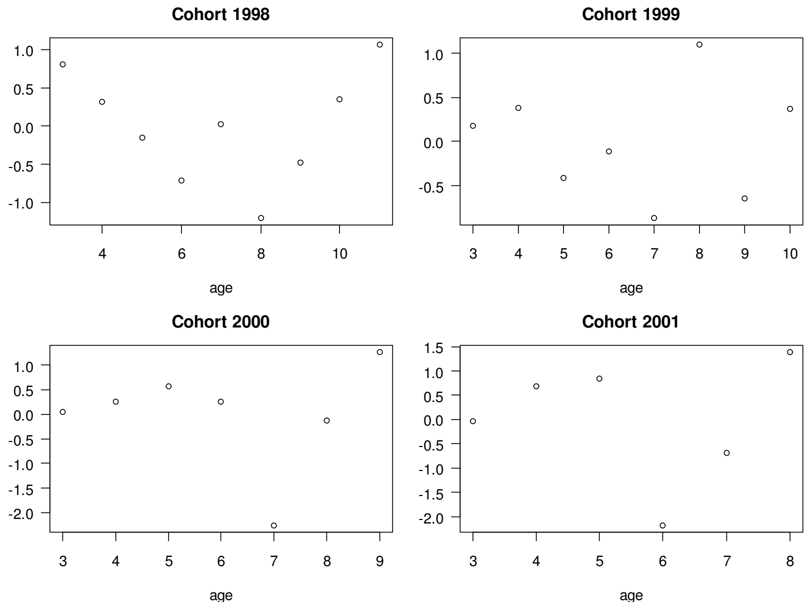
Appendix Figure 3A. Residuals from the regression estimator applied to the commercial diving fleet. Analyses were conducted by year (i.e. using synthetic cohorts), with observed zeros replaced by $\delta = 0.001$.



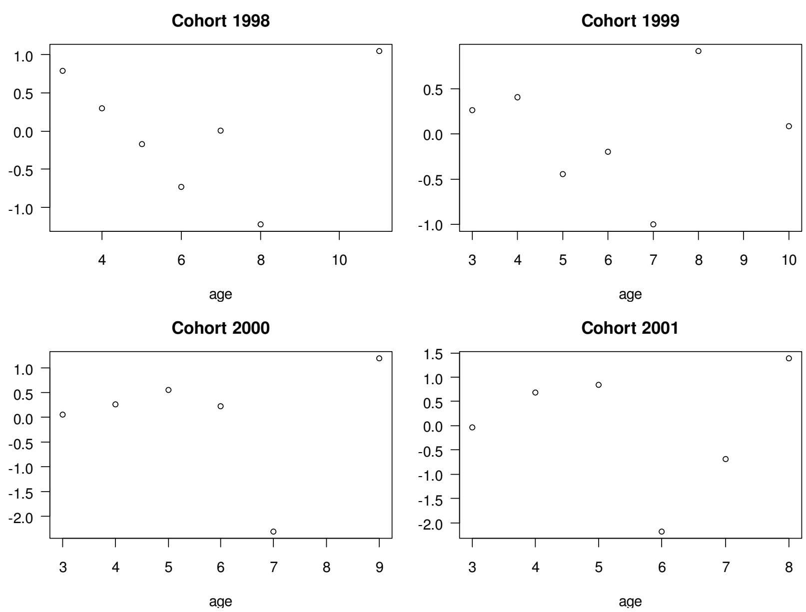
Appendix Figure 3B. Residuals from the regression estimator applied to the commercial diving fleet. Analyses were conducted by year (i.e. using synthetic cohorts), with observed zeros removed.



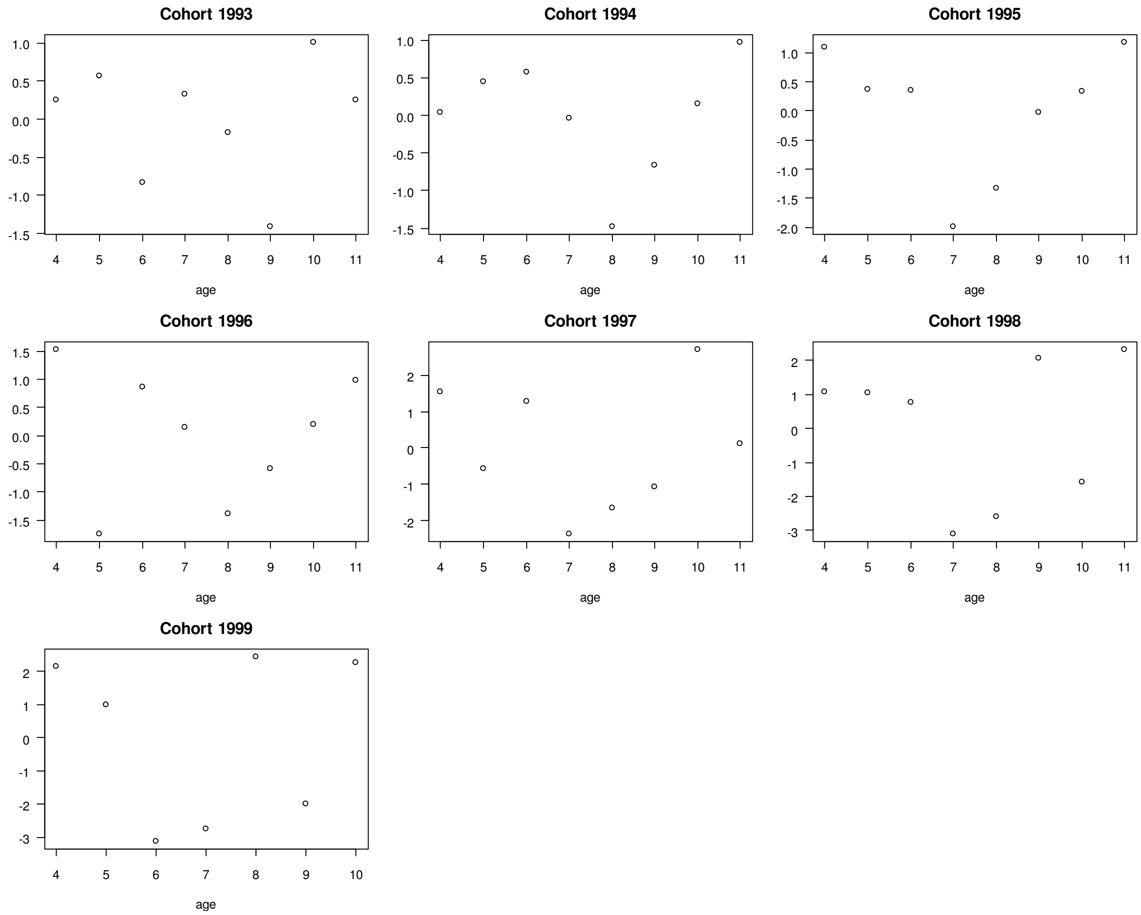
Appendix Figure 4A. Residuals from the regression estimator applied to the for-hire fleet. Analyses were conducted on true cohorts (year of age-0 indicated), with observed zeros replaced by $\delta = 0.001$.



Appendix Figure 4B. Residuals from the regression estimator applied to the for-hire fleet. Analyses were conducted on true cohorts (year of age-0 indicated), with observed zeros removed.



Appendix Figure 5A. Residuals from the regression estimator applied to the commercial handline fleet. Analyses were conducted on true cohorts (year of age-0 indicated), with observed zeros replaced by $\delta = 0.001$.



Appendix Figure 5B. Residuals from the regression estimator applied to the commercial handline fleet. Analyses were conducted on true cohorts (year of age-0 indicated), with observed zeros removed.