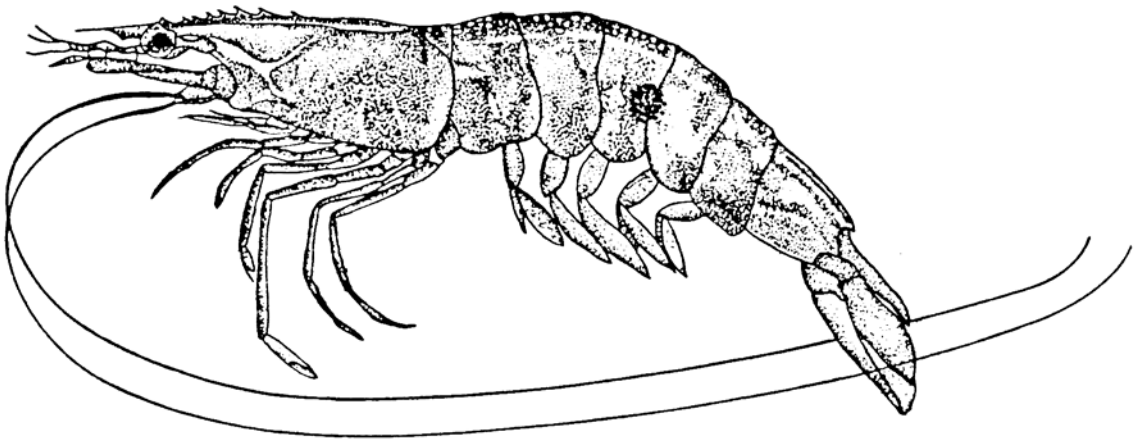
Stock Assessment of Pink Shrimp (*Farfantepenaeus duorarum*) in the U.S. Gulf of Mexico for 2011



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1. ABSTRACT

This assessment examined the pink shrimp (*Farfantepenaeus duorarum*) population behavior when parameterized with over 25 years of commercial pink shrimp data from 1984 - 2011. In the model runs, CPUE estimates, size selectivity, spawning biomass, and numbers of recruits were generated. In addition, the incorporation of direct fishery independent surveys of shrimp abundance into the model greatly improves the precision (i.e., tuning) of this and future assessments.

The new Stock Synthesis based shrimp stock assessment model generates spawning stock biomass outputs in terms of pounds of spawning biomass, the number of recruits, and fishing mortality (F) values. Spawning biomass and recruitment for the 2011 biological year fishing season were 23,929 metric tons and 1.6 billion individuals respectively. Note that the 2011 biological year only includes 6 months of data, so the biological year 2010 should be considered as well. Spawning biomass and recruitment for the 2010 season were 46,250 metric tons and 5.1 billion individuals respectively. Fishing mortality has been decreasing in recent years, with biological year, monthly weighted apical F of 0.02 being estimated for the 2011 fishing season.

2. INTRODUCTION

This report describes the stock assessment pink shrimp (*Farfantepenaeus duorarum* developed as a product of several Gulf of Mexico Fisheries Management Council, SSC Meetings convened in 2011 and 2012, and an SSC Shrimp Assessment workshop held in 2012. This assessment model was chosen as the best available science to model the population dynamics of Northern Gulf of Mexico pink shrimp. The modeling methodology uses a generalized stock assessment model, Stock Synthesis (SS-3), developed by Richard Methot (Methot 2009), and is parameterized with fishery data from 1984-2011.

3. METHODS

3.1. Model Overview

A Stock Synthesis (SS-3) model (Methot 2009, Schirripa et al, 2009) was parameterized, with time varying selectivity with a block approach, and a random walk of the Q parameter during select time periods of the fishery's history. This model data and settings are noted in subsequent sections noted below.

3.2. Data Sources

This model was parameterized in biological years, with the models starting in July 1984 and continuing through December 2011. Two years of dummy landings data were entered before July 1984 for a model burn-in period. This burn in period allowed for recruitment deviations or cycles to begin before the actual starting year data were called

into the model.

The model structure included 1 fleet:

1) Commercial Shrimp Inshore and Offshore Catch Combined (1984-2011; statistical zones 1-11)

and 2 indices of abundance:

1) SEAMAP Summer Groundfish Trawls (Fisheries-independent; 1987-2011)
2) SEAMAP Fall Groundfish Trawls (Fisheries-independent; 1987- 2011)

3.2.1. Commercial Catch Statistics – The Stock Synthesis assessment model was parameterized with pink shrimp commercial catch data including; directed fishing effort by year and month, i.e., effort for those trips where >90 percent of the catch were pink shrimp, used to calculate monthly CPUE; total catch; and catch by size, i.e., size composition data consisting of count of numbers of shrimp per pound; for statistical zones 1-11 from January 1984 through December 2011.

To calculate catch and CPUE statistics the methods outlined in Nance et al. (2008) were used. Beginning with pilot studies in 1999, an electronic logbook program (ELB) was initiated to augment shrimp fishing effort measurements. Gallaway *et al*. (2003a, 2003b) provides an in depth description of this ELB data collection program and data collection procedures. These ELB data are used to supplement the effort and location data collected by NMFS port agents and state trip tickets.

Total catch in pounds of shrimp tails by month was a primary input. Eleven count categories from 1984 to 2011 were used. Prior to 1984, shrimp catch was recorded in the 8 standard count categories. Beginning in 1984 shrimp catch data for the smallest sized shrimp, >67 count, were recorded at a finer scale, thus allowing us to partition this one small-sized category into four additional count categories, therefore having finer resolution for these smaller sized shrimp. This resulted in a total of 11 count categories for the data collected from 1984 to present; <15, 15-20, 21-25, 26-30, 31-40, 41-50, 51-67, 68-80, 81-100,101-115, and >115 (Hart and Nance 2010). These data are entered into the model as monthly catch in pounds in each of the eleven size bins for the years 1984-2011.

3.2.2. Growth curve and other population level rates – In exploratory runs growth parameters k and linf derived and reported by Phares (1981), with variability around the growth curve set to a coefficient of variation (CV) equal to 0.07, which was the CV of the size distribution of the larger sized shrimp presented in Berry (1967). Data inputs included a growth curve for each gender; natural mortality rate (0.3 per month as previously used in the historical VPA); and conversion factors to go from total length to the poundage breaks between the catch count categories. These data were entered as parameters in the models. Stock Synthesis estimated steepness in the spawner-recruit function and linf., with a starting size of 10 mm at age 1 month

through age 20 months.

3.2.3. Size Selectivity - A dome shaped (double normal) selectivity pattern with 4 estimated parameters was used, providing a good fit to the data. In addition, since SS-3 is an annual model; individual months were modeled as years (336 "years"). Selectivity was modeled to fluctuate in 12 "1-year" blocks beginning in July. This approach is equivalent to an annual model with July through June biological year fluctuations.

3.2.4. Catchability Q – Catchability was set as a random walk in the model, with Q allowed to randomly vary during January 2005 through October 2008. These select years correspond to those years when a large increase in CPUE is evident in the time series.

3.2.5. SEAMAP Data – SEAMAP data collected by NOAA Fisheries research vessels and State Fisheries agencies were used in the Stock Synthesis model. These SEAMAP sampling data were collected primarily from statistical zones 7-11. SEAMAP shrimp abundance indices using the delta log normal index from 2008-2011 and nominal CPUE data from 1987-2011 were model inputs. Size compositions for pink shrimp collected and measured in 1987-2011 during summer and fall cruises were also data inputs.

During the February 2012 workshop some members expressed concern that the SEAMAP data were collected from areas outside of the main pink shrimp fishing grounds (Figure 3.2.1). Their concerns were that these data have undo weight in the model estimates. To address this concern, I lowered the weight or degree of influence held by the survey data in these model runs by setting the SEAMAP lamda value to 0.1.

3.3. Model Configuration and Population Dynamics

3.3.1. Selectivity, Fishing Mortality, and Natural Mortality

For the commercial fishing fleet selectivity we used a double normal setup with selectivity modeled to fluctuate in 12 "1-year" blocks beginning in July. We used a constant natural mortality (M) setup (M=0.30) for the model. For a more detailed technical description of fishery selectivity, natural mortality M, and fishing mortality F settings used in Stock Synthesis, consult Appendix 1.

3.3.2. Time-Varying Parameters

The Stock Synthesis modeling framework allows time varying fleet-specific selectivity and catchability parameters. A blocking technique was employed to allow time varying selectivity in blocks of 12 months so changes in selectivity can occur each year (or block). As noted previously, Q was also allowed to vary through a random walk technique in the model. Similarly, R_0 (unfished recruitment) was allowed to be estimated while recruitment was modeled with monthly deviations.

3.3.3. Parameter Estimation

Stock Synthesis requires the model to be initialized with approximations for certain parameters (e.g., $S_{g,a}$, $F_{g,1}$, $Q_{u,1}$, steepness) which are then estimated by the model in preset phases. These initial approximations scale the parameters to biologically reasonable values, and facilitate the evaluation of parameters estimated in subsequent phases (F deviations, recruitment deviations, selectivity deviations, etc.).

4. RESULTS

4.1. Parameter Estimates and Model Setups

Table 4.1.1 shows the model setup in terms of selectivity, Q settings, SEAMAP emphasis settings, and steepness estimate.

4.2. Fishery Catch Rates (CPUE)

The fit showing observed and expected catch rates show how Stock Synthesis models the changes in catch rates over time. Catch rates have shown an increasing trend over the last several years. Fluctuations both within and between years were revealed, with a close fit of expected to observed catch rates in all of the modeling scenarios. The model fits to the fishery CPUEs are illustrated in figure 4.2.1. The model allowed a random walk of Q beginning in January 2005 through October 2008. The increase in Q occurred during those years when CPUE was showing an increasing trend towards record high levels. This is due in part because the model is compensating for the high catch rates by increasing catchability. Allowing Q to increase this way accounted for some of the uncertainty in the signal in the increasing CPUE versus the model compensating by only increasing biomass. This increase in Q during this time period is also supported by the trend in CPUE measured in the fishery independent SEAMAP data.

4.3. Generalized Size Comps

The model was fit to the size composition of the catch in the model. Because the pink

shrimp stock is modeled with months as "years" each month for the 26 year time period has a fit to the size composition data. Figure 4.3.1 illustrates the fit of the size composition aggregated across years. Overall, fits to catch at size was also good with no obvious patterns in the residuals evident (Figure 4.3.2).

4.4. Fishery Selectivity

The Stock Synthesis model results indicate that fishery selectivity tends to decline as shrimp get larger. This selectivity pattern matches the observed low occurrence of shrimp in the smallest count category, i.e., the largest sized shrimp. Figure 4.4.1 illustrates the size selectivity using the blocking approach.

4.5. SEAMAP CPUE, Size Composition, and Selectivity

The use of these fishery independent data has provided added information on some of the trends we see in the shrimp fishery, thus allowing us to better tune the models recruitment parameters. The summer and fall SEAMAP cruises reveal an increase in CPUE similar to the commercial fishery (Figures 4.5.1). Figure 4.5.2 shows the fit to the size composition data for 1987-2011 for summer and fall survey data with size composition data fits aggregated across all years. Pearson's residuals for these fits are shown in figures 4.5.3 and 4.5.4. Size selectivity curves for the SEAMAP surveys are shown in figure 4.5.5.

4.6. Fishing Mortality

Stock Synthesis reports fishing mortality rates by age and month. These rates were discussed at length during the shrimp stock assessment workshop. While Stock Synthesis reports annual Fs by age the pink shrimp model is parameterized with monthly data which SS-3 treats as years. Consequently Stock Synthesis outputs F values by age and month, e.g., for 2011 the number of F values is 12 months x 19 ages = 228 F values.

To deal with this large number of F's per year, the consensus of the working group was to calculate the F rates in the following manner:

$$\text{Weighted Average Monthly F} = \frac{\sum[Numbers\ by\ Age\ Matrix\ by\ Month]\times[F\ by\ Age\ Matrix\ by\ Month]}{\sum Numbers\ at\ Age\ by\ Month} \qquad \text{(Eq.1)}$$

Equation 1 resulted in the calculation of one weighted, i.e., numbers of shrimp at age, F-value per month; the weighted average monthly F across all ages. Fishing mortality rates have been decreasing, with the apical weighted monthly F for biological year 2011 equaling 0.02 (Figure 4.6.1).

4.7. Spawning Biomass and Recruitment

Spawning biomass and recruitment for the 2011 biological year fishing season were 23,929 metric tons and 1.6 billion individuals respectively (Figures 4.7.1 and 4.7.2). Note the 2011 biological year only includes 6 months of data, therefore, biological year 2010 (July 2010-June 2011) should be considered as well. Steepness for the spawner-recruit curve was estimated at 0.81. Spawning biomass and recruitment for the 2010 season were 46,250 metric tons and 5.1 billion individuals respectively.

5. CONCLUSIONS

The Stock Synthesis model developed provides outputs for new overfished and overfishing definitions for the Gulf of Mexico pink shrimp fishery. The stock has been showing an increasing trend in spawning biomass and recruitment in recent years, and a decreasing trend in fishing mortality, F. No indications of overfishing or of the fishery being in an overfished condition are evident. These newly suggested overfishing and overfished limits are discussed in the overfishing companion report (Hart and Nance 2012).

6. REFERENCES

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Schirripa, M. J., C. P. Goodyear, and R. D. Methot. 2009. Testing different methods of incorporating climate data into the assessment of US West Coast sablefish. ICES Journal of Marine Science: Journal du Conseil 2009 66(7):1605-1613.

Table 4.1.1. 2012 pink shrimp Stock Synthesis stock assessment model configuration and parameter overview.

Model Number	Selectivity Setup	Q Setup	Seamap Settings	Control File Name
3	Blocks	Random Walk	De-Emphasis lamba 0.1	Pink_2011_9c.ctl

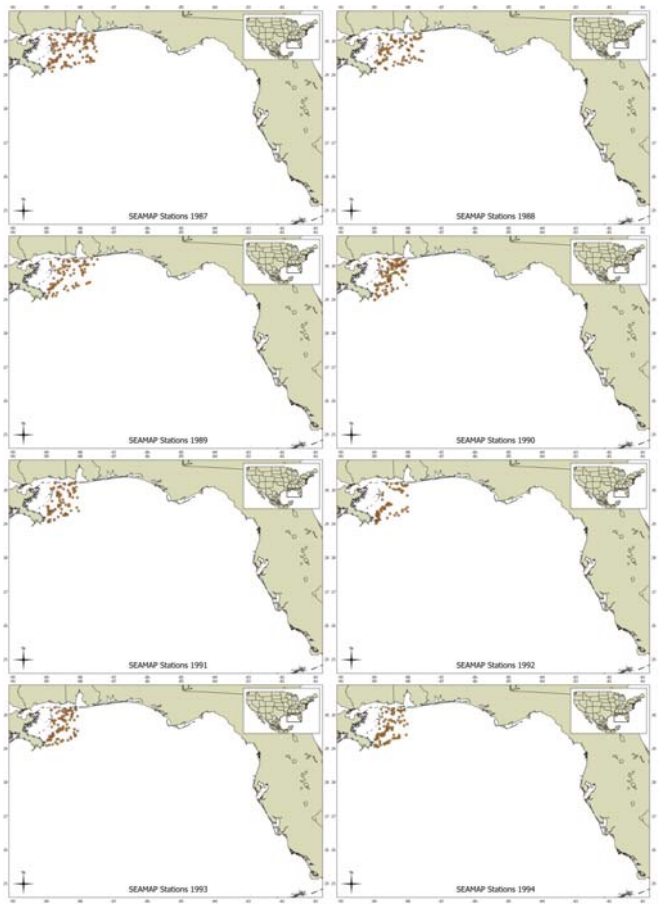

Figure 3.2.1 a. Pink shrimp SEAMAP sampling locations, 1987-1994.

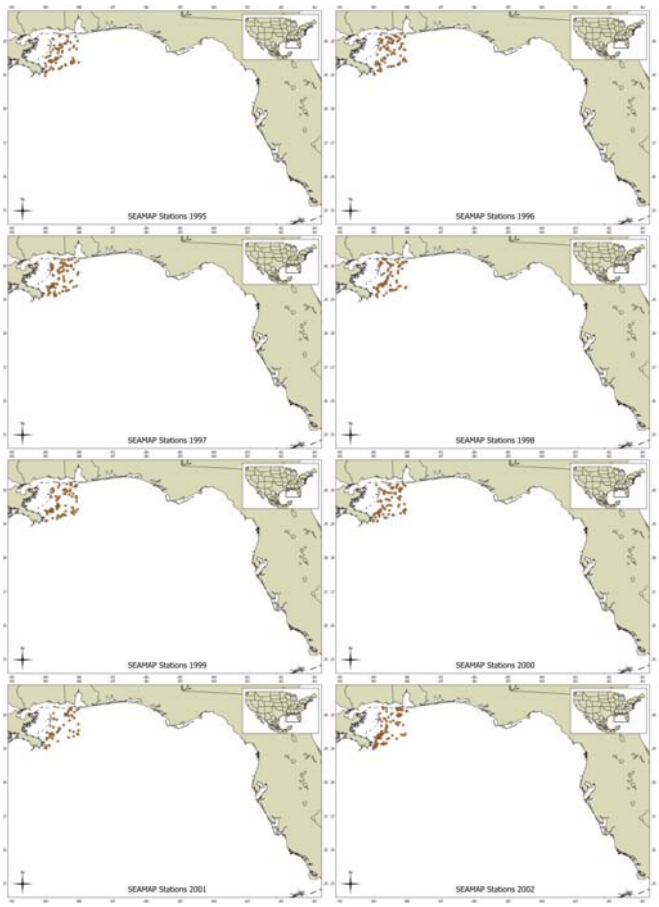

Figure 3.2.1 b. Pink shrimp SEAMAP sampling locations, 1995-2002.

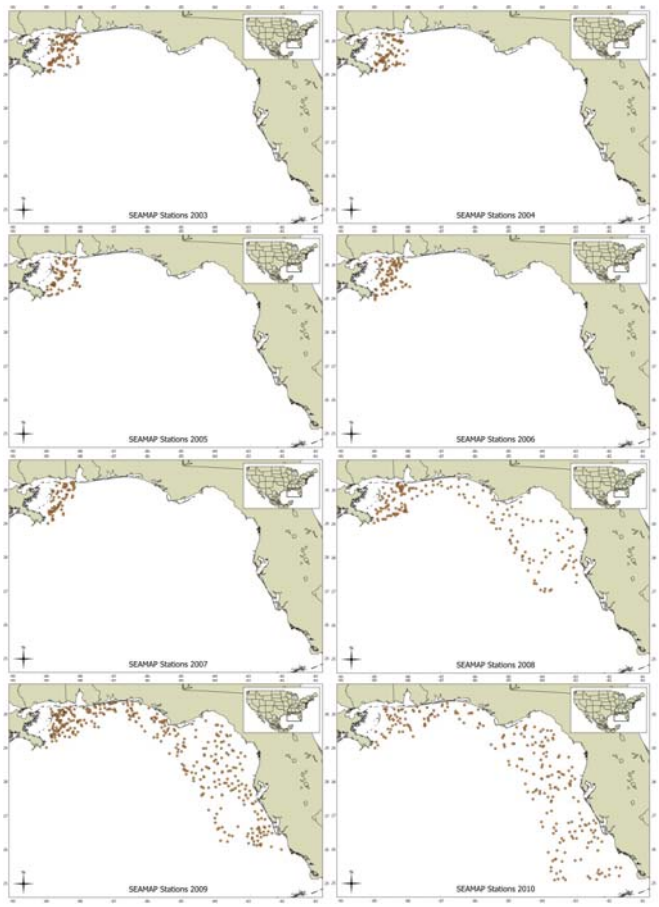

Figure 3.2.1 c. Pink shrimp SEAMAP sampling locations, 2003-2010.

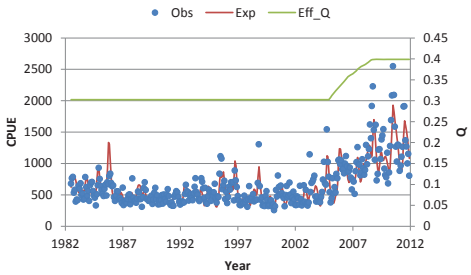

Figure 4.2.1. Pink shrimp CPUE and Q model fits.

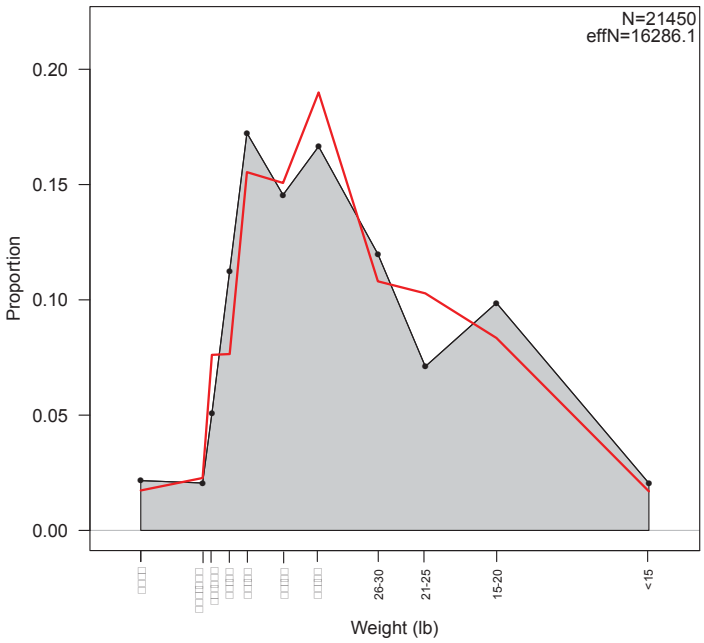

Figure 4.3.1. Size composition fits for the commercial pink shrimp fishery, 1984-2011.

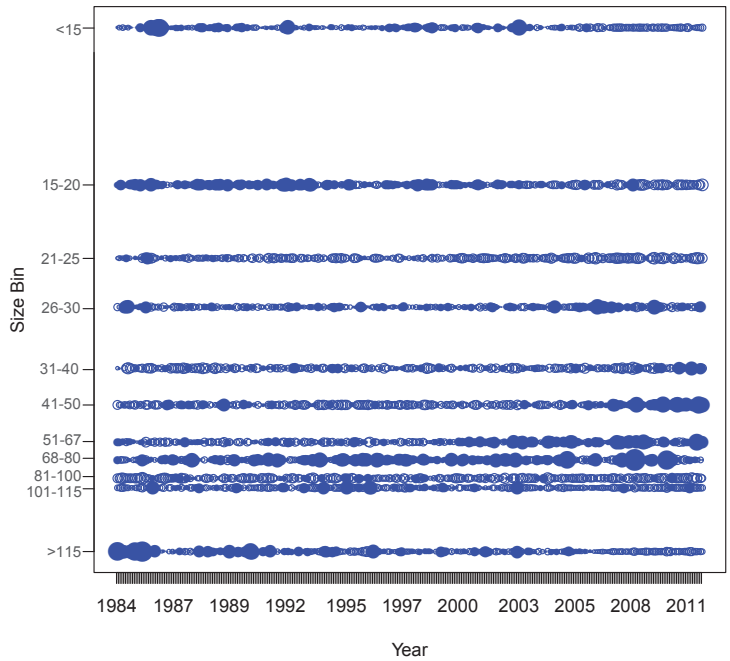

Figure 4.3.2. Residual fits for the commercial pink shrimp fishery, 1984-2011.

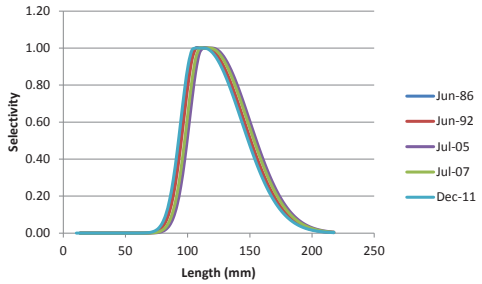

Figure 4.4.1. Pink shrimp commercial fleet size selectivity. Example years depicting the block setup.

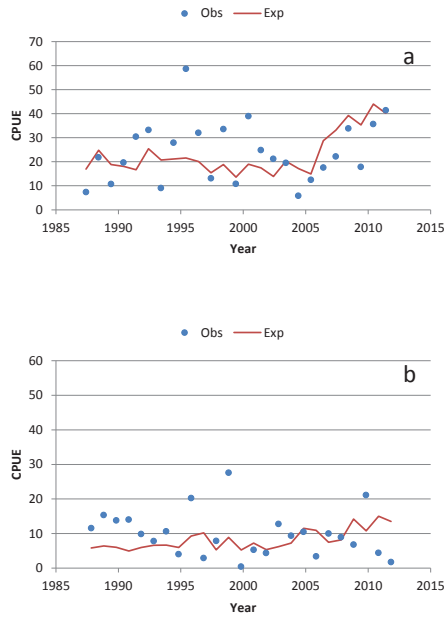

Figure 4.5.1. Pink shrimp survey fits for the Summer and Fall SEAMAP surveys, 1987-2011. Plot a is summer and plot b is fall surveys.

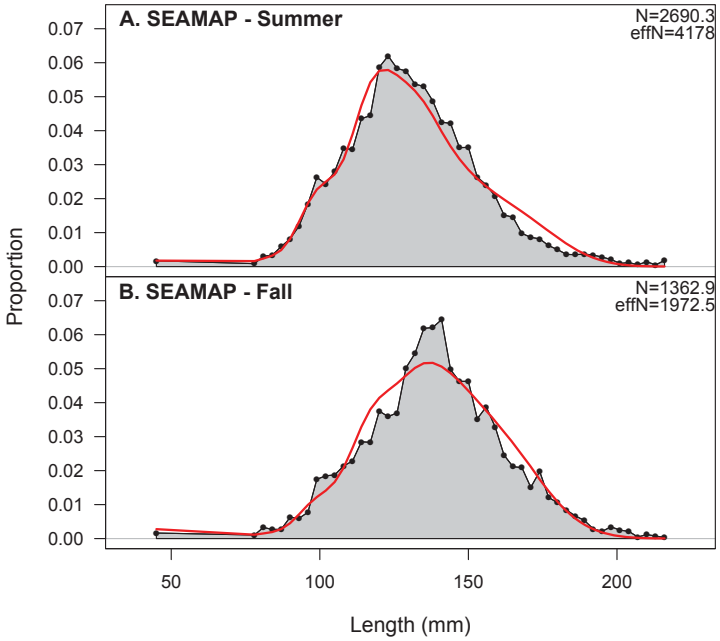

Figure 4.5.2. Size composition fits for the summer and fall SEAMAP surveys, 1987-2011.

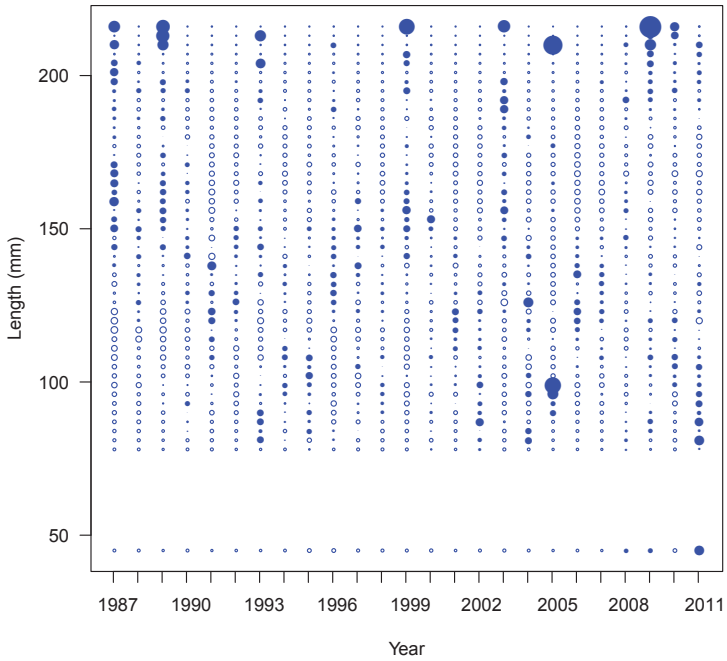

Figure 4.5.3. Residual fits for the summer SEAMAP survey, 1987-2011.

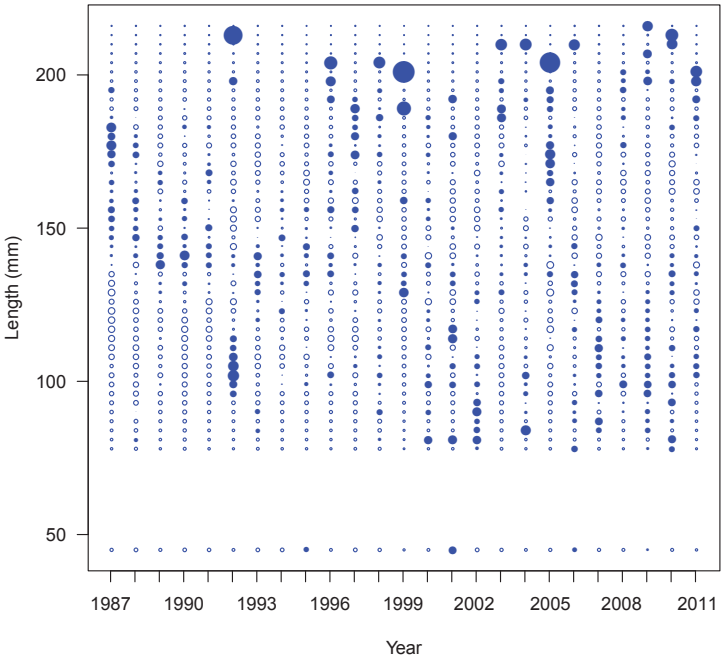

Figure 4.5.4. Residual fits for the fall SEAMAP survey, 1987-2011.

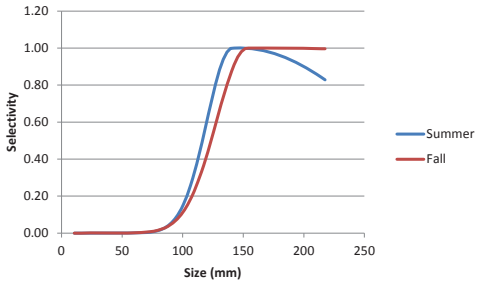

Figure 4.5.5. Pink shrimp size selectivity for the Summer and Fall SEAMAP surveys, 1987-2011.

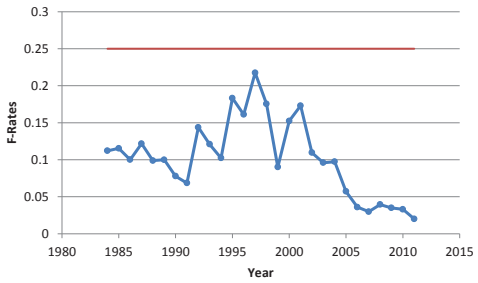

Figure 4.6.1. Pink shrimp weighted monthly apical F-values across ages 1-19 for 1984-2011.

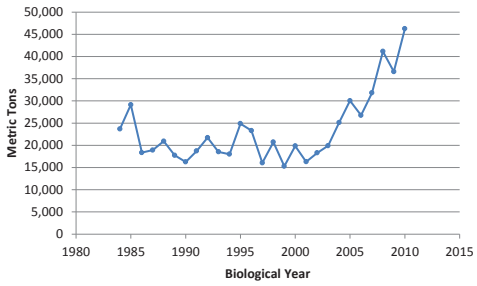

Figure 4.7.1. Pink shrimp spawning biomass estimates.

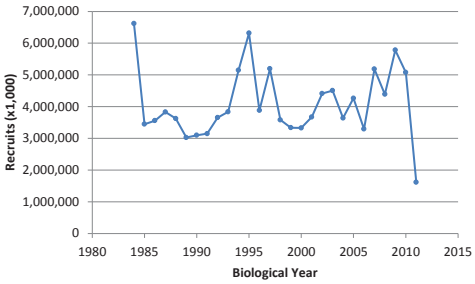

Figure 4.7.2. Pink shrimp biological year recruitment estimates. Note that biological year 2011 only includes 6 months of recruitment data, hence the low value seen in the figure.

Appendix 1. Stock Synthesis 3: Technical Description of Selectivity, Fishing Mortality, and Natural Mortality

Rick D. Methot and Chantel R. Wetzel

Selectivity

Double normal selectivity provides the flexibility to assume either a dome-shaped selectivity or an asymptotic selectivity by length through the use of an ascending limb, a plateau and a descending limb. These three components of the overall function are connected by steep logistic "joiners" to provide overall differentiability. Selectivity by length l is calculated as:

$$S_l = asc_l(1 - j_{1,l}) + j_{1,l}(1(1 - j_{2,l}) + j_{2,l} dsc_l) \tag{1}$$

Where the joiner functions, ascending, and descending components are:

$$\begin{aligned} j_{1,l} &= \left(1 + e^{\left(-20\frac{L_l' - \beta_1}{1+\left|L_l' - \beta_1\right|}\right)}\right)^{-1} \\ j_{2,l} &= \left(1 + e^{\left(-20\frac{L_l' - peak_2}{1+\left|L_l' - peak_2\right|}\right)}\right)^{-1} \\ asc_l &= e^{\left(\frac{-\left(L_l' - \beta_1\right)^2}{e^{\beta_3}}\right)} \\ dsc_l &= e^{\left(\frac{-\left(L_l' - peak_2\right)^2}{e^{\beta_4}}\right)} \end{aligned} \tag{1.1}$$

where:

L_l'	is the midpoint of data length bin l,
$L_{\min}'$	is the midpoint of the smallest data length bin,
$L_{\max}'$	is the midpoint of the largest data length bin, and
β_1	is the size at which selectivity=1.0 begins,
β_2	is the size at which selectivity=1.0 ends (this is the width of the top, peak2 is the endpoint),
β_3	determines the slope of the ascending section,
β_4	determines the slope of the descending section,

β_5 is the selectivity at $L'_{\min}$,

β_6 is the selectivity at $L'_{\max}$, and

$peak_2$ is defined as:

$$peak_2 = \beta_1 + L_{\text{width}} + \left(\frac{0.99L'_{\max} - \beta_1 - L_{\text{width}}}{1 + e^{-\beta_2}} \right) \tag{1.2}$$

where:

L_{width} is the length of the data length bins,

Fishing Mortality with Hybrid F

The hybrid fishing mortality method evokes both properties from the calculation of fishing mortality (*F*) by the Pope's approximation and the Baranov continuous catch equation. The method begins by calculating the mid-season harvest rate using Pope's approximation then this harvest rate is converted to an approximation of the Baranov continuous *F*. The *F* values for all fleets operating in that season and area are then tuned over a set number of iterations to match the observed catch for each fleet with its corresponding *F*. Differentiability is achieved by the use of Pope's approximation to obtain the starting value for each *F* and then the use of a fixed number of tuning iterations, typically 4.

The hybrid method calculates the harvest rate via the Pope's approximation then converts to an approximation of the corresponding *F* as:

$$\begin{aligned} temp_1 &= \frac{C_{obs,retained,f,t}}{B_t + 0.1C_{obs,retained,f,t}} \\ j_1 &= \left(1 + e^{(30(temp_1 - 0.95))}\right)^{-1} \\ temp_2 &= j_1 temp_1 + 0.95(1 - j_1) \\ F'_{f,t} &= \frac{-\ln(1 - temp_2)}{\text{season duration}_s} \end{aligned} \tag{2.1}$$

where:

$C_{obs,retained,f,t}$ is the observed retained catch for fishery *f* at time *t*, and

season duration_s is the length of the season *s*.

The formulation above is designed such that high harvest rates (above 0.95) are converted into an *F* that corresponds to a harvest rate of 0.95, thus provides a more robust starting point for subsequent iterative adjustment of this *F*.

The catch at time *t*, of gender γ of age *a* fish is calculated as:

$$C_{t,\gamma,a} = \frac{F_{t,f}}{Z^{1'}_{t,\gamma,a}} \left(S_{f,\gamma,a} N_{t,\gamma,a} \right) Z^{2'}_{t,\gamma,a} \tag{2}$$

where:

$N_{t,\gamma,a}$ is the number of fish at time *t*, for gender γ, and age *a*,

$S_{f,\gamma,a}$ is the selectivity for fishery *f* for gender γ and age *a*,

$Z^{1'}_{t,\gamma,a}$ is the total mortality at time *t* for gender γ and age *a*,

$Z^{2'}_{t,\gamma,a}$ is the survivorship at time *t* for gender γ and age *a*, and

$F_{t,f}$ is the apical fishing mortality rate at time *t* for fishery *f*.

The total mortality and survivorship is calculated as:

$$\begin{aligned} Z^{1}_{t,\gamma,a} &= M_{\gamma,a} + \sum_f \left(S_{f,\gamma,a} F_{t,f} \right) \\ Z^{2}_{t,\gamma,a} &= 1 - \exp^{\left(-\text{season duration}_f \cdot Z^{1}_{t,\gamma,a} \right)} \end{aligned} \tag{2.2}$$

where:

$M_{\gamma,a}$ is the natural mortality for gender γ and age *a*.

Then over several fixed number of iterations (typically four, but more in high *F* and multiple fisheries situations) fishing and total mortality is adjusted:

The first step is to calculate the ratio of the total observed catch over all fleets to the predicted total catch according to the current *F* estimates. This ratio provides an overall adjustment factor to bring the total mortality closer to what it will be after adjusting the individual *F*s.

$$\begin{aligned} \hat{C}_p &= \sum_f \sum_\gamma \sum_a \frac{F'_{t,f}}{Z^{1}_{t,\gamma,a}} \left(w_{\gamma,a} N_{t,\gamma,p,a} S_{f,\gamma,a} \right) Z^{2}_{t,\gamma,a} \\ Z^{adj} &= \frac{C_{obs,t,p}}{\hat{C}_p + 0.0001} \end{aligned} \tag{2.3}$$

where:

$w_{\gamma,a}$ is the body weight for gender γ and age a, and

$C_{obs,t,p}$ is the observed catch for time t for area p.

Then calculate what the total mortality would be if this adjuster was applied to all the Fs:

$$\begin{aligned} Z^{1'}_{t,\gamma,a} &= M_{\gamma,a} + Z^{adj}\left(Z^{1}_{t,\gamma,a} - M_{\gamma,a}\right) \\ Z^{2'}_{t,\gamma,a} &= 1 - \exp^{\left(-\text{season duration}_f Z^{1'}_{t,\gamma,a}\right)} \end{aligned} \tag{2.4}$$

The adjusted mortality rate is used to calculate the available biomass for each fishery, and then the new F estimate is estimated by the ratio of observed catch to available biomass, with a constraint to prevent unreasonably high F calculations:

$$\begin{aligned} temp_3 &= \sum_f \sum_\gamma \sum_a \left(w_{\gamma,a} N_{t,\gamma,p,a} S_{f,\gamma,a}\right) Z^{2'}_{t,\gamma,a} \\ F' &= \frac{C_{obs,retained,f,p,t}}{temp_3 + 0.0001} \\ j' &= \left(1 + \exp^{30\left(F' - 0.95 * F_{\max}\right)}\right)^{-1} \end{aligned} \tag{2.5}$$

with the updated estimate of F for time t for fishery f calculated as:

$$F_{t,f} = j'F' + (1 - j')F_{\max} \tag{2.6}$$

where:

$F_{\max}$ is the pre-specified maximum allowable F, typically set by user to be about 3.0.

Natural Mortality

Stock Synthesis can incorporate several alternative forms of natural mortality. The most basic and simple form of natural mortality is:

$$M_{\gamma,a} = \text{constant} \tag{3}$$

where the natural mortality rate is constant across ages a and equal for genders γ.

Lorenzen natural mortality is based on the concept that natural mortality varies over the life cycle of a fish, often by orders of magnitude, which is driven by physiological and ecological processes. The Lorenzen natural mortality rate is calculated as:

$$\beta_1 = L_{\infty,\gamma} \exp^{\left(\left(-k_\gamma \cdot \sum \text{season duration}\right)-1\right)}$$

$$\beta_2 = \frac{\alpha_\gamma}{\ln\left(L_{\gamma,a} \Big/ \left(\beta_1 + L_{\gamma,a}\right)\right)} \tag{4}$$

$$M_{\gamma,a} = \begin{cases} M_{\gamma,a} & a = 0 \\ \ln\left(L_{\gamma,a} \Big/ \left(\beta_1 L_{\gamma,a}\right)\right)\beta_2 & a < 0 \end{cases}$$

where:

$L_{\infty,\gamma}$ is the mean asymptotic size for gender γ,

k_γ is the von Bertalanffy growth coefficient for gender γ,

$L_{\gamma,a}$ is the mean size at age a for gender γ, and

α_γ is the pre-specified parameter for each gender that will the M at the reference age.