2014 Florida Sea Grant: Developing a size-structured stock assessment model for the spiny lobster, *Panulirus argus*, in the southeast United States

Methods

General process

The stock assessment model is developed to represent the dynamics of the whole spiny lobster stock in the southeast US. It starts from the year of 1990~1991 and ends at the year of 2009~2010. The duration that stock assessment model covers is determined by the length of fishery-dependent data, and can be increased when longer fishery-dependent time series data is collected in the future. The minimum size of lobsters considered in the stock assessment model is 46 mm carapace length (CL). It is also the size that 1% of female lobsters start to mature (SEDAR, 2010). To be consistent with the historical landing data, each size bin covers 5 mm CL. There is a total of 20 size bins. The largest size bin is a plus size bin that includes all lobster individuals larger than 146 mm CL. It assumes that lobsters larger than 146 mm CL have the same life history and fisheries process.

Two types of time steps have been considered in the stock assessment model. One is duration-fixed (denoted as "fixed time step type"), and the other is more dynamic (denoted as "dynamic time step type"). The former divides a year into two time steps: Wet (May to October) and Dry (November to next April). The later assumes the beginning of April as the start of the year. It also divides a year into two time steps: No fishing (April to July) and Spawning (August to next March). Both of these two types of time steps have their advantages. The "fixed time step type" uses standardized time step, therefore, the results are more comparable to other stocks, such as in the Caribbean and Mexico. Co-management of spiny lobster fisheries by countries around the Caribbean Sea have been advocated for a long time (WECAFC, 2002). A standardized stock assessment model could provide the foundation for the potential meta-population model, when the co-management need is promoted. The "dynamic time step type" is specially designed for spiny lobster in the southeast US. It is more realistic and provides a better fit to local fisheries regulations. There are four months with only natural mortality and eight months with both natural and fishing mortality occurring. However, the model structure needs to be adjusted when it is connected to other stocks (e.g. in a meta-population framework that connects all Caribbean spiny lobster stocks). In the stock assessment model, a switch has been added to allow end-users to choose between these two time-step types based on different management needs. Therefore, the model could become more flexible and generalized.

The stock assessment models last for 20 years; and each year contains 2 time steps. Therefore, there are a total of 40 time steps. At the beginning of every time step, a certain number of recruits grow into the model (from the pre-molt size smaller than 46 mm CL to the post-molt size larger than the 46 mm CL). During that time step, these recruits experience one or some of the following processes: dying due to natural mortality, being caught in the fishery, spawning or molting (growth). The surviving lobsters repeat these processes again and again with new recruits in the subsequent time steps. Specifically, the stock assessment model consists of five submodels: 1) a recruitment submodel that describes the recruitment dynamics; 2) a growth submodel that simulates the growth of the whole stock; 3) a catch-at-size submodel that predicts the size-based landings data based on the dynamics of stock structure; 4) an observational submodel that describes the relationship between stock abundance and catch-per-unit-efforts estimated from fisheries; and 5) an observational submodel that describes the relationship between predicted and observed landing size composition.

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Growth
The mark-recapture data provided by Florida Fish and Wildlife Conservation Commission is used to estimate growth. From 1967-2003, 6,891 lobsters were marked and recaptured by several institutions, such as the State of Florida, the University of Florida and so on (Muller et al., 1997; Ehrhardt, 2008). Fifty-one percent of them were female, and the remaining, 49 percent, were male. The sizes on both the mark and the recapture dates are measured; the time of liberty (days-at-large) can also be calculated.

Fisheries scientists have investigated a lot in modeling the growth of the Caribbean spiny lobster based on its molting process. Hoenig and Restrepo (1989) developed a Molt-No-Molt model to estimate the molting probability, which was related with the inter-molt period, as well as another two parameters: the elapsed time since the last molt, and the days-free between the released and recaptured dates. Meanwhile, the duration of the inter-molt period was also assumed as an exponential function of the CL at tag time. The observations could theoretically be classified into three types: no molt, molt once by chance, and molt at least once. The total likelihood was the product of the probability that each recorded days-free falls into the above three types. Parameters could be consequently estimated by maximizing the total likelihood. Muller et al. (1997) used generalize linear models to describe the growth procedure of the spiny lobster in two processes: molting probability and molting increment. The probability that an individual lobster molts in a given month was linked to a generalized linear function of its CL at tag time, time at large in days (referred to as days free in this manuscript as it is also the period between the released and recaptured dates), zone (using Big Pine Key as the boundary between the Upper and Lower Keys), recapture season (summer from May to October or winter from November to the next April) and sex (female or male) by a logit link function. For the growth increment, a lognormal error distribution was assumed with an identity link function; and the CL, days free, recapture season, zone and sex were also considered. The spiny lobster growth model was also described by Ehrhardt (2008) originated from Munro (1974). It used a regression method. Observation records were delivered into a set of pre-defined CL bins. A non-linear function was used to explore the relationship between the median inter-molt periods and the median size of those bins (Munro 1974) and then a linear function was taken to fit the pre-molt and post-molt CLs. Factors such as sex (female and male) and CL (<70 mm and >70 mm) were incorporated in the analyses as they were considered to cause variations in growth.

Although multiple growth models have been developed, few comparisons have been accomplished to identify a more appropriate one. That is because previous statistical analyses were based on diverse assumptions, constructed by unnested model equations, and fitted by different regression methods. It is hard to compare the results directly. In this study, previous statistical models were repeated, modified, and applied to the same data set to review their performances in growth estimation. Uncertainty of the parameters in each model is estimated using the bootstrapping resampling method.

An external individual-based model (IBM) is needed to generate a sex-specific sized-based growth transition matrix for the stock assessment model in both time steps of a year. As the IBM is developed to serve the stock assessment model, it needs to have a compatible model structure. Similar to the stock assessment model, the IBM simulates the life history and fisheries process of spiny lobster. However, one of the main differences is that the IBM uses a probabilistic approach: At each time step, each individual has probabilities of being caught in the fishery, or dying of natural mortality and (or) molting mortality, as well as growing, maturing, and spawning. The IBM focuses on the variation of individuals (Zhang et al., 2011). A cohort of pseudo recruits go over all the processes in IBM one by one. Each “pseudo recruit” represents a number of real recruit individuals. The IBM doesn’t stop until all individuals have died due to M or were landed as part of the catch. To ensure that all size bins are covered by the growth transition matrix, a long simulation time are used, i.e. 100 years, to allow spiny lobsters to grow into the last size bin (larger than 146 mm CL). All the information about the “pseudo recruit”, such as the sex, length, weight, and spawning status, are recorded at the end of each time step. This information has been summarized for the whole cohort. A growth transition matrix is one of the important outputs.

Another IBM output for the stock assessment model is the size composition of the Southeast US spiny lobster stock. The initial stock can be considered as a virgin stock, and its size composition can also be simulated by “burning-in” the IBM for hundreds of years with no fishing (only natural mortality) to allow the size composition approach equilibrium.

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Bayesian estimation

A Bayesian approach is used in this project to fit the stock assessment model to data. The basic theorem is to map the “posterior”, $f(\boldsymbol{\theta}|\boldsymbol{y})$, from the likelihood function of observed data, $f(\boldsymbol{y}|\boldsymbol{\theta})$, and the pre-determined “prior”, $f(\boldsymbol{\theta})$ (Dennis, 1996). Posterior $f(\boldsymbol{\theta}|\boldsymbol{y})$ represents the distribution of $\boldsymbol{\theta}$ after having observed $\boldsymbol{y}$; $\boldsymbol{y}$ can be observed, and $f(\boldsymbol{y})$ are considered independent with $\boldsymbol{\theta}$; $\boldsymbol{\theta}$ are treated as random variables; and $f(\boldsymbol{\theta})$ could be assumed from previous knowledge. The best estimator of $\boldsymbol{\theta}$ is the mode of $f(\boldsymbol{\theta}|\boldsymbol{y})$. Therefore, the product of likelihood $f(\boldsymbol{y}|\boldsymbol{\theta})$ and prior $f(\boldsymbol{\theta})$ also needs to be maximized. In this project, various likelihood functions have been adopted in the Bayesian stock assessment model, such as normal distribution (McAllister and Kirkwood, 1998), and robust multinomial distribution (Fournier et al., 1990).

Both non-informative and informative priors have used in this Bayesian approach. A non-informative prior usually uses uniform distribution, in which the lower and upper boundaries need to be pre-determined. An informative prior usually uses a normal or log-normal distribution, in which mean and variance need to be pre-determined. Sometimes fat-tailed or Cauchy distributions are used for informative priors, as they are more robust to prior mis-specifications, which are common in fisheries (Chen et al. 2000). Prior switches have added in the proposed stock assessment model to provide the end-users with different choices of probability functions for priors.