$$p(\boldsymbol{\theta} \mid \mathbf{y}) = \begin{Bmatrix} \mathbf{Q} \\ \mathbf{R} \\ \mathbf{A} \end{Bmatrix} \begin{matrix} \textit{uantitative} \\ \textit{esource} \\ \textit{ssessment} \end{matrix}$$

LLC

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Developing a stock assessment model for Alaskan crab stocks: literature review and initial scoping.

Overview

A literature review was conducted to evaluate the needs for Alaskan crab stock assessment models and to determine the types of models used for crab and crab-like species. The literature review included reviewing all Alaska crab assessments, reviewing other crab and crab like (e.g. lobster, shrimp) assessments, and reviewing general stock assessment models (e.g., Stock Synthesis(Methot 2005; 2009)). The objective was to list all the characteristics that are desirable in a crab model including those that have not been implemented in the Alaskan crab stock assessments. Reviewing existing general models identified specific features that facilitate the development and use of a general model. The literature was then assimilated to determine the best approach to develop a general crab model and what features need to be included.

The Alaskan snow crab model (Turnock and Rugolo 2010) is one of the more complex assessments applied to crab or crab-like species. It models several components of the stock (size, sex, shell condition, and maturity) and fits to abundance index and composition data. Other Alaskan crab assessments are of similar complexity (e.g. Bristol Bay red king crab, Norton Sound red king crab, and Aleutian Islands golden king crab). Several of the model assumptions are not consistent among the different stock assessments. The models need more flexibility in model assumptions similar to those available in existing general models to facilitate the investigation of alternative assumptions (e.g. using empirical estimates of survey selectivity), parameters that are estimated (e.g. natural mortality, growth, maturity, selectivity, recruitment), and data sets (e.g. survey abundance in numbers). The lack of spatial structure in the models is an obvious deficiency and would require substantial model development to implement.

There are several characteristics of a crab fishery, which differ from a typical finfish fishery that need to be included in a stock assessment model. Generally, there is inadequate information about the age of crabs and only length composition data is available. Crab fisheries are often managed using a minimum legal size and escape gaps in traps. Therefore, there is a knife edged selectivity and often a high exploitation rate for legal sized fish. This distorts the distribution of length at age and standard age structured fisheries models, like Stock Synthesis, cannot adequately model the changes in the distribution of length-at-age. Stock Synthesis includes growth morphs to allow changes in the length-at-age distributions, but it is not clear if these will adequately model the length-at-age distribution. Crabs also molt so that some crabs may not grow, which produces a growth curve that differs from those used in standard fisheries stock assessment models. A fully length based model is therefore the most appropriate stock assessment model to use for crab stocks. Due to the use of minimum legal size as a management tool and ban on retention of females or berried females, there is a significant amount of discards in crab fisheries. Therefore, any crab model should appropriately deal with discards and discard mortality.

Length based models require a growth transition matrix that determines how many fish move from each length category into the other length categories during a time period. This information is usually obtained from tagging data. However, there is also information about growth in the size composition data. Therefore, the tagging data should be integrated into the assessment model and the growth parameters estimated inside the assessment model. Tagging data can also provide information on biomass, mortality rates, and movement (if spatial structure is modeled) and therefore the tagging data should be integrated into the assessment model appropriately so that all the information from the tagging data can be used.

The Alaska crab assessments do not include spatial structure except by independently modeling different stocks. The populations show spatial structure in size, sex and other characteristics. This indicates that spatial structure may be an important component to include in the assessment models. Modeling spatial structure can be implemented in several ways

1) Sharing parameter values among areas
2) Sharing a common recruitment source
3) Catch originating from multiple populations
4) Exchange between sub-populations

There are many issues that need to be addressed when developing a stock assessment model, particularly if the model is designed to be general so that different assumptions can be tested or the model applied to different populations. The crab models separate the population into multiple partitions (e.g. size, sex, maturity, shell condition) and this requires special attention in how individuals transition between the partitions (e.g. grow or become mature), flexibility in combining data from different partitions (fitting to composition data aggregated over shell condition, separately for each shell condition, or so that the shell condition probabilities sum to one), and how different partitions share parameter values (e.g. males and females have the same growth rates).

Finally, evaluating the model and presenting information for management advice is an important component of stock assessment. This requires producing appropriate model output, estimating and evaluating reference points, and conducting forward projections. These are not discussed in this report, but they are an important consideration in developing a stock assessment model.

The information about stock assessment models presented in this report are based on the information available in the stock assessment reports and may be incomplete or inaccurate. The details will be updated based on feedback from the assessment authors if possible.

Options

There are three main model development options available and they differ in what they will provide and the amount of work that is required.

1) Obtain the code for the snow crab assessment model and make the desired changes. The code modified b Andre Punt may be preferable because it has been cleaned up and made more efficient. Only a moderate amount of work would be required to produce a snow crab assessment model that includes options to investigate different assumptions (excluding spatial structure). Making the model more general and applying it to other species would require more extensive work.

2) Creating code from scratch for a snow crab or general model. This would take more work than starting from the existing code, but would include the benefits of having a cleaner code that is fully understood by the developer and allows for a better structure for building a general model.

3) Use an existing general model. Stock synthesis is probably not appropriate for modeling Alaskan crab stocks because it is age based and it is not clear if the growth morph feature would adequately model crab population dynamics. The general model CASAL developed by NIWA in New Zealand can be applied using a length based model option and has many of the features needed for a crab assessment. Although, it may not be able to model molting appropriately. CASAL is currently being redeveloped and may include the required features, but will probably not be available for two years.

Further detailed information is presented in the following appendices:

Appendix I: Summary of Alaskan crab models
Appendix II: Developing a general crab model
Appendix III: Desirable characteristics of a general crab model
Appendix IV: Characteristics of Alaskan crab models
Appendix V: Characteristics of other crab and crab like assessments
Appendix VI: Characteristics of general stock assessment models

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Appendix I: Summary of Alaska crab models

Model structure

The populations are modeled with respect to size, sex, maturity, and shell condition, or some combination of these. Some models include stage structure, which is a combination of shell condition and size ranges. The model parameters can be common or different among these various characteristics. The model is always size structured except for the stage-structured models, which include size as part of the stage definitions. Several models only consider males. Several models include a terminal molt option.

F method

The models either 1) treat annual fishing mortality (F) as parameters with a lognormal penalty and fit to catch data or 2) assume that catch is known and occurs during a short period.

Selectivity/catchability

Selectivity is typically modeled using a logistic function and can be common or different between males and females or shell condition. An additional availability parameter is used so that the maximum selectivity for one sex (usually females) can be less than one. Other selectivity functions are used (e.g. broken stick), the logistic has been modified in one model using a parameter for specific size ranges, and stage specific selectivities estimated. Time blocks are used to allow differences in selectivity and catchability. Retention curves (e.g. logistic) are used to model discards. Availability is also shared between surveys to accomodate surveys that don't cover the whole area and to share catchability and allow comparisons among surveys.

Growth

Growth is generally based on a linear function of length and variability in growth is modeled using a gamma distribution. Parameters may be shared between males and females or different. Time blocks are used to allow growth to change over time. Stage specific (parameter for each stage) growth has also been used.

Recruitment

Recruitment is generally modeled as mean recruitment with annual penalized deviates and a gamma distribution to apportion recruitment to the size classes. No stock-recruitment model is used. In one case recruitment was estimated separately for males and females with penalty on 1:1 sex ratio. Another case limited the size classes for which recruitment can occur and estimated parameters representing the proportion in each size class.

Natural mortality

Generally, M is constant and independent of length and shell condition. However some models estimated time blocks, different M for males and females, or allowed changes with size (e.g. higher for the largest size group).

Molting

The probability of molting was modeled in a variety of ways. Both the logistic and inverse logistic were used. Molting probability could be the same or different for males and females and/or shell condition. In one case all immature individuals are assumed to molt annually while mature do not molt (terminal molt). Probability of molting was also allowed to change over time using a penalized random walk. The probability of molting was also stage specific in one model.

Initial conditions

Initial conditions were either 1) estimated numbers at length (this could be by sex, shell condition, and/or maturity) and smoothed with a penalty based on the first difference, with an overall scalar estimated for each component (e.g. shell condition) or 2) simply input based on relative proportions in the first survey (perhaps smoothed) and scaled with an estimated parameter.

Seasons

All models used an annual time step and modeled seasons by adjusting natural mortality for the timing of the fishery.

Maturity

Maturity was modeled either as 1) a logistic with the possibility of time blocks for the 50% maturity or annually estimated, or 2) size specific parameters smoothed with a penalty based on the second difference.

Data

Fishery

Total catch is either fit with a normal or lognormal distribution or assumed know without error. It is often separated into retained and total.

Composition data is usually by shell condition, sex, and size and fit using a variety of likelihoods including the robust multinomial, normal with binomial variance, or multinomial. It varies whether the composition is treated independently or if the composition sums to one over sex, shell condition, discards, and /or maturity.

CPUE is fit using a lognormal distribution and in some models separated by length group.

Discards

The model is fit to estimates of discard catch and to discard composition data in a manner similar to that explained above for catch. Often a handling mortality rate is assumed. Discard or retention selectivity curves are used to model the discards. This allows for missing discard data in some years. One assessment assumed that the discard fishing mortality was proportional to an effort series. Another assessment input the proportion legal by size and shell condition to model discards. Discard catch rates were also used as an index of abundance.

Survey

Survey data is fit using a lognormal likelihood. The survey indices were sometimes separated into abundance by sex, maturity, shell condition, size and/or stage.

Tagging

Tagging data was used outside the model to estimate a variety of quantities that were used in the assessment models including: growth and molting parameters, total mortality, natural mortality, and biomass.

Weighting and priors

Most models included the use of weights (lambdas) to weight the likelihood functions. Priors were used on M and mean growth parameters in some assessments.

Appendix II: Developing a general crab model

The following describes the steps that would be required to develop a general model for crab stock assessment.

Literature Review

1) Review all Alaska crab assessments
2) Review other crab and crab like (e.g. lobster) assessments
3) Review general models (e.g., stock synthesis—identify other models of interest)

The objective of this task is to list all the characteristics that are desirable in a crab model including those that have not been implemented in the Alaskan crab stock assessments. Reviewing existing general models will identify specific features that facilitate the development and use of a general model.

Scoping out a general crab model

Assimilate the literature review and discuss crab assessment models with stock assessment experts to determine the best approach to develop a general crab model and what features need to be included.

Develop general model stage I

Develop the general model so that is has, at a minimum, all the characteristics of the current snow crab assessment model. Document the model. Develop code to produce output, model diagnostics, calculation of management quantities, and forward projections.

Snow crab application

Apply the general model to Bering Sea snow crab using the data from the current stock assessment.
Develop the appropriate output and diagnostics required for the Crab Plan Team's terms of reference for stock assessment authors.

Develop general model stage II

Further develop the general model so that it can be applied to other Alaskan crab species and that it includes all the desirable features not currently available in the Alaskan crab assessments. Document the model.

Appendix III: Desirable characteristics of a general crab model

Model structure

The population dynamics model needs, at a minimum, the ability to model size, sex, maturity, and shell condition. Consideration should also be given to modeling area and stage structure. The model should have the abililty to eliminate some of these structures if they are not desired for a particular application. The model parameterization should be flexible enough so that any parameter can either be shared among structures of different. It may be reasonable to have a model that is always size structured. The model should include a terminal molt option. Time blocks and other forms of temporal variation (i.e. penalized deviates, covariates) should be options for all parameters. Bounds and priors should also be implemented to constrain parameter values.

F method

It is not clear what method should be used to model fishing mortality, however the allowance for multiple seasons of different lengths and positioning of population processes within these seasons should allow for known catch methods to be used (i.e. Popes approximation). If catch is uncertain and it is desirable to include this uncertain or if discard data is not available for some time periods, treating fishing mortality as parameters and fitting to catch or effort data may be appropriate.

Selectivity/catchability

A variety of selectivity models should be available including standard functions such the logistic, double normal, and broken stick, as well as selectivity curves that allow for length specific parameters with some form of smoothing. There may need to be an allowance for multiple selectivity curves for the same fishery to provide the ability to model, for example, escape gaps and minimum legal size as they change over time. The selectivity curves for each structure (e.g. females) should be allowed to deviate from having a maximum of one (e.g. with an estimated parameter for the maximum). Time variation is an important component of the selectivity and catchability parameters. There should be the ability to share selectivities among fisheries and/or surveys. Similar selectivity curves should be available for either discard rates or retention rates.

Growth

A variety of functions should be available for modeling growth including the standard approach that includes a linear model for mean growth and gamma distribution for variation in growth. Others functions should include the von Bertalanffy growth curve, the Richards or Schnute growth curves, and normal or lognormal distributions for variation in growth. There should also be the ability to directly input the growth transition matrix. It should be possible to estimate different growth parameters for each structure, share parameters among structures, and for growth to vary over time.

Recruitment

Recruitment should be modeled as mean recruitment with annual penalized bias corrected deviates. Tapering of the bias correction should be implemented. A variety of methods should be available to distribute the individuals among size classes including the gamma, normal, and lognormal distributions, and the ability to estimate length specific parameters constrained to certain length bins with smoothing penalties. It should be possible to assume that these are the same or different for the relevant model structures. The possibility of a stock-recruitment model should be included and this would require providing an age at recruitment.

Natural mortality

Natural mortality should be allowed to change with size and other model structures as well as vary over time.

Molting

A variety of methods should be provided to model molting probability including logistic and inverse-logistic functional forms. The probability of molting should be allowed to be the same or different among model structures and vary over time. Fixed assumptions such as terminal molt or molting every year should be possible.

Initial conditions

The modeling of initial conditions should be flexible and may differ depending what structures are modeled (e.g. area). Proportions in each size class by model structure could be provided or estimated with a smoothness penalty, and scaling parameters estimated. The initial conditions could be based on equilibrium assumptions with parameters such as fishing mortality, average recruitment, and recruitment deviates estimated. The fishing mortality used to create the initial conditions could be related to the fishing mortality in the first few years of the modeled time period.

Seasons

A flexible within year time step framework should be implemented so that both the number of time steps and the length of each time step is customizable. It may be desirable to change the time step structure partway through the time frame to accommodate different temporal structure of the data. The processes that operate during a time step should be customizable.

Maturity

Several approaches should be implemented to model maturity including the standard logistic, size specific parameters with a smoothing penalty, and specifying maturity at length. Temporal variability in maturity may be important.

Data

Fishery

If the model is fit to catch data it should have the option of a normal or lognormal distribution. It should be possible to fit to catch by fishery and by retained, discarded, and/or total.

Composition data should be flexible and allow for separation into the different model structures. The proportions should be allowed to sum to one over any combinations of the model structures. A variety of likelihoods should be available including multinomial, robust multinomial, normal with binomial variance, and lognormal with variance inversely proportional to the proportion.

CPUE should be fit using a lognormal distribution and the ability to fit CPUE grouped into different components of the model structure. The relationship between CPUE and abundance should have a parameter that allows for a nonlinear relationship.

Discards

Discards should be modeled in combination with the retained and/or total catch and use the same or similar procedures for catch, composition, and cpue. Handling mortality rates should be included and may need to differ by model structure. The discard or retention selectivity curves should be related to the total or retained selectivity curves to allow for missing discard data in some years. The ability to relate discard catch to some index may also be needed. The retention or discard selectivity curves should allow for inputting the proportion legal by size and shell condition.

Survey

Survey abundance data should be fit using a lognormal likelihood and have the ability to fit idices grouped into different components of the model structure. CPUE and survey data should be treated similarly. There should the ability to share selectivity and catchability parameters between surveys and commercial fleets/cpue. Multiple catchabilities/selectivities may need to be modeled for each survey/cpue to allow modeling of availability, selectivity, and the area covered by the index.

Tagging

Tagging data should be integrate into the model, particularly growth increment data so that both tagging and composition data can inform growth. Tagging data can also provide information on movement, mortality and abundance, but may require a different likelihood component.

Inference method, data weighting and priors

It should be possible to implement both maximum likelihood and Bayesian inference. The model should have the ability to weight different data components and allow for priors on all model parameters. Data weighting should include estimation of the standard deviations or additive factors for the standard deviations of likelihood functions, and arbitrary weighting factors that can be used for sensitivity analysis to weighting factors. Alternative likelihoods that allow for estimation of the sample size should be implemented for composition data (e.g. Punt's lognormal based likelihood with the variance inversely proportional to the proportion).

Appendix IV: Characteristics of Alaskan crab models

Model structure

Stock	Assessment structure	F method	Selectivity/catchability	Growth	recruitment
Eastern Bering Sea Snow Crab (Turnock and Rugolo 2010)	Size (5mm), Sex, maturity, shell condition, terminal molt	F as parameters with log-normal penalty fit to catch	Survey selectivity and catchability time blocks, separate survey catchability and selectivity for males and females, logistic functional form, retention selectivity by shell condition, model both availability and catchability so share availability between surveys	Linear function, equal intercept for males and females, gamma for variation	Annual lognormal deviates, gamma for length distribution, no stock-recruitment relationship
Bristol Bay red king crab (Zheng and Siddeek 2010)	Size (5mm), Sex, shell condition	F as parameters fit to catch, discard F proportional to potlifts, high-grading parameter	Selectivity and retention logistic, some sex specific, special selectivity for plus group. Male pot bycatch as broken stick. Trawl survey selectivity logistic with q, separate for males and females, time block	Linear, gamma for variation, time dependent for females	Annual lognormal penalized around mean, gamma for length distribution, separate for males and females with penalty on 1:1 sex ratio
Eastern Bering Sea Tanner crab (Rugolo and Turnock 2010)	New length based method being developed				
Pribilof Islands red king crab (Foy 2010a)	Survey biomass				
Pribilof District blue king crab (Foy 2010b)	Catch-survey analysis in preperation				
St. Matthew blue king crab (Zheng et al. 2010)	Stage (4 stages based on size and shell condition) males only	F as parameters fit to catch, penalty on F deviates	Survey, fishery, and bycatch selectivity stage specific	Stage specific	Annual deviate
Norton Sound red king crab (Zheng et al. 2010)	Size (10mm), shell condition, males only	Catch assumed known, occurs in short period	Logistic selectivity, time block for fishery selectivity, time block on catchability		Annual deviate, only enters first two size classes, estimate one proportion parameter
Aleutian Islands golden king crab (Pengilly 2010a; Siddeek et al 2010)	Size, shell condition, males only, two stocks with independent assessments	F as parameters fit to catch, penalize deviates around mean fishing mortality	Logistic selectivity modified with estimated constant (which is lower) for larger crabs, Time blocks for fishery selectivity and retention, time block for fishery catchability	Mean increment same for all sizes, gamma for variation	Lognormal penalty around mean (which could be a parameter), no bias correction, Gamma for length distribution
Pribilof Islands golden king crab (Pengilly 2010b)	None				
Adak red king crab, Aleutian Islands (Pengilly 2010c)	None				

Stock	Natural Mortality	Molting	Initial conditions	Seasons	Maturity
Eastern Bering Sea Snow Crab		All immature molt annually, mature don't molt	Numbers estimated at length, sex, and shell condition (unclear if also for maturity) and smoothed with first difference	Annual, M adjusted for fishery timing	Size specific parameters smoothed with second difference
Bristol Bay red king crab	Estimated, additional mortality in time blocks different for males and females, base M constant over length and shell condition	Estimated for male negative logistic, equal to one for female	Smoothed survey size and shell composition from first survey with estimated scaling parameters by sex		50% maturity time blocks or annual estimates
Eastern Bering Sea Tanner crab					
Pribilof Islands red king crab					
Pribilof District blue king crab					
St. Matthew blue king crab	Fixed or estimated, time block	Stage specific and varies over time with random walk with penalty on deviate. Includes shell classification error (unclear how it is used)	Relative numbers in each stage based on first survey, absolute abundance scaling parameter	Annual	
Norton Sound red king crab	Same M for old and new shell, changes with size (last group higher)	Same molting probabilities for old and new shell, molting timing changes compared to survey so adjusts for growth. Molting probability inverse logistic	Relative numbers in each size and shell condition based on first survey, absolute abundance scaling parameter	Annual, M adjusted for fishery timing	
Aleutian Islands golden king crab		Probability of molting logistic, same probability for old and new shell	Estimate initial proportion at length and overall abundance scalar by shell condition, first difference penalty by shell condition	Annual, M adjusted for fishery timing	
Pribilof Islands golden king crab					
Adak red king crab, Aleutian Islands					

Data

Stock	Fishery	Discards	Survey	Tagging	Inference method, data weighting and priors
Eastern Bering Sea Snow Crab	Catch normal likelihood, separate for retained and total. Shell condition, sex, and size composition using robust multinomial likelihood. CPUE using lognormal likelihood	Sex and size composition using robust multinomial likelihood. Assumed handling mortality rate. Discard selection curve used for early years without data	Total biomass by sex and maturity separately using lognormal likelihood. Sex, size, and shell condition composition using robust multinomial likelihood.		Uses likelihood weighting factors (i.e. lambdas), priors on M and mean growth parameters
Bristol Bay red king crab	Catch using lognormal likelihood. Size and shell condition composition using normal likelihood with binomial variance. CPUE available but not used.	Size, shell condition, sex composition using normal likelihood with binomial variance. Effort used to model discards	Abundance by sex size, and shell condition using lognormal likelihood.	Used for growth estimation outside model	
Eastern Bering Sea Tanner crab					
Pribilof Islands red king crab					
Pribilof District blue king crab					
St. Matthew blue king crab	Catch lognormal likelihood. Stage composition normal likelihood with binomial variance. CPUE available but not used.	Total discards lognormal likelihood. Assumed level of handling mortality	Index in the four stages using lognormal likleihood	Used to estimate Z and M outside model	
Norton Sound red king crab	Total catch assumed known. Size and shell condition composition multinomial likelihood and. Effort (CPUE) lognormal likelihood.	Proportion legal by size and shell condition used directly in model	Index using lognormal likelihood	Used to calculate growth and molting probabilities outside model, also total abundance (unclear if used)	Uses likelihood weighting factors (i.e. lambdas)
Aleutian Islands golden king crab	Total retained catch lognormal likelihood. Size composition normal likelihood with binomial variance. CPUE by length bin lognormal likelihood.	Total discards lognormal likelihood. Size composition normal likelihood with binomial variance, CPUE by length bin lognormal likelihood.	Pot survey CPUE by length bin lognormal likelihood	Used for growth estimation outside model	
Pribilof Islands golden king crab					
Adak red king crab, Aleutian Islands					

Appendix V: Characteristics of other crab and crab like models

Model structure

Stock	Assessment structure	F method	Selectivity/catchability	Growth	recruitment
New Zealand Lobster (Haist et al. 2009)	Stock/area, sex, length, maturity. Bayesian. Parameters can be stock specific or common. Movement specific to to a given size range, year range, and direction. Movement parameters estimated annually.	Finite or instantaneous	Selectivity double normal or logistic. Sex specific and time block. Seasonal vulnerability can be shared between sexes. Mature and immature assumed to have same selectivity.	Schnute (1981) continuous growth model. Sex specific. Immature and mature assumed to have same growth. Density dependence. Variation in growth is normal with sd proportional to growth increment.	Lognormally distributed, no stock-recruitment relationship, equal sex ratio, distributed over sizes using a normal distribution truncated at smallest size.
South coast rock lobster, South Africa (Johnston and Butterworth 2002)	Age, sex, area. No movement. Some parameters shared among areas and recruitment from common stock-recruitment relationship.	Popes approximation	Logistic (sex and area annual variation with penalty), Sex specific. Female selectivity scaled so max is not one (vulnerability). Selectivity normalized for given length range to make catchability consistent.	Length-at-age normally distributed with mean based on von Bertalanffy. Differs between males and females and between areas. Sd proportional to mean length. Linf sex and area specific but K and t0 common. Weight at age differ by area	Annual deviate in proportion of recruitment to each population penalized, parameter for mean proportion to each stock, annual autocorrelated non bias corrected penalized deviate. Equal sex ratio. Three parameter stock-recruitment model based on spawning biomass of all stocks.
West coast rock lobster, South Africa (Johnston and Butterworth 2005)	Size (1mm) and sex	Catch taken at start of season	Three parameter logistic, but modified for different fisheries and sexes (e.g. broken stick for small, linear with time for females). Sex specific, Female selectivity scaled so max is not one (vulnerability).	Adult sex specific, juveniles equal for males and females. Adults linear growth increment with intercept varying with time based on linear interpolation between data sets. Juvenile growth is a quadratic function of length with time blocks. Growth estimated outside model. Variation normally distributed truncated at +-2sd, some lobster can shrink. Sd a linear function of	Only in first 15 size classes and uniformly distributed. Equal sex ratio. Beverton-Holt stock-recruitment curve used to penalize some recruitments and a linear trend in between

				both growth increment and length for adults and for juveniles a function of both inter-molt period sd (constant) and growth increment (exponential of length)	
American lobster (Chen et al. 2005, Anonymous 2009)	Sex, length (5mm CL)	Finite (original) or instantaneous	Commercial selectivity separated into legal size, gear characteristics (escape gap), conservation measures (discarding berried females), and other. All fixed except for other. Some vary over time, sexes, and quarters. Others can be lognormal or normal (original). Legal and conservation components based on changes in MLS and escape gaps. Survey selectivity was double logistic, with the possibility of single logistic either increasing or decreasing. Original has logistic with lower bound for survey selectivity. Survey selectivity shared for quarter and sex, but catchability differs.	Calculated outside model, vary by season, no growth in some seasons, sex specific. Includes maturity and probability of molting.	Lognormal with (original) or without bias corrected penalized deviate, penalized, proportion at length fixed and only for first three size groups. No stock-recruitment. Sex ratio of recruits estimated.
New Zealand Scampi (Tuck et al. 2010)	Length (1mm) and sex. (May be spatial and maturity as well)		Logistic and assumed constant over time, but can vary with sex, season, and spatial strata. Seasonal changes in relative catchability between sexes.	Sex specific, estimated inside the model. Fit to tag and aquarium data. Can be in more than one season and differ among seasons.	Beverton-Holt stock-recruitment relationship. Recruitment distribution into size classes is normaly distributed.

Stock	Natural Mortality	Molting	Initial conditions	Seasons	Maturity
Haist et al. (2009)		Not used	500 iterations with constant recruitment, no movement and constant estimated F	Flexible number of time steps and can change over time, but equally spaced. Growth, maturity, recruitment and movement can occur in each time step.	Probability of maturing logistic
Johnston and Butterworth (2008) South coast rock lobster South Africa		Not used		None	
Johnston and Butterworth (2005) west coast rock lobster South Africa	Small lobster have different M with linear increase to larger sizes, sex specific, constant over time	Adults once a year. Juveniles multiple times a year, inter-molt period is linear function of size	Starts from virgin	None	
American lobster (East Coast, modified from Chen et al. 2005)			Scaling parameter for male an female, initial proportions based on equilibrium conditions with F similar to those at beginning of model	Quarterly, growth and recruitment in some quarters, some parameters can vary by quarter	
New Zealand Scampi	Constant and assumed known			Three seasons per year. Some parameters vary by season.	Either as part of the model structure with logistic probability of maturing, or simple the proportion mature models as a logistic. Binomial likelihood for proportion mature.

Data

Stock	Fishery	Discards	Survey	Tagging	Inference method, data weighting and priors
Haist et al. (2009)	CPUE nonlinear relationship estimated. Length composition summed to one over males and females	Retention curve	Pre-recruit indices, but not used.	Used in model to estimate growth.	
Johnston and Butterworth (2008) South coast rock lobster South Africa	CPUE lognormal likelihood. Size composition lognormal likelihood with variance inversely proportional to proportion. Composition sums to one over male and female.			In previous models used inside model	Priors on growth parameters (by sex and area for Linf) and steepness of the stock-recruitment relationship.
Johnston and Butterworth (2005) west coast rock lobster South Africa	CPUE lognormal likelihood. Male and female size composition treated separately using a lognormal likelihood with variance inversely proportional to proportion. Percent females in catch binomial likelihood with sample size calculated based on fit	A single discard mortality rate parameter applied to lobster less than a certain size.		Used to estimate growth outside model.	
American lobster (East Coast, modified from Chen et al. 2005)	Catch lognormal likelihood, estimate F for males and females and quarter by year. CPUE and size comp by quarter and sex. Size comp did not sum to one over sexes. Robust normal likelihood with binomial variance for length composition. (Original also had normal and t-distribution likelihoods). Dynamic binning to ensure proportions in tails greater than or equal to 0.01. Original includes nonlinear density dependent relationship between CPUE and abundance		Lognormal likelihood index.		Bayesian or MLE framework. Iterative reweighting to estimate sd's and sample sizes.
New Zealand Scampi	CPUE and length frequency by season and spatial strata. Multinomial likelihood for length frequency data.		Abundance index, length frequency data.		Bayesian, priors on survey catchability (prior on M used in previous assessment)

Appendix VI: Characteristics of general stock assessment models

Model structure

Stock	Assessment structure	F method	Selectivity/catchability	Growth	recruitment
Punt's Australian lobster model (Andre Punt personal communication)	Size, area, sex structured. Also includes MPAs. Movement is not size specific, can be sex specific, specify which areas it occurs between (including MPA), input which seasons it occurs. Variable sizes of length bins. Has to include recreational and illegal catch.	Total catch assumed known, but approximates with same selectivity for all gears.	Differs between fishery and survey. Includes: sex specific, logistic (time block), specified or estimated by length bin or range of lengths, mirror other selectivity. Also sex specific vulnerability to scale peak of selectivity by season. Includes a MLS (time block) that is knife edged (like switch). Catchability can change over time with a constant rate between given years.	Input as a matrix, estimated based on Von bertalanffy or polynomial, can occur in multiple seasons, can be sex, area, or season specific, unclear what variation in growth is when estimated from model. Can average multiple growth transition matrices to use. Weight at length can be area and sex specific and input by length or using a functional form.	Split between sexes based on parameter, annual bias corrected deviates, uses tapering for sd, can occur in multiple seasons, specify the proportion that goes to each length class separately by sex and area, proportion that goes to MPA based on relative size of MPA to area it is in, recruitment can be split between two years. Egg production can be area and sex specific and input by length or using a function.
Stock Synthesis (Methot 2005; 2009)	Age, sex, area, growth morph. Includes migration but not described here.	Popes approximation, continuous estimating F and fitting to catch, or continuous F solving the catch equation	Multiple methods ranging from functional forms to age specific parameters. Length-specific, age-specific or both. The six parameter double normal (two half normals with different variances joined with a flat top) is the most commonly used. Can have one fishery/survey mirror another's selectivity. Many of the parameters including selectivity allow several options for time variation; time blocks, random penalized deviates, trend based on a half normal as a function of time, random walk, covariate. Options are available to keep the time varying parameters within the bounds set for the original parameter. Male (or female) selectivity is modeled either as an offset of female (or male) selectivity, or using parameters which are offset from the other gender. If offset from	von Bertalanffy or Richards, normal variation of length at age, length at age is modeled as a function of length at the previous age to allow for temporal changes in the parameters , CV or sd a linear function of age or length. Cohort specific growth implemented as a penalized deviate. Growth patterns and growth morphs, multiple growth morphs can be used to account for the effect of size specific selectivity in the population size structure at age. Growth morphs can also be used to account for genetic variability in growth and the difference in growth among areas. However, when an individual changes areas it	Beverton-Holt with flat-top, standard Beverton-Holt, Ricker, or recruitment estimated with no distributional assumption. Lognormal bias corrected deviate, tapering of bias correction, autocorrelation, covariate on deviates, virgin recruitment, or steepness, seasonal parameters, recruitment cycles, recruitment can be distributed among area or growth morphs with estimated proportions. Design matrix for assignment of recruitment to area/season/growth pattern and can estimate as parameters. Fixed sex ratio.

			the selectivity it uses, a broken stick. Retention is a logistic function of size with an extra parameter for the asymptotic retention rate, an offset to the inflection point is available for males, discard mortality has same functional form as retention.	maintains the growth parameters of its area of origin. Growth different or same between sexes, various time variation (see selectivity). Empirical weight at age data (only for catch-at-age models).	
CASAL (Bull et al. 2005)	Age or sex structured, sex, maturity, and/or growth-path, area, stock, and tag. All modeled as a general concept called a partition. Includes migration but not described here. Ogives have a number of different parametric forms in CASAL and you can use any of these for any ogive parameter. CASAL does both age and size based models, but the focus here is size based.	Popes approximation or solving the Baranov catch equation	Ogives have a number of different parametric forms in CASAL and you can use any of these for any ogive parameter. Examples are logistic, knife_edge, double_normal, and the most flexible parameterisation allvalues (a separate parameter for each age/size by partition penalized by a smoothing penalty).	Can have multiple grow episodes per year, each episode can apply to one stock, or all stocks equally, and applies to all areas equally, uses Francis (Francis 1988) parameterisation of the growth increment von-Bertalanffy curve and an alternative form that has an exponential decay. Growth variability is normally distributed. Standard deviation is proportional to growth increment with a minimum.	Stock recruitment relationship (Ricker, Beverton-Holt), temporal deviates, covariate (exponential, arctan, logistic, identity, linear combination), constant recruitment offset for first few years. Penalty on recruitment deviates. Distribution is normal and can be sex and stock specific. Parameter for the sex ratio of recruits.

Stock	Natural Mortality	Molting	Initial conditions	Seasons	Maturity
Punt's Australian lobster model	Independent of area, sex, size, and time	Not modeled	Based on iterating a number of years, fishing mortality based on average over first few years of the modeling time period, recruitments estimated for some years/ages in initial conditions,	Multiple seasons per year with different lengths and M is adjusted by length of time period, each season can include or not include a process (growth, recruitment, movement)	Not modeled, except in calculating number of eggs through egg relationship.
Stock Synthesis	Single value for all ages, broken stick (piecewise linear) where the number of breakpoints can be set, scaled Lorenzen curve where the curve is scaled to an estimable value at a given age, or an age-specific vector read in and fixed. Male natural mortrality can be implemented as an offset from females, various time variation (see selectivity).	Not modeled	Estimate numbers at age by recruitment offset, fishing mortality for each gear, and age-specific penalized deviates. Fit to equilibrium catch..	Flexible seasons for catch. Fraction of M set for each season. Recruitment can occur during any season. Growth and M interpolated over seasons.	Maturity can be input as age specific or modeled using a logistic. Fecundity can be based on a function of weight at age.
CASAL	Natural mortality is applied to all areas and can depend on sex, maturity, stock, and age or size class. Disease mortality includes a temporal covariate and a age/size selectivity	Not modeled	The algorithm for determining the equilibrium state in a size-based model involves running the model over a number of simulated years with constant recruitment. An initial recruitment to create the equilibrium abundance, or numbers at age/size estimated by sex if desired.	Time steps within a year with one or more processes in each time step, allows specification of exact order of events using multiple time steps. Within a time step there is a default order of events.	Can occur in multiple seasons, apply to one stock, or all stocks equally, applied in one area, or all areas equally. Maturation ogive determines the rates of maturation, not the proportions of mature fish. Also has option for proportion mature at size/age.

Data

Stock	Fishery	Discards	Survey	Tagging	Inference method, data weighting and priors
Punt's Australian lobster model	Log normal likelihood for catch, CPUE lognormal likelihood. Size composition multinomial likelihood, can be one or combine two areas, sexes sum to one.	Not modeled	CPUE and survey index lognormal likelihood. Can share sd among series. Pre specified time changes in catchability. Can have two qs for survey with one shared with CPUE to scale for season. Size composition multinomial likelihood, can be one or combine two areas, sexes sum to one. Laval indices lognormal likelihood, enter years between index measurement and recruitment to model.	Only used for exploitation rate and movement or capture conditioned movement. No growth increment.	Uniform with bounds. MLE or Bayesian inference.
Stock Synthesis	Catch normal likelihood. CPUE lognormal likelihood, CPUE nonlinear term. Mean body weight normal likelihood. Length, age, weight, age at length composition multinomial likelihood with additive constant and tail compression. Mean size at age normal likelihood. Aging error matrix	Discard catch normal likelihood. Modeled using retention selectivity curves.	Treated like CPUE and fishery composition	Tagging for exploitation rate, biomass, and movement not growth.	Bounds on all parameters, Soft bounds based on the symmetrical beta, priors on most parameters, unifrom, normal, lognormal, symmetric beta, nonsymmetric beta, many parameters defined as offsets from other parameters. E.g. males offset of females, facilitates hypothesis testing and sharing of values among parameters. There are several types of offsets (e.g. additive, multiplicative exponential), estimate additive constant for abundance likelihood standard deviation, iterative reweighing, lambdas
CASAL	Abundance, absolute or relative catch-at- age/size (can be split by sex), size-age data	Modeled using a retention curve.	Abundance, absolute or relative numbers-at age/size.	Tag-release by size/age class, tag-recapture data binomial likelihood. Growth	Estimate additive sd, cv, or sample size to represent process error. Priors on all or most parameters.

	(options on what part of the sampling is random, i.e. random at size), proportions mature by age/size, proportions migrating by size/age (by sex or both combined), age/size-at-maturation, selectivity-at-age/size. All data by area. Aging error matrix. Various likelihoods are available including multinomial, normal with binomial variance, robust normal, binomial, robust normal approximation to the binomial, normal, lognormal, normal-log, robust lognormal. CASAL has a facility to add new likelihoods			estimation (without release numbers) uses the multinomial likelihood of the proportions observed at size, given the expected proportions at size in the tagged population, with the sample size determined by the number of individuals recaptured. (does not keep track of individuals)	Uniform, uniform on log scale, normal, lognormal, normal-log, beta with min and max, multivariate normal, multivariate normal-log. Smoothing penalties are also used for ogives. Penalties are also applied make parameters similar. CASAL has a facility to change the model parameterization, add new likelihoods, and add new priors.