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Data weighting for tagging data in integrated size-structured models

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ABSTRACT

Increasingly, stock assessments for hard-to-age species such as crabs, prawns, rock lobsters, and abalone are being based on integrated size-structured population dynamics models that are fit to a variety of data sources. These data sources include tagging data to inform growth. Diagnostic statistics and plots have been developed to explore how well integrated population models fit the data types typically used for assessment purposes (index data, size- and age-compositions, and conditional age-at-length data). However, such statistics and plots are not available for tagging data, when these data are used to estimate growth. This paper outlines two diagnostic statistics that can be used to evaluate fits to tagging data, and develops a method based on 'Francis weighting' for weighting tagging data in integrated models. For illustration, the methods are applied to Aleutian Islands golden king crab (*Lithodes aequispinus*) in Alaska, and tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in Australia's Northern Prawn Fishery. Some degree of growth model mis-specification was revealed for *P. semisulcatus*, and there were conflicts in the data for the tiger prawns. The standard errors for the estimates of mature male biomass for golden king crab were larger when the tagging data were downweighted based on the proposed weighting method. This serves to emphasise that assessments and their interpretations can be impacted by how tagging data are weighted.

1. Introduction

There is an increasing trend towards the use of integrated size-structured stock assessments for species that are difficult to age (Punt et al., 2013). For example, assessments for crab stocks off Alaska are based on size-structured population dynamics models that often divide the population into new and old shell crab (i.e., crab that did and did not moult the previous season; e.g., snow crab *Chionoecetes opilio*; Turnock and Rugolo, 2014; and red king crab *Paralithodes camtschaticus*; Zheng and Siddeek, 2014) while the assessment of tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) in Australia's Northern Prawn Fishery (NPF) is based on a sex- and size-structured population dynamics model (Punt et al., 2010; Buckworth et al., 2015).

Integrated size-structured stock assessment methods make use of several sources of data. For example, assessments of golden king crab *Lithodes aequispinus* in the Aleutian Islands, Alaska, include data on landings in numbers, the size-composition of the landings, the size-composition of observer records for all crab arriving on deck, catch-rate indices for the retained component of the catch, and tagging data (Siddeek et al., in press). In contrast, assessments of tiger prawns in the NPF are based on weekly catch and effort data, survey indices of abundance, survey and commercial size-composition data, and tagging data. However, it is not uncommon for information in data sources to be in conflict with each other to some extent (e.g., Richards, 1991). Thus, each data type (and each data point within each data type) included in a stock assessment needs to be assigned a weight. In principle, this weight should relate to the deviation between the data point and its expected value (Punt, in this issue), although on occasion weights reflect a subjective evaluation of the reliability of the data type (e.g., ICCAT, 2013). However, it is not straightforward to objectively select weights, and history reveals that data weighting can be influential on assessment results (e.g., Richards, 1991).

The primary purpose of the tagging data in the assessments of Aleutian Islands golden king crab and of tiger prawns in the Northern Prawn Fishery is to allow growth (rather than fishing mortality)

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to be estimated. The component of the likelihood function for the tagging data (Punt et al., 2009) is:

$$L = \prod_i \left(\frac{S_{C_i}[\boldsymbol{X}^{T_i}]_{R_i,C_i}}{\sum_j S_j[\boldsymbol{X}^{T_i}]_{R_i,j}} \right) = \prod_i p(C_i|R_i, T_i) \quad (1)$$

where T_i is the time-at-liberty for the i[th] recapture, **X** is the size-transition matrix (which specifies the probability of growing from one size-class to each of the same or larger size-classes), R_i is size-class in which the i[th] recapture was when it was released, C_i is the size-class in which the i[th] recapture was when it was recaptured, and S_j is the selectivity of an animal in size-class j (logistic for the example applications reported here). The size-transition matrix can separate the processes of moulting from those of growth given moult (e.g., Zheng and Siddeek, 2014) or represent the combined effects of moulting and growth given moult within a single model (e.g., Punt and Kennedy, 1997; Haist et al., 2009). The form of the size transition matrix for the case in which moulting is modelled explicitly is:

$$\boldsymbol{X} = \boldsymbol{X}' Q + \boldsymbol{I}(\boldsymbol{I} - \boldsymbol{Q}) \quad (2)$$

where **Q** is a diagonal matrix with values given by the probability of moulting, **X**′ is a matrix where each column is for a size before moult and each entry in each column is the probability of growing to that size given the size being represented by the column, and **I** is the identity matrix.

Eq. (1) treats each recapture as a Bernoulli trial, i.e., each tagged animal is treated as a single data point, independent from all the others. However, there will be overdispersion if tagging is such that some of the tagged animals are pseudoreplicates. This can happen if groups of tagged animals are released together and hence may have moved together and hence been subject to the same environmental conditions and prey fields. Consequently, the growth and probability of recapturing an animal are not independent of those for some of the other tagged animals. To account for overdispersion, the size-composition data used in the current configuration of the assessment methods for one example fishery is upweighted and for one is downweighted, but this is not currently the case for the tagging data. Accounting for this overdispersion requires that the right hand side of Eq. (1) is raised to a power (equivalent to multiplying the logarithm of the right hand side of Eq. (1) by an overdispersion factor). Several approaches (e.g., McAllister and Ianelli, 1997; Francis, 2011; Punt, in this issue) have been developed to estimate overdispersion factors for size-composition data, and these approaches have been used to weight the size-composition data for Aleutian Islands golden king crab and tiger prawns in the NPF. However, methods have not been developed to explore whether the growth model is mis-specified, whether there is overdispersion, and how tagging data used in size-structured stock assessment methods should be weighted.

This paper provides diagnostic statistics for evaluating the fits to tag-recapture data within size-structured integrated assessment models and for estimating an overdispersion factor for weighting tagging data. The approach follows the spirit of the approach of Francis (2011). The proposed diagnostics and weighting factors are illustrated using Aleutian Islands golden king crab and *P. semisulcatus* and *P. esculentus* in the NPF. These two cases were selected because although the assessments are both based on size-structured models, that for Aleutian Islands golden king crab is male-only, has an annual time step, and considers 5 mm size-classes. In contrast, the assessments for *P. semisulcatus* and *P. esculentus* are based on a sex-structured model that has a weekly time-step and 1 mm size-classes.

2. Material and methods

2.1. Diagnostic statistics

Two diagnostic statistics are considered. Both statistics are computed by time-at-liberty. The first diagnostic statistic is a comparison of frequencies of observed numbers recaptured by size-class versus the model-predicted distribution for size-classes at recapture. The latter distribution is:

$$\hat{P}_j = \sum_i p(j|k_i) \quad (3)$$

where $\hat{P}_j$ is the expected number of recaptures in size-class j, and $p(j|k_i)$ is the probability that the i[th] individual (which was released in size-class class k) was recaptured in size-class j (see Eq. (1)).

The second diagnostic statistic involves plotting the observed mean recapture size, $\bar{P}_L^{obs}$, versus release size-class L, along with the expected distributions of size-at-recapture, as a function of size-class-at-release, characterized by the expected (mean) size-at-recapture $\hat{\bar{P}}_L$ and the standard error of the observed mean size-at-recapture SE$[\hat{\bar{P}}_L]$, i.e.:

$$\hat{\bar{P}}_L = \sum_j \bar{L}_j p(j|L)\,;\ \mathrm{SE}[\hat{\bar{P}}_L] = \sqrt{\sum_j \frac{(\bar{L}_j - \hat{\bar{P}}_L)^2}{N_L}} \quad (4)$$

where $\bar{L}_j$ is the mid-point of size-class j, and N_L is the number of releases of animals in size-class L.

2.2. Data weighting

Francis weighting (Francis, 2011) involves defining the overdispersion factor for catch size-composition data as the inverse of the variance of the standardized residuals for the mean size of the catch. By analogy, the weight W that should be assigned to the tagging composition of the likelihood is given by:

$$W^{-1} = var\left[\frac{(\bar{P}_L^{obs} - \hat{\bar{P}}_L)}{\mathrm{SE}[\hat{\bar{P}}_L]}\right] \quad (5)$$

In common with the diagnostic statistics, the weighting factors can be computed separately by time-at-liberty and by sex.

Data weighting would entail applying standard methods for weighting compositional data (e.g., Punt, in this issue) and the above method for weighting the tagging data iteratively until convergence occurs. If the data are in conflict, it may be that this process will not converge, and the weights for some subsets of the data will increase without limit while the weights for other subsets will be reduced to zero (Punt, in this issue).

2.3. Applications

2.3.1. Aleutian Islands golden king crab

Siddeek et al. (in press) outline the stock assessment model used for golden king crab in the Aleutian Islands region. In relation to the tagging data, rectangular, king crab pots were used to capture crabs for tagging in all experiments, with the exception of the 1991 experiment where smaller, conical pots were used. Tagged animals were released during summer (July–September) before the fishery started. Location, date, and fishing depth were recorded for each pot retrieved. Upon pot retrieval, the carapace lengths (CL) of crabs were measured to the nearest millimetre and shell condition (old or new) recorded. Isthmus-loop ("spaghetti") tags were used to tag crabs (Gray, 1965), and tagged crabs were released on or adjacent to the capture location. The majority of tag recaptures were obtained