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ASSESSMENT AND TAG PROGRAM ADAPTION METHODS FOR EXPLORATORY FISHERIES IN THE CAMLR CONVENTION AREA: AN EXAMPLE APPLICATION FOR DIVISION 58.4.3A

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Abstract

A methodology for the initial stock assessment and adaption of catch limits and tagging rates is presented for new and exploratory stocks in the CAMLR Convention Area. The assessment methodology is designed to be able to accommodate mark–recapture data, catch (legal and illegal, unreported and unregulated (IUU)) and relative abundance data into an integrated assessment framework when more detailed data are not available – namely catch-at-length/age data and tagging data at-length/age. A simple algorithm, based upon the Petersen abundance estimator, is defined whereby catch limits and tagging rates can be adjusted together to define tagging levels that will produce an expected abundance estimate in the following year of a given precision whilst ensuring the sustainable exploitation of the stock as per the CCAMLR management procedure. The combination of the assessment and tagging rate adaption methods can then form the basis of an early management plan for exploratory fisheries. The accuracy of the catch limit and tag-rate adaption algorithm is tested using the assessment results for toothfish in CCAMLR Subarea 48.3 and the assessment method is applied to the catch (legal and IUU) and mark–recapture data for Patagonian toothfish (*Dissostichus eleginoides*) in Division 58.4.3a with catch limit and tag-rate recommendations being made given the assessment results and using the catch limit/tag-rate adaption algorithm.

Résumé

Présentation d'une méthodologie permettant l'évaluation du stock initial et l'adaptation des limites de capture et des taux de marquage pour les stocks exploités dans des pêcheries nouvelles ou exploratoires de la zone de la Convention CAMLR. La méthode d'évaluation est conçue de façon à ce que les données de marquage–recapture, les données de capture (licites et illicites, non déclarées et non réglementées (INN)) et les données d'abondance relative puissent être prises en compte dans une structure d'évaluation intégrée lorsque des données plus détaillées ne sont pas disponibles – à savoir des données de capture selon la longueur et l'âge et des données de marquage selon la longueur et l'âge. Un algorithme simple, basé sur l'estimateur d'abondance de Petersen, est défini pour permettre d'ajuster ensemble les limites de capture et les taux de marquage afin de déterminer les niveaux de marquage qui produiront avec une précision donnée une estimation de l'abondance prévue l'année suivante tout en garantissant l'exploitation durable du stock conformément à la procédure de gestion de la CCAMLR. La combinaison des méthodes d'évaluation et d'adaptation des taux de marquage peut ensuite constituer la base d'un premier plan de gestion des pêcheries exploratoires. L'exactitude de l'algorithme d'adaptation des limites de capture et des taux de marquage est testée au moyen des résultats de l'évaluation de la légine dans la sous-zone 48.3 de la CCAMLR ; la méthode d'évaluation est appliquée aux données de capture (légale et INN) et de marquage–recapture de la légine australe (*Dissostichus eleginoides*) de la division 58.4.3a et des recommandations sont émises sur les limites de capture et les taux de marquage compte tenu des résultats de l'évaluation et en utilisant l'algorithme d'adaptation pour la limite de capture et les taux de marquage.

Резюме

Представлена методика первоначальной оценки запаса и адаптации ограничений на вылов и коэффициентов мечения для новых и поисковых запасов в зоне действия Конвенции АНТКОМ. Эта методика оценки предназначена для того, чтобы включить данные мечения–повторной поимки, а также данные о вылове (законном и незаконном, нерегистрируемом и нерегулируемом (ННН)) и об относительной численности в структуру комплексной оценки, когда более подробные данные не имеются – а именно, данные о размерном/возрастном составе улова и данные мечения по длине/возрасту. Определен простой алгоритм, основанный на оценке численности по Петерсену, с помощью которого можно одновременно менять ограничения на вылов и коэффициенты мечения для определения уровней мечения, которые дадут ожидаемую оценку численности на следующий год при заданной точности и при этом обеспечат устойчивую эксплуатацию запасов в соответствии с процедурой управления АНТКОМ. Сочетание методов адаптации оценки и коэффициентов мечения затем может послужить основой плана первоначального управления для поисковых промыслов. Точность алгоритма адаптации ограничений на вылов и коэффициентов мечения проверяется по результатам оценки клыкача в Подрайоне 48.3 АНТКОМ, и этот метод оценки применяется к данным по вылову (законному и ННН) и по мечению–повторной поимке патагонского клыкача (*Dissostichus eleginoides*) на Участке 58.4.3а, при этом делаются рекомендации относительно ограничения на вылов и нормы мечения с учетом результатов оценки и с использованием алгоритма адаптации ограничения на вылов/коэффициента мечения.

Resumen

Se presenta una metodología para la evaluación inicial del stock y la adaptación de los límites de captura y las tasas de marcado para los stocks explotados por las pesquerías nuevas y exploratorias en el Área de la Convención. La metodología de evaluación está diseñada para incorporar los datos de marcado-recaptura, los datos de captura (legal e ilegal, no declarada y no reglamentada (INDNR)) y los datos de la abundancia relativa en un marco integrado de evaluación cuando no se dispone de datos más detallados – concretamente, de datos de captura por talla/edad y del marcado por talla/edad. Se define un algoritmo sencillo basado en el estimador de la abundancia de Petersen, que permite combinar los límites de captura y las tasas de marcado para definir los niveles de marcado que permitirán derivar una estimación de la abundancia esperada en el año próximo, con una precisión dada, asegurando a la vez la explotación sostenible del stock de acuerdo con el enfoque de ordenación de la CCRVMA. La combinación de los métodos de evaluación y de adaptación de la tasa de marcado podría entonces formar la base de un plan inicial de ordenación para las pesquerías exploratorias. La precisión del algoritmo de adaptación del límite de captura y la tasa de marcado se prueba utilizando los resultados de la evaluación de los stocks de austromerluza de la Subárea 48.3 de la CCRVMA, y el método de evaluación se aplica a los datos de captura (legal e INDNR) y de marcado-recaptura de la austromerluza negra (*Dissostichus eleginoides*) en la División 58.4.3a. Se formulan las recomendaciones sobre límites de captura y tasas de marcado inferidas de los resultados de la evaluación y utilizando el algoritmo de adaptación del límite de captura y la tasa de marcado.

Keywords: exploratory fisheries, interim management, Division 58.4.3a, *D. eleginoides*, CCAMLR

Introduction

Many of the major fisheries for *Dissostichus* spp. in the CAMLR Convention Area (Hillary et al., 2006; Dunn and Hanchet, 2007; Candy and Constable, 2008) now have fully integrated age-structured stock assessments, of differing features and complexities, that can deal with the large amount and variety of age- and length-structured data available. However, when there is a lack of reliable or sufficiently abundant data to parameterise these more complex models, which has become apparent in the case of by-catch species (Agnew et al., 2006) and for new and exploratory fisheries, then it would be useful to have a simpler alternative framework that can deal with less-detailed data but will still be able to give indications of stock abundance and potential catch limits. Tagging programs have provided the basis for assessment in CCAMLR Subarea 48.3 (Hillary et al., 2006) and in the Ross Sea (Dunn et al., 2007) and tagging is a pre-requisite for fishing in new and exploratory areas in the Convention Area. While minimum tagging rates (in terms of fish tagged per tonne landed) are set, there is currently a lack of a coherent methodology for adapting the tagging rate in conjunction with changes in catch limit and stock size towards attaining a certain precision in the stock assessment abundance estimates.

In this paper, the Pella-Tomlinson model (Pella and Tomlinson, 1969) is employed as the basis of the population dynamics – the model is a biomass dynamics model and so contains no direct age-structured information, apart from the intrinsic rate of increase parameter, r. This allows users to simply input catch data (legal and IUU) as biomass values, and both CPUE and mark–recapture information can also be included in the assessment model. A Bayesian framework is employed to attempt to account for the uncertainty in the model parameters. For the catch limit/tagging-rate adaption algorithm the Lincoln-Petersen (Seber, 1982) method is used to derive a formula that gives the expected coefficient of variation of the abundance estimate in terms of the number of releases and recaptures, which can in turn be expressed in terms of the tagging rate per tonne caught, the catch taken and the postulated underlying exploitable biomass. This relationship is shown to be extremely useful in terms of defining suitable catch levels and tagging rates required to obtain a given precision in the Petersen abundance estimate – assumed to be a reasonable proxy for the abundance estimate one might expect in the assessment. The aim is to provide an assessment and tag-program management process that can be used in the period when the tagging data can be used to estimate abundance, but the standard of data (both catch and tagging) is not yet good enough to move to a more realistic assessment model.

The catch and tagging data for the Patagonian toothfish (*Dissostichus eleginoides*) in Division 58.4.3a are used as the example stock and related assessment data – the precision of the length-frequency data is low compared to that in assessed areas and the number of tag-returns in particular is not large enough to allow splitting of these returns into their relevant length classes, as is customary in the more data-rich assessments. Any methodology that could be used in the new/exploratory/by-catch fishery context should be able to deal with both tagging data and be able to account for potential IUU fishing, and the Division 58.4.3a data gives an opportunity to test the proposed methodology in this context. To show the reliability of the precision relationship, the predicted abundance precision using the mark and recapture data for *D. eleginoides* in Subarea 48.3 is then compared to the precision in the abundance predicted by the integrated stock assessment. To show the potential usefulness of the catch limit and tagging-rate adaption algorithm, the assessment results were then used for *D. eleginoides* in Division 58.4.3a (in terms of sustainable catch limits as per the CCAMLR decision rules) and potential catch limits and tagging rates were looked at that would be expected to achieve a given abundance precision for the following year.

Population dynamics model

As mentioned, the Pella-Tomlinson biomass dynamics model is employed as the basis of the population dynamics model. The standard Schaefer production model is a special case of this model, and the dynamics of the biomass, B, are given by:

$$B_{y+1} = B_y + rB_y\left(1 - B_y^{m-1}\right) - C_y^L \big/ K - C_y^{IUU} \big/ K. \quad (1)$$

Here, y denotes the relevant year, r is the intrinsic rate of increase of the population, m is a parameter that governs the shape and symmetry of biomass growth and the MSY characteristics, and K is the carrying capacity, and the biomass is expressed relative to this value, for reasons that will be explained later on. The catches, C, are split into legal (L) and illegal, unregulated and unreported (IUU) so the tagging data may be included in the model, which will become clear later on. Such a model is a deliberate simplification and lacks many of the advantageous features of the more complex, age/length-structured type models – annual recruitment, selectivity functions, maturity and growth. However, in the Bayesian framework it is possible to incorporate a lot of the age-specific biological information into prior information for the r parameter.

To be able to include the tag data within the framework, there must be an effective tag attrition model that simulates the dynamics of the tagged fish over time. For a given release event, r, define the number of tags released as T_r. The predicted dynamics of this tagged population over time is as follows:

$$T_{r,y+1} = T_{r,y} \times \exp\left(-M - TS(\tau)\right) \times\left(1 - h_y^L - h_y^{IUU}\right). \quad (2)$$

For the first year of release, y^*, the number of tags in the population is immediately reduced by using the relevant tag mortality parameter. The shedding rate, TS, is a function of the time-at-liberty, τ, and M is simply the natural mortality. The tag-shedding rate, $TS(\tau)$, is usually estimated via double-tagging experiments (Hampton and Kirkwood, 1990) and (assuming double-tagging of fish) the tag-shedding rate employed here is the same as that assumed for *D. eleginoides* in Subarea 48.3 (Hillary et al., 2006) which is a rate of $\mu = 0.0036$ per year: $TS(\tau) = \exp(-\mu\tau)$. The legal and illegal harvest rates seen in equation (2) are simply defined as

$$h_y^{L,IUU} = \frac{C_y^{L,IUU}}{B_y \times K}. \quad (3)$$

Probability model for observations

For dealing with relative/absolute abundance data, such as CPUE or survey biomass data, a standard normal-log relationship can be assumed between the stock biomass and the abundance data, I:

$$p(I|...) = \prod_{y_1} \frac{1}{\sqrt{2\pi\sigma_{y,I}^2}} \exp\left(-\frac{\left(\ln\left(I_y\right) - \ln\left(\hat{I}_y\right)\right)^2}{2\sigma_{y,I}^2} \right) \quad (4)$$

where the predicted index, $\hat{I}$, is given by the following

$$\hat{I}_y = qB_y \exp\left(-\tau^m M\right) \times \left(1 - \tau^L h_y^L - \tau^{IUU} h_y^{IUU}\right). \quad (5)$$

Here q is the usual catchability constant and the τ parameters denote the proportions of natural, legal and IUU fishing mortality that occur before the abundance series was observed. For multiple series there will likely be multiple values of these estimated (q) and fixed (τ) parameters. The variance term in equation (4) is a composite of observation (bar) and process error (PE):

$$\sigma_{y,I}^2 = \bar{\sigma}_{y,I}^2 + \sigma_{PE}^2. \quad (6)$$

There are a number of recapture models that may be assumed – binomial and Poisson are just two of potentially many. For this work a (potentially over-dispersed) binomial recapture model is assumed, and the main reason for this choice is that this is the form of recapture model assumed in the CASAL (Bull et al., 2005) model most commonly used to assess *Dissostichus* spp. in the Convention Area.

Binomial recapture model

In a given year, the probability of recapturing a tagged fish in the legal fleet can be defined as follows:

$$\pi_y^r = h_y^L \times \pi_y^d \times \left(1 - \kappa_y h_y^{IUU}\right). \quad (7)$$

In equation (7) the π^d term is the tag detection and reporting probability; κ is the proportion of IUU fishing that has already occurred before the legal fleet was active. Given R recaptures and T tags in the population, the model for the recapture events is:

$$p\left(R_{r,y}|\ldots\right) = \frac{T_{r,y}!}{R_{r,y}!\left(T_{r,y} - R_{r,y}\right)!} \left(\pi_y^r\right)^{R_{r,y}} \left(1 - \pi_y^r\right)^{T_{r,y} - R_{r,y}}. \quad (8)$$

With regards to process error concerns for the recapture probability models, this is a model-specific issue and fairly technical. Specifics of the potential considerations required are detailed in Appendix 1.

Priors and penalties

When working in a Bayesian framework, there is a need to define prior distributions for the parameters and also define some penalty terms to dissuade the estimator from going into regions of parameter space that are not sensible. Estimated parameters are the q parameters (catchability) for the relative abundance series; the r and K parameters of the Pella-Tomlinson model (the shape parameter m is not estimated but fixed) and the process error parameters for the relative abundance series. For the q parameters, log(q) is estimated and a normal prior is assumed for these parameters – the reason for this is that this prior combines with the lognormal-likelihood to give a normal distribution for the conditional posterior, making it very easy and efficient to draw samples of q in the Gibbs sampling regime used to sample from the parameter posterior distribution. For K an improper uniform prior is assumed – no information is added to the likelihood for all values of K – but for r a lognormal prior is assumed, so that prior information on this parameter (which can be obtained as seen later) may be included if available, and if the data are lacking information on both r and K (as is often the case), one can constrain the estimator given the information available *a priori*. The process error parameters are assumed to have a uniform distribution. There are two penalties assumed within the objective function – the first is a catch-limit penalty whereby catch cannot exceed population size in a given year, and the second is a tagging penalty whereby a mean weight is assumed to define total stock numbers so that the number of tags released cannot exceed the number of fish in the population.

Algorithm for adapting the catch limit and tagging rate

In this section an algorithm for adapting catch limit and tagging rates is presented that works using a single release event, with a recapture event in the following year/season, as required. As mentioned, the Lincoln-Petersen abundance estimator (Seber, 1982) is employed and, from a fisheries context it relates, in any given year/season, the number of animals tagged and available to be caught, $\tilde{T}$; the number of animals recaptured, R; the number of fish in the reference catch (the catch taken from the population that is scanned for tags), C; and the total number of fish in the population, N. The (unbiased) estimate of the population, $\hat{N}$, is given by the following:

$$\hat{N} = \frac{(\tilde{T}+1)(C+1)}{(R+1)} - 1 \quad (9)$$

As described in Seber (1982), the associated variance of this estimate is

$$\text{var}(\hat{N}) = \frac{(\tilde{T}+1)(C+1)(\tilde{T}-R)(C-R)}{(R+1)^2(R+2)} \quad (10)$$

The coefficient of variation would then be given by

$$CV(\hat{N}) = \sqrt{\frac{(\tilde{T}-R)(C-R)}{(\tilde{T}+1)(R+2)(C+1)}} \quad (11)$$

if one assumes that $N >> 1$. The expression in equation (11) is too complex and catch here is expressed in numbers, yet one would ideally prefer to be able to include catch information as a biomass variable so some simplifications of this expression are proposed that are readily applicable to a catch limit management situation. First, assuming that $C >> R > 1$, then

$$\frac{C-R}{C+1} \approx 1 \quad (12)$$

and so

$$CV(\tilde{N}) \approx \sqrt{\frac{(\tilde{T}-R)}{(\tilde{T}+1)(R+2)}} \quad (13)$$

and is, in fact, never an under-estimator of the CV, given that the expression in equation (12) is always less than one. So it is possible to eliminate the catch numbers from the expression, but still present are the number of recaptures (which can never be known *a priori*). One of the key assumptions of such an estimator is that the tagged animals are well mixed (statistically speaking indistinguishable in terms of spatial distribution and catchability) and if this assumption is valid, then the exploitation rate experienced by the population, ξ, can be estimated by both the ratio of the number of recaptures to the number of tags available to be caught, $R/\tilde{T}$, and the catch biomass to the exploitable stock biomass, CB/EB. So, equation (13) can now be expressed purely in terms of the number of tags present in the population and the exploitation rate:

$$CV(\tilde{N}) = \sqrt{\frac{\tilde{T}(1\text{-}\xi)}{(\tilde{T}+1)(\xi\tilde{T}+2)}} \quad (14)$$

The final factor to consider is the issue of dispersion – the expression in equation (14) assumes a hypergeometric recapture model (Seber, 1982) but one might expect and indeed see (Hillary et al., 2006; Dunn et al., 2007) evidence of departures from the assumed recapture distribution in the actual tagging data. Specifically, the data might be more (over-dispersed) or less (under-dispersed) variable than would be predicted by whatever underlying recapture distribution was assumed (Poisson, binomial, hypergeometric etc.). For convenience, the over–under dispersion coefficient is denoted φ and it is simple to include this term in the expression for the abundance CV, as the CV will scale proportionally with the square root of the dispersion:

$$CV(\tilde{N}) = \sqrt{\frac{\varphi\tilde{T}(1-\xi)}{(\tilde{T}+1)(\xi\tilde{T}+2)}} \quad (15)$$

The expression for the CV in abundance in equation (15) now contains only the number of releases (via the tags available in the population which is obviously a combination of tagging/natural mortality, shedding rate and within-season recaptures) and the exploitation rate – how hard the population is being fished – and the dispersion value.

For a given non-zero exploitation rate (i.e. so that, theoretically, tags can be recovered from the tagged population) the CV in abundance will begin to decrease with approximately $1/\sqrt{\tilde{T}}$, which mirrors the classical inverse square-root law of standard error versus sample size. It must be pointed out though that really it is the number of recoveries that governs the precision, not simply the number of releases. Indeed the expression in equation (15) is simply a slightly more complex version of the $1/\sqrt{R}$ estimate of the abundance CV as stated in Seber (1982). For a given number of tag-releases, the CV in abundance is at a maximum at zero exploitation rate (as one would expect, given that the population is not being fished and, hence, there would be no recaptures to base an abundance estimate on). For an exploitation rate of one, the CV in abundance is zero – this is to be expected, given the entire population has been fished so one should know its size perfectly. The main point is that, the higher the number of tags in the population and the higher the exploitation rate, then the lower the CV in the abundance – these two factors combine to give a higher number of recaptures which, as stated, is the governing factor in the precision of the abundance estimate. With regards to the value of the dispersion φ it is clear that for over/under-dispersed tagging data (with dispersion greater/

Table 1: Catch (legal and IUU) for *Dissostichus eleginoides* in Division 58.4.3a.

Year	Legal catch	Estimated IUU catch
2004	0	0
2005	100	98
2006	88	0
2007	2	0

less than 1) the CV will increase/decrease and for truly binomial data the CV expression collapses into that in equation (14).

To demonstrate the actual applicability of the method, a comparison between the predicted abundance CV using the formula in equation (15) to the actual CV in abundance as predicted by the integrated stock assessment applied to this stock (Hillary et al., 2006; SC-CAMLR, 2006) is made. In 2005 the number of tags released that were not recaptured in the same season, *TR*, was 4 660. Given natural mortality, tag-induced mortality and tag-shedding rates *M*, *TM* and *TS* respectively, and the within-season recaptures, *RS*, the number of tags present in the population in the following year is:

$$\tilde{T} = TR \times \exp(-M - TM - TS) - RS. \qquad (16)$$

From the integrated stock assessment, the predicted exploitation rate was 0.08 for 2006 with 130 recaptures of tagged fish in 2006. Values of the dispersion in the assessment (specific to each release event) range from around 1.43 to 2.14. Equation (15) gives a predicted abundance CV of between 0.096 and 0.12, compared to the actual CV in the exploitable biomass in 2006 from the stock assessment of 0.103. The CV in the integrated stock assessment will be determined by all the recapture events (and their dispersion values) so it is encouraging that the prediction of the CV from the 2006 data using the proposed estimator encompasses the actual assessment CV.

The CV estimator in equation (15) is, by design, simplistic but should prove a useful tool for predicting the expected accuracy of an abundance estimate without having to resort to using a complex simulation – something of interest to the potential assessment and management of exploratory fisheries, given very little information is usually available to parameterise such a complex experimental design simulation.

The example case: *D. eleginoides* in Division 58.4.3a

Catch and IUU estimates for this stock are available from the CCAMLR Secretariat and these data go back to 2004. Table 1 details the legal and estimated IUU catch in Division 58.4.3a from 2004 to 2007.

With respect to the tagging program in this area, the tag-release data from 2005 and the recapture data for 2006 (i.e. no within-season recaptures) are used – 199 animals were tagged and released in 2005, none were recaptured in 2005 and five were recaptured in 2006. No animals were reported recaptured in any other areas.

Parameter estimation scheme

For the most basic case, the parameters to be estimated would be the population parameters *r* and *K* (henceforth, it is assumed that one would not estimate the shape parameter, *m)* and (if CPUE data are used) the catchability and process error terms in the CPUE probability model. In addition, if required, process error terms for the recapture models (Appendix 1) would also be defined. A Bayesian framework is assumed, so prior distributions for the estimated parameters must be defined. For the example case, a quasi non-informative uniform prior (Box and Tiao, 1973; Bernardo, 2003) for the carrying capacity, *K*, is assumed, but (given that only one year of recapture data and no long and contrasting CPUE series are available) an informative lognormal prior for *r* is parameterised, using the stock-recruit, maturity and natural mortality values for a similar stock (*D. eleginoides* in Subarea 48.3: Hillary et al., 2006) and life-history theory (see Appendix 1). There are no CPUE data, and no estimate process error terms for the recapture model are estimated (given only one recapture event); this defines the assessment parameter set and their associated prior distributions.

For the sake of simplicity, it is assumed that the shape parameter for the Pella-Tomlinson population, *m*, is set equal to 2, which collapses the model down to a Schaefer model, although the potential influence of this parameter could be explored for stocks such as these. The already defined catch limit (total catch may not exceed stock abundance) and tagging limit (there must be enough fish left in the population to tag) penalties were activated in the assessment runs.

The model itself is written in C++ and uses a Gibbs MCMC sampler (Geman and Geman, 1984) to obtain a sample from the joint posterior distribution of the two parameters *r* and *K*. The convergence of the resultant Markov chains was verified using standard MCMC convergence statistics (Brooks and Roberts, 1998) and 1 000 samples of the parameters (and the associated biomass trajectories) were retained from an initial sample of 100 000 (i.e. the chains were 'thinned' to remove any auto-correlation).

For the single recapture event the median and 95% credible interval of predicted tag-returns is 3.6 (1.1–8.4) where five recaptures were actually reported. While the 95% credible interval of expected recoveries easily includes the observed recoveries, the median predicted number of recoveries (and, albeit less so, the mean; not shown here) is lower than the observed number of recoveries. This would suggest that the model is perhaps overestimating the size of the population and this is largely driven by the penalty term which does not allow the stock to be completely taken in any given year. The uncertainty in *r* and *K* means that a population size that would, for the given catch data, return the observed number of tags would be very close to being fished-out, at least for certain parameter draws from the joint posterior. As a result, the model seems to slightly underestimate the number of tags returned, which is in turn a likely overestimate (at least with respect to the admittedly limited tag data) of population size. This potential overestimation of population size is driven by the catch-limit penalty acting to stop the population going into regions where the catch cannot be taken in a given year or years.

No dispersion terms were estimated for the recapture event for obvious reasons: there is only one recapture event and, clearly, the model can predict the observed recaptures (when thinking of the spread of predicted recaptures) without requiring any further process error. When one includes multiple release and recapture events this will, perhaps, not be the case. From Figure 1 it is clear that there is little predicted decline in the stock size from 2004 to 2007, but a large amount of uncertainty in the stock dynamics (with a CV of 0.722 for the biomass in 2007). From the predicted exploitation rates in Figure 2 it can be seen that historic rates (for both fleets) are also highly uncertain but probably never exceeded 8%. The 2007 exploitation rates are predicted to be very low.

Only tagging information was used in this particular example as standardised CPUE data were not available, however, even a short series of such data can add value. While a long and contrasting relative abundance series is usually required to accurately estimate at least abundance (*K*) if not both, abundance and reproductive potential (*r* and *K* together), likelihood profiles from established toothfish stock assessments (Hillary et al., 2006) have shown that even short, flat relative abundance data hold information. This information is on minimum likely values of parameters, such as *K*, which can be very important in an immature stock assessment, such as that detailed in this paper. It is for this reason that one should not easily discount the potential value of information of even short CPUE or survey series.

Potential catch limit scenarios

One of the main purposes of an assessment is to allow the setting of a catch/effort limit, given some harvest control rule. This model should still be considered a proto-assessment of sorts but one can still apply the CCAMLR decision rules (Hillary et al., 2006) to see what level of legal catch limit might be appropriate – the assumption is made that there is no IUU catch in the projection scenarios. With a sample of the biomass and population parameters one can easily assess a relevant catch limit, as per the CCAMLR decision rules, but one key extra component is incorporating the recruitment uncertainty used in the age-structured model projections (Hillary et al., 2006) for such stocks. This model has no annual recruitment dynamics, and to a degree the stock-recruitment uncertainty is accounted for in the *r* parameter's posterior distribution. However, to assume that there is no further uncertainty in the projected stock dynamics does not stand to reason so, while currently unable to assign a suitable value for this future uncertainty, its inclusion and any potential effects on management advice is explored. This future process error was introduced into the projection/management model as a lognormal multiplier of future stock biomass, for the given CV, not as additional uncertainty in either *r* or *K*.

A simple bisection algorithm was used to find the catch limit that satisfies the CCAMLR decision rules for this species and a long-term yield of 113 tonnes was predicted for the base-case (no future process error) and the depletion rule, not

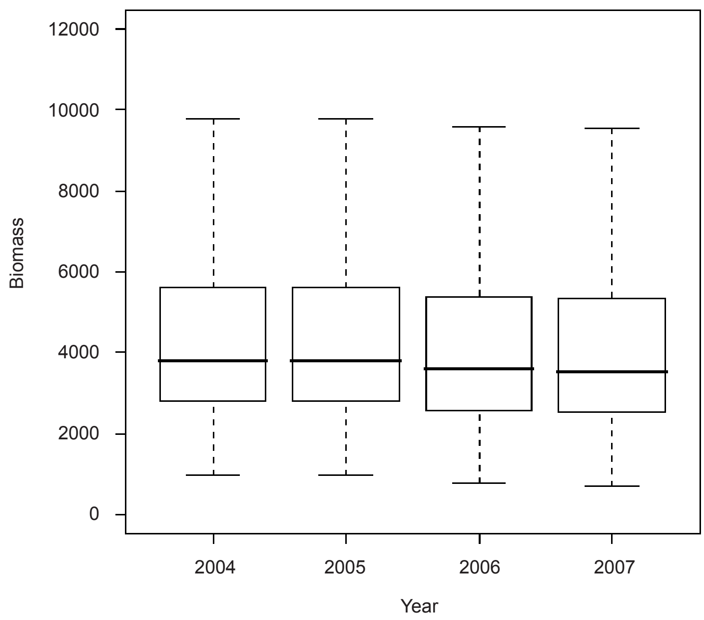

Figure 1: Box plot of the exploitable biomass dynamics of *Dissostichus eleginoides* in Division 58.4.3a showing that there is little predicted decline in the stock, but a lot of uncertainty (CV of current predicted biomass is 0.722).

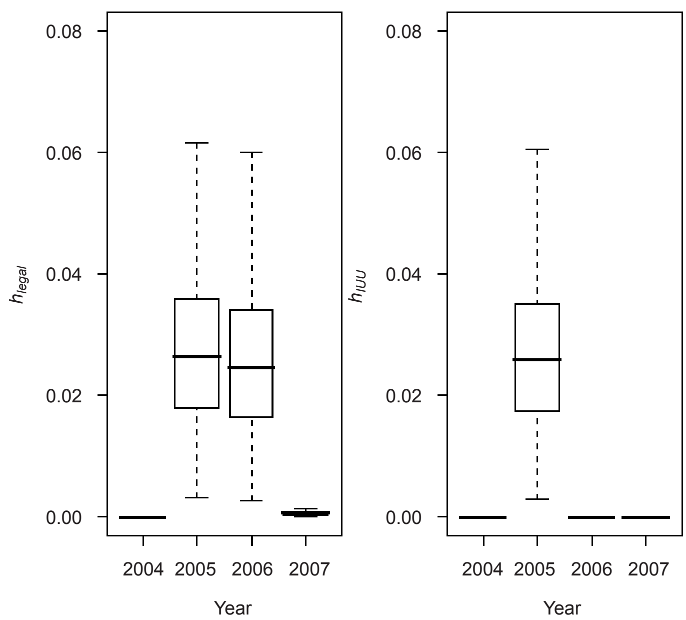

Figure 2: Predicted exploitation rates for the legal (left) and IUU (right) fleets. In years with no catches these will obviously be zero, and 2007 total harvest rate is predicted to be very low.

Table 2: The catch limit with a 5, 10 and 20% future process error CV. As with the no process error case, the depletion rule, not the escapement rule, dictated the catch limit. Percentage reduction in catch limit, relative to the catch limit set with no future process error, is given in parentheses.

Process error CV	5%	10%	20%
Catch limit	105 tonnes (7.1%)	103 tonnes (8.8%)	86 tonnes (24%)

Table 3: Required tagging rate per tonne given the four potential catch limit scenarios (with differing levels of process error used in the catch limit calculation) given the current median biomass that would give expected future abundance CVs of 0.33 and 0.5.

Catch limit:	113 tonnes	105 tonnes	103 tonnes	86 tonnes
CV = 0.33	2.4	2.8	2.9	4.2
CV = 0.5	0.63	0.69	0.76	1.1

the escapement rule, was the deciding factor in the estimated catch limit. Table 2 lists the results for different levels of future process error. What is interesting, is the potential effect that different levels of future process error seem to have. Table 3 shows the predicted catch limits for 5, 10 and 20% CVs for this error terms (assumed lognormal in the projection model) – there seemed to be little difference between a 5 and 10% error, but the 20% CV yielded a significant decrease in the catch limit set (nearly 25%), when compared to the catch limit predicted without any such error at all (113 tonnes).

For all cases, given the large uncertainty in the stock dynamics, it was the depletion rule, not the escapement rule, which dictated the catch limit. Given this fact, it is perhaps not so surprising that increasing the future process error CV might affect the predicted catch limit in such a non-linear way. The depletion rule is concerned with the proportion of time the stock spends below 20% of K (in this case), not its status relative to 20% of K in the final year of projection. One might then expect that increasing the future process error term would, in conjunction with already highly uncertain stock dynamics, rapidly increase the frequency with which the stock goes below the limit reference point of 20% of K. As has been seen with the other more complex toothfish assessments, it is the balance between the precision of current stock status and the level of future variability which ultimately determines which rule dominates the catch limit calculation, and by acquiring more informative data for a stock such as this one, future potential catch limits might not be so dominated by the depletion rule and also the relevant future process error levels.

The derived relationship between the expected abundance CV and the tagging rates and catch limits is now used to predict the tagging rates that, given the different levels of potential catch limit and current (median) biomass, would be required to give a future expected abundance CV of 0.33 and 0.5 respectively. From Table 3, which details the results, it is clear (and not unexpected) that lower catch limits require higher tagging rates to achieve the same expected abundance CV, and that a lower threshold abundance CV required lower tagging rates for the same catch limit. In relation to the fishery in Division 58.4.3a, the tagging rate in 2005 was two tags per tonne which, for a required abundance CV of 0.33, would likely not be adequate with a catch limit in the range suggested here. However, for a target CV of 0.5 this kind of tagging rate would be expected to be acceptable.

Discussion

This paper presents a framework for performing proto-stock assessments for exploratory fisheries and a framework for adapting an ongoing tagging program to better achieve strategic management goals. The assessment model itself is capable of incorporating IUU as well as legal catches, CPUE and mark–recapture data. Although not a pre-requisite, a Bayesian estimation approach is employed, to both account for a likely lack of available information on key stock-specific productivity parameters, and explicitly account for the uncertainty in the stock dynamics.

The applicability of the assessment model and tagging program adaption process is demonstrated using the catch (legal and IUU) and mark–recapture data for *D. eleginoides* in Division 58.4.3a and is, to the author's knowledge, the first attempt to assess the status of this stock. Given the estimated stock dynamics, long-term yields were calculated, as per the CCAMLR decision rules for this stock, assuming differing levels of future biomass-related process error. The calculated long-term yields were sensitive to the level of future process error assumed. There appeared to be substantial reductions in catch limit as the process error CV was increased from 5–10% to 20% – most likely an interaction between the uncertainty in the stock dynamics historically and the specifics of the depletion rule, given it was always the depletion rule that set the catch limit in these trials. Future catch limits for this stock ranged between 86 and 113 tonnes (depending on the level of process error assumed) which are all less than the historic 250 tonne limit set for this species in Division 58.4.3a, suggesting a potential decrease in the catch limit, at least until more data are collected, as this assessment is driven solely by one year of recapture data. As for optimal tagging rates, for the given catch limits, if the aim was to obtain a tagging dataset that would give us a predicted abundance CV of 0.33, then recent tagging levels (around 2 tags per tonne) were suggested to be too low and that a range of around 2.5 to 4 tags per tonne would be preferable. Clearly with a lower required abundance CV the tagging rate per tonne would be lower, and perhaps more preferable by the fishing industry, but one thing would be important to consider in this regard:

For this case, given the limited datasets available for assessment purposes, the assessment precision in terms of biomass is low (a CV of around 0.7 for current biomass), and in the catch limit calculations it is the depletion rule, not the escapement rule, that is the key in determining long-term yield. With higher tagging rates and more recoveries one would very likely gain a more accurate estimate of stock abundance, and this decreased uncertainty may well make way for higher and potentially more stable sustainable catch limits, given the expected decrease in abundance uncertainty and how this interacts with the decision rules.

More established toothfish stock assessments with tagging programs that have been running for several years show that consistent abundance information between the various tagging release (and subsequent recapture) events rapidly decreases the uncertainty in the key abundance parameters. The methodology presented here is designed to adapt single release events to give more accurate abundance estimates in the following year only. It appears that the reduction in abundance uncertainty may follow a more rapid decline than would be predicted by the simple methodology presented here, when one takes account of multiple release and recapture events, and future work should look to using simulation methods to explore the ramifications of such an effect on both management advice and tagging programs.

Conclusions

The framework presented in this paper could be most useful as an assessment and interim management method for new and exploratory fisheries and potentially by-catch species. It is these fisheries which have the least information and this type of approach allows the inclusion of more basic data (not disaggregated by age or length) and crucially tagging data, which has become so integral to other stock assessments. Furthermore, there is potential for using information derived from similar stocks with more mature stock assessments via the Bayesian approach. There is little to be gained by applying such a method to the more informative stock datasets, given that the CASAL-type approach has greater realism and data-inclusivity, but when the quality of information is not good enough for such an approach, then it is hoped that the framework developed in this paper will be useful.

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APPENDIX 1

Using life-history theory and Monte Carlo techniques to develop an informative prior for *r* is a relatively well established approach (McAllister et al., 2001) when it is likely that the data will lack the contrast required to estimate such a parameter. For this particular case, there is one recapture event with which to estimate stock size which, given the catches, suggests there is very little chance at all in obtaining a reliable estimate of *r* from the data alone. Normally, the *r* parameter is defined either as the solution to the Euler-Lotka equation (Fisher, 1930) or as the logarithm of the lead eigenvalue of the Leslie matrix, although in the paper by Myers et al. (1997) assumptions about the stock-recruit curve and maturity were made to reduce the equation for *r* to a simpler algebraic form. The FLR (Kell et al., 2007) software package FLBayes is used to estimate *r* given Monte Carlo distributions for the age-at-maturity, the slope of the stock-recruit curve at the origin (assumed Beverton-Holt and defined by steepness) and natural mortality. For steepness, a uniform distribution between 0.65 and 0.85 was assumed (so that the mean is the assumed value for *Dissostichus* spp. of 0.75), for *M* a value of 0.13 with a 10% CV, and for age-at-maturity a value of 13 years with again a CV of 10%. The resultant distribution for *r* had a mean of 0.15 and a CV of 0.24 – this was then used to parameterise an informative lognormal prior for *r* in the Bayesian analysis detailed in the main text.