Abalone spatial- and age-structured assessment model results for Zones A, B, C and D in 2005

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SUMMARY

A summary is presented of the results obtained from the 2005 Reference-case model that was fit to Zones A, B, CNP, CP and D in combination (hereafter referred to as the "combined ABCD model"). The full details of the spatial- and age-structured production model (ASPM) are provided in Appendix 1.

Model results estimate a pristine spawning biomass, B_0^{sp} (in tonnes), of 11930, 6190, 6890 and 7900 for Zones A, B, C and D respectively. The current spawning biomasses of abalone in Zones A, B and D are estimated at ca. 38 %, 40 % and 28 % respectively of their pre-exploitation levels. The "nonpoached" CNP and "poached" CP areas of Zone C are estimated at ca. 23 % and 10 % respectively with the inshore region particularly depleted: the model predicts zero remaining abalone in the inshore CP area. Natural mortality is reasonably estimated and in Zones C and D, the additional mortality estimated for 0-yr old abalone (due to the ecosystem-change effect) corresponds to near zero current annual survival rates. Poaching is severely impacting the resource, with Zone A particularly impacted in recent years. The combined Zones A-D model-predicted 2005 poaching estimate of 1150 MT (corresponding to the assumption that, on average, 19% of all poached abalone are confiscated) is more than six times the legal 2005 commercial TAC for these zones.

INTRODUCTION

This document provides preliminary results from fitting the abalone spatial- and age-structured production model (ASPM) to Zones/Subareas A, B, CNP, CP and D in combination (hereafter referred to as the "combined ABCD model") using the updated 2005 data as presented in WG/AB/05/05/01, WG/AB/05/05/04, WG/AB/05/05/06 and WG/AB/05/05/017. As the poaching catch-at-age data have been reworked this year, these data are shown in Table 1 of this document in the form as input to this year's model. The full details of the spatial- and age-structured production model are provided in Appendix 1 and 2 of this document (see also WG/AB/05/05/03). A summary of model parameters and some of the basic features of the model are given in Tables 2 and 3.

Although prior attempts have been made to model the Zone A component of the abalone resource, parameter estimation has generally proved problematic because the CPUE data for this Zone do not show much contrast. Specifically, model estimates of the pre-exploitation spawning biomass *K* for this zone tend to get very large. Previously we advised that the most pragmatic approach for handling this problem seems to be to fix as many parameters as possible and then to estimate either *K* or natural mortality *M*. Our preferred approach is to estimate *K* and fix *M* as it seems reasonable to assume a common *M* for the abalone resource.

Following last year's method, in the discussion below, we define "a reasonable estimate of *K*" as a value of *K* < 15 000 MT.

A summary of the main features of the combined ABCD Reference-case model is given below:

- i) Fix the inshore recruitment proportion for all Zones equal to 0.9;
- ii) Estimate all selectivity μ parameters (i.e. don't fix μ(CS) = 0 which would correspond to flat selectivity for the old abalone in the commercial catch);
- iii) Fix selectivity for the industry survey to 1 for all ages;
- iv) Poaching levels constrained to be not less than twice the no. of confiscations;
- v) Use poaching trend scenario II (MCM option);
- vi) Downweight all catch-at-age data by a multiplicative factor of 0.1 in the negative log likelihood;
- vii) "Old" survey and 2002 industry survey catch-at-age data are included and are downweighted by a factor of 0.1;
- viii) Fix the inshore-offshore migration parameter for subarea CP equal to HALF that for CNP;
- ix) Fix the inshore-offshore migration parameter for Zones B, A and D equal to the CNP migration parameter;
- x) Allow *M* to be age-dependent;
- xi) Estimate the rate/extent of decline for recruitment in Zones C and D (cf. Appendix 2).
- xii) Modify the likelihood function for the age-composition data by replacing the predicted proportions by the observed proportions when defining the variance of the proportions-at-age;
- xiii) assume that p_{poach} relates to the exploitation rate for poachers rather than the catch by this sector;
- xiv) Assume historic catch multiplier for Zone A: *Cmult* = 1.5
- xv) ignore the FIAS age-composition data for the deepwater strata.

Parameters

The Reference-case ABCD model estimates the following 29 parameters:

1) B_0^{sp} for A, B, CNP, CP and D [5 parameters]
2) Inshore-offshore migration parameter ρ (CP) [1 parameter]
3) Poaching estimate for yr with assumed highest level of poaching: $CP_{\max}$ estimated for A, B, C (combined), and D. [4 parameters]
4) $\boldsymbol{p}_{\textbf{poach}}$ (cf. xiii above) [1 parameter] – equates roughly to old assumption that 10% of the Zone C poaching take is from CNP;
5) $M_a : \mu$ $(\lambda = 0.2)$ where the formulation to model age-dependent mortality rates is $M_a = \mu + \frac{\lambda}{a+1}$. Natural mortality parameter assumed common to all Zones [1 parameter]

6) Two “recruitment failure” effect parameters common to CNP, CP and D: a steepness of recruitment failure parameter ν and a maximum increase in mortality parameter M_{max}. [2 parameters]
7) Three parameters for each of five selectivity functions (assumed common to all Zones) [15 parameters]

RESULTS

Model parameter estimates as well as log-likelihood contributions for the Reference case combined ABCD model and some sensitivities are summarised in Tables 5 and 6. Table 4 shows last year’s base-case model for comparison with this year’s model. The Reference-case model fit to the abundance indices and catch-at-age data are presented in Figs. 2 to 13.

Note that on average, the Reference-case model assumes a confiscation percentage success rate over the past 5 years in Zones A-D of 19% (A: 8%; B: 34%; C: 18%; D:14%) (Table 5). This is similar to the confiscation percentage success rate estimated by policing operations (Marcel Kroese, pers. commn) and to estimates from an attempt to estimate compliance confiscation success rates from data from the NGO Traffic Hong Kong office (Mackenzie and Burgener 2004).

Model results for the Reference case are similar to last year’s assessment except that a much higher poaching catch is estimated for Zone A, with the consequence that the estimated current depletion for Zone A (total spawning biomass at 38% of the pristine level and as low as 18% in the inshore area) is also lower than previous estimates. This is largely driven by the recent FIAS index of abundance which is an order of magnitude lower than the previous value.

The model shows generally reasonable fits to all indices with the exception of the fit to the CPUE trend for Zone A. However, the fit to the Zone A FIAS data is good (Fig. 5) and hence this may be adequate for current purposes, especially considering that attempts to improve the Zone A fit lead to considerable deterioration in the fits to other zones.

The historic production data from the 1960’s constitute a form of “CPUE” index and hence are compared to the combined (A+B+CNP+CP+D) commercially exploitable biomass trajectory (Fig. 8). They compare reasonably well suggesting that the model is adequately capturing the resource decline that took place during the 1960’s.

Catch-at-age comparisons

Comparisons between observed and model-predicted catch-at-age proportions corresponding to the 2002 Industry/MCM survey (Fig. 9) suggest these are reasonably good and represent substantial improvements on earlier attempts at fitting these data.

To assist in identifying potential yearly patterns in the catch-at-age residuals, the standardized residuals ($\varepsilon_{y,a} \rightarrow \frac{\left(\ell n\, p^i_{y,a} - \ell n\, \hat{p}^i_{y,a}\right)}{\sigma^i / \sqrt{\hat{p}^i_{y,a}}}$) have been plotted (Figs. 10-13). Some indications of systematic effects in the residuals are evident. For example, the model systematically predicts too many age 14-15 abalone caught during the 1980's (subarea CNP) and too many age 14 abalone corresponding to the commercial catch-at-age data for Zones A (Fig. 10), B (Fig. 11) and D (Fig. 13). This may reflect errors with the cohort slicing or that the model overestimates the number of older abalone. The Zone CNP commercial catch-at-age data is somewhat atypical as it shows a very large proportion of age 15+ animals – the model underestimates the proportion of animals in this age classes but not by a substantial amount (Fig. 12). The fit to the recent Zone A FIAS catch-at-age data is reasonable.

In general, the patterns of residuals do not indicate any very obvious model-misspecification. However, the selectivity functions may warrant some further exploration to see whether it is possible to improve the residuals for the fits to the proportions-at-age data to reflect better randomness and homoscedasticity. Although the poaching sector is thought to have possibly changed its mode of fishing during recent years by moving into deeper waters (A. MacKenzie, MCM, pers. commn), there are no obvious indications from the residuals of any changes in selectivity over time for the poaching or any of the other sectors.

Parameter estimates

Model results suggest a pristine spawning biomass, B_0^{sp}, of 2363 and 4523 tonnes respectively for subareas CNP and CP, and hence a total Zone C spawning biomass of ca. 6890 tonnes. The difference in the pristine spawning biomass estimates $B_0^{sp}[CNP]$ and $B_0^{sp}[CP]$ are in the main due to the partitioning of the historic zone C catch data between the two subareas. The pristine spawning biomass estimates for the other zones are on a similar scale to the Zone C estimates, with 11930, 6190 and 7900 tonnes estimated for Zones A, B and D respectively (Table 5). These values are similar to those used in last year's assessment.

The broad similarities in the catchability coefficient estimates $\hat{q}^{CPUE}$ (Table 5) for the Zones A, B, CP and D are as expected given their approximately equal habitat areas and the similarities in the standardised catch rates over much of the 1980s (Fig. 2-4). The reason for the much higher $\hat{q}^{CPUE}$ estimate for subarea CNP is presumably because of the assumption that commercial fishing was confined to the offshore model region only (in contrast to inshore and offshore regions as for the other zones) with effect from 1966.

The Reference-case selectivity estimates are illustrated in Fig. 1. The estimated commercial and recreational selectivity functions reflect the fact that the minimum legal size corresponds to an age of approximately 9 years, whereas the estimated poaching selectivity function reflects the fact that sub-legal-size animals are caught. The minimum size of animals caught has been set at 3 compared to 4 in last year's model. However, the Reference case model estimates that relatively few 3 and 4 year old animals are caught by the poaching sector (Fig. 1). When the selectivity of the 3 and 4-yr olds was forced to be higher in a model sensitivity, the corresponding estimated biomasses of both Zones A and D were unrealistically high. Thus the change to using the new poaching catch-at-age data this year has not had a great impact on model results (Table 5). Because the FIAS transects are situated inshore, the estimated FIAS selectivity function (Fig. 1) concurs with the observation of Tarr (1993) that the mean size of *H. midae* increases with depth.

Based on the results of the Reference-case model, the current spawning biomasses of abalone in Zones A, B and D are estimated at ca. 38 %, 40 % and 28 % respectively of their pre-exploitation levels (Table 5, Figs. 13-14, 16). The "nonpoached" CNP and "poached" CP areas of Zone C are estimated at ca. 23 % and 10 % (Table 5, Fig. 15) respectively of their pre-exploitation levels. The inshore region is particularly depleted, with the model predicting zero remaining abalone in the inshore CP area (Table 5).

An additional diagnostic that has at times been checked for the abalone model is the mean mass of abalone in the commercial catches. The AWG suggested that this should be checked for CNP for 2004 because of the recent size composition data differing from that in previous years. As shown in Fig. 17, the mean mass in 2004 has increased and this is reflected in the model as well. This has been attributed to n absence of small abalone in this area.

Sensitivity tests

Sensitivity to input values for model parameters, assumptions and model structure have been examined throughout the model development process, and changes and improvements made accordingly. However, it has not always been possible to rely on strict model selection criteria such as Likelihood Ratio Tests (*LRT*) and Akaike Information Criterion scores (*AIC*) (Burnham and Anderson 2002) because of the following:

i) Constraints are imposed on certain parameters such as the model poaching estimates. This was necessary because in some cases the best fit model estimates were clearly unrealistic. For example, in cases where the model estimate of the number of abalone poached from a zone was less than the known number of illegal abalone catches confiscated for that zone (e.g. Zone B – Table 5).

ii) The best fit estimate (using the Reference-case combined ABCD model) of the historic catch multiplier parameter C_{mult} (Zone A) is a factor of 3 or more but this value has been deemed unrealistically high by the AWG. This is because part of the motivation for introducing Zonal TAC's in 1986/7 was to better balance effort across the fishing grounds by, for example, setting the TAC in Zone A higher than the historic commercial catch from that part of the coast (Dichmont *et al*. 2000). There were compensating decreases in Zone B and the extremely popular Zone D (Dichmont *et al*. 2000), suggesting that historic catches in Zone A are not likely to have been as high as indicated by the model estimate. Thus even though freeing the C_{mult} parameter results in a significantly improved fit to the model overall, and to the Zone A CPUE data in particular, this parameter was fixed at what was considered a more realistic value of 1.5.

iii) The choice of Poaching Scenario II was essentially motivated on the basis that the AWG considered it to be based on the best interpretation of available information rather than being chosen on the grounds of formal model selection criteria.

The following sensitivity tests are presented in this document, where Case I) is termed the Reference Case:

a) Case II) Sensitivity to only using the same poaching catch-at-age data as used last year (i.e. the new data are not included and it is assumed that the youngest age of capture is 4 yrs and not 3 yrs);
b) Case III) Sensitivity to excluding the 2004 CNP commercial catch-at-age data;

c) Case IV) Sensitivity to fixing μ(CS) = 0 which would correspond to flat selectivity for the old abalone in the commercial catch;
d) Case V) Sensitivity to fixing (i.e not estimating separately) the Zone A pristine spawning biomass value as equal to the Zone B model estimate;
e) Case VI) Sensitivity to fixing the Zone A CPmax value (i.e. maximum poaching value) to a lower value than the (high) value estimated by the model in the Reference case; and
f) Case VII) Sensitivity to fixing historic catch multiplier to 1.0 instead of 1.5.

A summary of model results for these six sensitivity tests s presented in Tables 6 and 7.

Projections

Preliminary 20-yr projection results are given at the end of Tables 5-7 for a single scenario that assumes future commercial catches stay constant at the current levels (with recreational catches set at zero) and that future poaching is the average of the 2003 and 2004 estimated poaching levels (assumed to remain at this level for all future years).

Literature cited

Burnham, K.P. and D.R. Anderson 2002. *Model Selection and Multi-Model Inference: a Practical Information-Theoretic Approach*. Springer, New York. 353 pp.

Dichmont, C.M., Butterworth, D.S. and K.L. Cochrane 2000. Towards adaptive approaches to management of the South African abalone (*Haliotis midae*) fishery. S. Afr. J. Mar. Sci. **22**: 33-42.

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Appendix 1. The base-case inshore/offshore population model used for estimating resource dynamics parameters and projecting biomass trends

The description which follows is for Zone C but the same equations apply to the other Zones.

1 Dynamics

For each subarea, the dynamics of the **inshore** component are given by:

(A1) $N^I_{y+1,0} = r_I \cdot R(B^{sp}_{y+1})$

(A2) $N^I_{y+1,a+1} = \left(N^I_{y,a} e^{-\frac{M_a}{4}} - C^I_{y,a}\right) e^{-\frac{3M_a}{4}}$ $\quad 0 \le a \le 4$

(A3) $N^I_{y+1,a+1} = \left((1-\rho) \cdot N^I_{y,a} e^{-\frac{M_a}{4}} - C^I_{y,a}\right) e^{-\frac{3M_a}{4}}$ $\quad 5 \le a \le z\text{-}2$

(A4) $N^I_{y+1,z} = ((1-\rho) \cdot N^I_{y,z} e^{-\frac{M_z}{4}} - C^I_{y,z}) e^{-\frac{3M_z}{4}} + ((1-\rho) \cdot N^I_{y,z-1} e^{-\frac{M_{z-1}}{4}} - C^I_{y,z-1}) e^{-\frac{3M_{z-1}}{4}}$

where $N^I_{y,a}$ is the *inshore* number of abalone of age *a* at the start of Model year *y*,

ρ is the proportion of inshore animals of age *a* ($5 \le a \le z$) that move offshore at the start of Model year *y*,

$C^I_{y,a}$ is the total number of abalone of age *a* taken by recreationals and by poachers in Model year *y*, as well as the *inshore* number of abalone taken by the commercial fishery,

$R(B^{sp})$ is the recruitment vs spawner biomass relationship assumed (see below),

r_I is the proportion of the recruits which settle inshore,

M_a is the (time-invariant) natural mortality rate on abalone of age *a*, and

z is the largest age considered (i.e. corresponding to a "plus group").

Similarly, for each subarea, the dynamics of the **offshore** component are given by:

(A5) $N^O_{y+1,0} = r_O \cdot R(B^{sp}_{y+1})$

(A6) $N^O_{y+1,a+1} = \left(N^O_{y,a} e^{-\frac{M_a}{4}} - C^O_{y,a}\right) e^{-\frac{3M_a}{4}}$ $\quad 0 \le a \le 4$

(A7) $N^O_{y+1,a+1} = \left((N^O_{y,a} + \rho \cdot N^I_{y,a}) e^{-\frac{M_a}{4}} - C^O_{y,a}\right) e^{-\frac{3M_a}{4}}$ $\quad 5 \le a \le z\text{-}2$

(A8) $N^O_{y+1,z} = ((N^O_{y,z} + \rho \cdot N^I_{y,z}) e^{-\frac{M_z}{4}} - C^O_{y,z})\, e^{-\frac{3M_z}{4}} + ((N^O_{y,z-1} + \rho \cdot N^I_{y,z-1}) e^{-\frac{M_{z-1}}{4}} - C^O_{y,z-1})\, e^{-\frac{3M_{z-1}}{4}}$

where $N^O_{y,a}$ is the *offshore* number of abalone of age *a* at the start of Model year *y*,

r_O is the proportion of the recruits which settle offshore (= 1-r_I), and

$C^O_{y,a}$ is the *offshore* number of abalone of age *a* taken by the commercial fishery.

The commercial abalone fishery season currently extends from October to June but several historic changes in the commencement and closure dates for the commercial fishing season are on record. For reasons of internal consistency in the assessment process, a standard Model or fishing year *y* is thus taken to run from October of year *y*-1 to September of year *y*. The population model used here assumes pulse fishing (Pope's approximation – Pope 1984), rather than the more customary Baranov catch equations which assume continuous fishing through the year (Baranov 1918). Pope's approximation has been used in order to simplify computations. As long as mortality rates are not too high, the differences between the Baranov and Pope formulations will be minimal. The approximation of the fishery as a pulse catch at the start of each calendar year is here considered to be of sufficient accuracy given that most of the catch is made over the October-March period, and because the annual catches from this long lived resource are not that large a fraction of the overall biomass. This last reason also constitutes the justification for treating inshore-to-offshore movement as a pulse at the start of the Model year. The equations reflect the fact that catches are subtracted at the end of the first quarter of the Model year (i.e. in the middle of the October-March period of high catches). As the fishery-independent surveys (FIAS) are conducted only towards the end of the second quarter of the Model year, comparisons with the abundance indices obtained from FIAS are made at time $y+\frac{1}{2}$ in terms of the model whereas comparisons with the CPUE data are made at time $y+\frac{1}{4}$ in the model.

Because different sectors of the fishery exhibit different selectivity patterns with age, the following five sectors are explicitly differentiated in the model: the commercial fishery sector (mostly offshore); the recreational sector (mostly inshore); the poaching/illegal sector (mostly inshore), the fishery-independent survey (inshore and offshore) and the "old survey" (inshore and offshore).

The equations given below are applied separately to each of the inshore and offshore components of the two subareas CNP and CP.

The total number of abalone of age *a* caught each year ($C_{y,a}$) is given by:

(A9) $$C_{y,a} = \sum_s C^s_{y,a}$$

where *s* indicates the sector of the fishery (e.g. commercial, recreational, poaching).

The annual catch by mass (C^s_y) for sector *s* is given by:

(A10) $$C^s_y = \sum_{a=3}^{z} w_{y,a+1/4} C^s_{y,a}$$

where $w_{y,a+1/4}$ is the mass of an abalone of age *a* at the end of the first quarter of Model year *y* (note however that only the plus group mass $w_{y,z}$ is year-dependent in the model formulation pursued and that the plus group mass is modelled separately for the inshore and offshore components). The summation is taken from age *a* = 3 as no abalone of a size corresponding to ages below 3 are taken by any of the fishing sectors.

A von Bertalanffy growth equation is used to relate shell length ℓ (mm) to age in years (*t*), and is based on tagging data from Betty's Bay (Tarr 1995):

(A11) $$\ell(t) = \ell_\infty[1 - e^{-\kappa(t-t_0)}]$$

The relationship between *shell length* (mm) and abalone whole wet mass (g) is based on data from the Betty's Bay and Danger Point areas and is determined using the following power relationship:

(A12) $$w_{y,a} = w(y,t=a) = c\cdot(\ell)^d$$

Note that mass-at-age is year-independent for abalone of age $a < z$ and that $w_{y,a+\frac{1}{4}} = w(y,t=a+\frac{1}{4})$ is computed for use in calculating the sector-specific exploitable biomasses after the first quarter of each year (see below). However, the mass-at-age for the plus group varies over time, depending on the average age of the inshore and offshore plus group components in year *y*, $\bar{z}_y^I$ and $\bar{z}_y^O$ respectively, which are calculated as:

(A13) $$\bar{z}_y^I = \frac{\left(\bar{z}_{y-1}^I+1\right)\left(\left(1-\rho\right)N_{y,z}^I - C_{y,z}^I\right)e^{-M_z} + z\cdot\left(\left(1-\rho\right)N_{y,z-1}^I - C_{y,z-1}^I\right)e^{-M_{z-1}}}{N_{y,z}^I}$$

(A14) $$\bar{z}_y^O = \frac{\left(\left(\bar{z}_{y-1}^O+1\right)\left(N_{y,z}^O - C^O{}_{y,z}\right)+\left(\bar{z}_{y-1}^I+1\right)\rho\, N_{y,z}^I\right)e^{-M_z} + z\cdot\left(N_{y,z-1}^O+\rho\, N_{y,z-1}^I - C_{y,z-1}^O\right)e^{-M_{z-1}}}{N_{y,z}^O}$$

The above is an approximation only (as it ignores, e.g., the fact that catches are subtracted not at the start of the year but at the end of the first quarter of each year) but is considered sufficiently accurate for present purposes.

The recreational catch by mass in year *y* is given by:

(A15) $$C_y^s = \sum_{a=8}^{z-1} w_{a+1/4} N_{y,a}^I\left(1-\rho\right)e^{-M_a/4} S_a^s F_y^s + w_{y,\bar{z}_y+1/4}^I N_{y,z}^I\left(1-\rho\right)e^{-M_z/4} S_z^s F_y^s$$

and the poaching catch by mass in year *y* by:

(A16) $$C_y^s = w_{4+1/4} N_{y,4}^I\, e^{-M/4} S_4^s F_y^s + \sum_{a=5}^{z-1} w_{a+1/4}\, N_{y,a}^I\left(1-\rho\right)e^{-M/4} S_a^s F_y^s + w_{y,\bar{z}_y+1/4}^I\left(1-\rho\right)N_{y,z}^I\, e^{-M/4} S_z^s F_y^s$$

where S_a^s is the fishing selectivity-at-age for sector *s* (this pattern is assumed not to change over time), $w_{y,\bar{z}_y+1/4}^I$ is the mean mass of the inshore plus group with average age $\bar{z}_y + 1/4$ after the first quarter of Model year *y*, and F_y^s is the fishing "mortality" (strictly here that proportion of the numbers present after the first quarter of the Model year which are caught) at a reference age, set for these computations to be $a = 11$ for all sectors. Based on an analysis of confiscated abalone samples, the minimum age of animals assumed caught by the poaching sector is 4 years, so that for this sector $S_a^s = 0$ for $a < 4$. Note also (cf. Eqn. A16) that there is no inshore-offshore movement of animals aged four and younger. The commercial and recreational sectors are both assumed not to catch animals below the legal size limit, so that for these sectors $S_a^s = 0$ for $a < 8$.

In the case of the recreational sector (which reports in terms of numbers rather than mass), estimates of the annual catch by mass are computed using equation (A15) but it is necessary to first compute the fishing "mortality" F_y^s, using the following relation for the numbers caught in year *y*:

(A17) $$N_y^s = \sum_{a=8}^{z} N_{y,a}^I (1-\rho) e^{-M_a/4} S_a^s F_y^s$$

The relative proportions of the Zone C recreational catch (i.t.o. numbers) taken from the two subareas CP and CNP is assumed to be proportional to the relative lengths of the coastline (CP:CNP = 1:2).

The amount of poached abalone is estimated in terms of numbers and hence the following relation is used to compute the fishing "mortality" F_y^s for the poaching sector in year *y*:

(A18) $$N_y^s = \sum_{a=5}^{z} N_{y,a}^I (1-\rho) e^{-M_a/4} S_a^s F_y^s + N_{y,4}^I e^{-M_4/4} S_4^s F_y^s$$

Equations (A15) to (A18) assume that poaching and recreational activities occur exclusively in the inshore region. In the case of the commercial sector, the 0-2 m depth range is thought to be the only habitat that is almost never fished by commercial divers encroaching inshore because the shallow depth prevents boats from operating easily in these waters. Inshore encroachment by commercial divers is seen as being particularly common in areas that do not have residential houses along the beachfront. Thus, whereas this is thought to be a relatively minor problem in subarea CNP, inshore encroachment by commercial fishers is considered to have been a problem throughout the history of the fishery in subarea CP (and in all the other zones).

Thus, whereas the commercial catch by mass in year *y* in subarea CP is given by:

(A19) $$C_y^s = \sum_{a=8}^{z-1} w_{a+1/4} \left(N_{y,a}^I + N_{y,a}^O\right) e^{-M_a/4} S_a^s F_y^s + \left(w_{y,\bar{z}_y+1/4}^I N_{y,z}^I + w_{y,\bar{z}_y+1/4}^O N_{y,z}^O\right) e^{-M_z/4} S_z^s F_y^s$$

in subarea CNP, the commercial catch by mass in year *y* is given by equation (A19) above for years prior to 1967, and by equation (20) for years 1967 onwards:

(A20) $$C_y^s = \sum_{a=8}^{z-1} w_{a+1/4} \left(N_{y,a}^O + \rho\, N_{y,a}^I\right) e^{-M_a/4} S_a^s F_y^s + \left(w_{y,\bar{z}_y+1/4}^O N_{y,z}^O + \rho\, w_{y,\bar{z}_y+1/4}^I N_{y,z}^I\right) e^{-M_z/4} S_z^s F_y^s$$

where $w_{y,\bar{z}_y+1/4}^O$ is the mean mass of the offshore plus group with average age $\bar{z}_y + 1/4$ after the first quarter of Model year *y*.

The exploitable ("available") components of abundance for the recreational and poaching sectors are both expressed in terms of population numbers and are computed using Eqn. (A21) below for the recreational sector and Eqn. (A22) for the poaching sector:

(A21) $$B_y^{exp,s} = \sum_{a=8}^{z} S_a^s (1-\rho) N_{y,a}^I e^{-M_a/4}$$

(A22) $$B_y^{exp,s} = \sum_{a=5}^{z} S_a^s (1-\rho) N_{y,a}^I e^{-M_a/4} + S_4^s N_{y,4}^I e^{-M_4/4}$$

On the other hand, the exploitable components of abundance for the commercial sector operating in subareas CP (all years) and CNP (years prior to 1967) are computed as:

(A23) $$B_y^{exp,s} = \sum_{a=8}^{z-1} S_a^s w_{a+1/4}\left(N_{y,a}^I + N_{y,a}^O\right)e^{-M/4} + S_z^s\left(w_{y,\bar{z}_y+1/4}^I N_{y,z}^I + w_{y,\bar{z}_y+1/4}^O N_{y,z}^O\right)e^{-M/4}$$

and in the case of subarea CNP, exploitable biomass for years from 1967 onwards is computed as:

(A24) $$B_y^{exp,s} = \sum_{a=8}^{z-1} S_a^s w_{a+1/4}\left(N_{y,a}^O + \rho N_{y,a}^I\right)e^{-M_a/4} + S_z^s\left(w_{y,\bar{z}_y+1/4}^O N_{y,z}^O + \rho\, w_{y,\bar{z}_y+1/4}^I N_{y,z}^I\right)e^{-M_z/4}$$

In the case of FIAS, which for these purposes can be considered as another fishery sector *s*, "available" population numbers are given by:

(A25) $$N_y^{exp,s} = \sum_{a=5}^{z} S_a^s\left((1-\rho)N_{y.a}^I e^{-M_a/4} - C_{y,a}^I\right)e^{-M_a/4}$$

The summation is from age a = 5 as only animals larger than 100mm shell length are recorded so as to reduce uncertainty in the estimates due to the non-emergent/cryptic behaviour of juveniles. This corresponds to a minimum sampling age of approximately 5 years, so that for this sector $S_a^s = 0$ for $a < 5$.

The proportion of the resource harvested each year (F_y^s) by sector *s* is given by:

(A26) $$F_y^s = C_y^s \;/\; B_y^{exp,s}$$

so that numbers-at-age removed each year by the poaching and recreational sectors can be computed from:

(A27) $$C_{y,a}^s = S_a^s F_y^s (1-\rho) N_{y,a}^I e^{-\frac{M_a}{4}}$$ for $a \geq 5$ and

(A28) $$C_{y,a}^s = S_a^s F_y^s N_{y,a}^I e^{-\frac{M_a}{4}}$$ for $a = 4$ (poaching catches)

In the case of the commercial sector, the numbers-at-age removed each year from subarea CP is given by:

(A29) $$C_{y,a}^s = S_a^s F_y^s\left(N_{y,a}^I + N_{y,a}^O\right)e^{-M_a/4}$$

The commercial numbers-at-age removed from subarea CNP for each of the years prior to 1967 is given by equation (A29) above, and then by equation (A30) below as from 1967:

(A30) $$C_{y,a}^s = S_a^s F_y^s\left(N_{y,a}^O + \rho \cdot N_{y,a}^I\right)e^{-M_a/4}$$

2 Spawning biomass - recruitment relationship

The spawning biomass for each subarea in year *y* is given by:

(A31) $$B_y^{sp} = \sum_{a=1}^{z-1} f_a w_a\left(N_{y,a}^I + N_{y,a}^O\right) + f_z\left(w_{y,\bar{z}_y}^I N_{y,z}^I + w_{y,\bar{z}_y}^O N_{y,z}^O\right)$$

where f_a is the proportion of abalone of age *a* that are mature. Note that this formulation assumes independence of subareas in terms of recruitment, *viz*. the recruitment in one subarea depends only on the spawning biomass in that subarea and not on the biomass in adjoining subareas.

The number of recruits in each of the two subareas at the start of Model year *y* is related to the spawner stock size by a stock-recruitment relationship. A Beverton-Holt form (Beverton and Holt, 1957) is assumed, i.e. :

(A32) $$R\left(B_y^{sp}\right)=\frac{\alpha\, B_y^{sp}}{\beta + B_y^{sp}}$$

Note from equations (A1) and (A5) that the relative proportion of recruits settling inshore versus offshore in each subarea is determined by parameter r_I.

In order to work with estimable parameters that are more meaningful biologically, the stock-recruit relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, B_0^{sp}, and the "steepness" of the stock-recruit relationship, where "steepness" is the fraction of pristine recruitment that results when spawning biomass drops to 20% of its pristine level, i.e.

(A33) $$hR_0 = R\left(0.2B_0^{sp}\right)$$

from which it follows that:

(A34) $$h = 0.2\left[\beta + B_0^{sp}\right]/\left[\beta + 0.2B_0^{sp}\right]$$

and hence:

(A35) $$\alpha = \frac{4hR_0}{5h-1}$$ and:

(A36) $$\beta = \frac{B_0^{sp}(1-h)}{5h-1}$$

3 Starting values for biomass trajectories

The resource is assumed to be at the deterministic equilibrium (corresponding to an absence of harvesting) at the start of 1951, the initial year considered here. Given a value for the pre-exploitation spawning biomass B_0^{sp} of abalone, together with the assumption of an initial equilibrium age structure, it follows that on a subarea basis:

(A37) $$B_0^{sp} = R_0 \cdot \left[\sum_{a=1}^{z-1} f_a w_a \exp\left(-\sum\nolimits_{a'=0}^{a-1} M_{a'}\right) + f_z w_{0,\bar{z}_0} \frac{\exp\left(-\sum\nolimits_{a'=0}^{z-1} M_{a'}\right)}{1-\exp\left(-M_z\right)}\right]$$

which can be solved for R_0. Note that here $w_{0,\bar{z}_0}$ means the equilibrium value of this quantity prior to exploitation, computed using the equilibrium plus group mean age $\bar{z}_0$, where:

(A38)
$$\bar{z}_0 = z + \frac{e^{-M_{z-1}}}{1-e^{-M_z}}$$

The initial **inshore** numbers at age for the projections, corresponding to the deterministic equilibrium, are:

(A39)
$$\begin{aligned}
N^I_{0,0} &= r_I R_0 \\
N^I_{0,a+1} &= N^I_{0,a} e^{-M_a} && 0 \le a \le 4 \\
N^I_{0,a+1} &= N^I_{0,a}(1-\rho)e^{-M_a} && 5 \le a \le z-2 \\
N^I_{0,z} &= \frac{N^I_{z-1}(1-\rho)e^{-M_{z-1}}}{1-(1-\rho)e^{-M_z}}
\end{aligned}$$

Similarly, the initial **offshore** numbers at age, corresponding to the deterministic equilibrium, are:

(A40)
$$\begin{aligned}
N^O_{0,0} &= (1-r_I)R_0 \\
N^O_{0,a+1} &= N^O_{0,a} e^{-M_a} && 0 \le a \le 4 \\
N^O_{0,a+1} &= N^O_{0,a} e^{-M_a} + N^I_{0,a}\rho e^{-M_a} && 5 \le a \le z-2 \\
N^O_{0,z} &= \frac{N^O_{z-1}e^{-M_{z-1}} + \rho\left(N^I_{0,z}e^{-M_z} + N^I_{0,z-1}e^{-M_{z-1}}\right)}{1-e^{-M_z}} && a = z
\end{aligned}$$

It follows from the steady-state solutions to these equations that the inshore and offshore equilibrium plus group mean ages are as follows:

(A41)
$$\begin{aligned}
\bar{z}^I_0 &= z + \frac{(1-\rho)e^{-M_{z-1}}}{1-(1-\rho)e^{-M_z}} \\
\bar{z}^O_0 &= z + \frac{e^{-M_{z-1}}}{1-e^{-M_z}} + \frac{\rho\, e^{-M_{z-1}}}{\left(1-e^{-M_z}\right)\left(1-(1-\rho)e^{-M_z}\right)} \cdot \frac{N^I_{0,z}}{N^O_{0,z}}
\end{aligned}$$

Numbers-at-age for subsequent years are then computed by means of equations (A1)-(A36).

4 Parameter Values

Input parameters:
The following fixed parameter values are used in the model. The three von Bertalanffy parameters are from Tarr (1995) and the two mass-length relationship parameters were computed in this study:

ℓ_∞ = 172.76 mm

κ = 0.186 yr^{-1}

t_0 = 0 yr (and is assumed to correspond to October because Tarr (1995) tagged animals *in situ* in October and November)

c = 0.000098 gm/mm$^{3.155}$

d = 3.1549

with the computations assuming a plus group at age z = 15 yrs.

The proportion of abalone of age a that are mature is approximated by f_4 = 0.25, f_5 = 0.5, f_6 = 0.75 and f_a = 1 for $a \geq 7$ (Tarr 1995).

Moreover, the base-case assumes that h = 0.7. The base-case value of the steepness parameter h corresponds roughly to the median (h = 0.74) of a distribution of h values for stock-recruit functions fitted to the fisheries stock recruitment database developed by R.A. Myers and colleagues (Myers *et al*. 1995a).

Estimable parameters:

The sector-specific fishing selectivities S_a^s (including those for FIAS) are assumed to follow the functional form:

(A42) $$S_a^s = \frac{P \cdot e^{-\mu a}}{1 + e^{-\delta(a - \tilde{a})}}$$

where μ, δ and $\tilde{a}$ are three estimable parameters that control the shape of the function and P is simply a scalar fixed at a value such that S_{11}^s = 1.00. In essence, μ controls the slope of the right hand limb of the function, δ controls the steepness of the ascending left hand limb, and $\tilde{a}$ shifts the function to the left or right, all in relation to age a.

The assumption that commercial selectivity parameters are the same for the inshore and offshore compartments might seem severe, given the greatly different age profiles of abalone in the inshore and offshore areas. Note however that only a small component of the commercial fishing takes place in the inshore region (the numbers of commercially exploitable size in that region being small), so that even if the assumption is in error, the impact on results should not be substantial.

Under the assumption that the sampling methodology is the same inshore and offshore, the same selectivity parameters are used for the inshore and offshore FIAS sectors. A separate selectivity function is used to compute model-predicted catch-at-age when fitting to the "old survey" data and it is again assumed that the same parameters apply to the inshore and offshore regions.

5 The likelihood function

The likelihood function which is maximised in the parameter estimation process is based on equations developed by Geromont and Butterworth (1999). The model is fitted to CPUE and FIAS abundance and catch-at-age data from all sectors (commercial, recreational, poaching, old survey and FIAS) and the contributions by each of these to the negative of the log-likelihood (-*ln L*) calculated as described below.

Abundance data:

The likelihood contribution is calculated assuming that the observed abundance index is log-normally distributed about its expected value:

(A43) $$I_y^s = \hat{I}_y^s e^{\varepsilon_y^s} \qquad \text{or} \qquad \varepsilon_y^s = \ln(I_y^s) - \ln(\hat{I}_y^s)$$

where I_y^s is the abundance index for year *y* and sector *s*,

$\hat{I}_y^s = q^s\, B_y^{exp,s}$ is the corresponding model estimated value, where $B_y^{exp,s}$ is the model value for exploitable resource biomass corresponding to sector *s*, given by equations (A21- A24) (if the index refers to numbers, $B_y^{exp,s}$ is replaced by $N_y^{exp,s}$ - see equation (A25)).

q^s is the constant of proportionality for abundance series corresponding to sector *s*, and

ε_y^s from $N\left(0,\left(\sigma_y^s\right)^2\right)$.

The contribution of the abundance data to the negative of the log-likelihood function (after removal of constants) is given then by:

(A44) $$-\ln L = \sum_s \left[\sum_y \ln \sigma_y^s + \left(\varepsilon_y^s\right)^2 / 2\left(\sigma_y^s\right)^2 \right]$$

Variance unspecified: (CPUE abundance series)

In this case the standard deviation of the residuals for the logarithms of abundance series *s* is assumed to be independent of *y*, and is estimated in the fitting procedure by its maximum likelihood value:

(A45) $$\hat{\sigma}^s = \sqrt{\frac{1}{n_s}\sum_y \left(\ln I_y^s - \ln \hat{I}_y^s\right)^2}$$

where n_s is the number of data points for the abundance series corresponding to sector *s*.

The catchability coefficient q^s for sector *s*'s abundance index is estimated by its maximum likelihood value:

(A46) $$\ln \hat{q}^s = \frac{1}{n_s}\sum_y \left(\ln I_y^s - \ln \hat{B}_y^{exp,s}\right)$$

Variance specified: (FIAS data)

The catchability coefficient q^s for such a sector's abundance index is estimated by its maximum likelihood value which, for the case of a log-normal error distribution, is given by:

(A47) $$\ln\hat{q}^s = \frac{\sum_y 1\big/\left(\sigma_y^s\right)^2\left(\ln I_y^s - \ln\hat{B}_y^{exp,s}\right)}{\sum_y 1\big/\left(\sigma_y^s\right)^2}$$

where $\left(\sigma_y^s\right)^2 = \ln\left(1+\left(CV_y\right)^2\right)$ and the coefficient of variation (CV_y) of the resource abundance estimate for year *y* is input.

Catches-at-age:

The likelihood contribution is calculated assuming a log-normal error distribution and by making an adjustment (suggested by A. Punt, pers. commn) to weight in relation to the observed proportions so that undue importance is not attached to poorly represented age classes:

(A48) $$-\ln L = \sum_s\sum_y\sum_a\left[\ln\left(\sigma_c^s\Big/\sqrt{p_{y,a}^s}\right) + p_{y,a}^s\left(\ln(\delta + p_{y,a}^s) - \ln(\delta + \hat{p}_{y,a}^s)\right)^2\Big/2\left(\sigma_c^s\right)^2\right]$$

where $p_{y,a}^s = C_{y,a}^s\Big/\sum_{a'}C_{y,a'}^s$ is the observed proportion of abalone caught/sampled by sector *s* in year *y* that are of age *a*,

$\delta = 0.05$ is a constant included because not all of the $p_{y,a}^s$ values are nonzero,

σ_c^s is the standard deviation associated with the catch-at-age data for sector *s*, estimated in the fitting procedure by:

(A49) $$\sigma_c^s = \sqrt{\sum_y\sum_a p_{y,a}^s\left(\ln(\delta + p_{y,a}^s) - \ln(\delta + \hat{p}_{y,a}^s)\right)^2\Big/\sum_y\sum_a 1}$$

and $\hat{p}_{y,a}^s = \hat{C}_{y,a}^s\Big/\sum_{a'}\hat{C}_{y,a'}^s$ is the model-predicted proportion of abalone caught/sampled by sector *s* in year *y* that are of age *a*.

For subarea CNP, the earliest catch-at-age data are from 1980 and hence correspond to the period during which all commercial catches are assumed taken from the offshore region, so that $\hat{C}_{y,a}^s$ is given by:

(A50) $$\hat{C}_{y,a}^s = \left(N_{y,a}^O + \rho\, N_{y,a}^I\right)e^{-\frac{M_a}{4}}S_a^s F_y^s$$

whereas for subarea CP, $\hat{C}_{y,a}^s$ is determined as follows:

(A51) $$\hat{C}_{y,a}^s = \left(N_{y,a}^I + N_{y,a}^O\right)e^{-\frac{M_a}{4}}S_a^s F_y^s$$

The model-predicted recreational catch-at-age data is based on abalone assumed caught from both the CNP and CP subareas, such that for this sector:

(A52) $$\hat{C}^s_{y,a} = \left((1-\rho_{CNP}) N^{I_{CNP}}_{y,a} + (1-\rho_{CP}) N^{I_{CP}}_{y,a} \right) e^{-\frac{M_a}{4}} S^s_a F^s_y$$

except in the case of the single year's (1997) recreational catch-at-age data from subarea CP, for which $\hat{C}^s_{y,a}$ is computed as:

(A53) $$\hat{C}^s_{y,a} = (1-\rho) N^{I_{CP}}_{y,a} e^{-\frac{M_a}{4}} S^s_a F^s_y$$

The poached catch is taken primarily from the inshore region of subarea CP and hence Eqn. (A53) above is used to calculate $\hat{C}^s_{y,a}$ for the poaching sector.

The FIAS, "old survey" and industry survey catches-at-age are similarly incorporated into the negative of the log-likelihood, except that comparisons with observed proportions are made at mid-year rather than after the first quarter of each Model year. Data from the inshore FIAS stations is assumed to correspond to the inshore model region whereas data from the deep FIAS stations is assumed to correspond to the offshore model region. The 0-5 m and 5-15 m "old survey" data are assumed to respectively correspond to the inshore and offshore model regions. Thus, for each subarea, the inshore FIAS and inshore "old survey" model-predicted numbers of abalone of age *a* sampled are computed as:

(A54)
$$\hat{C}^s_{y,a} = \left(N^I_{y.a} e^{-\frac{M_a}{4}} - C^I_{y,a} \right) e^{-\frac{M_a}{4}} S^s_a F^s_y \qquad a < 5$$
$$\hat{C}^s_{y,a} = \left((1-\rho) N^I_{y.a} e^{-\frac{M_a}{4}} - C^I_{y,a} \right) e^{-\frac{M_a}{4}} S^s_a F^s_y \qquad a \geq 5$$

and $\hat{C}^s_{y,a}$ for the deep FIAS and offshore "old survey" are given by:

(A55)
$$\hat{C}^s_{y,a} = \left(N^O_{y.a} e^{-\frac{M_a}{4}} - C^O_{y,a} \right) e^{-\frac{M_a}{4}} S^s_a F^s_y \qquad a < 5$$
$$\hat{C}^s_{y,a} = \left(\left(N^O_{y.a} + \rho\, N^I_{y,a} \right) e^{-\frac{M_a}{4}} - C^O_{y,a} \right) e^{-\frac{M_a}{4}} S^s_a F^s_y \qquad a \geq 5$$

Data from the 2002 industry "total population size composition" survey are assumed representative of the entire Zone C area and hence $\hat{C}^s_{y,a}$ for the industry survey is computed by summing over mid-year inshore and offshore regions for both CNP and CP.

Inspection of the various –ln *L* contributions has revealed that the catch-at-age –ln *L* contributions are substantially larger than those for CPUE and the FIAS series, in part because they include many more data points as a result of summation over age as well as year. This is questionable as the $p^s_{y,a}$ values for a given *y* and *s* are not likely to be independent of each other (as implicitly assumed by equation (A48)), because the cohort-slicing method used to provide the catch-at-age information from length composition data likely introduces positive correlation. The catch-at-age –ln *L* contributions are thus downweighted by a multiplicative factor of 0.1, thereby downscaling these contributions to a similar order of magnitude as the CPUE and FIAS contributions.

References

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Appendix 2 – Incorporating the "ecosystem-change"effect

Method for modelling increased juvenile mortality

1. The following formulation was used to model age-dependent natural mortality rates M_a :

$$M_a = \mu + \frac{\lambda}{a+1} \qquad \text{(A2.1)}$$

where parameter μ was estimated in the model-fitting process and λ was either estimated or set equal to a constant (e.g. 0.2 for all cases shown here).

2. The number of new recruits to the population from 1994 onwards is no longer reduced to 10% of the 1993 level as in previous model versions, but is instead determined in the same way as for the earlier years, i.e. by using the Beverton – Holt stock-recruit function.

3. To model the rate and extent of the "recruitment failure" effect, two new parameters were introduced: a steepness of recruitment failure parameter ν and a maximum increase in mortality parameter M_{max}. An exponential increase in the M_0 mortality rate is assumed to have occurred as from year *y*, where different values of the starting year *y* were tried and the rate of increase in M_0 is determined by parameter ν . M_0 is assumed to increase continuously up to a maximum value M_{max} and then remains constant at this value from years y_{Mmax} forwards. For example, Combined B&C Model I in 2002 was as follows: μ = 0.138 (estimated), λ = 0.2 (fixed), first year with increase M_0 is 1990, ν = 0.227 (estimated) and M_{max} = 3.856 (estimated).

As *M* values are more easily understandable when converted to survival rates *S* (= the proportion of that age-class surviving from one year to the next), M_0 values will be discussed in terms of S_0 instead. The above parameter values thus translate into a situation where currently only 2.1% of abalone recruits survive into the second year compared to 71% in the absence of this "recruitment failure" effect.

Table 1. Catch at age matrix for the POACHED data from zones A, B, C and D for the period 1995-2005. The total number (*n*) of animals in each sample of lengths is shown in the second column. Note that the size data shown in italics are based on relatively small samples of confiscated abalone (≤500) and these data have thus been excluded from the model. The Reference-case model assumes that the Zone C data are all from the poached subarea CP. Data are from Maharaj et al. (2005) and are shown in terms of proportional abundance per age class per model year, with the 5- group representing abalone in ages 3 to 5 and the 12+ group representing all animals aged 12 years or older. The proportions in age classes 3 to 5 and 12 to 15+ have been lumped together to reduce the number of categories containing a proportional abundance less than 2% in any one year.

Zone A	**n**	**5-**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**
1996	*174*	*0.270*	*0.299*	*0.282*	*0.082*	*0.030*	*0.026*	*0.000*	*0.011*
1997	4586	0.111	0.074	0.141	0.163	0.116	0.108	0.060	0.228
1998	3776	0.045	0.072	0.139	0.165	0.117	0.120	0.074	0.270
2000	1370	0.247	0.184	0.196	0.162	0.081	0.064	0.022	0.045
2001	*177*	*0.000*	*0.000*	*0.017*	*0.024*	*0.072*	*0.113*	*0.108*	*0.666*
2002	608	0.291	0.217	0.219	0.124	0.048	0.040	0.031	0.030
2003	1494	0.374	0.122	0.134	0.104	0.068	0.062	0.028	0.108
2004	931	0.472	0.185	0.105	0.074	0.040	0.035	0.015	0.074
2005	*99*	*0.024*	*0.016*	*0.030*	*0.113*	*0.208*	*0.174*	*0.119*	*0.315*
Zone B	**n**	**5-**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**
1995	*112*	*0.000*	*0.000*	*0.045*	*0.118*	*0.320*	*0.277*	*0.093*	*0.148*
1996	*229*	*0.009*	*0.017*	*0.083*	*0.119*	*0.098*	*0.203*	*0.098*	*0.374*
1997	3180	0.095	0.085	0.114	0.124	0.095	0.104	0.062	0.321
1998	1466	0.025	0.045	0.084	0.136	0.133	0.118	0.063	0.395
2000	2734	0.103	0.087	0.144	0.186	0.132	0.129	0.061	0.157
2001	3028	0.159	0.108	0.142	0.127	0.090	0.093	0.066	0.214
2002	3237	0.227	0.110	0.152	0.143	0.094	0.100	0.052	0.122
2003	6821	0.286	0.135	0.139	0.121	0.073	0.075	0.040	0.130
2004	3321	0.432	0.106	0.102	0.080	0.052	0.049	0.035	0.144
2005	1929	0.288	0.174	0.161	0.110	0.062	0.058	0.034	0.113
Zone C	**n**	**5-**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**
1994	*473*	*0.004*	*0.025*	*0.150*	*0.325*	*0.203*	*0.144*	*0.071*	*0.077*
1995	*551*	***0.010***	*0.042*	*0.111*	*0.194*	*0.164*	*0.210*	*0.104*	*0.165*
1996	2409	0.082	0.156	0.211	0.158	0.086	0.070	0.029	0.208
1997	2933	0.083	0.085	0.135	0.148	0.099	0.112	0.061	0.276
1998	2403	0.215	0.141	0.149	0.143	0.084	0.082	0.042	0.144
2000	3043	0.068	0.077	0.121	0.146	0.097	0.095	0.062	0.333
2001	2315	0.176	0.144	0.207	0.183	0.098	0.077	0.031	0.083
2002	1150	0.149	0.151	0.154	0.122	0.087	0.099	0.053	0.185
2003	1516	0.145	0.069	0.093	0.096	0.064	0.076	0.055	0.402
2004	1063	0.392	0.222	0.109	0.095	0.031	0.037	0.017	0.097
2005	770	0.179	0.105	0.122	0.096	0.066	0.059	0.037	0.336
Zone D	**n**	**5-**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**
1994	*78*	*0.000*	*0.026*	*0.064*	*0.072*	*0.085*	*0.023*	*0.033*	*0.697*
1995	*358*	*0.003*	*0.014*	*0.042*	*0.079*	*0.086*	*0.064*	*0.036*	*0.677*
1996	*463*	*0.020*	*0.021*	*0.060*	*0.089*	*0.076*	*0.133*	*0.104*	*0.497*
1997	702	0.128	0.077	0.078	0.109	0.078	0.108	0.085	0.336
1998	1477	0.070	0.120	0.155	0.153	0.089	0.092	0.056	0.266
2000	795	0.052	0.088	0.135	0.155	0.064	0.093	0.060	0.352
2001	*351*	*0.009*	*0.028*	*0.043*	*0.067*	*0.055*	*0.121*	*0.112*	*0.566*
2002	1416	0.043	0.016	0.042	0.072	0.159	0.104	0.080	0.483
2003	1575	0.062	0.069	0.107	0.112	0.094	0.104	0.070	0.381
2004	581	0.039	0.059	0.083	0.137	0.073	0.080	0.065	0.463
2005	*107*	*0.095*	*0.110*	*0.112*	*0.123*	*0.123*	*0.099*	*0.050*	*0.286*

Table 2. Summary description of model parameters and definitions of other abbreviated terms utilised in the text. The parameters listed in the Table are defined in more detail in Appendix 1.

Parameter	Description	Units
$B_0^{sp} = K$	Pre-exploitation (assumed to be 1951) spawning biomass	MT
$B^{sp}, B^{sp}_{insh}, B^{sp}_{offsh}$	Spawning biomass (total per zone), Inshore spawning biomass, Offshore spawning biomass	MT
ρ	Rate at which inshore animals move offshore at the start of each Model year	yr^{-1}
r_I	Proportion of the recruits which settle inshore	-
$CP_{\max}$ (number) (zone)	The total number of abalone poached in the year corresponding to the poaching maximum for the zone under consideration	no.
$CP_{\max}$ (MT) (zone)	The poaching maximum in terms of mass	MT
C_{mult}	Historic catch multiplier for Zone A	-
p_{poach}	Parameter that specifies the relative exploitation rate effected by poachers in subareas CP and CNP	-
$M_a : \mu$ $(\lambda = 0.2)$ $\left(M_a = \mu + \frac{\lambda}{a+1}\right)$	Age-dependent mortality rate parameters; M_0 is the mortality rate of 0-yr old animals; M_{15} is the plus group mortality rate etc.	yr^{-1}
υ	Parameter that controls the steepness of the function describing an increase in 0-yr old mortality due to the ecosystem-change effect	-
$M_{\max}$	Maximum increase in 0-yr old mortality rate due to the ecosystem-change effect	yr^{-1}
$\hat{a}$ (sector)	Selectivity parameter for sector as indicated; shifts the selectivity function to the left or right	-
μ (sector)	Selectivity parameter that controls the slope of the right hand limb of the function	-
δ (sector)	Selectivity parameter that controls the steepness of the ascending left hand limb of the selectivity function.	-
Other definitions		
Zone	Fishery area / management unit: Zones A-G	
CNP, CP	Two subareas comprising Zone C, with CNP subject to less poaching historically than CP	
FIAS	Fishery Independent Abalone Survey	
FIAS N_{2003}/N_{1951}	FIAS depletion statistics expressing depletion in terms of *number* rather than mass	
CS	Commercial sector	
RS	Recreational sector	
PS	Poaching sector (corresponding to illegal catches)	
FS	Parameters pertaining to FIAS	
OS	Parameters pertaining to the Old Surveys conducted during the 1980's	
IS	Industry/MCM joint full population surveys conducted in 2002	
Co/Po_{yr}	Confiscations (i.t.o. number) as a proportion of the model-estimated number of animals poached in year *yr*.	
CI	Confidence Interval (typically 95% CI) determined by likelihood profile method	
LRT	Likelihood Ratio Test	
MSY	Maximum Sustainable Yield	
MSYL	Maximum Sustainable Yield Level	
TAC	Total Allowable Catch (annual catch allocation)	

Table 3. Summary of model assumptions and structure pertaining to the base-case combined ABCD model that simultaneously fits the model to the data for all the zones. All zones are assumed to comprise an inshore and offshore compartment and Zone C is further subdivided into a “poached” subarea CP and “nonpoached” subarea CNP. Parameter values are either fixed externally, “fixed” based on the Zone C values estimated in the model fit, or are estimated simultaneously for all zones.

	Common	Zone A	Zone B	Zone C – subareas CNP & CP	Zone D
B_0^{sp}		Estimate	Estimate	Estimate (2 par)	Estimate
M	Estimate (1 par)				
Estimate p_{poach}		n/a	n/a	Estimate (1 par)	n/a
Include catch multiplier parameter C_{mult}?		Yes – fix = 1.5	No	No	No
Poaching amount fixed or estimated in model-fitting process? Does it hit the constraint?		Estimate	Estimate (hits 50% constraint)	Estimate (1 par)	Estimate
Year poaching increase assumed to start		1997	1995	1994	1994
Year poaching at maximum level		2004	2002	1995	2002
Migration parameter ρ fixed or estimated in model-fitting process?	Estimate 1 common par for A, B, CNP and D			$\rho_{CP} = 0.5\rho_{CNP}$	
Proportion of recruitment occurring inshore fixed or estimated?		Fix = 0.9	Fix = 0.9	Fix = 0.9	Fix = 0.9
Downweight catch-at-age data?		Yes	Yes	Yes	Yes
Model ecosystem-change effect?		No	No	Yes (2 pars)	Yes – fix using Zone C parameter estimates
Selectivity parameters	Estimate 15 parameters simultaneously for all zones				

Table 4. **Model year 2004** results for comparison with current results. Best fit estimates of the pre-exploitation spawning biomass B_0^{sp} (or *K*) for the "poached" CP and "nonpoached" CNP areas of Zone C, and for each of Zones A, B and D, the estimated natural mortality estimates M_a, the inshore-offshore migration parameters ρ (yr^{-1}), the proportions of recruitment in each subarea that occur inshore versus offshore r_I, and the poaching maximum $CP_{\max}$ (i.t.o. NUMBERS), which is marked with an asterisk in cases where these values hit constraint boundaries. The $CP_{\max}$ estimates are also shown in terms of biomass and the years to which these estimates apply are given in the row below. Minimum values of the negative of the log-likelihood function are also shown. The estimated selectivity parameters are shown for the commercial sector (CS), recreational sector (RS), poaching sector (PS), FIAS (FS) and the old 1980's survey (OS). Note that for the 2002 industry survey (IS), $S_a^{IS} = 1$. Note also that all -*ln*L contributions from catch-at-age data have been multiplied by 0.1 as an *ad hoc* adjustment to compensate for likely positive correlation in these data.

Model	I) ABCD BASE_CASE Model scenario				
No. parameters	30				
Zone	**CNP**	**CP**	**B**	**A**	**D**
Poaching Scenario	II	II	II	II	II
Ave Confiscation %	**18%**		**39%**	**26%**	**10%**
B(0) ^{sp}	2064	4691	5721	9412	7733
ρ	0.000952	0.000476	0.000513	0.000513	0.000513
r^I	0.9	0.9	0.9	0.9	0.9
Cpmax (no.)		539497	9.33E+05	813890	415908
Cpmax (MT)		324	474	382	284
Cpmax (YEAR)		1995	2002	2004	2002
Cmult (Zone A)				1.50	
M_{15}	0.144				
Confiscation proportion	Zone C				
%Co/Po$_{2000}$	0.16		0.34	0.23	0.09
%Co/Po$_{2001}$	0.15		0.31	0.20	0.08
%Co/Po$_{2002}$	0.15		0.32	0.21	0.08
%Co/Po$_{2003}$	0.22		0.47	0.31	0.12
%Co/Po$_{2004}$	0.24		0.50	0.33	0.13
Ave prop over last 5 yrs	0.18		0.39	0.26	0.10
Mean CS Fishing mortality	0.10	0.13	0.15	0.04	0.07
Catches					
Ccomm(2004)	4	6	165	35	10
Crec(2004)	0.0	0.0	0.0	0.0	0.0
Cpoa(2004)	31.6	125.7	99.4	447.6	139.4
Catch total (2004) MT	35.6	131.7	264.4	482.6	149.4
	CNP	**CP**	**B**	**A**	**D**
Depletion statistics					
B^{sp}(2004)/*K* (Insh. + Offsh)	0.31	0.20	0.45	0.67	0.27
B^{sp}(2004)/*K* (Insh.)	0.21	0.08	0.43	0.66	0.13
B^{sp}(2004)/*K* (Offsh.)	0.39	0.40	0.49	0.67	0.46
B^{total}(2004)/*K*	0.28	0.18	0.50	0.69	0.24
$B^{commercial}$(2004)/*K*	0.29	0.24	0.36	0.61	0.33
FIAS N_{2004}/N_{1951}	0.14	0.03	0.48	0.66	0.09

	CNP	CP	B	A	D
-lnL CPUE	-46.050	-39.828	-37.712	-37.697	-31.840
-lnL FIAS	-7.712	9.350	-7.726	-6.643	-2.499
-lnL age CS	-7.867	-10.444	-15.788	-15.291	-7.889
-lnL age RS	-6.698	-0.007	-8.098	-1.406	-7.297
-lnL age PS		-1.053	-3.843	-1.905	1.385
-lnL age FIAS	-6.055	-0.537	-6.305	-2.004	-5.133
-lnL age OS inshore		-1.587	-1.378	-2.730	-1.175
-lnLage OS offsh.		-1.459	-0.977	-2.704	-0.475
-lnL age IS insh+offsh.	-0.847		-1.030		
-lnL zone subtotal	-120.796		-82.857	-70.379	-54.924
-*ln*L TOTAL	**-328.956**				
σ CPUE	0.084	0.093	0.126	0.126	0.161
σ age CS	0.114	0.090	0.075	0.078	0.116
σ age RS	0.063	0.201	0.057	0.124	0.074
σ age PS		0.159	0.095	0.121	0.198
σ age FIAS	0.063	0.124	0.074	0.125	0.090
σ OS insh.		0.040	0.048	0.051	0.060
σ OS offsh.		0.050	0.074	0.054	0.102
σ IS	0.062		0.035		
q CPUE	0.00205523	0.000744	0.000615	0.000224	0.000341

	CP	**B**	**A**	**D**
Depletion comp. yr	1981	1982	1986/87	1983
Insh OBS	0.33	0.67	0.33	0.36
Insh PRED	0.58	0.58	0.85	0.67
Offsh OBS	0.24	0.54	0.20	0.50
Offsh PRED	0.36	0.36	0.72	0.51

Table 5. **Model year 2005.** Best fit estimates of the pre-exploitation spawning biomass B_0^{sp} (or K) for the "poached" CP and "nonpoached" CNP areas of Zone C, and for each of Zones A, B and D, the estimated natural mortality estimates M_a, the inshore-offshore migration parameters ρ (yr^{-1}), the proportions of recruitment in each subarea that occur inshore versus offshore r_I, and the poaching maximum $CP_{\max}$ (i.t.o. NUMBERS), The $CP_{\max}$ estimates are also shown in terms of biomass and the years to which these estimates apply are given in the row below. The estimated selectivity parameters are shown for the commercial sector (CS), recreational sector (RS), poaching sector (PS), FIAS (FS) and the old 1980's survey (OS). Note that for the 2002 industry survey (IS), $S_a^{IS} = 1$.

Model	I) ABCD reference case					II) Sensitivity - with old poach caa data only					III) Sensitivity - without CNP caa data for 2004				
No. parameters			29					29					29		
Zone	**A**	**B**	**CNP**	**CP**	**D**	**A**	**B**	**CNP**	**CP**	**D**	**A**	**B**	**CNP**	**CP**	**D**
Poaching Scenario	II	II	II	II	II	II	II	II	II	II	II	II	II	II	II
Ave confiscation %	8%	34%	18%		14%	8%	34%	21%		11%	8%	34%	18%		14%
B(0)^{sp}	11928	6186	2364	4523	7895	16328	6008	2100	4691	7807	11928	6201	2326	4521	7895
ρ	0.000592	0.000592	0.000592	0.000296	0.000592	0.000531	0.000531	0.000917	0.000459	0.000531	0.000598	0.000598	0.000598	0.000299	0.000598
r^I	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Cpmax (no.)	3037060	1.19E+06		661088	330392	2955900	1.19E+06		594849	416154	3037150	1.19E+06		661109	330407
Cpmax (MT)	1181	572		338	207	1342	617		325	269	1179	572		338	207
Cpmax (YEAR)	2004	2002		1995	2002	2004	2002		1995	2002	2004	2002		1995	2002
Cmult (Zone A)	1.50					1.50					1.50				
Ppoach			0.29					0.29					0.29		
M_0			0.318					0.318					0.319		
M_1			0.218					0.218					0.219		
M_2			0.185					0.185					0.185		
M_3			0.168					0.168					0.169		
M_4			0.158					0.158					0.159		
M_5			0.152					0.152					0.152		
M_6			0.147					0.147					0.147		
M_7			0.143					0.143					0.144		
M_8			0.140					0.140					0.141		
M_9			0.138					0.138					0.139		
M_{10}			0.136					0.136					0.137		
M_{11}			0.135					0.135					0.135		
M_{12}			0.134					0.134					0.134		
M_{13}			0.132					0.132					0.133		
M_{14}			0.132					0.132					0.132		
M_{15}			0.131					0.131					0.131		
ν (steepness of recruitment failure)			0.2463					0.2482					0.2463		
Mmax (Recruitment failure scale parameter|)			9.99998					9.99998					9.99998		
h	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
a(CS)			8.99933					8.99822					8.99936		
a(RS)			8.95777					8.99895					8.95637		
a(PS)			4.99633					5.76854					4.99642		
a(FS)			5.81674					6.22234					5.80402		
a(OS)			6.84223					6.79682					6.84222		
a(IS)			-					-					-		
μ(CS)			0.000718					0.000452					0.000747		
μ(RS)			0.000776					0.000467					0.000758		
μ(PS)			7.89E-05					0.000243					8.02E-05		
μ(FS)			0.001141					0.000596					0.001116		
μ(OS)			0.001165					0.001174					0.001165		
μ(IS)			-					-					-		
δ(CS)			593.943					324.209					594.049		
δ(RS)			3.51806					382.531					3.54213		
δ(PS)			348.232					1.58194					347.876		
δ(FS)			1.12728					0.900446					1.13466		
δ(OS)			0.676136					0.637555					0.676124		
δ(IS)			-					-					-		

Table 5 cont. Minimum values of the negative of the log-likelihood function. Note that all -*ln*L contributions from catch-at-age data have been multiplied by 0.1 as an *ad hoc* adjustment to compensate for likely positive correlation in these data. Projection results shown assume that future commercial and poaching catches remain at the current levels.

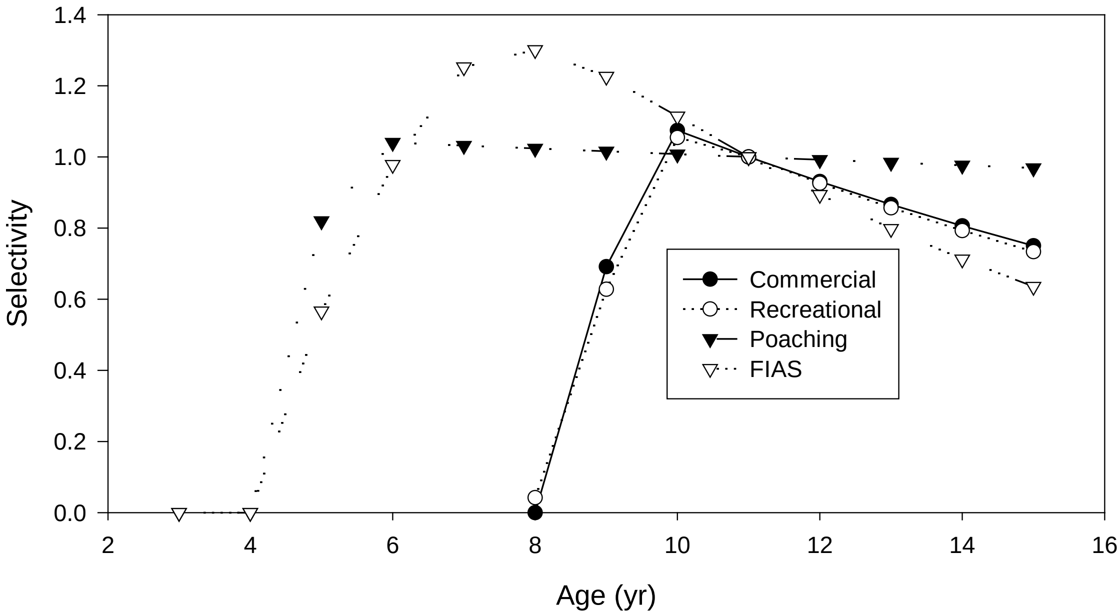
Model	I) ABCD reference case					II) Sensitivity - with old poach caa data only					III) Sensitivity - without CNP caa data for 2004			
	A	**B**	**CNP**	**CP**	**D**	**A**	**B**	**CNP**	**CP**	**D**	**A**	**B**	**CNP**	**CP**
-*ln* L CPUE	-27.773	-37.384	-45.864	-46.145	-31.507	-33.549	-35.963	-45.685	-44.395	-31.376	-27.805	-37.327	-45.866	-46.113
-*ln* L FIAS	-5.653	-2.409	-7.418	9.276	-2.128	8.521	-2.909	-7.743	8.448	-2.175	-5.645	-2.389	-7.420	9.300
-*ln* L age CS	-13.032	-18.411	-6.864	-10.601	-8.938	-11.145	-18.137	-6.572	-11.445	-9.459	-13.188	-18.414	-7.692	-10.547
-*ln* L age RS	-1.504	-8.218	-7.054	-0.057	-6.998	-1.076	-8.023	-6.678	-0.108	-7.799	-1.504	-8.220	-7.076	-0.060
-*ln* L age PS	-3.306	-2.289		-1.182	-2.370	-2.487	-3.549		0.210	2.694	-3.294	-2.273		-1.158
-*ln* L age FIAS	-6.209	-7.635	-4.834	-0.030	-4.386	-1.652	-6.678	-5.172	-0.100	-5.631	-6.222	-7.630	-4.872	-0.033
-*ln* L age OS inshore	-2.968	-1.245		-1.609	-1.072	-3.290	-1.312		-1.541	-1.178	-2.951	-1.246		-1.614
-*ln* Lage OS offsh.	-2.814	-0.970		-1.207	-0.729	-2.962	-1.085		-1.448	-0.669	-2.811	-0.969		-1.210
-*ln* L age IS insh+offsh.		-0.860	-0.659				-1.010	-0.672				-0.856	-0.662	
-*ln* L zone subtotal	-63.258	-79.420	-124.019		-58.130	-47.640	-78.666	-122.893		-55.592	-63.419	-79.324	-124.787	
-*ln* L TOTAL			**-324.826**					**-304.791**					**-325.464**	
σ CPUE	0.204	0.139	0.090	0.055	0.175	0.162	0.147	0.090	0.060	0.176	0.203	0.139	0.090	0.055
σ age CS	0.093	0.067	0.122	0.091	0.111	0.105	0.068	0.125	0.086	0.107	0.092	0.067	0.116	0.092
σ age RS	0.120	0.056	0.059	0.187	0.077	0.140	0.057	0.063	0.174	0.069	0.120	0.055	0.059	0.186
σ age PS	0.094	0.138		0.166	0.116	0.105	0.100		0.194	0.250	0.095	0.139		0.167
σ age FIAS	0.061	0.068	0.079	0.146	0.101	0.139	0.078	0.074	0.142	0.083	0.060	0.068	0.078	0.145
σ OS insh.	0.046	0.054		0.039	0.065	0.039	0.051		0.041	0.059	0.046	0.054		0.039
σ OS offsh.	0.052	0.075		0.061	0.084	0.049	0.068		0.050	0.088	0.052	0.075		0.061
σ IS		0.043	0.078				0.036	0.077				0.043	0.078	
q CPUE	0.000186	0.000574	0.00247607	0.000992	0.000353	0.000115	0.000605	0.00208729	0.000831	0.00035	0.000187	0.000571	0.00256026	0.000993
Confiscation percentage			Zone C					Zone C					Zone C	
%Co/Po$_{1994}$		0.04	0.02		0.02		0.04	0.02		0.01		0.04	0.02	
%Co/Po$_{1995}$		0.15	0.07		0.06		0.15	0.08		0.05		0.15	0.07	
%Co/Po$_{1996}$		0.19	0.09		0.08		0.19	0.10		0.06		0.19	0.09	
%Co/Po$_{1997}$	0.02	0.09	0.04		0.04	0.02	0.09	0.05		0.03	0.02	0.09	0.04	
%Co/Po$_{1998}$	0.03	0.14	0.06		0.06	0.03	0.14	0.07		0.04	0.03	0.14	0.06	
%Co/Po$_{1999}$	0.03	0.14	0.07		0.06	0.03	0.14	0.08		0.05	0.03	0.14	0.07	
%Co/Po$_{2000}$	0.06	0.27	0.13		0.11	0.07	0.27	0.15		0.09	0.06	0.27	0.13	
%Co/Po$_{2001}$	0.06	0.24	0.11		0.10	0.06	0.24	0.13		0.08	0.06	0.24	0.11	
%Co/Po$_{2002}$	0.06	0.25	0.12		0.10	0.06	0.25	0.14		0.08	0.06	0.25	0.12	
%Co/Po$_{2003}$	0.09	0.37	0.17		0.15	0.09	0.37	0.20		0.12	0.09	0.37	0.17	
%Co/Po$_{2004}$	0.08	0.35	0.17		0.14	0.08	0.35	0.19		0.11	0.08	0.35	0.17	
%Co/Po$_{2005}$	0.12	0.50	0.33		0.20	0.12	0.50	0.37		0.16	0.12	0.50	0.34	
Ave prop over last 5 yrs	**0.08**	**0.34**	**0.18**		**0.14**	0.08	0.34	0.21		0.11	**0.08**	**0.34**	**0.18**	
Mean CS Fishing mortality	0.03	0.12	0.11	0.15	0.05	0.02	0.13	0.10	0.13	0.05	0.03	0.12	0.11	0.15
Catches														
Ccomm(2005)	10	145	4	6	10	10	145	4	6	10	10	145	4	6
Cpoa(2005)	890.2	86.3	83.1	4.6	90.5	1140.5	91.8	49.8	11.3	111.6	889.2	86.4	82.2	4.6
Catch total (2005) MT	900.2	231.3	87.1	10.6	100.5	1150.5	236.8	53.8	17.3	121.6	899.2	231.4	86.2	10.6
	A	**B**	**CNP**	**CP**	**D**	**A**	**B**	**CNP**	**CP**	**D**	**A**	**B**	**CNP**	**CP**
Depletion comp. yr	1986/87	1982		1981	1983	1986/87	1982		1981	1983	1986/87	1982		1981
Insh OBS	0.33	0.67		0.33	0.36	0.33	0.67		0.33	0.36	0.33	0.67		0.33
Insh PRED	0.86	0.59		0.46	0.65	0.90	0.56		0.53	0.64	0.86	0.59		0.47
Offsh OBS	0.20	0.54		0.24	0.50	0.20	0.54		0.24	0.50	0.20	0.54		0.24
Offsh PRED	0.75	0.36		0.28	0.48	0.81	0.34		0.31	0.48	0.75	0.36		0.28
Depletion statistics														
$B^{sp}(2005)/K$ (Insh. + Offsh)	0.38	0.40	0.23	0.10	0.28	0.52	0.37	0.26	0.14	0.24	0.38	0.40	0.22	0.10
$B^{sp}(2005)/K$ (Insh.)	0.18	0.36	0.12	0.00	0.15	0.37	0.33	0.12	0.00	0.10	0.18	0.36	0.12	0.00
$B^{sp}(2005)/K$ (Offsh.)	0.61	0.44	0.35	0.30	0.44	0.71	0.41	0.35	0.32	0.42	0.61	0.44	0.34	0.30
$B^{total}(2005)/K$	0.43	0.44	0.21	0.09	0.26	0.56	0.41	0.23	0.12	0.22	0.43	0.44	0.20	0.09
$B^{commercial}(2005)/K$	0.36	0.32	0.20	0.12	0.34	0.47	0.27	0.26	0.16	0.30	0.36	0.33	0.20	0.12
FIAS N_{2005}/N_{1951}	0.09	0.48	0.03	0.00	0.09	0.31	0.40	0.05	0.00	0.07	0.09	0.48	0.03	0.00
Projections	**A**	**B**	**CNP**	**CP**	**D**	**A**	**B**	**CNP**	**CP**	**D**	**A**	**B**	**CNP**	**CP**
Ccomm(2006)	10.0	145.0	4.0	6.0	10.0	10.0	145.0	4.0	6.0	10.0	10.0	145.0	4.0	6.0
Cpoa(2006) (NUMBERS)	2698420	226187	109015	86626	123401	2626310	226194	63387	105014	155433	2698510	226174	107702	87310
Cpoa(2006) (MT)	758	98.6	48.1	0.8	99	1227	105.5	38.7	2.9	121	757	98.7	44.7	0.8
Catch total (2006) MT	768.1	243.6	52.1	6.8	109.2	1236.8	250.5	42.7	8.9	131.4	767.3	243.7	48.7	6.8
$B^{sp}(2010)/K$	0.27	0.41	0.09	0.05	0.13	0.34	0.38	0.12	0.07	0.11	0.27	0.42	0.09	0.05
$B^{sp}(2025)/K$	0.16	0.42	0.03	0.02	0.13	0.22	0.39	0.06	0.04	0.09	0.16	0.43	0.03	0.02
$B^{sp}(2025)/Bsp(2005)$	0.70	1.04	0.42	0.54	0.46	0.66	1.04	0.47	0.55	0.46	0.70	1.04	0.42	0.54
$B^{sp}(2025)/Bsp(2005)$	0.42	1.06	0.13	0.25	0.46	0.42	1.06	0.24	0.33	0.38	0.42	1.07	0.13	0.25

Table 6. Sensitivity to assuming mu(cs) = 0 and to fixing the Zone A pristine spawning biomass value equal to the Zone B estimate.

Model	I) ABCD reference case					IV) Sensitivity - fix mu (cs) = 0.0					V) Fixing Zone A B0 to the Zone B value				
No. parameters			29					28					28		
Zone	**A**	**B**	**CNP**	**CP**	**D**	**A**	**B**	**CNP**	**CP**	**D**	A	B	CNP	CP	D
Ave confiscation %	8%	34%	18%		14%	8%	34%	17%		14%	18%	34%	18%		7%
B(0)sp	11928	6186	2364	4523	7895	11928	5765	2314	4480	7895	6551	6551	2266	4638	12525
Cpmax (no.)	3037060	1.19E+06		661088	330392	3037230	1.19E+06		684306	330409	1396690	1.19E+06		617648	667804
Cpmax (MT)	1181	572		338	207	1180	563		352	207	504	570		318	437
Cpmax (YEAR)	2004	2002		1995	2002	2004	2002		1995	2002	2004	2002		1995	2002
Cmult (Zone A)	1.50					1.50					1.50				
Ppoach			0.29					0.29					0.37		
M0			0.318					0.323					0.309		
M15			0.131					0.136					0.122		
ν (στεεπνεσσ οφ ρεχρυιτμεντ φαιλυρε)			0.2463					0.2463					0.2471		
Mmax (Recruitment failure scale parameter|)			9.99998					9.99998					10		
a(CS)			8.99933					8.9989					8.99853		
a(RS)			8.95777					8.92412					8.98916		
a(PS)			4.99633					4.99814					4.82635		
a(FS)			5.81674					5.80182					6.0023		
a(OS)			6.84223					6.84223					5.22288		
μ(ΧΣ)			0.00071835					0					0.000885		
μ(ΡΣ)			0.000776198					0.000401374					0.000947		
μ(ΠΣ)			7.88711E-05					8.06484E-05					8.48E-05		
μ(ΦΣ)			0.00114111					0.000927272					0.001022		
μ(ΟΣ)			0.00116481					0.00116481					0.000578		
δ(ΧΣ)			593.943					804.723					224.873		
δ(ΡΣ)			3.51806					5.50834					25.8701		
δ(ΠΣ)			348.232					433.651					1.93838		
δ(ΦΣ)			1.12728					1.16864					0.954556		
δ(ΟΣ)			0.676136					0.676131					0.76988		
Model	I) ABCD reference case					IV) Sensitivity - fix mu (cs) = 0.0					V) Fixing Zone A B0 to the Zone B value				
	A	B	CNP	CP	D	A	B	CNP	CP	D	A	B	CNP	CP	D
-lnL CPUE	-27.773	-37.384	-45.864	-46.145	-31.507	-28.677	-40.303	-44.693	-46.037	-31.769	-23.266	-36.049	-47.690	-45.903	-28.398
-lnL FIAS	-5.653	-2.409	-7.418	9.276	-2.128	-5.116	-2.777	-7.386	9.683	-2.070	-4.931	-2.645	-7.173	9.165	-2.426
-lnL age CS	-13.032	-18.411	-6.864	-10.601	-8.938	-9.980	-17.202	-5.254	-11.056	-10.195	-15.020	-18.833	-7.009	-10.829	-10.815
-lnL age RS	-1.504	-8.218	-7.054	-0.057	-6.998	-1.422	-8.098	-6.781	-0.092	-7.291	-1.467	-8.204	-7.127	-0.031	-8.593
-lnL age PS	-3.306	-2.289		-1.182	-2.370	-3.009	-1.630		-0.802	-2.194	-3.133	-2.545		-1.046	-3.953
-lnL age FIAS	-6.209	-7.635	-4.834	-0.030	-4.386	-5.895	-7.458	-4.895	-0.047	-4.616	-6.436	-7.776	-4.747	-0.040	-5.202
-lnL age OS inshore	-2.968	-1.245		-1.609	-1.072	-2.822	-1.370		-1.598	-1.121	-2.064	-1.101		-1.633	-1.191
-lnLage OS offsh.	-2.814	-0.970		-1.207	-0.729	-2.785	-0.824		-1.152	-0.609	-2.877	-1.104		-1.111	-2.405
-lnL age IS insh+offsh.		-0.860	-0.659				-1.053	-0.662				-0.683	-0.609		
-lnL zone subtotal	-63.258	-79.420	-124.019		-58.130	-59.706	-80.715	-120.648		-59.865	-59.194	-78.939	-125.546		-62.983
-lnL TOTAL			-324.826					-320.934					-326.663		
s CPUE	0.204	0.139	0.090	0.055	0.175	0.197	0.123	0.094	0.055	0.174	0.244	0.146	0.083	0.056	0.199
σ αγε ΧΣ	0.093	0.067	0.122	0.091	0.111	0.113	0.072	0.137	0.088	0.102	0.082	0.065	0.121	0.090	0.098
σ αγε ΡΣ	0.120	0.056	0.059	0.187	0.077	0.123	0.057	0.062	0.178	0.074	0.122	0.056	0.058	0.194	0.062
σ αγε ΠΣ	0.094	0.138		0.166	0.116	0.100	0.153		0.175	0.121	0.098	0.133		0.169	0.084
σ αγε ΦΙΑΣ	0.061	0.068	0.079	0.146	0.101	0.064	0.070	0.078	0.145	0.097	0.058	0.067	0.080	0.145	0.089
σ ΟΣ ινση.	0.046	0.054		0.039	0.065	0.049	0.048		0.039	0.063	0.069	0.061		0.038	0.059
σ ΟΣ οφφση.	0.052	0.075		0.061	0.084	0.053	0.084		0.063	0.092	0.051	0.067		0.065	0.023
σ ΙΣ		0.043	0.078				0.034	0.078				0.054	0.083		
θ ΧΠΥΕ	0.0001862	0.000574	0.00247607	0.000992	0.000353	0.000158	0.000603	0.00206318	0.000876	0.000301	0.000488	0.000544	0.002647	0.001029	0.000183
Confiscation percentage			Zone C					Zone C					Zone C		
%Co/Po2004	0.08	0.35	0.17		0.14	0.08	0.35	0.17		0.14	0.18	0.35	0.18		0.07
%Co/Po2005	0.12	0.50	0.33		0.20	0.12	0.50	0.31		0.20	0.26	0.50	0.32		0.10
Mean CS Fishing mortality	0.03	0.12	0.11	0.15	0.05	0.02	0.13	0.09	0.14	0.05	0.07	0.11	0.11	0.15	0.03
Catches															
Ccomm(2005)	10	145	4	6	10	10	145	4	6	10	10	145	4	6	10
Cpoa(2005)	890.2	86.3	83.1	4.6	90.5	901.3	84.1	81.1	4.5	90.0	380.9	85.2	68.7	5.4	186.3
Catch total (2005) MT	900.2	231.3	87.1	10.6	100.5	911.3	229.1	85.1	10.5	100.0	390.9	230.2	72.7	11.4	196.3
	A	B	CNP	CP	D	A	B	CNP	CP	D	A	B	CNP	CP	D
Depletion comp. yr	**1986/87**	**1982**		**1981**	**1983**	**1986/87**	**1982**		**1981**	**1983**	1986/87	1982		1981	1983
Insh OBS	0.33	0.67		0.33	0.36	0.33	0.67		0.33	0.36	0.33	0.67		0.33	0.36
Insh PRED	0.86	0.59		0.46	0.65	0.87	0.57		0.49	0.68	0.72	0.60		0.45	0.78
Offsh OBS	0.20	0.54		0.24	0.50	0.20	0.54		0.24	0.50	0.20	0.54		0.24	0.50
Offsh PRED	0.75	0.36		0.28	0.48	0.76	0.33		0.30	0.50	0.53	0.36		0.26	0.65
Depletion statistics															
Bsp(2005)/K (Insh. + Offsh)	0.38	0.40	0.23	0.10	0.28	0.40	0.38	0.22	0.10	0.29	0.28	0.39	0.20	0.10	0.34
Bsp(2005)/K (Insh.)	0.18	0.36	0.12	0.00	0.15	0.19	0.34	0.10	0.00	0.14	0.15	0.35	0.08	0.00	0.13
Bsp(2005)/K (Offsh.)	0.61	0.44	0.35	0.30	0.44	0.62	0.41	0.35	0.30	0.44	0.40	0.43	0.32	0.29	0.53
Btotal(2005)/K	0.43	0.44	0.21	0.09	0.26	0.44	0.42	0.20	0.09	0.26	0.32	0.43	0.18	0.10	0.31
Bcommercial(2005)/K	0.36	0.32	0.20	0.12	0.34	0.37	0.28	0.22	0.13	0.36	0.24	0.33	0.19	0.12	0.40
FIAS N2005/N1951	0.09	0.48	0.03	0.00	0.09	0.10	0.45	0.02	0.00	0.09	0.09	0.45	0.01	0.00	0.07
Projections	A	B	CNP	CP	D	A	B	CNP	CP	D	A	B	CNP	CP	D
Ccomm(2006)	**10.0**	**145.0**	**4.0**	**6.0**	**10.0**	**10.0**	**145.0**	**4.0**	**6.0**	**10.0**	10.0	145.0	4.0	6.0	10.0
Cpoa(2006) (NUMBERS)	2698420	226187	109015	86626	123401	2698580	226177	112014	89261	123408	1240960	226191	97645	88998	249425
Cpoa(2006) (MT)	758	98.6	48.1	0.8	99	817	96.6	29.0	0.9	99	324	97.5	8.6	1.1	203
Catch total (2006) MT	768.1	243.6	52.1	6.8	109.2	826.6	241.6	33.0	6.9	108.7	334.2	242.5	12.6	7.1	212.9
Bsp(2010)/K	0.27	0.41	0.09	0.05	0.13	0.28	0.39	0.09	0.05	0.13	0.21	0.40	0.10	0.06	0.17
Bsp(2025)/K	0.16	0.42	0.03	0.02	0.13	0.17	0.40	0.03	0.03	0.14	0.14	0.41	0.03	0.02	0.13
Bsp(2025)/Bsp(2005)	0.70	1.04	0.42	0.54	0.46	0.70	1.05	0.43	0.53	0.45	0.77	1.03	0.48	0.56	0.51
Bsp(2025)/Bsp(2005)	0.42	1.06	0.13	0.25	0.46	0.43	1.07	0.15	0.27	0.48	0.51	1.04	0.16	0.24	0.39

Table 7. Sensitivity to fixing the Zone A CPmax value and to setting Cmult = 1.0 instead of 1.5.

Model	I) ABCD reference case					VI) Fixing Zone A Cpmax					VII) Fixing Cmult = 1				
No. parameters			29					28					29		
Zone	**A**	**B**	**CNP**	**CP**	**D**	A	B	CNP	CP	D	A	B	CNP	CP	D
Ave confiscation %	8%	34%	18%		14%	22%	34%	24%		8%	9%	34%	21%		13%
B(0)sp	11928	6186	2364	4523	7895	7948	7200	2111	5001	12621	16400	6411	2111	4678	7815
Cpmax (no.)	3037060	1.19E+06		661088	330392	1100000	1.19E+06		479245	553962	2832480	1.19E+06		590242	356387
Cpmax (MT)	1181	572		338	207	419	554		250	341	1167	566		311	220
Cpmax (YEAR)	2004	2002		1995	2002	2004	2002		1995	2002	2004	2002		1995	2002
Cmult (Zone A)	1.50					1.50					1.00				
Ppoach			0.29					0.31					0.29		
M0			0.318					0.287					0.310		
M15			0.131					0.100					0.123		
ν (στεεπνεσσ οφ ρεχρυιτμεντ φαιλυρε)			0.2463					0.2439					0.2606		
Mmax (Recruitment failure scale parameter|)			9.99998					9.99998					9.99998		
a(CS)			8.99933					8.99945					8.99918		
a(RS)			8.95777					8.9983					8.99938		
a(PS)			4.99633					5.12868					5.37087		
a(FS)			5.81674					5.98944					5.79618		
a(OS)			6.84223					6.53543					6.82407		
μ(ΧΣ)			0.00071835					0.001445					0.00094		
μ(ΡΣ)			0.000776198					0.000354					0.000348		
μ(ΠΣ)			7.88711E-05					0.000196					0.00017		
μ(ΦΣ)			0.00114111					0.000444					0.000207		
μ(ΟΣ)			0.00116481					0.000933					0.001181		
δ(ΧΣ)			593.943					295.146					420.692		
δ(ΡΣ)			3.51806					235.33					604.599		
δ(ΠΣ)			348.232					1.70627					1.20389		
δ(ΦΣ)			1.12728					1.00862					1.00832		
δ(ΟΣ)			0.676136					0.60474					0.6876		
Model	I) ABCD reference case					VI) Fixing Zone A Cpmax					VII) Fixing Cmult = 1				
	A	B	CNP	CP	D	A	B	CNP	CP	D	A	B	CNP	CP	D
-lnL CPUE	-27.773	-37.384	-45.864	-46.145	-31.507	-30.014	-32.360	-46.873	-43.263	-28.313	-33.523	-35.958	-46.963	-45.425	-31.472
-lnL FIAS	-5.653	-2.409	-7.418	9.276	-2.128	0.563	-4.513	-7.751	7.728	-2.257	5.827	-3.264	-7.581	9.982	-2.312
-lnL age CS	-13.032	-18.411	-6.864	-10.601	-8.938	-14.726	-18.889	-7.405	-10.561	-10.878	-11.847	-18.781	-7.408	-11.064	-8.603
-lnL age RS	-1.504	-8.218	-7.054	-0.057	-6.998	-1.578	-8.332	-6.394	-0.175	-8.387	-1.224	-8.279	-6.739	-0.142	-5.342
-lnL age PS	-3.306	-2.289		-1.182	-2.370	-2.757	-1.452		-1.150	-2.327	-2.910	-2.060		-0.441	-1.217
-lnL age FIAS	-6.209	-7.635	-4.834	-0.030	-4.386	-4.065	-6.773	-5.129	-0.152	-5.636	-2.105	-7.158	-4.911	-0.197	-5.160
-lnL age OS inshore	-2.968	-1.245		-1.609	-1.072	-2.434	-1.213		-1.487	-1.145	-2.853	-1.294		-1.624	-1.170
-lnLage OS offsh.	-2.814	-0.970		-1.207	-0.729	-2.543	-0.711		-1.521	-1.868	-2.426	-0.845		-1.456	-0.747
-lnL age IS insh+offsh.		-0.860	-0.659				-0.441	-0.556				-0.731	-0.622		
-lnL zone subtotal	-63.258	-79.420	-124.019		-58.130	-57.554	-74.684	-124.667		-60.811	-51.059	-78.369	-124.451		-56.023
-lnL TOTAL			-324.826					-317.715					-309.902		
s CPUE	0.204	0.139	0.090	0.055	0.175	0.186	0.170	0.086	0.064	0.199	0.162	0.147	0.086	0.057	0.176
σ αγε ΧΣ	0.093	0.067	0.122	0.091	0.111	0.084	0.065	0.118	0.092	0.097	0.100	0.065	0.118	0.088	0.113
σ αγε ΡΣ	0.120	0.056	0.059	0.187	0.077	0.117	0.055	0.066	0.158	0.064	0.133	0.055	0.062	0.166	0.098
σ αγε ΠΣ	0.094	0.138		0.166	0.116	0.106	0.158		0.167	0.117	0.102	0.143		0.184	0.148
σ αγε ΦΙΑΣ	0.061	0.068	0.079	0.146	0.101	0.089	0.077	0.075	0.140	0.083	0.128	0.073	0.078	0.138	0.089
σ ΟΣ ινση.	0.046	0.054		0.039	0.065	0.058	0.055		0.044	0.061	0.048	0.051		0.038	0.060
σ ΟΣ οφφση.	0.052	0.075		0.061	0.084	0.058	0.091		0.048	0.035	0.061	0.082		0.050	0.083
σ ΙΣ		0.043	0.078				0.073	0.089				0.051	0.082		
θ ΧΠΥΕ	0.0001862	0.000574	0.00247607	0.000992	0.000353	0.000402	0.00058	0.003029	0.00116	0.00021	0.000123	0.000578	0.002685	0.000987	0.000391
Confiscation percentage			Zone C					Zone C					Zone C		
%Co/Po2004	0.08	0.35	0.17		0.14	0.23	0.35	0.23		0.08	0.09	0.35	0.21		0.13
%Co/Po2005	0.12	0.50	0.33		0.20	0.33	0.50	0.40		0.12	0.13	0.50	0.35		0.19
Mean CS Fishing mortality	0.03	0.12	0.11	0.15	0.05	0.06	0.12	0.13	0.15	0.03	0.01	0.12	0.12	0.15	0.06
Catches															
Ccomm(2005)	10	145	4	6	10	10	145	4	6	10	10	145	4	6	10
Cpoa(2005)	890.2	86.3	83.1	4.6	90.5	339.6	78.0	33.0	18.2	141.2	964.3	83.2	58.6	5.2	92.4
Catch total (2005) MT	900.2	231.3	87.1	10.6	100.5	349.6	223.0	37.0	24.2	151.2	974.3	228.2	62.6	11.2	102.4
	A	B	CNP	CP	D	A	B	CNP	CP	D	A	B	CNP	CP	D
Depletion comp. yr	**1986/87**	**1982**		**1981**	**1983**	1986/87	1982		1981	1983	1986/87	1982		1981	1983
Insh OBS	0.33	0.67		0.33	0.36	0.33	0.67		0.33	0.36	0.33	0.67		0.33	0.36
Insh PRED	0.86	0.59		0.46	0.65	0.75	0.60		0.42	0.75	0.91	0.60		0.47	0.64
Offsh OBS	0.20	0.54		0.24	0.50	0.20	0.54		0.24	0.50	0.20	0.54		0.24	0.50
Offsh PRED	0.75	0.36		0.28	0.48	0.55	0.34		0.21	0.60	0.84	0.36		0.27	0.45
Depletion statistics															
Bsp(2005)/K (Insh. + Offsh)	0.38	0.40	0.23	0.10	0.28	0.36	0.33	0.23	0.12	0.36	0.54	0.38	0.21	0.11	0.25
Bsp(2005)/K (Insh.)	0.18	0.36	0.12	0.00	0.15	0.22	0.25	0.12	0.01	0.10	0.34	0.33	0.08	0.00	0.06
Bsp(2005)/K (Offsh.)	0.61	0.44	0.35	0.30	0.44	0.44	0.37	0.29	0.26	0.52	0.70	0.42	0.32	0.29	0.40
Btotal(2005)/K	0.43	0.44	0.21	0.09	0.26	0.39	0.36	0.21	0.12	0.34	0.57	0.42	0.19	0.11	0.23
Bcommercial(2005)/K	0.36	0.32	0.20	0.12	0.34	0.34	0.29	0.21	0.14	0.41	0.51	0.32	0.21	0.13	0.30
FIAS N2005/N1951	0.09	0.48	0.03	0.00	0.09	0.16	0.31	0.07	0.00	0.06	0.26	0.39	0.01	0.00	0.03
Projections	A	B	CNP	CP	D	A	B	CNP	CP	D	A	B	CNP	CP	D
Ccomm(2006)	**10.0**	**145.0**	**4.0**	**6.0**	**10.0**	10.0	145.0	4.0	6.0	10.0	10.0	145.0	4.0	6.0	10.0
Cpoa(2006) (NUMBERS)	2698420	226187	109015	86626	123401	977350	226172	47080	89725	206905	2516660	226307	83968	84943	133110
Cpoa(2006) (MT)	758	98.6	48.1	0.8	99	356	90.9	36.0	2.4	154	1026	96.1	6.7	1.1	80
Catch total (2006) MT	768.1	243.6	52.1	6.8	109.2	365.6	235.9	40.0	8.4	163.9	1036.0	241.1	10.7	7.1	90.2
Bsp(2010)/K	0.27	0.41	0.09	0.05	0.13	0.29	0.33	0.12	0.08	0.23	0.38	0.39	0.10	0.06	0.14
Bsp(2025)/K	0.16	0.42	0.03	0.02	0.13	0.20	0.30	0.06	0.03	0.16	0.23	0.39	0.04	0.04	0.12
Bsp(2025)/Bsp(2005)	0.70	1.04	0.42	0.54	0.46	0.80	1.00	0.55	0.62	0.63	0.70	1.03	0.49	0.56	0.55
Bsp(2025)/Bsp(2005)	0.42	1.06	0.13	0.25	0.46	0.55	0.93	0.24	0.28	0.43	0.42	1.04	0.19	0.33	0.47



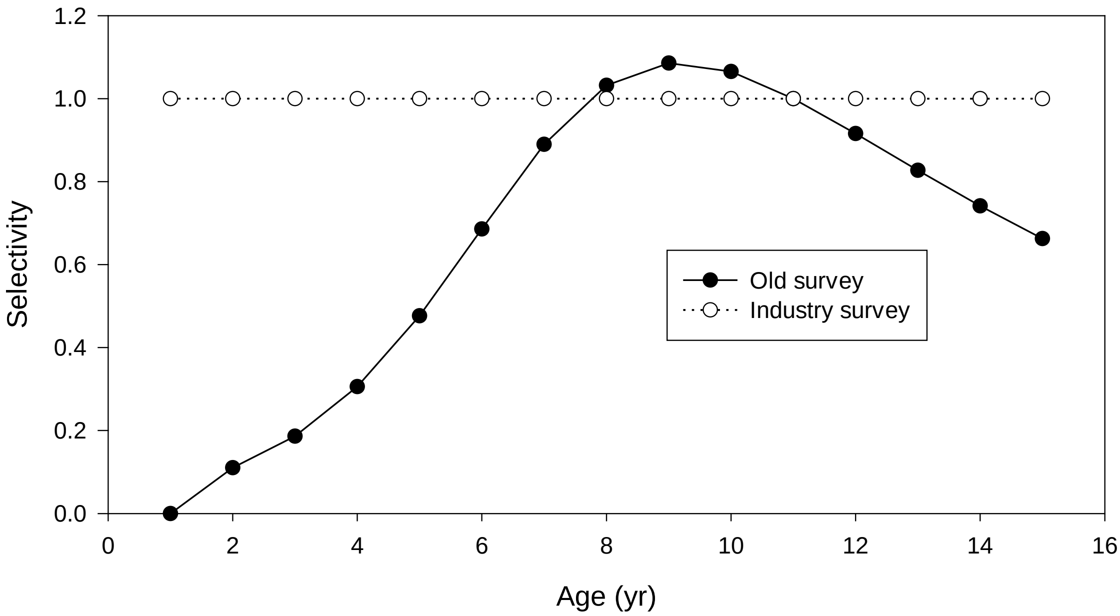
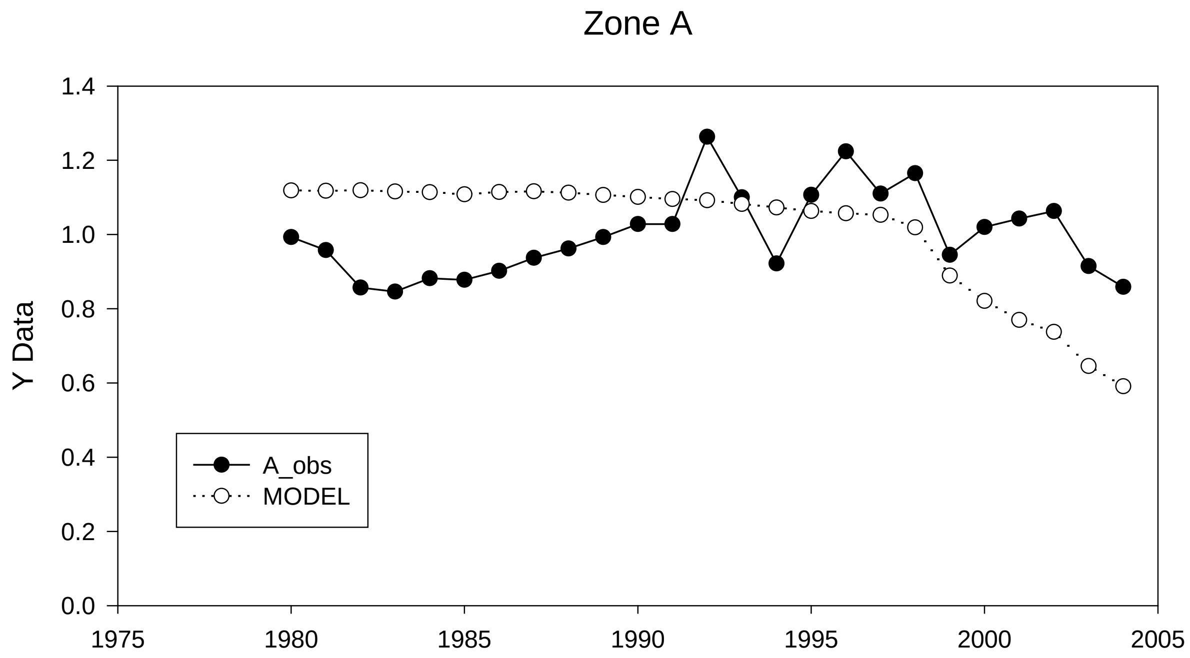


Fig. 1. Plots of the Reference-case combined ABCD model selectivity functions estimated for the commercial, recreational and poaching fishery sectors, and for FIAS and the old 1980's surveys. A description of the general functional form used is given in Appendix 1 and the fitted parameter values are listed in Table 4. A uniform value is assumed for the industry/MCM survey because of the extractive nature of the sampling methodology used. Note that the estimates for commercial and recreational are very similar, with the plot over-printing the recreational estimates.



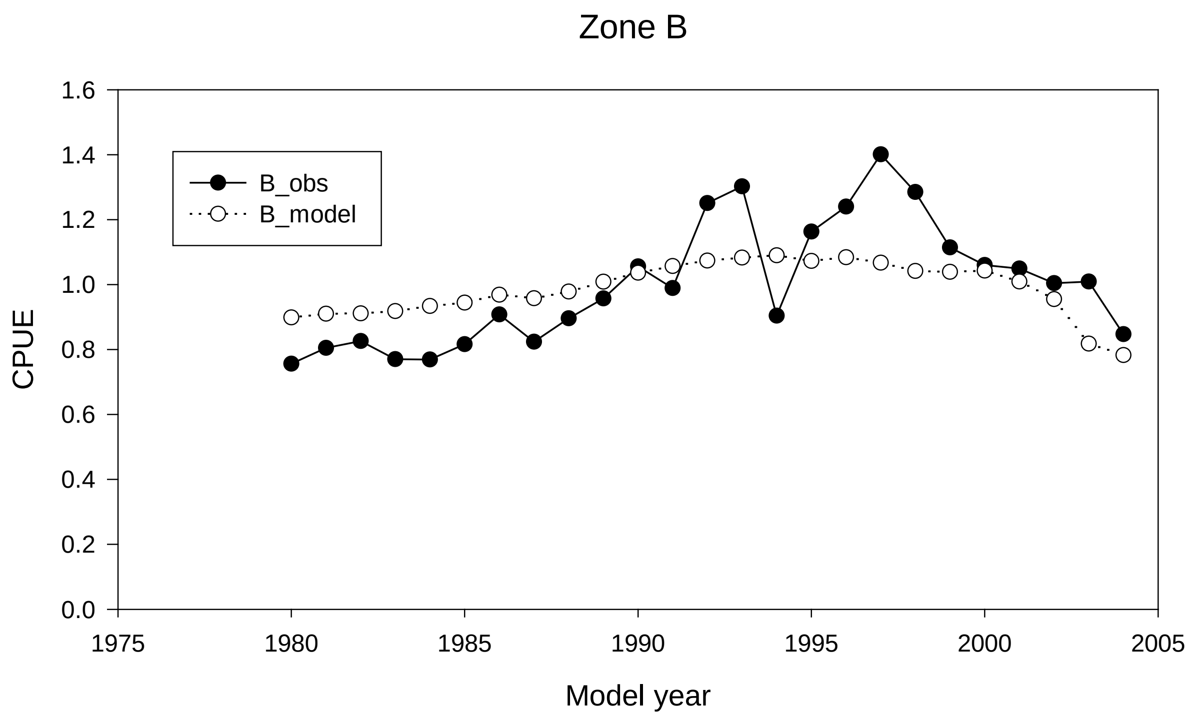
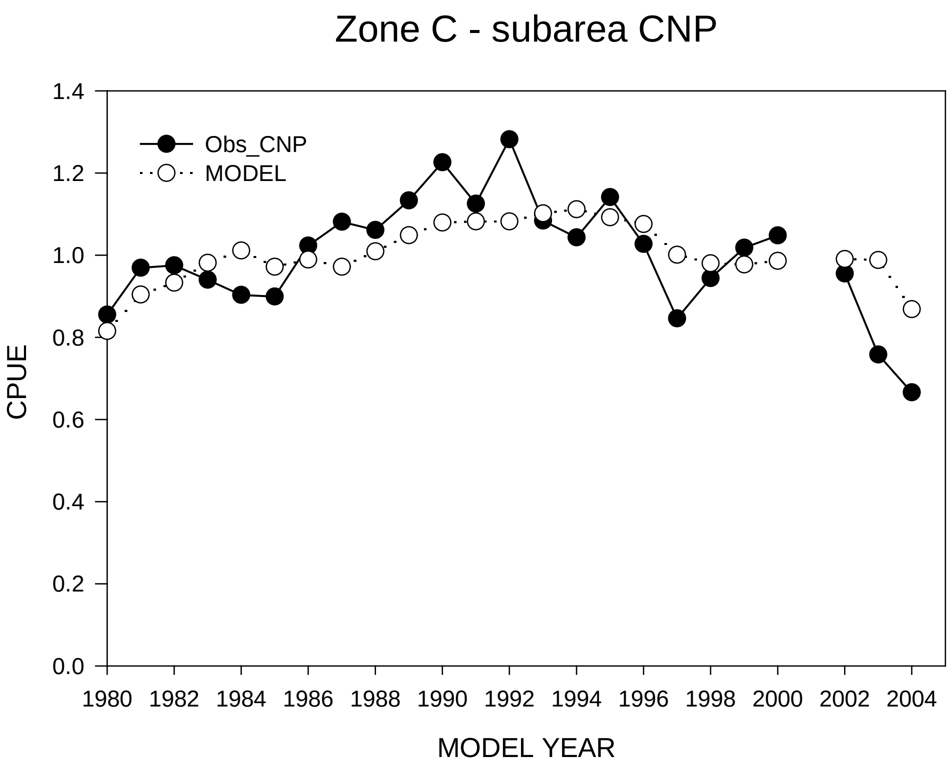


Fig. 2. Comparisons between the standardised CPUE and model-predicted CPUE values (for the Reference-case combined ABCD model) for each of Zones A and B.



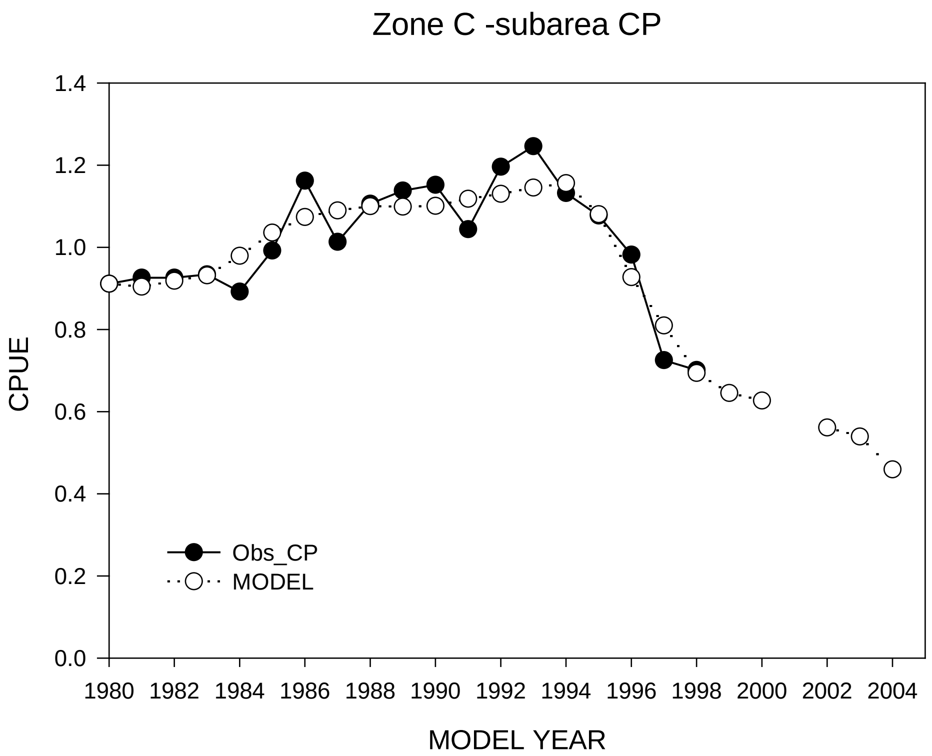


Fig. 3. Comparisons between the standardised CPUE and model-predicted CPUE values (for the Reference-case combined ABCD model) for each of Zones CNP and CP.

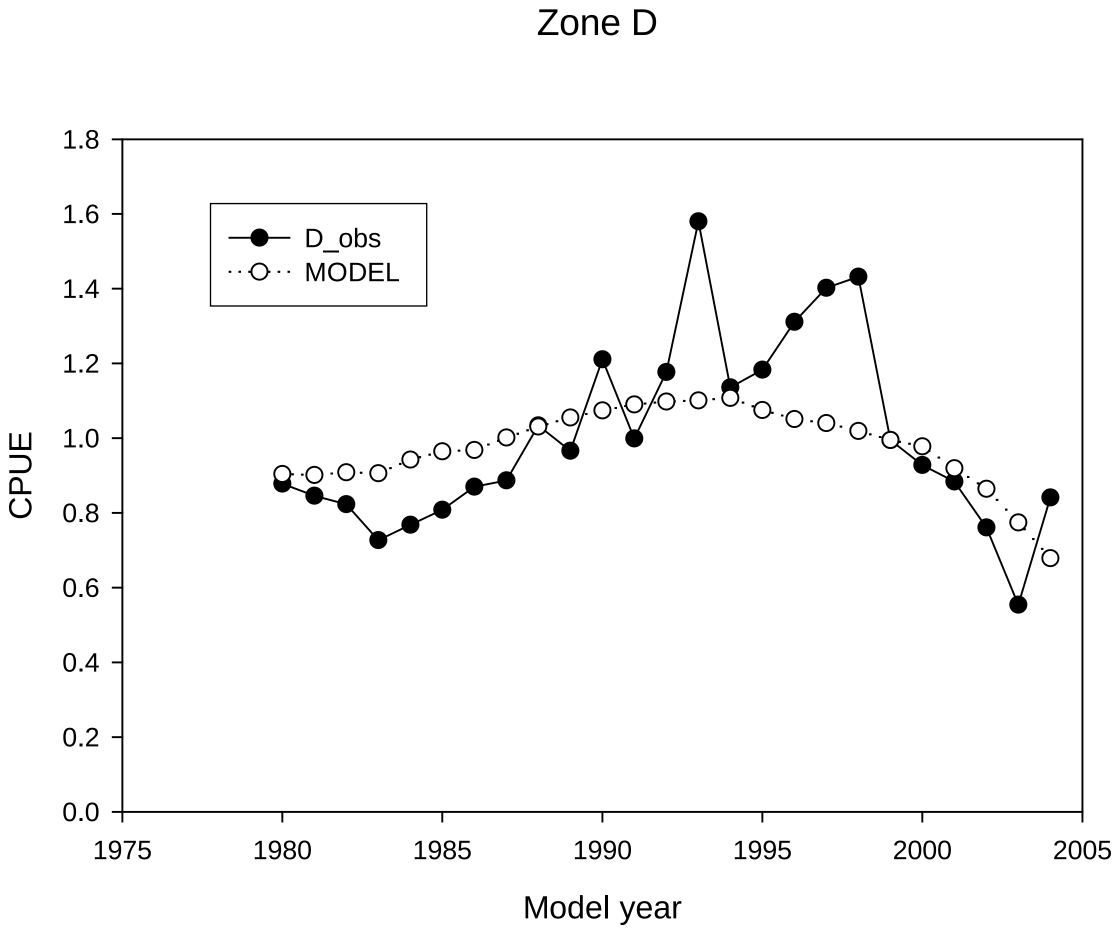
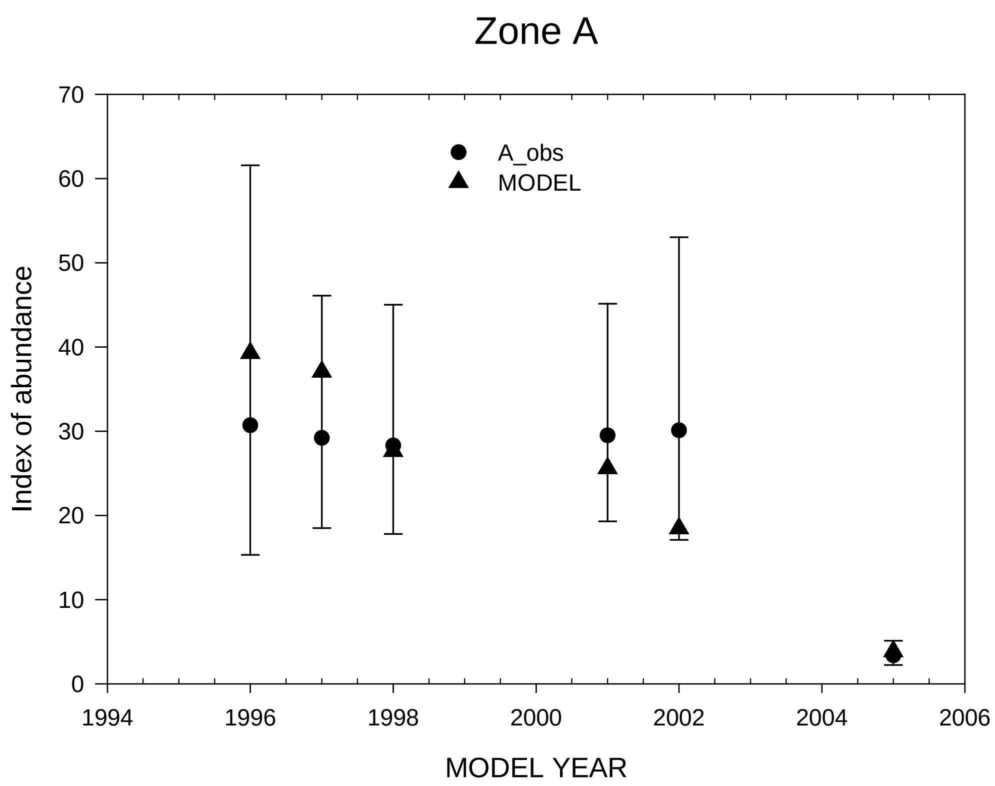


Fig. 4. Comparisons between the standardised CPUE and model-predicted CPUE values (for the Reference-case combined ABCD model) for Zone D.



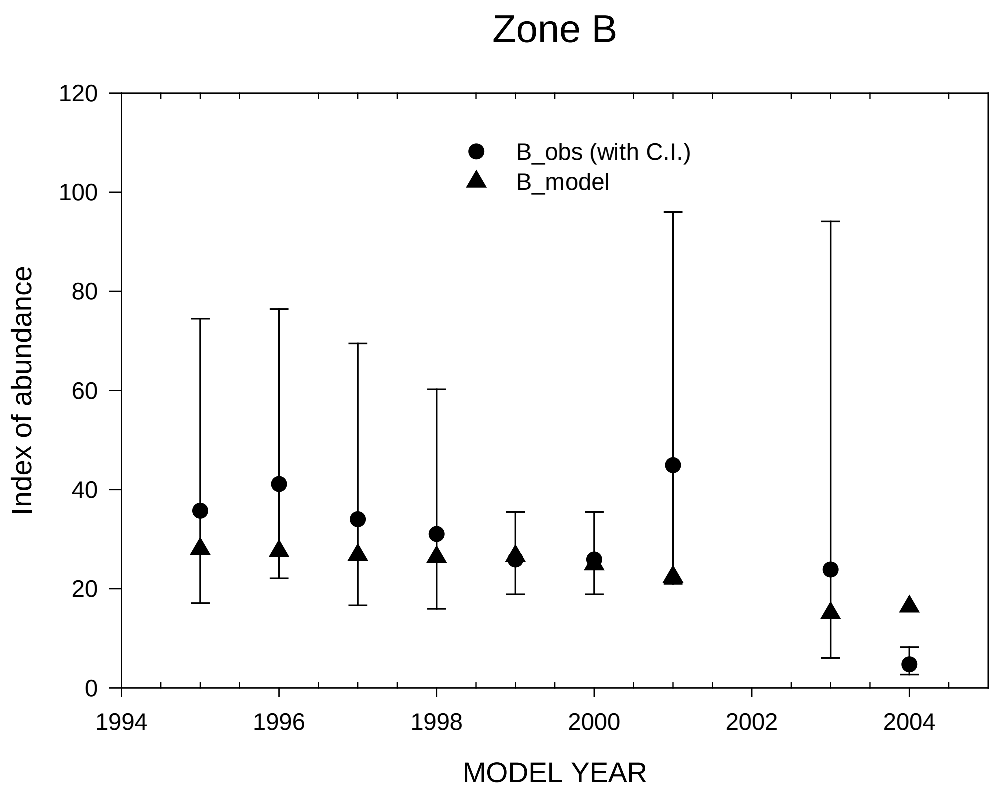


Fig. 5 Comparison of model-predicted (Reference-case combined ABCD model) and observed FIAS trends for each of Zones A and B. Note that 95% confidence intervals have been computed as estimate*exp(±1.96*CV).

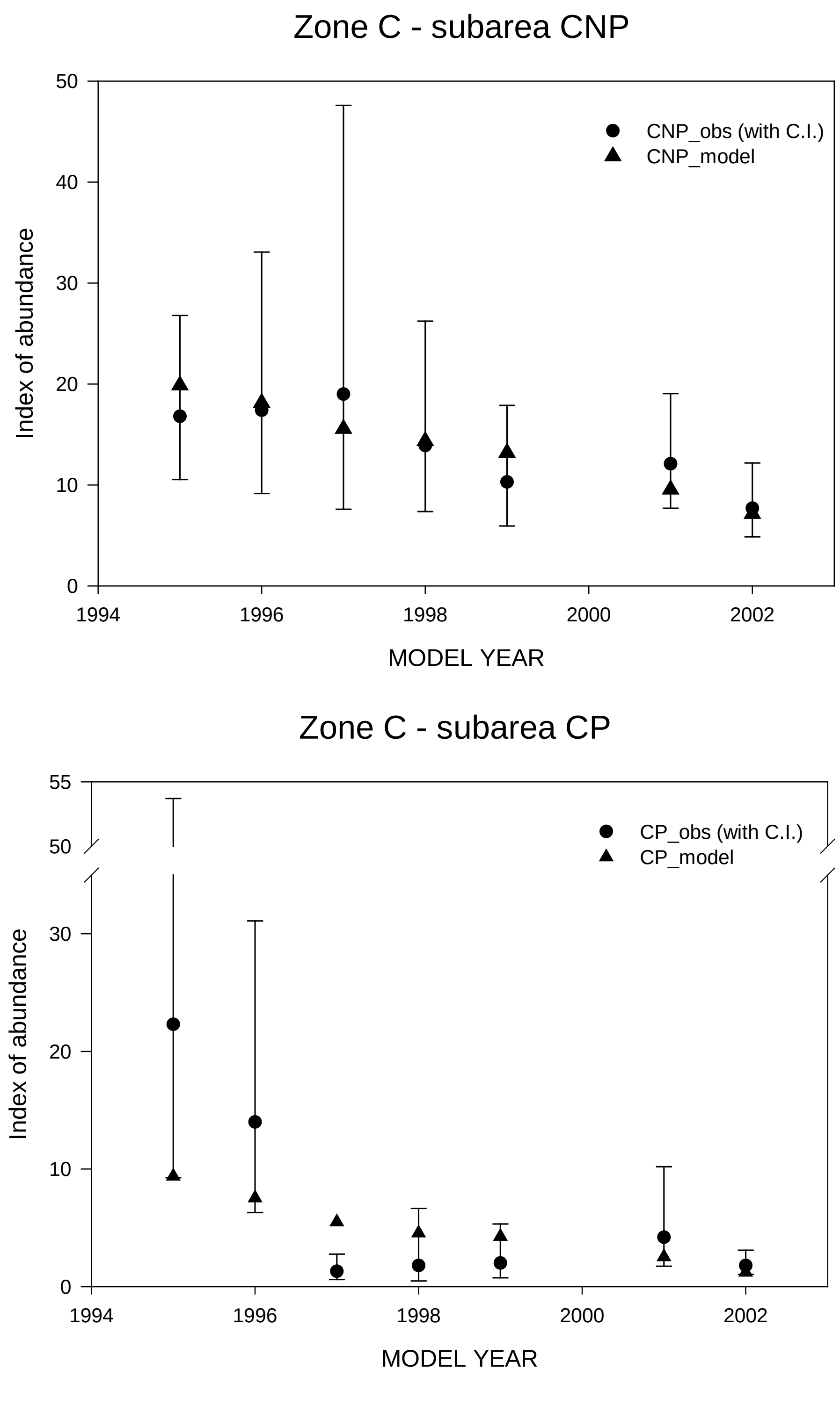


Fig. 6. Comparison of model-predicted (Reference-case combined ABCD model) and observed FIAS trends for each of subareas CNP and CP in Zone C. Note that 95% confidence intervals have been computed as estimate*exp(±1.96*CV). Note the break inserted on the y-axis for subarea CP for ease of viewing purposes (because it allows amplification of the rest of the figure).

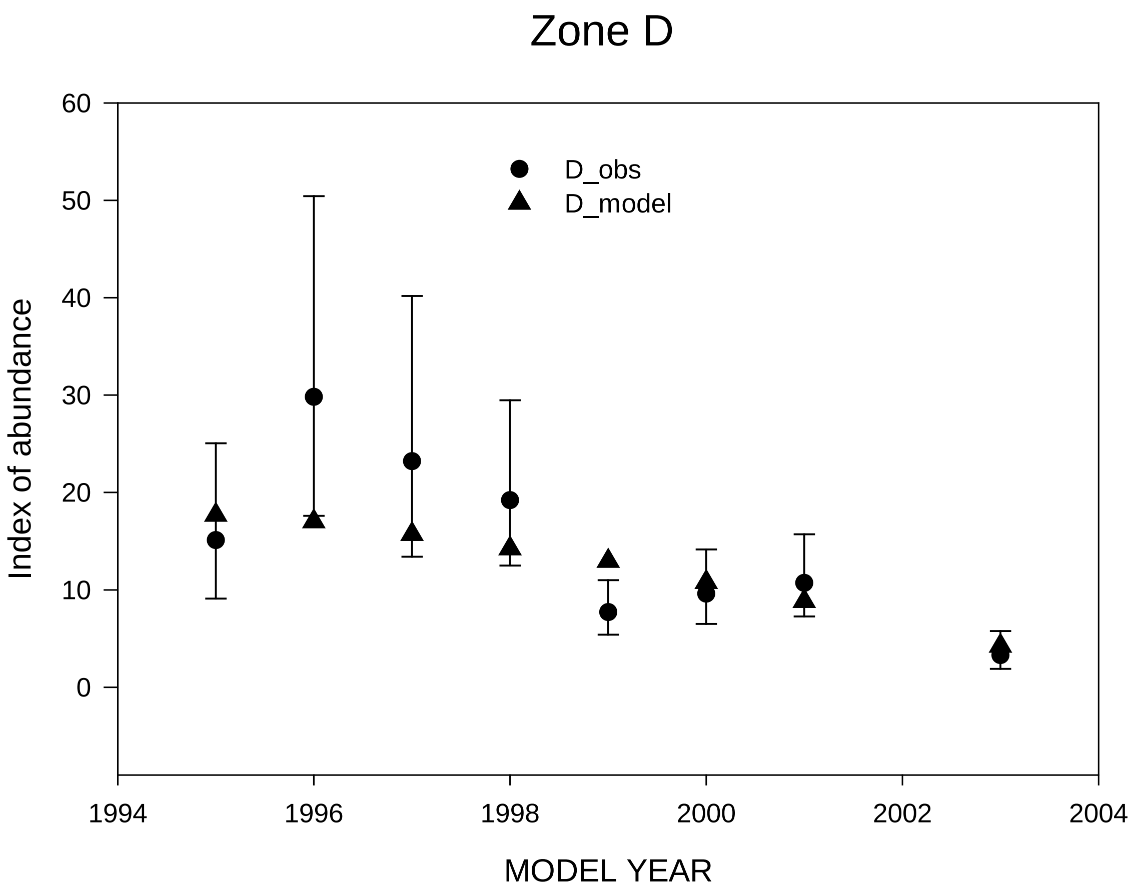


Fig. 7 Comparison of model-predicted (Reference-case combined ABCD model) and observed FIAS trends for each of Zone D. Note that 95% confidence intervals have been computed as estimate*exp(±1.96*CV).

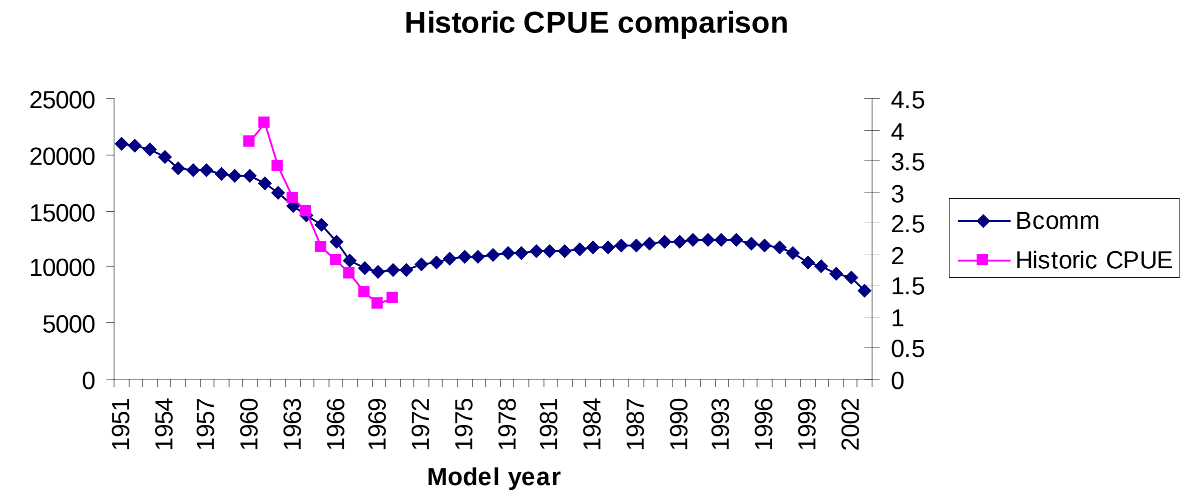


Fig. 8. Comparison of commercial exploitable biomass for Zones A, B, CNP, CP and D combined with historic "CPUE" data for the Reference-case combined ABCD model

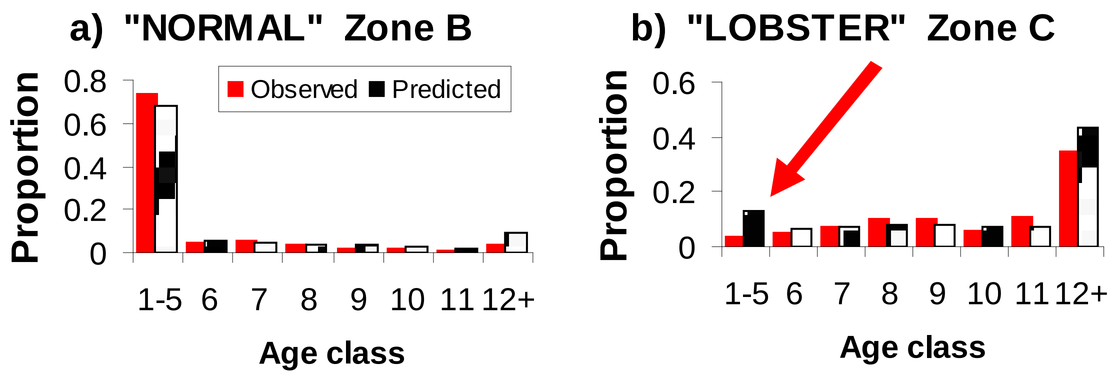


Fig. 9. Comparisons between (a) Zone B and (b) Zone C observed and model-predicted catch-at-age proportions corresponding to the Industry/MCM 2002 full population survey. Note that a uniform selectivity function was assumed because of the extractive sampling methodology used

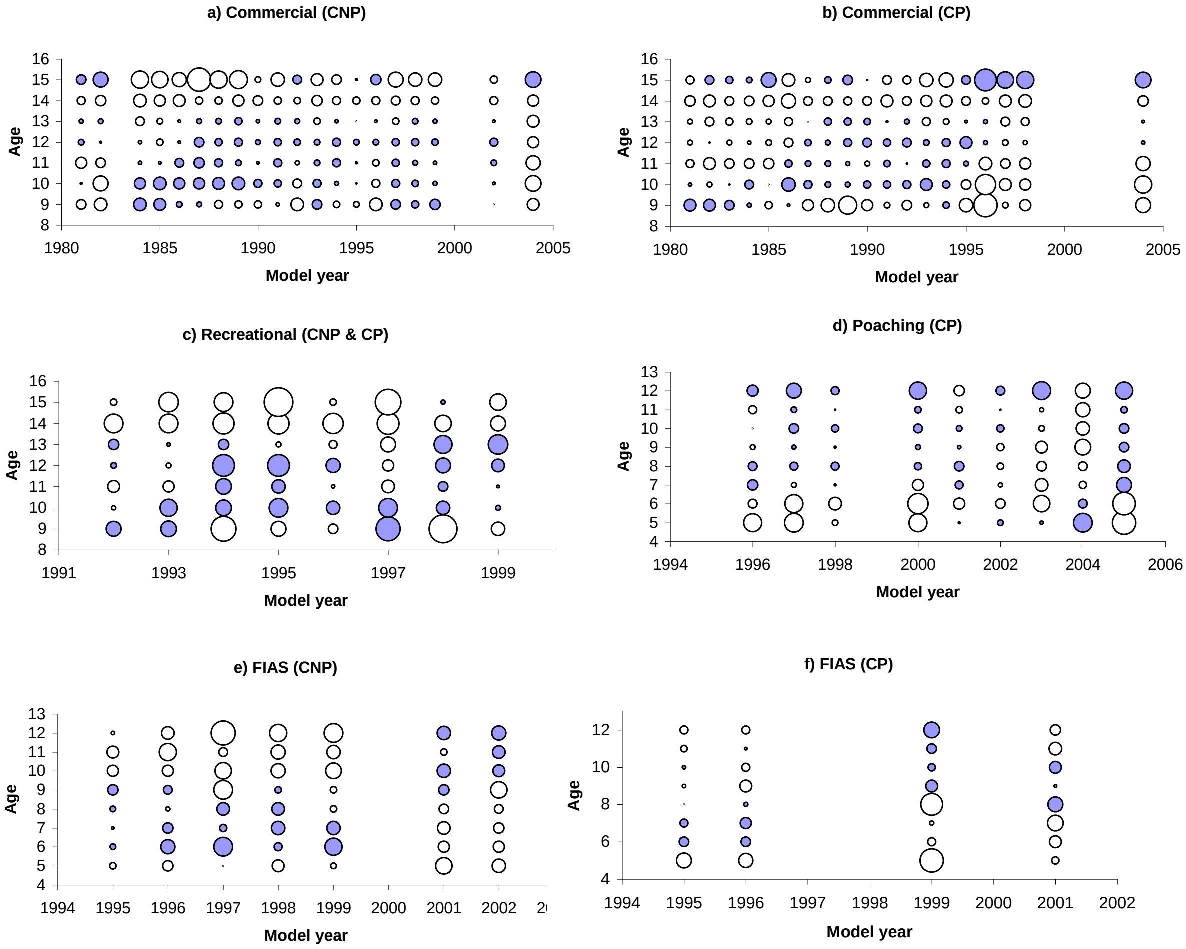


Fig. 10. Catch-at-age residuals for Zone C for a) the commercial data for subarea CNP, b) the commercial data for subarea CP, c) the recreational data (fitted to subareas CNP and CP combined), d) the poaching data (assumed to derive from subarea CP), e) the FIAS data for subarea CNP and f) the FIAS data for subarea CP for the Reference-case combined ABCD model. The size (radius) of the "bubble" in the plots is proportional to the corresponding standardized residual ((ln(obs)-ln(pred))/(sigma/sqrt(pred))). White bubbles represent negative residuals and grey bubbles represent positive residuals.

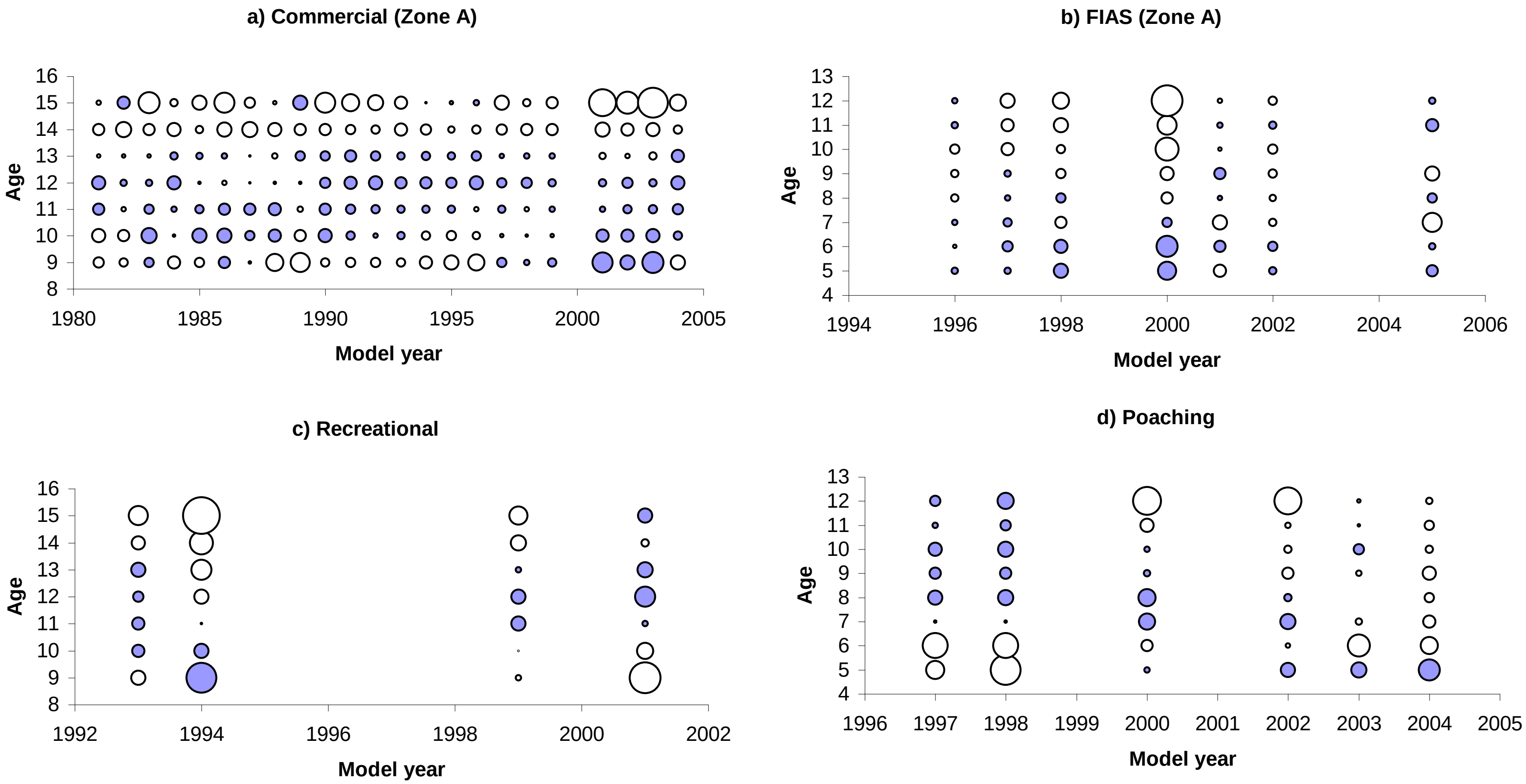


Fig 11. Catch-at-age residuals for Zone A for a) the commercial data, b) the FIAS data, c) the recreational data and d) the poached sector (based on confiscation data) for the Reference-case combined ABCD model. The size (radius) of the “bubble” in the plots is proportional to the corresponding standardized residual ((ln(obs)-ln(pred))/(sigma/sqrt(pred))). White bubbles represent negative residuals and grey bubbles represent positive residuals.

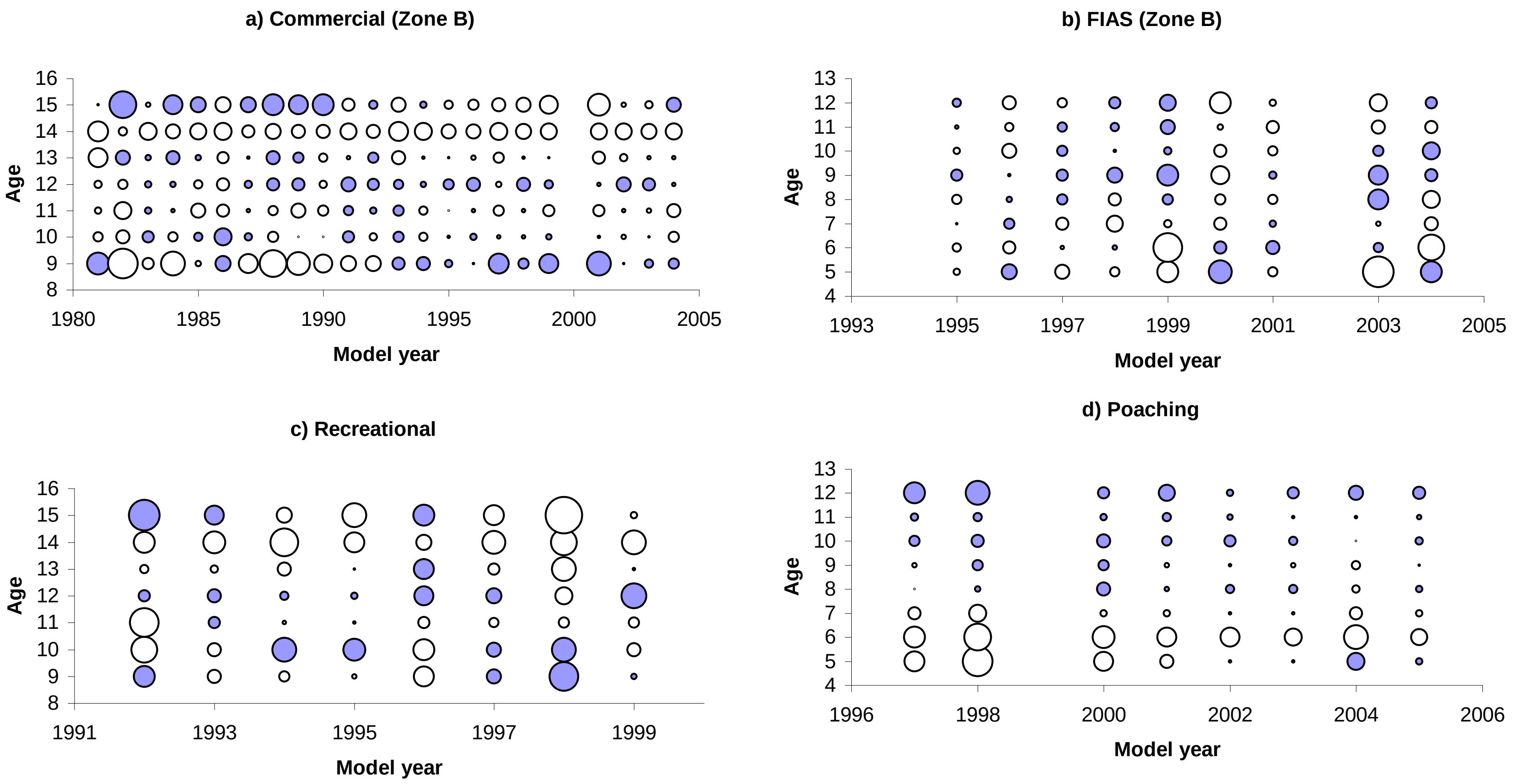


Fig 12. Catch-at-age residuals for Zone B for a) the commercial data, b) the FIAS data, c) the recreational data and d) the poached sector (based on confiscation data) for the Reference-case combined ABCD model. The size (radius) of the "bubble" in the plots is proportional to the corresponding standardized residual ((ln(obs)-ln(pred))/(sigma/sqrt(pred))). White bubbles represent negative residuals and grey bubbles represent positive residuals.

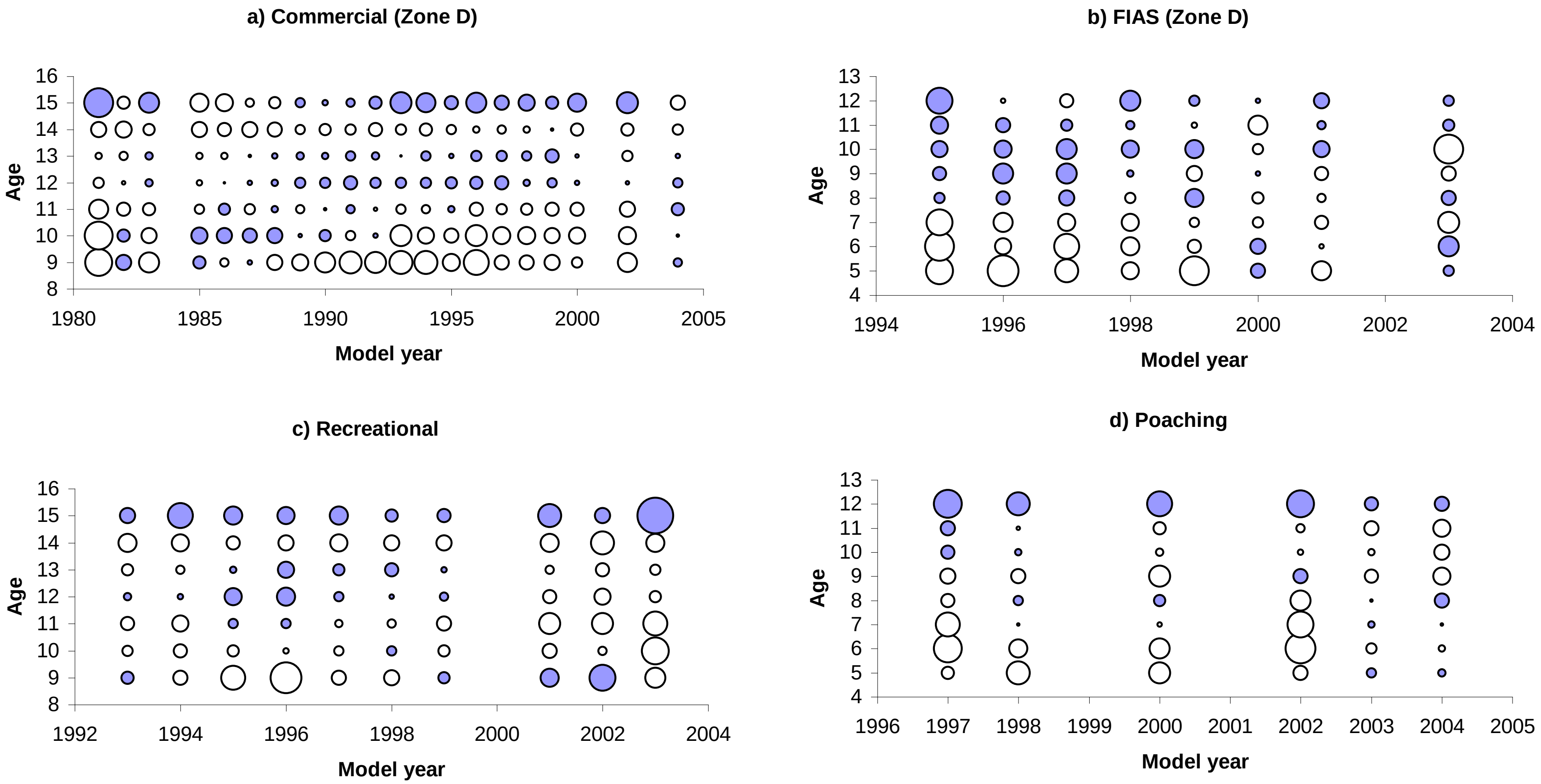
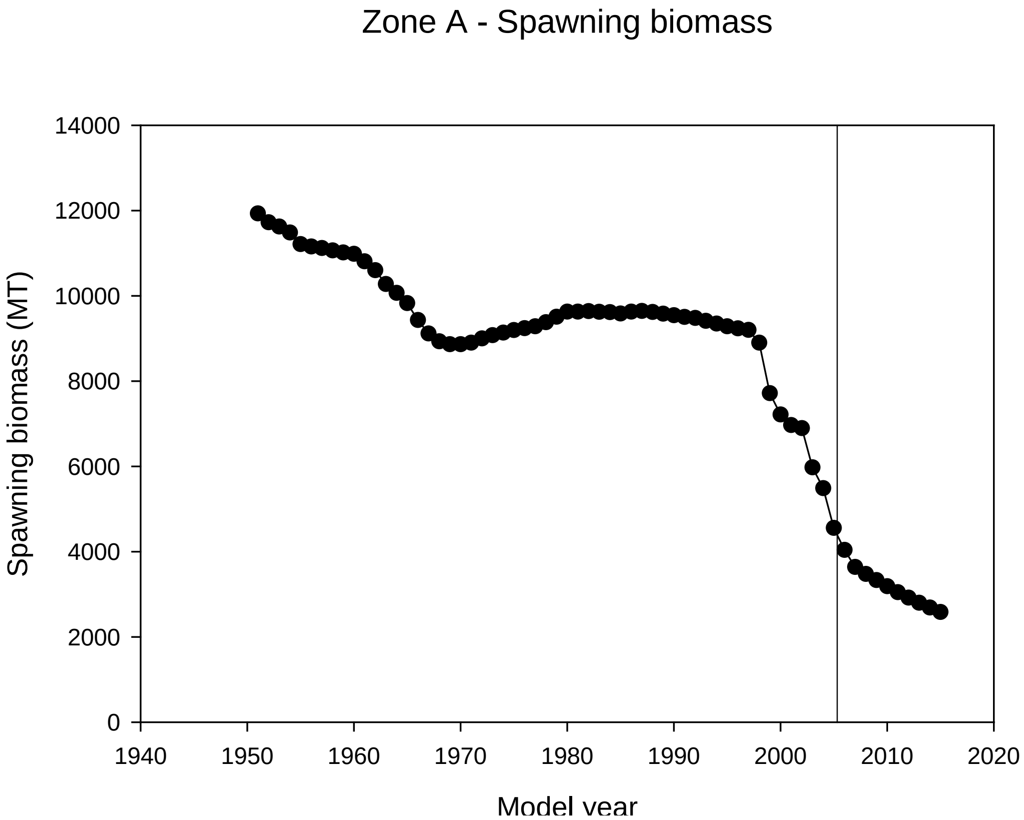


Fig 13. Catch-at-age residuals for Zone D for a) the commercial data, b) the FIAS data, c) the recreational data and d) the poached sector (based on confiscation data) for the Reference-case combined ABCD model. The size (radius) of the “bubble” in the plots is proportional to the corresponding standardized residual ((ln(obs)-ln(pred))/(sigma/sqrt(pred))). White bubbles represent negative residuals and grey bubbles represent positive residuals.



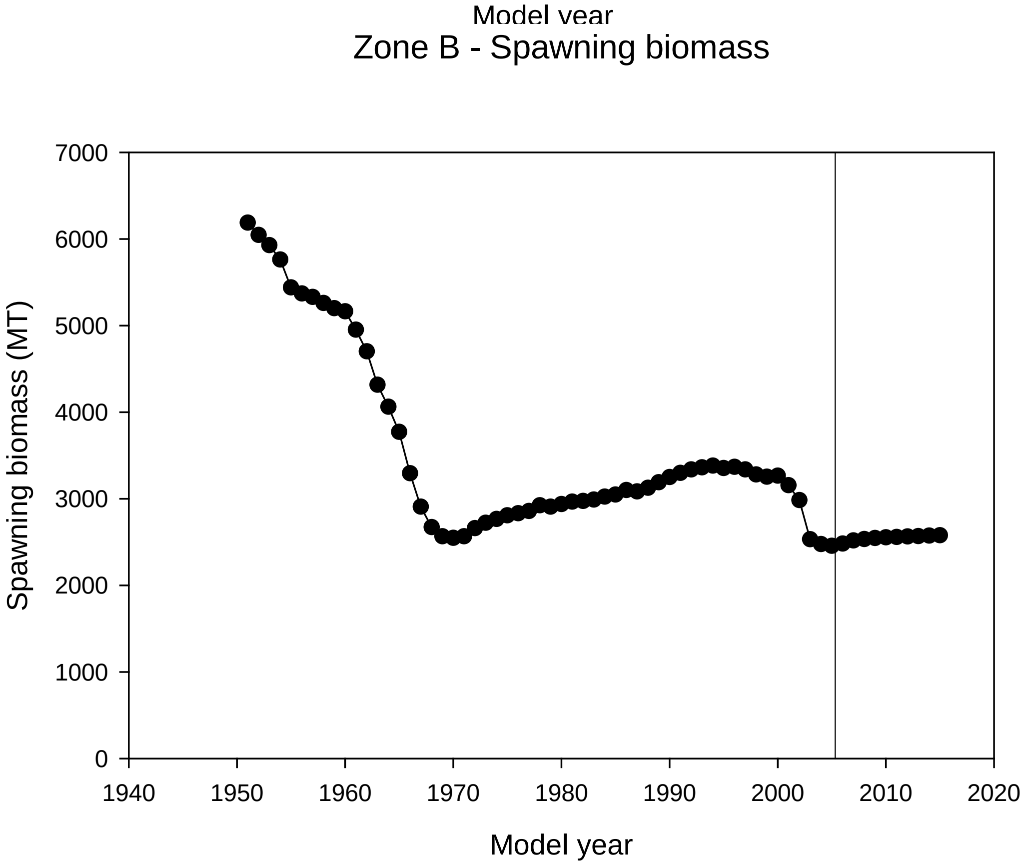
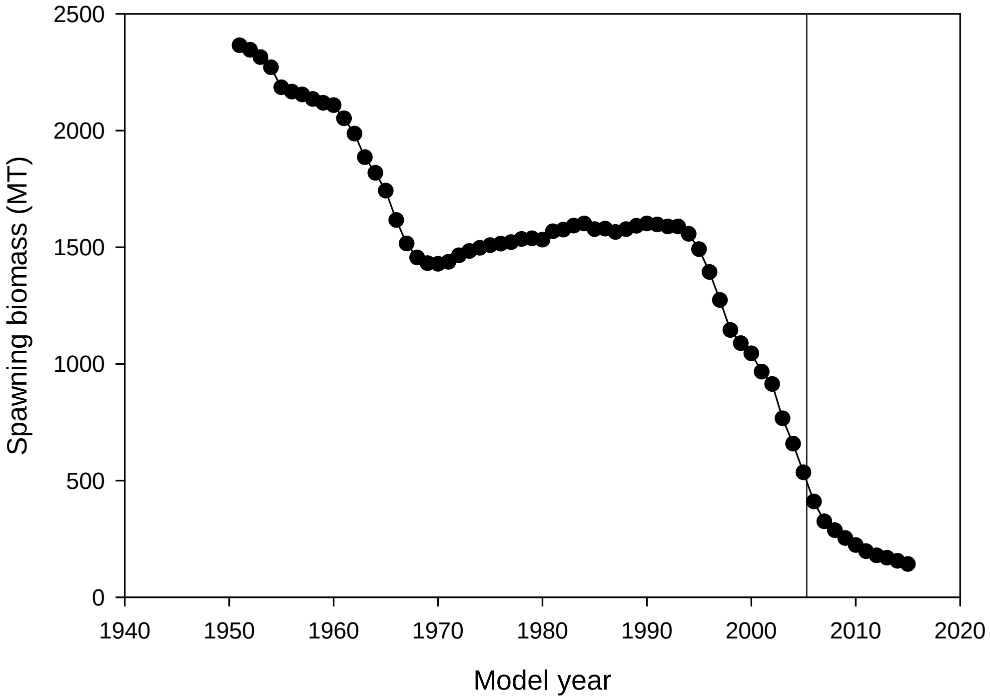


Fig. 14. Reference-case combined ABCD model total (inshore + offshore) spawning biomass trajectories shown for a) Zone A and b) Zone B. Note that the 10-yr projections shown represent scenarios under which future poaching levels are assumed to remain at the current estimated level (average of 2004 and 2005) and future commercial catches remain constant at the current level.

Zone CNP - Spawning biomass



Zone CP - Spawning biomass

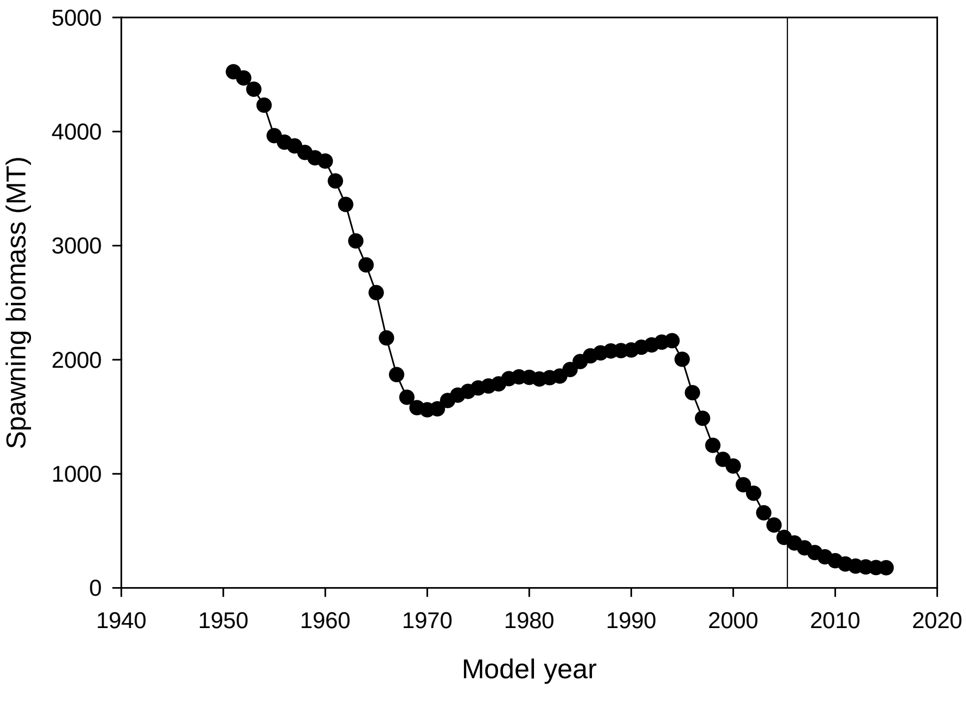


Fig. 15. Reference-case combined ABCD model total (inshore + offshore) spawning biomass trajectories shown for Zone C a) CNP and b) CP. Note that the 10-yr projections shown represent scenarios under which future poaching levels are assumed to remain at the current estimated level (average of 2004 and 2005) and future commercial catches remain constant at the current level.

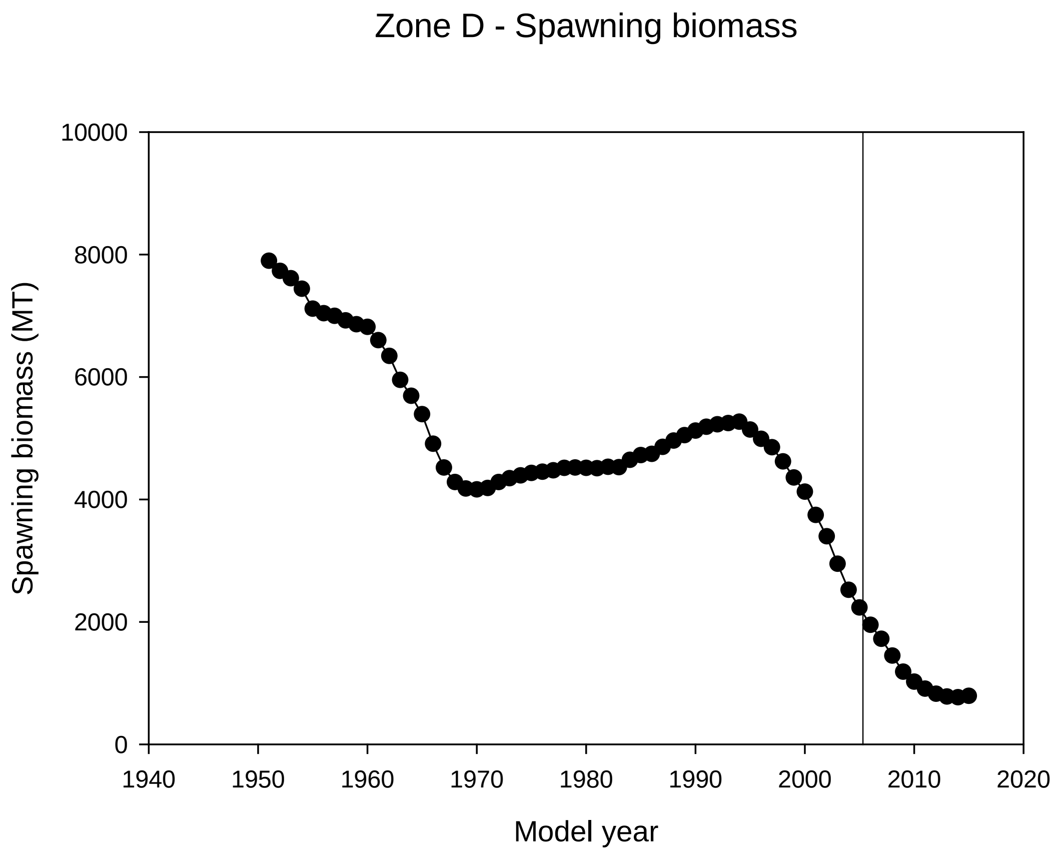


Fig. 16. Reference-case combined ABCD model total (inshore + offshore) spawning biomass trajectory shown for Zone D. Note that the 10-yr projections shown represent scenarios under which future poaching levels are assumed to remain at the current estimated level (average of 2004 and 2005) and future commercial catches remain constant at the current level.

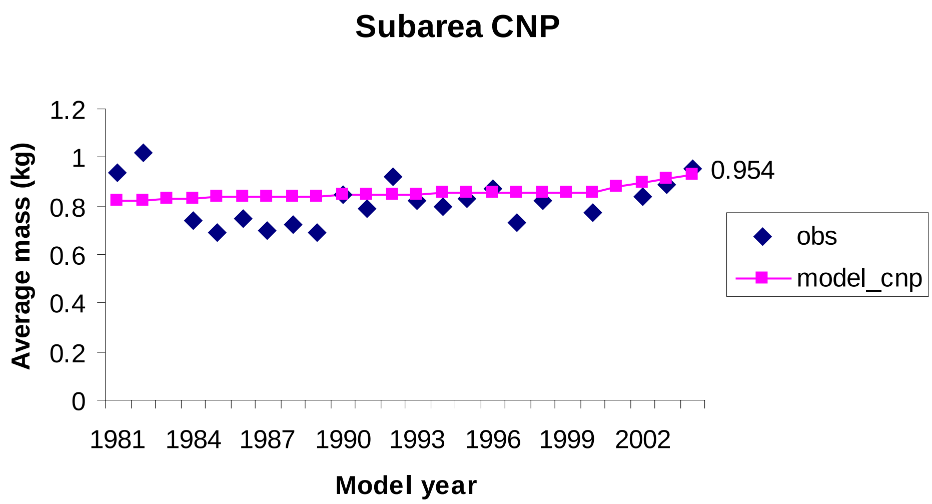


Fig. 17. Comparison between observed average mass (kg) of commercial abalone in CNP and model-predicted average mass.