ALTERNATIVE STRUCTURAL MODELS FOR THE NORTHEAST CHATHAM RISE ORANGE ROUGHY FISHERY

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ABSTRACT

INTRODUCTION

A particular difficulty with assessments of the Orange Roughy resource on the Northeast Chatham Rise is the seeming inability of standard population models, with their standard assumptions of a linear relationship between CPUE and survey indices to abundance, to simultaneously reflect the trends of all these indices. Especially concerning is that while the outputs from these models suggest a recovery in abundance for the *Spawning Box* after about 1992, the CPUE and hydroacoustic survey results for that period indicate the reverse.

A number of mechanisms have been suggested that might be able to resolve these inconsistencies: resident-and-transient fish (related perhaps to spawning migrations), seasonal patterns, hyperdepletion, disturbance, intermittent aggregation, effort saturation and fishing behaviour (Anon. 2005). The purpose of this paper (following a proposal in Anon. 2005) is to investigate this using a simple age-aggregated population model as a basis.

For the purpose of these analyses, the fishery is considered to be comprised of three grounds: the *Spawning Box* (which includes the *Eastern Flats*), the *Andes* and the *Eastern Hills*.

The analyses that follow explore two of the mechanisms suggested: first (briefly) seasonal patterns, and then resident-and-transient fish.

DATA UTILISED

The primary data used for these analyses are restricted to annual catch and abundance indices for the three grounds considered. In some cases, these data are available split for within and outside the May-August spawning season. Table 1 gives catches, Table 2 acoustic and trawl survey indices of abundance, and Table 3 CPUE indices.

These data were provided primarily by Matt Dunn, with Pamela Mace and Ian Hampton adding helpful advice.

METHODOLOGY

Basic Model

Given that only catch and abundance indices are to be considered, the population model used (to achieve the desired simplicity) is an age-aggregated biomass model, which is developed and motivated in Appendix 1. The model requires input of a parameter value related to somatic growth, for which the associated von Bertalanffy and weight-length parameters are given in Table 4.

The instance where this basic model if fitted separately to data for each of the three grounds is termed the “Reference Case”.

Seasonal Model

Attempts were made to model the *Spawning Box* (plus *Eastern Flats*) by a two-component population model where both residents and transients were present (and catchable) during the spawning season, but only residents outside this season. These attempts achieved little success or additional insight, and further there was a paucity of abundance indices available pertaining to outside the spawning season.

These attempts were therefore not pursued further, and are not reported in detail here.

Resident-and-Transient Model

This model considers that the catches and abundance indices for each ground reflect some combination of a resident population specific to that ground and a (migrating) transient population which mixes fully and is available for capture on all grounds (though to differing extents). Appendix 2 provides the mathematical details of this model.

RESULTS

Basic Model

Fig. 1 shows fits of the Reference Case model (applications of the Appendix 1 model to each ground separately) to the abundance index data. Note that this Reference Case model is a special case of the Resident-and-Transient model with $K^t = 0$ and all $\lambda^{i,j}$'s also zero. The fits to the more recent CPUE and the acoustic survey estimates for the *Spawning Box* illustrate the fundamental inconsistency: a predicted population model trend in the reverse direction (increasing) to that suggested by both of these indices (decreasing).

Fig. 2 compares some of these Reference Case fits with those for an alternative choice for $M-g$ of 0.015 rather than 0.035, i.e. assuming a longer-lived and less productive resource. This improves the fit to the more recent CPUE and acoustic survey estimates for the *Spawning Box*, but the recent population trend, although not increasing at as high a rate as for the Reference Case, remains slightly positive rather than downward as the abundance indices suggest.

Resident-and-Transient Model

Table 5 provides parameter estimates and likelihood values for the various fits of this model considered.

Fig. 3 shows fits to the abundance indices for the Reference Case choice of $M-g=0.035$. Four fits are shown corresponding to four values for the transient carrying capacity K^t: zero (the Reference Case), 100 000, 300 000 and estimated (in the model fit at some 349 000 tons). The likelihood surface is multi-model, with a global maximum that is very unstable: small shifts of K^t away from its best-estimate value see qualitatively different solutions with λ for the recent *Spawning Box* CPUE series switching from a very small to a rather large value. The K^t-estimated results (only) are able to reproduce the recent downward trends in this CPUE series and the acoustic survey index, essentially through estimating K^r for the residents at the *Spawning Box* to be much lower than for the other cases considered. The fit to the *Andes* CPUE is somewhat improved for the Resident-andTransient model compared to the Reference Case. In contrast, there is little difference for the fit for the *Eastern Hills*, which is “controlled” by a severe lack of fit to the acoustic survey estimates.

Corresponding plots for the choice of $M-g=0.015$ are shown in Fig. 4. In this case both the input choice K^t = 300 000 tons and the estimated value of K^t of some 436 000 tons are able to reflect the trends for recent indices for the *Spawning Box*.

Fig. 5 compares biomass estimates for the resident and transient populations for $M-g=0.035$ for the case were K^t is estimated.

In Fig. 6, absolute acoustic estimates of biomass are compared to the various model fits for $M-g=0.035$. None of the models shown fit these absolute estimates well, but the fact that these estimates (themselves uncertain) are contained within the range of model outputs suggests that there is scope within this model framework for closer correspondence.

DISCUSSION

CONCLUSIONS

ACKNOWLEDGEMENTS

Interactions with Matt Dunn, Pamela Mace and Ian Hampton are gratefully acknowledged.

REFERENCE

Anon. 2005. Review of methods and data used in orange roughy stock assessments. Report of the first workshop 10-12 October 2005.

Appendix 1

The Basic Age-Aggregated Population Model

The fundamental model used has the form:

$$B_{t+1} = B_t \, e^{g-M} - C_t + R_t \tag{A1.1}$$

where B_t is the (assumed recruited = mature) biomass at the start of year *t*,
g is the parameter that accounts for somatic growth (see equation A1.7 below),
M is the natural mortality rate,
C_t is the catch during year *t*, and
R_t is recruitment to the recruited biomass at the end of year *t*.

Note that this equation is very simple, *inter alia* to ease computations and to more readily clarify the key drivers of the dynamics. Since the ages at recruitment and maturity of orange roughy on the Chatham Rise are about 30 years, which is longer than the fishery has been operative, the recruitments that have entered the fishery to date have all arisen from spawning biomasses that had yet to be impacted by the fishery. Since the intention here is to be as parsimonious as possible (and therefore to attempt to avoid introducing the possibility of non-equilibrium conditions prior to exploitation), the assumption is made that:

$$R_t = R \tag{A1.2}$$

and hence from the assumption of unexploited equilibrium at the commencement of the fishery $(B_1 = K)$:

$$B_{t+1} = B_t \, e^{g-M} - C_t + K\left[1 - e^{g-M}\right] \tag{A1.3}$$

The parameter *g* is a surrogate for the effect of somatic growth given an underlying age-structure. If at pre-exploitation equilibrium N_a is the number of fish of age *a* with weight w_a, then of the 30+ biomass at the start of the year:

$$B^{30+} = \sum_{a=30}^{\infty} w_a \, N_a \tag{A1.4}$$

the mass remaining at the end of the year will be:

$$B^{31+} = \sum_{a=30}^{\infty} w_{a+1} \, N_{a+1} = \sum_{a=30}^{\infty} w_{a+1} \, N_a \, e^{-M} \tag{A1.5}$$

The fact that the equation for B^{31+} involves w_{a+1} rather than w_a (the effect of somatic growth) means that:

$$B^{31+} > e^{-M}\ B^{30+} \qquad \text{(A1.6)}$$

for which adjustment is made by introducing the parameter g defined by:

$$B^{31+} = e^{g}\ e^{M}\ B^{30+} \qquad \text{(A1.7)}$$

Calculations based on the growth parameters of Table 4 coupled to the conventional assumption of M = 0.045 yield $g \approx 0.01$. For lower values of M, g does decline, but the dynamics is governed only by the combination M-g. Analyses in the main text accordingly use M-g = 0.035 for the Reference Case, and consider sensitivities to this composite parameter. (Clearly g depends also on fishing mortality to some extent, but this has been ignored here in the interests of parsimony.)

Fitting to Data

This paper treats all indices as relative for the purposes of estimating model parameters, and in the interests of initial simplicity accords each index value a $CV \approx 0.3$. If I_t is the value of index I in year t, then assuming log-normality:

$$I_t^i = q^i\ B_t\ e^{\varepsilon_t^i} \qquad \text{where } \varepsilon_t^i \text{ from N}(0,0.3^2) \qquad \text{(A1.8)}$$

where q^i is the constant of proportionality (catchability for CPUE indices or multiplicative bias for acoustic estimates of biomass).

Parameters are then estimated by maximising a likelihood L where:

$$-\ell\text{n}\, L = \sum_i \sum_t \left[\ell\text{n}\, 0.3 + \left(\ell\text{n}\, \text{I}_\text{t}^\text{i} - \ell\, q^i - B_t\right)^2 / \left(2\text{x}0.3^2\right)\right] \qquad \text{(A1.9)}$$

A closed form solution exists for the q^i 's:

$$\sum_t \ell\text{n}\, \hat{q}^i = \sum_t \left[\ell\text{n}\, I_t^i - \ell\text{n}\, B_t\right] \qquad \text{(A.10)}$$

leaving "carrying capacity" K as the only parameter for which a non-linear minimisation search is required.

Note that care must be taken in using this model for projections into the future, as the rationale for the assumption $R_t = R$ for the past will lose validity after more than a few years into the future.

Apendix 2

The Resident-and-Transient Model

This approach assumes a transient population $\left(B^t\right)$ present throughout the overall area, some fraction of which is available for capture at each of the fishing grounds (*j*), together with resident populations $B^{r,j}$ at each of these grounds, each of which is confined to that ground. The equations for the dynamics are:

$$B_{t+1}^t = B_t^t\, e^{g-M} - C_t^t + K^t\left[1-e^{g-M}\right] \tag{A2.1}$$

$$B_{t+1}^{r,j} = B_t^{r,j}\, e^{g-M} - C_t^{r,j} + K^{r,j}\left[1-e^{g-M}\right] \tag{A2.2}$$

where *j*=1 refers to the *Spawning Box* (plus *Eastern Flats*) ground;
j=2 refers to the *Andes* ground; and
j=3 refers to the *Eastern Hills* ground

The indices are related to these abundances by:

$$I_t^{i,j} = q_t^{i,j}\left(B_t^{r,j} + \lambda^{i,j}\, B_t^t\right)e^{\varepsilon_t^{i,j}} \qquad \varepsilon_t^{i,j} \text{ from } N\left(0,0.3^2\right) \tag{A2.3}$$

where $\lambda^{i,j}$ is the fraction of the transient biomass that is "sampled" by index *I* on ground *j* relative to the fraction of the resident biomass that is similarly sampled. Again in the interests of simplicity, the $\lambda^{i,j}$ are constrained:

$$0 \le \lambda^{i,j} < 1 \qquad \text{for all } i,j \tag{A2.4}$$

[One could argue for further or fancier constraints, but such would be beyond the scope of this paper.]

It remains to link the (observed) catches made on each ground C_t^j to the removals from the different populations $\left(C_t^{r,j}, C_t^{t,j} \text{ where} \sum_{j=1}^{3} C_t^{t,j} = C_t^t\right)$. This is done by assuming that the catch split between residents and transients on a particular ground is in the same ratio as their contributions to CPUE, so that if *i*=1 is the CPUE index for ground *j*:

$$C_t^{t,j} / C_t^{r,j} = \lambda^{1,j}\, B_t^t / B_t^{r,j} \tag{A2.5}$$

For the *Spawning Box*, for which three CPUE series are available (Table 3), the λ for Box (In) series is applied until 1993, and the λ for the Box (In and Out) from 1994.

Thus for *Andes*, for example, projecting the dynamics forward gives B_t^t and $B_t^{r,2}$ at the start of year *t*, and hence:

$$\mu_t = \lambda^{1,2} B_t^t / B_t^{r,2} \tag{A2.6}$$

Thus $C_t^{t,2}/C_t^{r,2} = \mu_t$ and $C_t^2 = C_t^{t,3} + C_t^{r,2}$ are known, so that:

$$C_t^{r,2} = C_t^2 / (1+\mu_t) \text{ and}$$
$$C_t^{t,2} = C_t^2 \, \mu_t / (1+\mu_t) \tag{A2.7}$$

Fitting to Data

Equation A1.9 generalises readily by summing over grounds:

$$-\ell n\, L = \sum_j \sum_i \sum_t \left[\ell n\, 0.3 + \left\{ \ell n\, I_t^{i,j} - \ell n\, q^{i,j} - \ell n\left(B_t^{r,j} + \lambda^{i,j} B_t^t\right)\right\}^2 / \left(2\text{x}0.3^2\right)\right] \tag{A2.8}$$

Again there are closed form solutions for the $\hat{q}^{i,j}$. The estimable parameters of the model are the four carrying capacities $\left(K^t, K^{r,1}, K^{r,2}, K^{r,3}\right)$ and eight λ parameters corresponding to the various relative abundance indices. As different indices may index different components of resident and transient populations, no relationships between the $q^{i,j}$'s or $\lambda^{i,j}$'s are imposed.

Table 1. Yearly (fishing year) catches of orange roughy (in tons, and rounded to the nearest to n) taken from the grounds considered in this paper. The notation of, for example, "1980" for year refers to the period October to December of 1979 together with the period January to September of 1980. The terms "In" and "Out" below refer to whether the catches were taken within or outside of the spawning season (which is taken to be May-August). Note that both here and in the Tables and Figures following "*Spawning Box*" is shorthand for the *Spawning Box* together with the *Eastern Flats*.

Year	Ground								
	Spawning Box			***Andes***			***Eastern Hills***		
	All year	**In**	**Out**	**All year**	**In**	**Out**	**All year**	**In**	**Out**
1980	38817	36522	2295	—	—	—	—	—	—
1981	20966	20888	78	—	—	—	—	—	—
1982	23498	23498	0	—	—	—	—	—	—
1983	7451	7390	60	—	—	—	—	—	—
1984	22559	22497	62	—	—	—	—	—	—
1985	26326	26242	83	—	—	—	—	—	—
1986	30083	29468	615	—	—	—	—	—	—
1987	30493	30446	47	—	—	—	—	—	—
1988	21314	21283	31	—	—	—	2	2	0
1989	26205	25774	431	33	8	25	0	0	0
1990	20524	20324	200	143	143	0	196	196	0
1991	8771	7329	1442	125	0	125	7473	3484	3989
1992	2165	1420	745	8715	1611	7104	3598	2164	1434
1993	610	404	206	3358	793	2565	1382	283	1099
1994	450	0	450	3543	83	3460	1378	423	955
1995	1125	590	535	1407	141	1266	1794	530	1264
1996	1999	1633	366	1192	42	1150	1023	227	796
1997	2119	1803	316	667	165	502	1494	755	739
1998	2672	2161	511	1425	4	1421	933	202	731
1999	1526	1047	480	1132	43	1089	1443	393	1050
2000	1678	1077	601	1999	96	1903	1399	541	858
2001	1406	1026	380	1244	54	1190	1244	871	373
2002	3641	2853	788	2415	116	2299	1110	43	1067
2003	3614	3253	361	3038	212	2826	1028	332	696
2004	4472	2639	1833	1713	133	1580	767	112	655

Table 2. Abundance indices of orange roughy obtained from hydroacoustic surveys and research trawl surveys for the grounds considered in this paper.

a) Target acoustic indices of abundance in tons, though generally treated as a relative index.

Year	**Ground**	
	Spawning Box	***Eastern Hills***
	Relative	**Relative**
1980	__	__
1981	__	__
1982	__	__
1983	__	__
1984	__	__
1985	__	__
1986	__	__
1987	__	__
1988	__	__
1989	__	__
1990	__	__
1991	__	__
1992	__	__
1993	__	__
1994	__	__
1995	__	__
1996	__	__
1997	__	__
1998	__	__
1999	__	__
2000	__	40900
2001	__	__
2002	42286	__
2003	35821	9766
2004	30464	655
2005	27221	__

Table 2 cont. Abundance indices of orange roughy obtained from hydroacoustic surveys and research trawl surveys for the grounds considered in this paper.

b) Research trawl indices of abundance.

Year	*Spawning Box*
1980	—
1981	—
1982	—
1983	—
1984	130000
1985	111000
1986	77000
1987	60000
1988	73000
1989	54000
1990	34000
1991	—
1992	22000
1993	—
1994	61000
1995	—
1996	—
1997	—
1998	—
1999	—
2000	—
2001	—
2002	—
2003	—
2004	—

Table 3. Abundance indices for orange roughy obtained from standardised commercial CPUE series for the grounds considered in this paper. "In" and "Out" have the same meanings as in Table 1, and "In and Out" refers to the whole year.

Year	Ground						
	Spawning Box			*Andes*	*Eastern Hills*		
	***Box* (In)**	***Box* (In and Out)**	***Eastern Flats* (In)**	**Out**	**All year**	**In**	**Out**
1980	1.185	—	—	—	—	—	—
1981	1.274	—	—	—	—	—	—
1982	0.996	—	1.003	—	—	—	—
1983	1.048	—	1.775	—	—	—	—
1984	1.289	—	1.444	—	—	—	—
1985	1.471	—	1.506	—	—	—	—
1986	1.092	—	1.140	—	—	—	—
1987	1.047	—	0.809	—	—	—	—
1988	1.171	—	0.713	—	—	—	—
1989	—	—	—	—	—	—	—
1990	0.563	—	0.393	2.213	—	—	—
1991	0.769	—	—	2.977	3.700	0.343	0.906
1992	0.576	—	—	4.133	1.771	3.491	3.560
1993	—	—	—	3.429	2.696	2.255	1.568
1994	—	—	—	2.335	2.153	5.188	2.235
1995	—	—	—	1.076	1.125	1.434	2.332
1996	—	1.299	—	0.579	1.020	1.451	0.952
1997	—	1.012	—	0.702	1.392	1.294	0.832
1998	—	1.146	—	0.538	0.443	1.192	0.711
1999	—	1.093	—	0.665	0.616	0.458	0.312
2000	—	1.467	—	0.697	0.736	0.809	0.486
2001	—	0.838	—	0.549	0.814	1.404	0.452
2002	—	0.778	—	0.572	0.492	1.041	0.423
2003	—	0.909	—	0.428	0.446	0.551	0.437
2004	—	0.697	—	0.312	0.459	1.286	0.283

Table 4. Biological parameter values assumed for the assessments conducted. The values given for the somatic growth related parameter *g* (see Appendix 1 for explanation) and natural mortality *M* are those used to provide *M*-*g*=0.035 as assumed for the Reference Case.

Parameter	***Value***
von Bertalanffy growth	
ℓ_∞ (cm)	37.55
κ (yr^{-1})	0.062
t_0 (yr)	-1.59
Weight length relationship	
a	9.21×10^{-8}
b	2.71
Somatic growth $g\left(\mathrm{yr}^{-1}\right)$	0.01
Natural mortality $M\left(\mathrm{yr}^{-1}\right)$	0.045

Table 5. Results for Resident-and-Transient model fits to the abundance index data. The quantity σ reflects the standard deviation of the residuals of the fit to the model index in question. Biomass units are tons.

a) Case M-g = 0.035.

Quantity		K^t			
		0	**100 000**	**300 000**	**349 018 (est)**
Spawning Box	K^r	329 559	259 745	111 945	34 788
	B^r_{2005}/K^r	0.491	0.475	0.452	0.064
Andes	K^r	26 490	16 259	16 769	17 232
	B^r_{2005}/K^r	0.056	0.032	0.033	0.033
Eastern Hills	K^r	20 425	19 821	19 824	19 861
	B^r_{2005}/K^r	0.046	0.045	0.045	0.045
	B^t_{2005}/K^t	—	0.590	0.614	0.588
λ (σ)					
Spawning Box	**CPUE (In)**	— (0.241)	0.318 (0.248)	0.354 (0.220)	0.473 (0.207)
	CPUE (In & Out)	— (0.288)	1.000 (0.269)	1.000 (0.260)	0.015 (0.174)
	CPUE (E. Flats)	— (0.252)	7.9×10^{-5} (0.232)	3.3×10^{-5} (0.218)	2.4×10^{-5} (0.221)
	Acoustic	— (0.181)	0.999 (0.169)	0.998 (0.169)	0.024 (0.024)
	Trawl	— (0.309)	4.6×10^{-5} (0.289)	9.5×10^{-6} (0.282)	4.6×10^{-6} (0.287)
Andes	**CPUE**	— (0.364)	0.0212 (0.280)	0.007 (0.278)	0.0067 (0.277)
Eastern Hills	**CPUE**	— (0.397)	0.0019 (0.391)	6.7×10^{-4} (0.391)	6.0×10^{-4} (0.391)
	Acoustic	— (1.286)	1.5×10^{-7} (1.291)	4.7×10^{-8} (1.291)	4.2×10^{-8} (1.291)
-ln L	**Spawning Box**	-34.23	-35.65	-37.24	-39.89
	Andes	-7.041	-11.53	-11.61	-11.68
	Eastern Hills	19.37	19.24	19.22	19.21
	Total	-21.90	-27.94	-29.63	-32.36

Table 5 cont. Results for Resident-and-Transient model fits to the abundance index data. The quantity σ reflects the standard deviation of the residuals of the fit to the model index in question. Biomass units are tons.

b) Case *M-g* = 0.015.

Quantity		K^t			
		0	**100 000**	**300 000**	**435 609 (est)**
Spawning Box	K^r	360 422	277 895	103 008	45 683
	B^r_{2005}/K^r	0.349	0.298	0.092	0.039
Andes	K^r	30 400	16 052	16 977	16 762
	B^r_{2005}/K^r	0.067	0.015	0.016	0.016
Eastern Hills	K^r	23 796	20 249	20 522	20 470
	B^r_{2005}/K^r	0.046	0.022	0.022	0.022
	B^t_{2005}/K^t	—	0.441	0.479	0.527
λ (σ)					
Spawning Box	**CPUE (In)**	— (0.243)	0.475 (0.244)	0.480 (0.226)	0.366 (0.194)
	CPUE (In & Out)	— (0.251)	3.9×10^{-4} (0.247)	1.7×10^{-5} (0.168)	0.020 (0.168)
	CPUE (E. Flats)	— (0.250)	1.2×10^{-4} (0.233)	4.5×10^{-5} (0.210)	0.0016 (0.218)
	Acoustic	— (0.163)	0.998 (0.143)	0.035 (0.037)	0.018 (0.020)
	Trawl	— (0.293)	7.8×10^{-5} (0.276)	1.8×10^{-5} (0.253)	4.0×10^{-6} (0.257)
Andes	**CPUE**	— (0.383)	0.0377 (0.280)	0.013 (0.281)	0.0080 (0.281)
Eastern Hills	**CPUE**	— (0.424)	0.0139 (0.406)	0.0045 (0.406)	0.0028 (0.406)
	Acoustic	— (1.192)	1.1×10^{-7} (1.120)	3.2×10^{-8} (1.116)	2.0×10^{-8} (1.117)
-ln L	**Spawning Box**	-35.83	-36.88	-40.56	-41.23
	Andes	-5.814	-11.54	-11.48	-11.48
	Eastern Hills	17.16	13.27	13.11	13.12
	Total	-24.48	-35.15	-38.93	-39.59

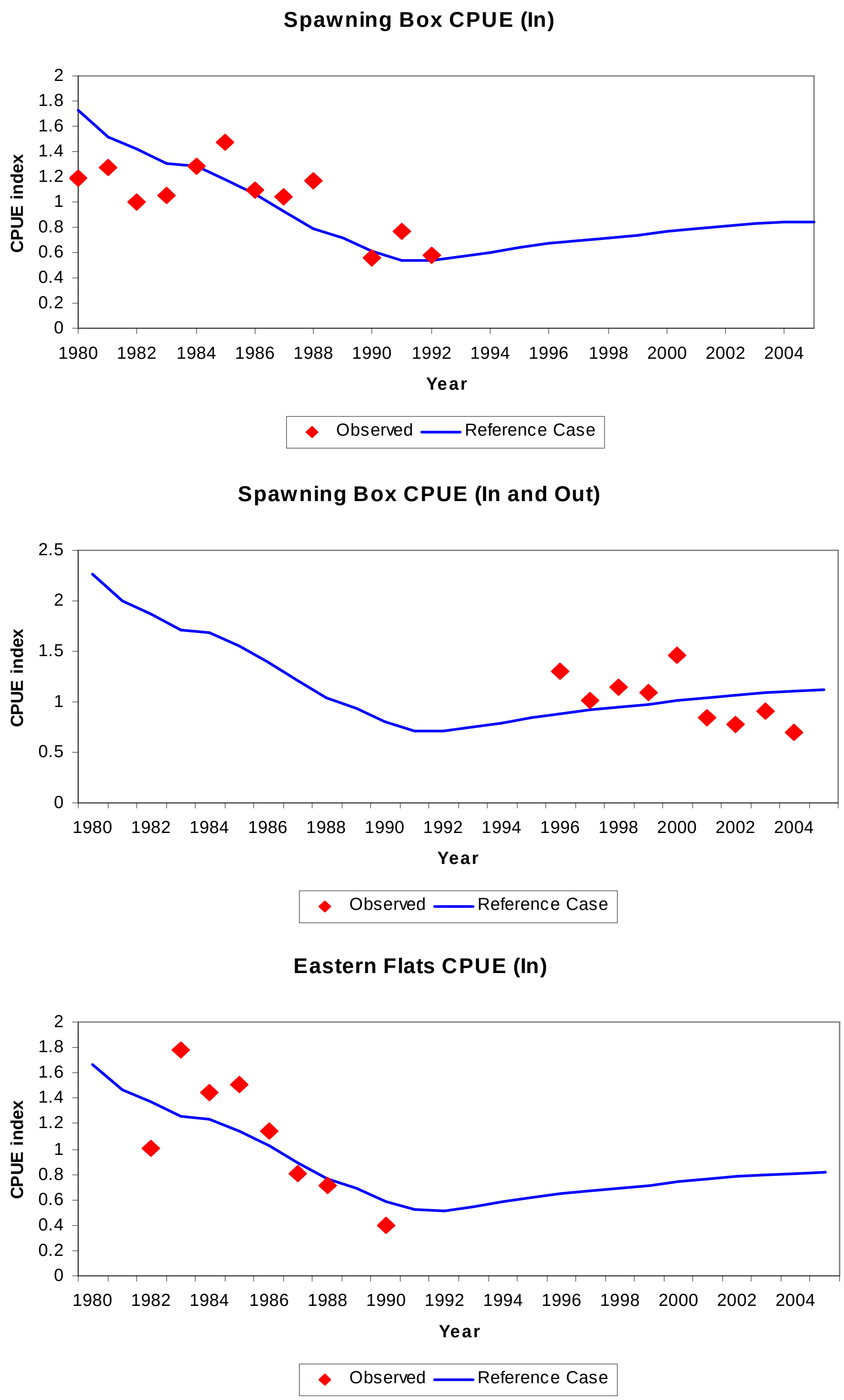
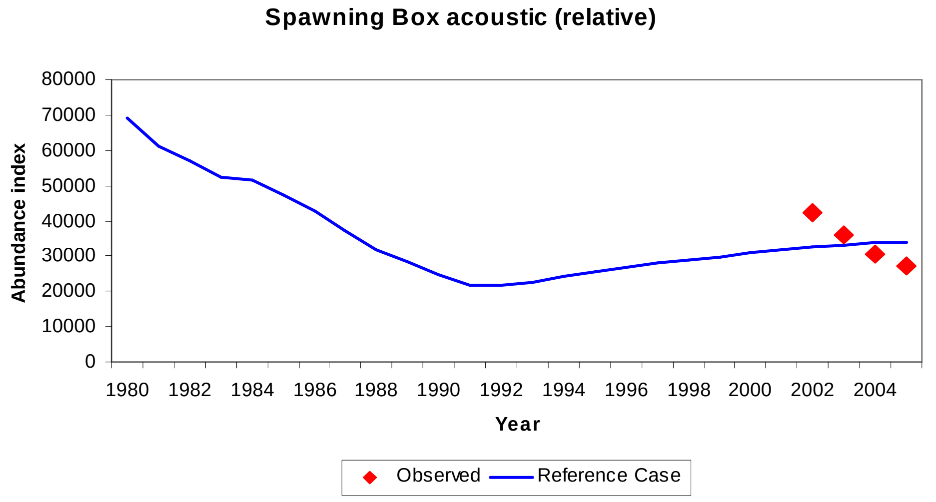
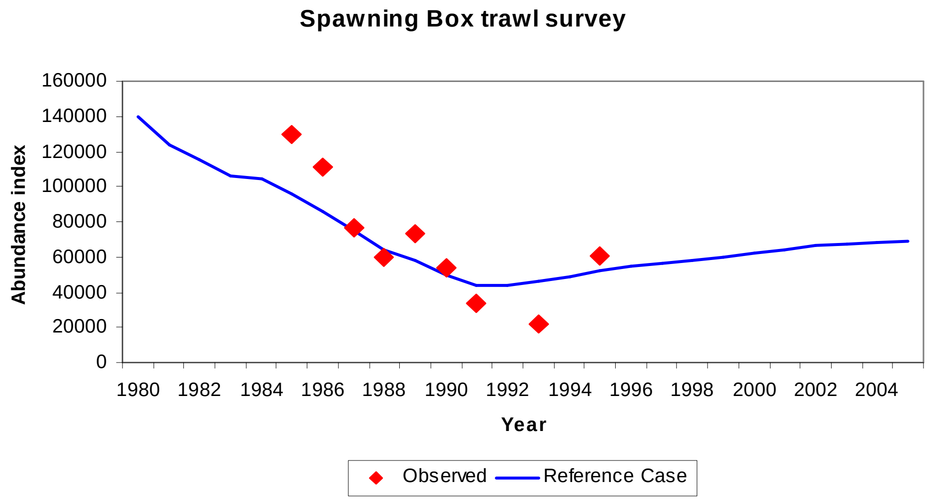


Figure 1. Comparison of model fits to the data indices of abundance for the Reference Case given the associated value for *M-g* of 0.035.





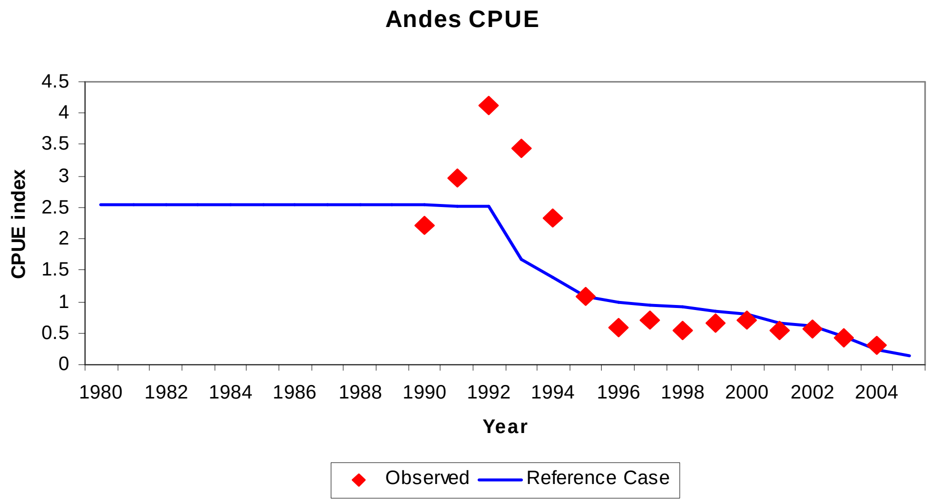
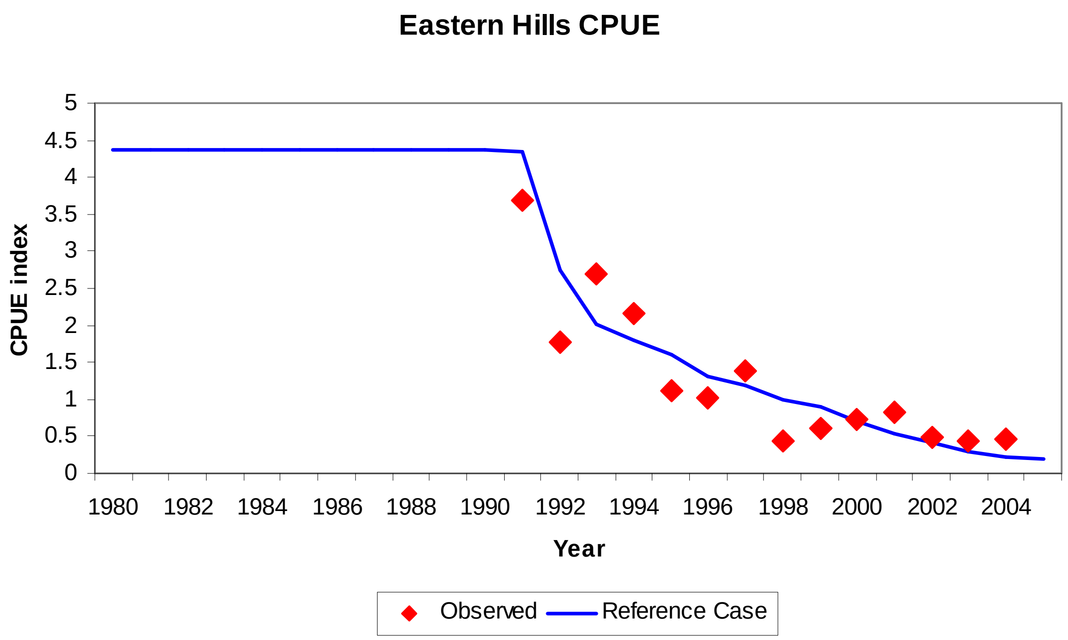


Figure 1 cont. Comparison of model fits to the data indices of abundance for the Reference Case given the associated value for *M-g* of 0.035.



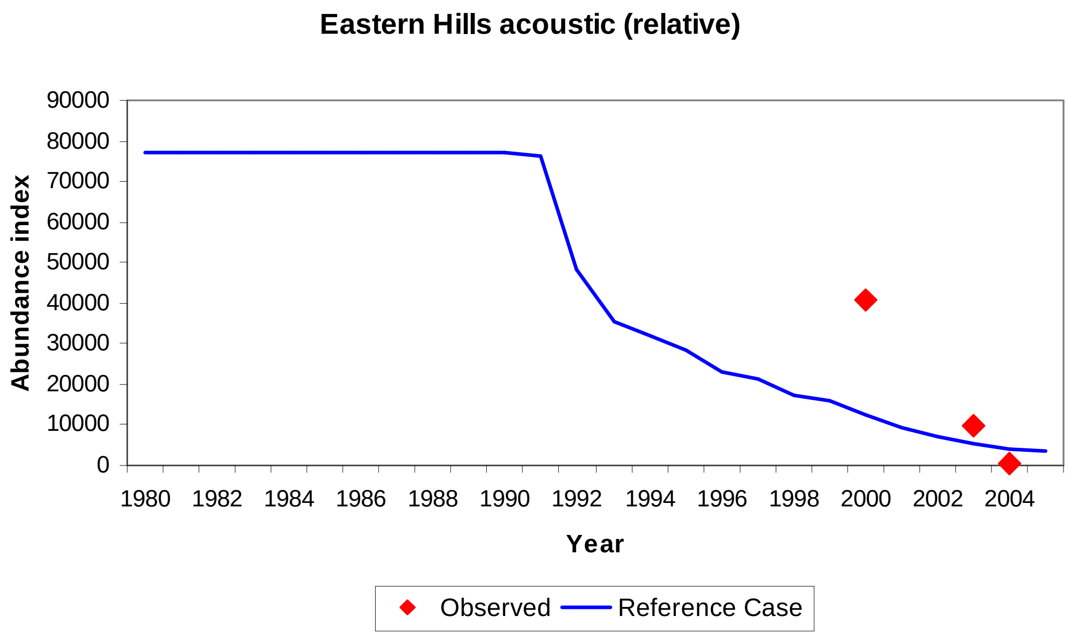


Figure 1 cont. Comparison of model fits to the data indices of abundance for the Reference Case given the associated value for *M-g* of 0.035.

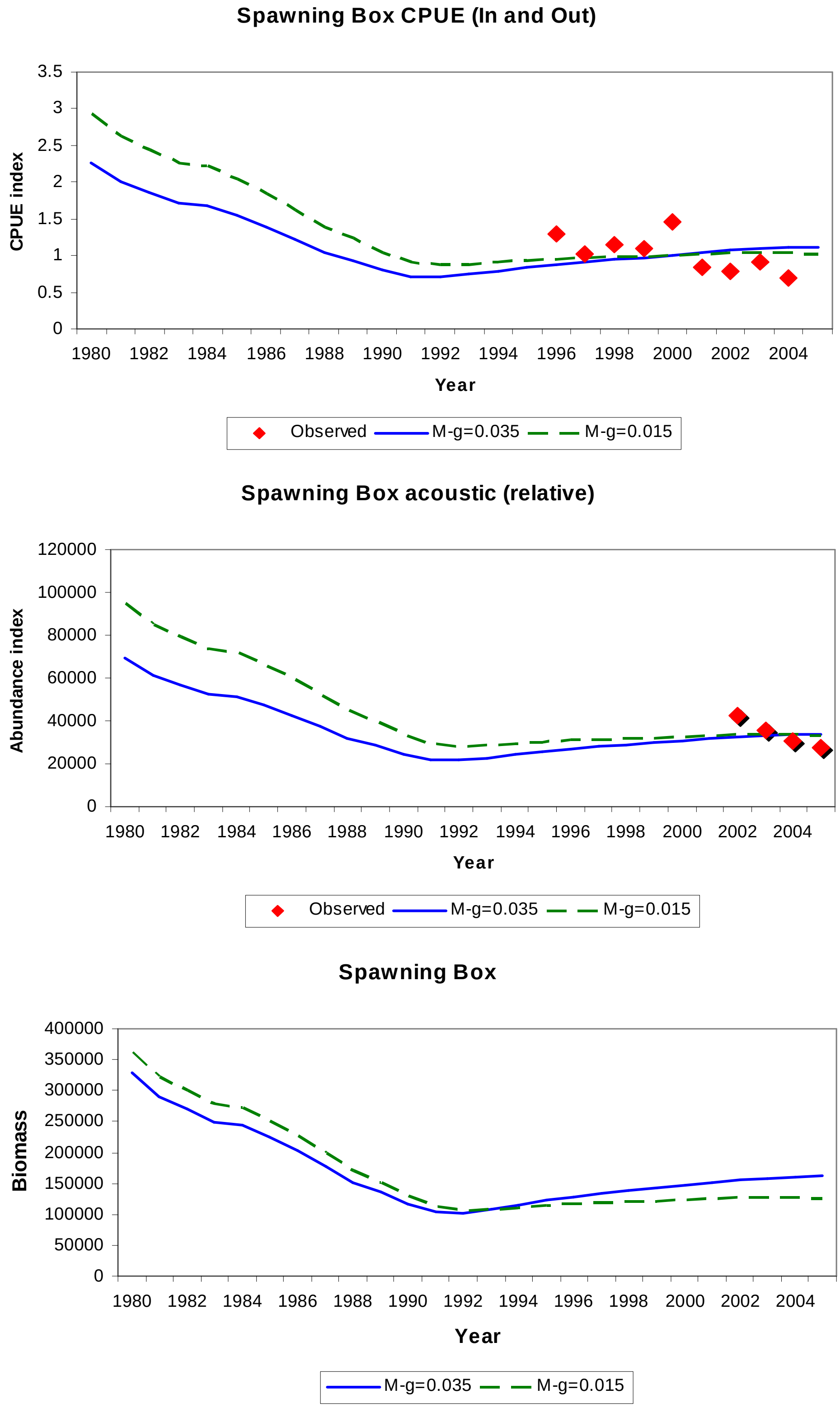


Figure 2. Comparison of model fits to the data indices of abundance for the Reference Case with its associated value of *M-g* = 0.035 and for a lower value of 0.015

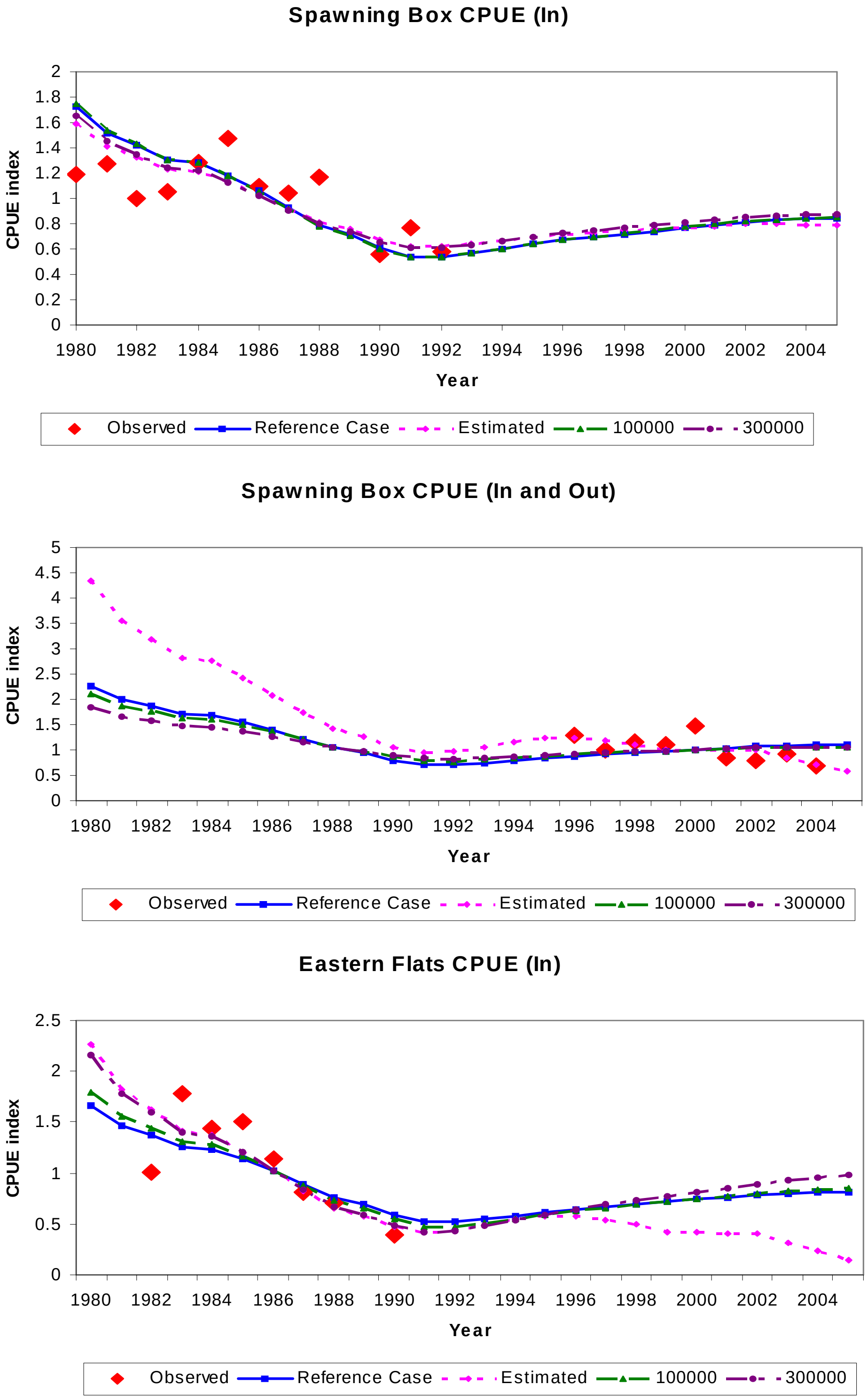


Figure 3. Comparison of Resident-and-Transient model fits to the data indices of abundance for the various models fitted given the Reference Case value for *M-g* of 0.035. The different options shown reflect alternative choices for the transient carrying capacity (K^t) in tons – note that the estimated value is 349 000 tons, and the Reference Case corresponds to $K^t = 0$.

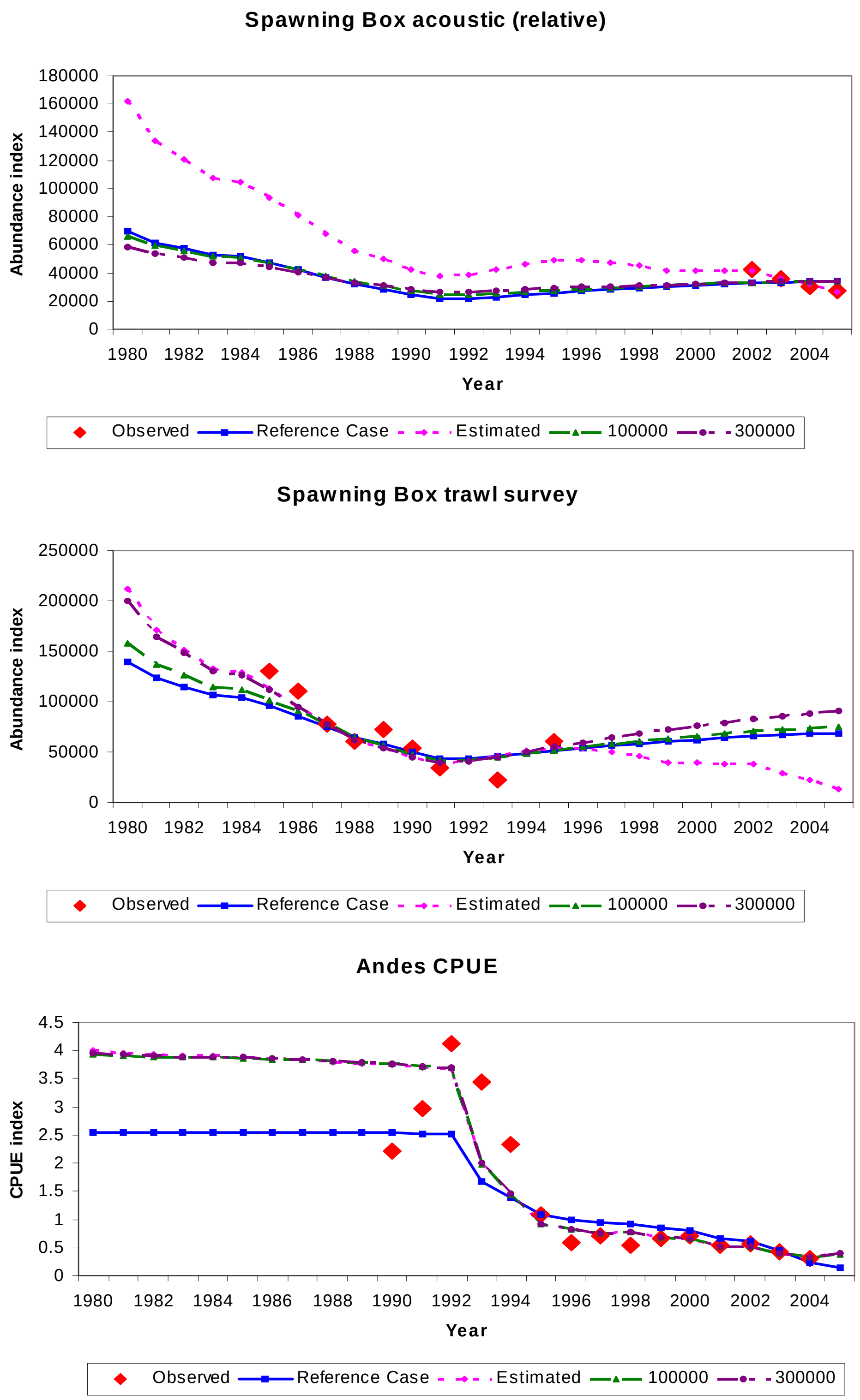
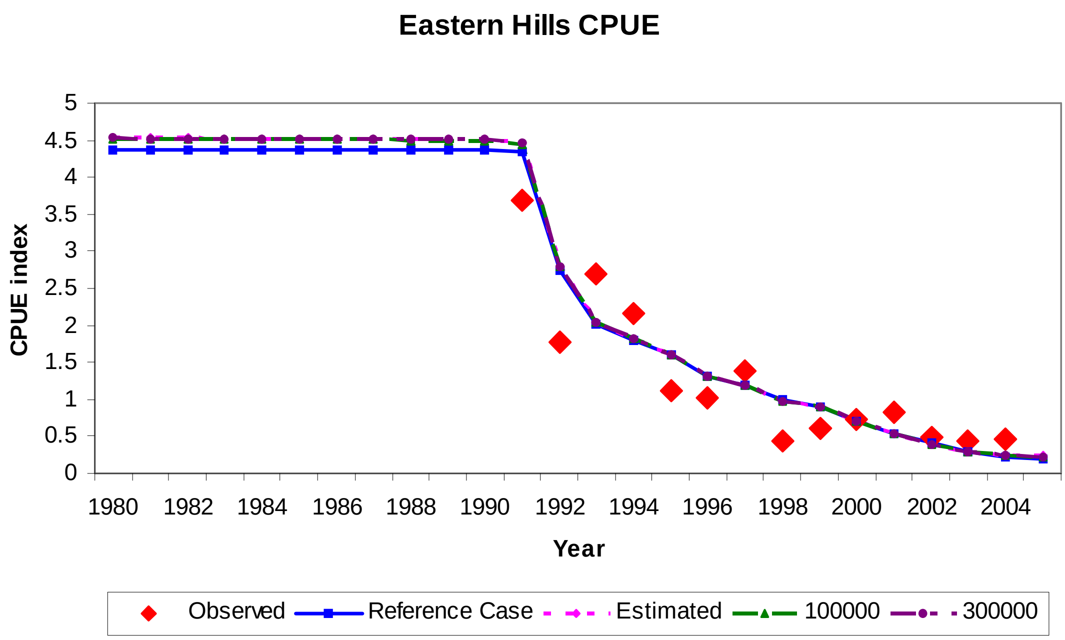


Figure 3 cont. Comparison of Resident-and-Transient model fits to the data indices of abundance for the various models fitted given the Reference Case value for *M-g* of 0.035. The different options shown reflect alternative choices for the transient carrying capacity (K^t) in tons – note that the estimated value is 349 000 tons, and the Reference Case corresponds to K^t = 0.



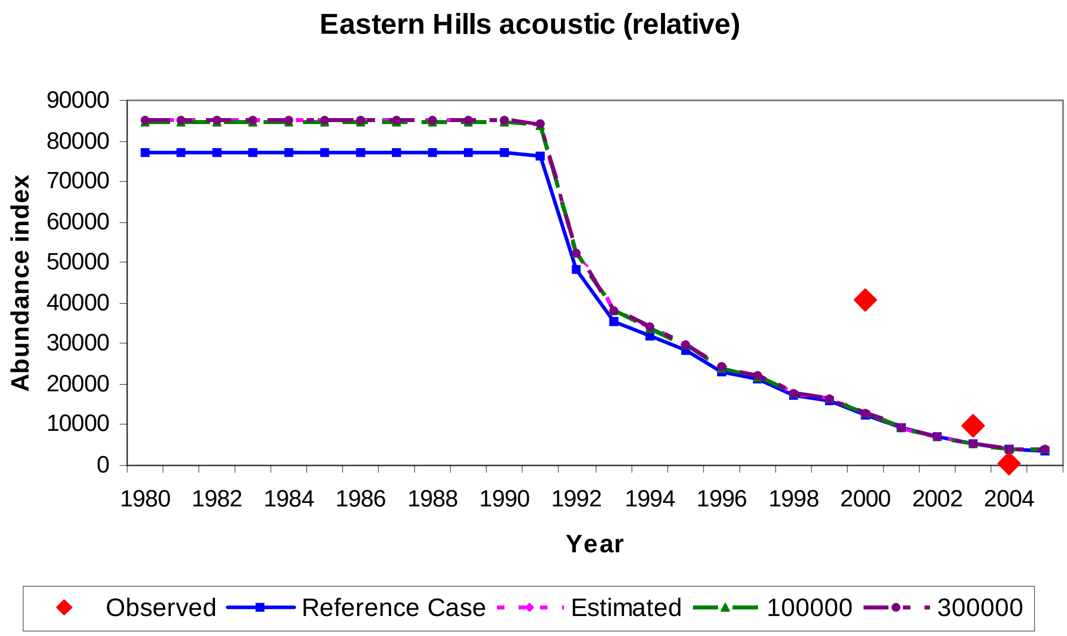


Figure 3 cont. Comparison of Resident-and-Transient model fits to the data indices of abundance for the various models fitted given the Reference Case value for *M*-*g* of 0.035. The different options shown reflect alternative choices for the transient carrying capacity (K^t) in tons – note that the estimated value is 349 000 tons, and the Reference Case corresponds to $K^t = 0$.

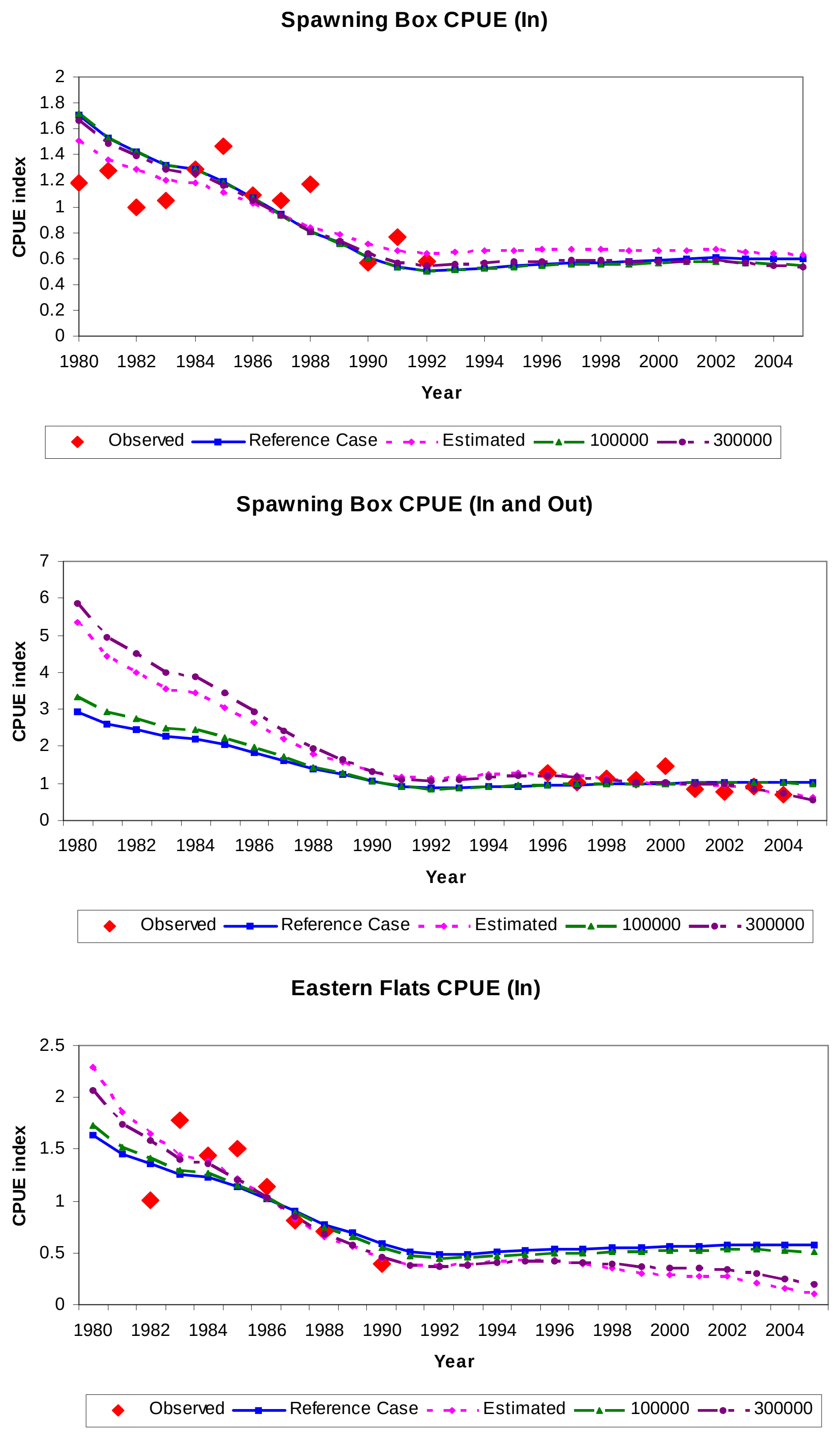


Figure 4. Comparison of Resident-and-Transient model fits to the data indices of abundance for the various models fitted given the Reference Case value for *M-g* of 0.015. The different options shown reflect alternative choices for the transient carrying capacity (K^t) in tons – note that the estimated value is 435 600 tons, and the Reference Case corresponds to $K^t = 0$.

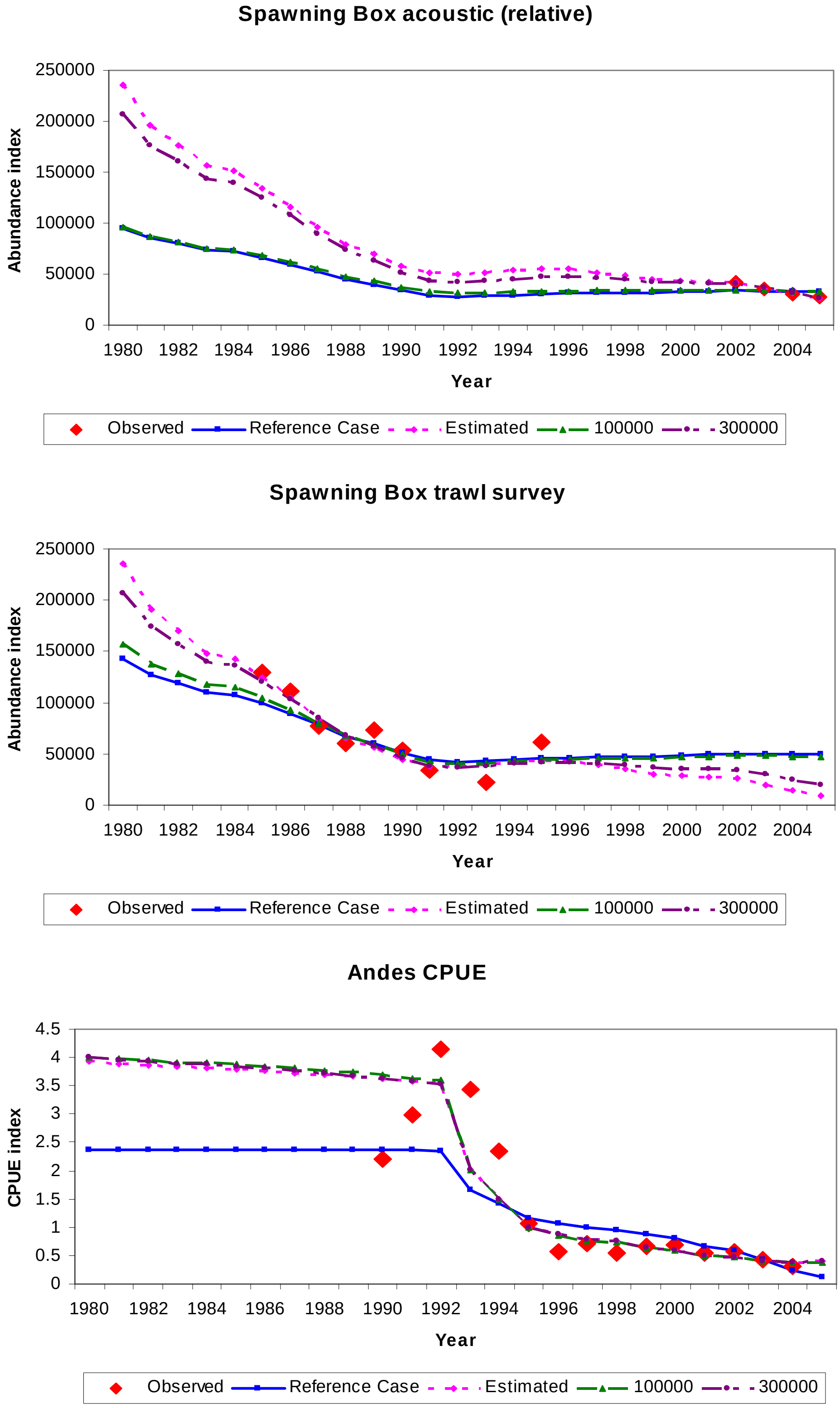
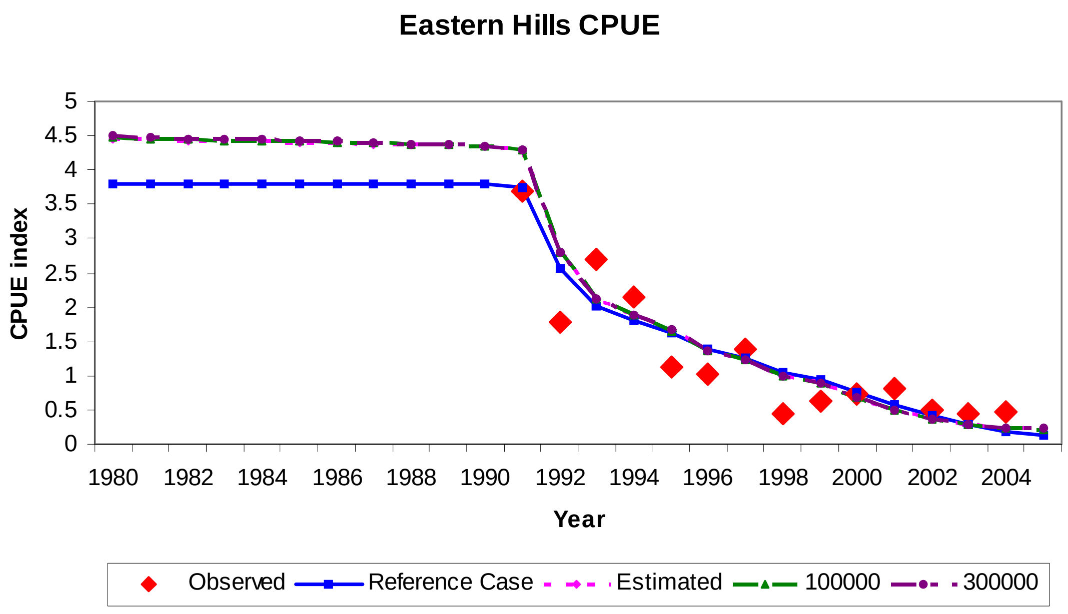
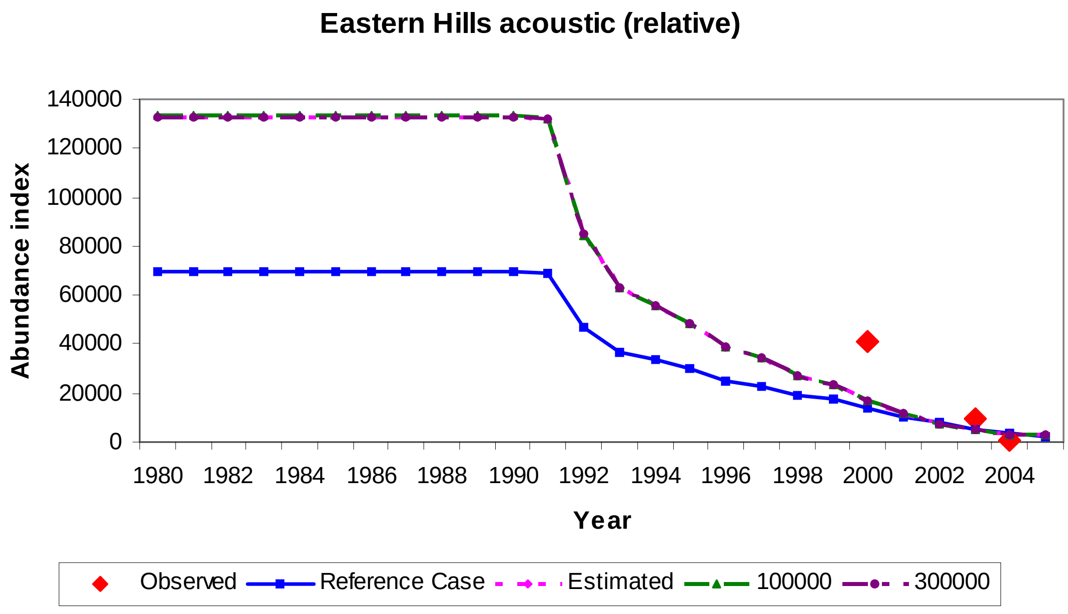


Figure 4 cont. Comparison of Resident-and-Transient model fits to the data indices of abundance for the various models fitted given the Reference Case value for *M-g* of 0.015. The different options shown reflect alternative choices for the transient carrying capacity (K^t) in tons – note that the estimated value is 435 600 tons, and the Reference Case corresponds to $K^t = 0$.





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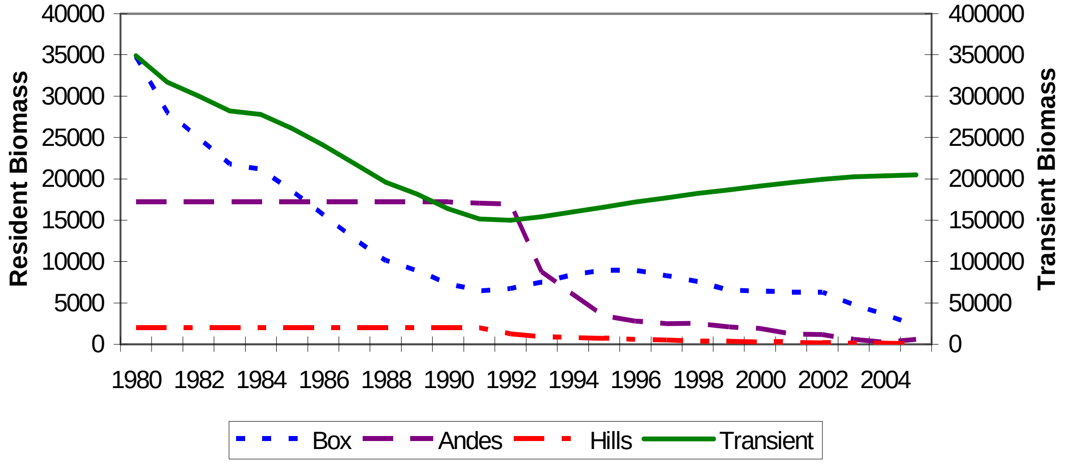

Figure 5. Resident and transient biomass trajectories for the Reference Case choice of *M-g* = 0.035 for the case where K^t is estimated (note the different scale for the latter).

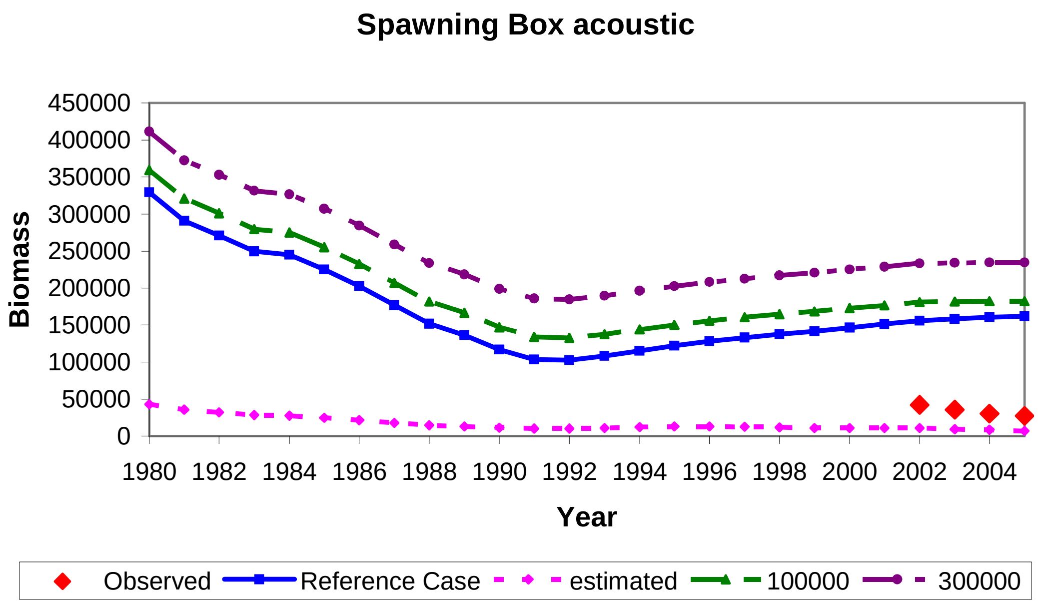

Figure 6. Comparison of the estimated spawning biomass ($B^r + \lambda B^t$) trajectories pertinent to the acoustic index of abundance for the *Spawning Box* for the variants considered. The plotted observed acoustic index is shown in absolute terms.

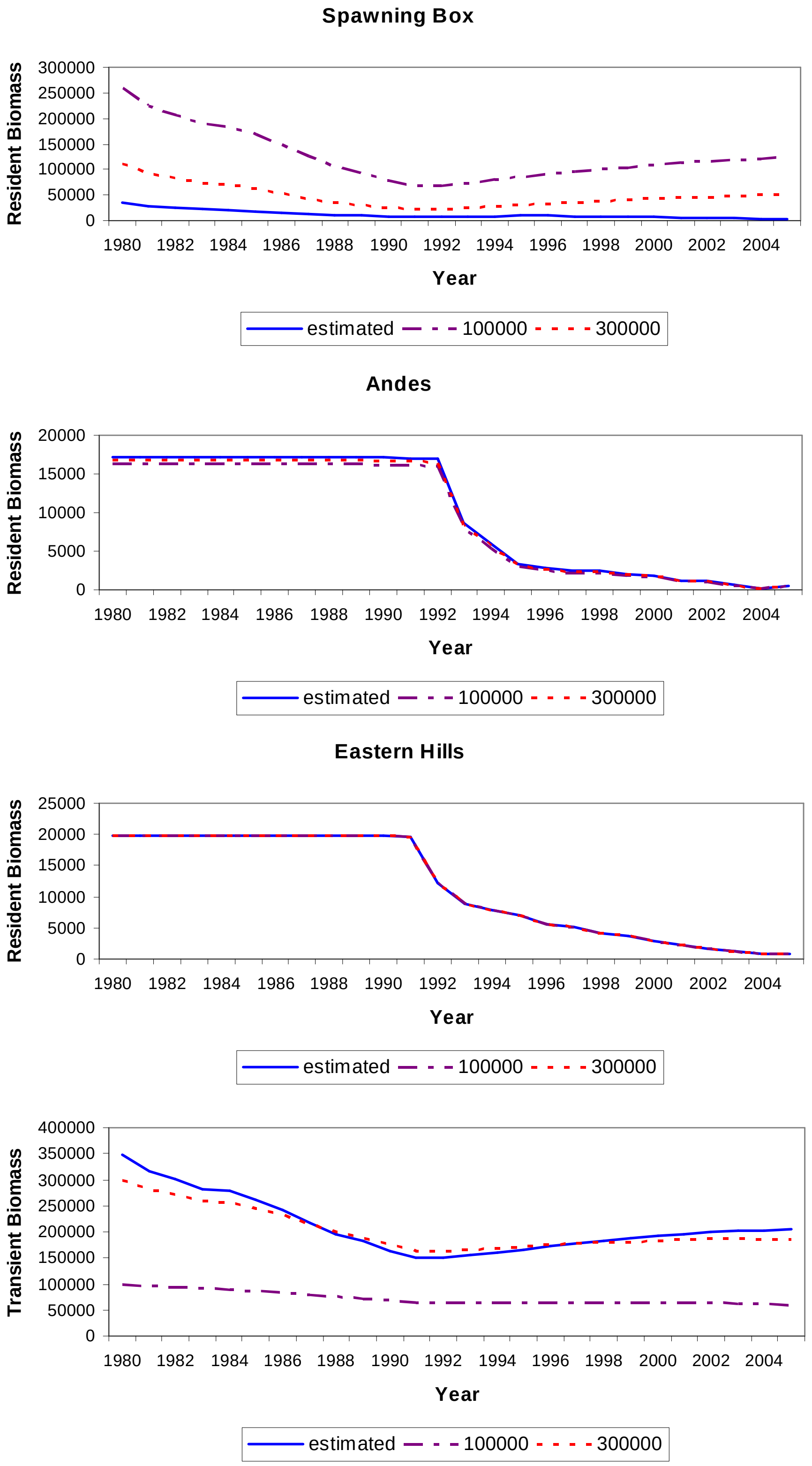

Figure 7. Comparison of the estimated resident biomass trajectories for the *Spawning Box*, *Andes* and *Eastern Hills* grounds for the various models fitted, as well as for the transient biomass trajectories for these models for the Reference Case value for *M-g* of 0.035.