New Zealand Fisheries
Assessment Report
2009/24
May 2009
ISSN 1175-1584

Assessment of the KAH 1 fishery for 2006

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New Zealand Fisheries Assessment Report 2009/24
May 2009

Published by Ministry of Fisheries
Wellington
2009

ISSN 1175-1584

Hartill, B. (2009).
Assessment of the KAH 1 fishery for 2006.
New Zealand Fisheries Assessment Report 2009/24. 43 p.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

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***New Zealand Fisheries Assessment Report 2009/24.* 43 p.**

This report documents Bayesian age structured modelling of the KAH 1 fishery using NIWA's stock assessment software package, CASAL. It is uncertain whether kahawai in New Zealand belong to multiple stocks, or a single national stock, and, because of this the first stock assessment considered a single national stock. In this assessment only the kahawai population in the Quota Management Area KAH 1 has been considered, as almost all available data have been collected from this area. Migrations to and from KAH 1 were assumed to have little effect on the biomass and composition of the kahawai stock in this area.

Almost all observational data that have been collected from KAH 1 have been collected on a regional basis, as there is good evidence to suggest that there are consistent age structured differences in the schools resident in East Northland, Hauraki Gulf, and the Bay of Plenty. It is generally accepted that there is considerable movement by kahawai between these regions, although the nature of this exchange is unknown. Because data were not available to estimate this process, it was assumed that all fisheries interacted with a common population. The effect of each fishery on a common population was, therefore, determined by its selectivity and associated catch history, regardless of its spatial origin. A fishery's selectivity is, therefore, as much a proxy for availability as it is for gear selectivity.

Four key sources of uncertainty were identified during the development of this model, which were: the rate of natural mortality (M), the steepness of a stock recruitment relationship (h), historical levels of recreational harvest, and the utility of available indices of abundance. None of these uncertainties can be resolved given our current state of knowledge, and it is highly improbable the recreational catch history levels will ever be known. Because of this uncertainty there was no single model which could be considered to be a "base" or "reference" model, against which a small number of sensitivities could be compared. Issues of structural uncertainty (process error), therefore, transcended those of statistical uncertainty (observation error), which are usually evaluated using techniques such as Bayesian sampling or bootstrapping.

A grid search of the four axes of uncertainty suggested that the magnitude and manner of their influence on the 36 models examined differed. The assumed rate of natural mortality explained most of the differences observed, although the range of values offered to the model was considered to be at the outside range of plausibility. Lower values of natural mortality resulted in higher levels of estimated fishing mortality, lower yields, and lower current biomass, although there was little contrast in estimates of virgin biomass. Increased levels of natural mortality were offset by estimated selectivity ogives which were shifted to the right, resulting in reduced fishing mortality. The model, therefore, acted as an integrated catch curve, in which the slope of each age distribution's right hand limb was approximated by mediating between an assumed natural mortality value and a consequential estimate of fishing pressure.

The second most influential axis of uncertainty was the axis relating to the assumed recreational catch history. Choice of assumed recreational catch history had little influence on the predicted stock status (B_{06}/B_{MSY}), although a higher assumed catch resulted in higher estimates of total available yield. The model was largely insensitive to the assumed steepness of a stock recruitment relationship and the selection of abundance indices which were used.

Regardless of these sources of uncertainty, it is likely that the current spawning biomass is above B_{MSY}, and current removals are less than almost all estimates of deterministic MSY. These results suggest that it is unlikely that the KAH 1 stock will decline below B_{MSY}, given current catch levels and recruitment as assumed by the model. Model projections are used to evaluate future management options.

1. INTRODUCTION

Kahawai (*Arripis trutta*) populations support valued customary, recreational, and inshore commercial fisheries (Hartill & Walsh 2005). A related, though far less common, species (*A. xylabion*) is also caught around the top of the North Island.

Although customary fisheries for kahawai are among the first described by early European settlers, levels of exploitation are thought to have been relatively light up until the mid 1970s, when the commercial harvest rapidly increased as a multi-species purse seine fishery was developed. Recreational fishers began to express some concern about commercial fishing pressure in the early 1990s. The most recent kahawai stock assessment is a stock reduction model by Bradford (1996, 1997a). In this assessment New Zealand's kahawai resource was modelled as a single New Zealand wide stock

> "*..because of the difficulty in estimating immigration to and emigration from the kahawai Fishstocks as they are defined*" (Bradford 1997a).

This issue, and several others discussed by Bradford, are still relevant to the assessment which is described here.

Unlike the previous assessment of an assumed national stock, this assessment is for the KAH 1 Quota Management Area only, as this is where most of the observational data have been collected and most harvesting currently takes place. This requires the implicit assumption that the degree of immigration to and emigration from KAH 1 is negligible. The stock assessment presented here is an age structured model which was implemented using the NIWA software package CASAL (Bull et al. 2005).

Overall objective

1. To conduct a stock assessment for kahawai (*Arripis trutta* and *Arripis xylabion*) including estimating biomass and sustainable yields.

Specific objectives

1. To develop abundance indices for important kahawai fisheries.

2. To develop a stock assessment model for kahawai in New Zealand fisheries waters that allows estimation of biomass and sustainable yields and takes account of spatial considerations.

3. To conduct a stock assessment, including estimating biomass and sustainable yields' for kahawai in New Zealand fisheries waters.

Work in relation to the first specific objective of this programme was reported by McKenzie et al. (2007).

2. METHODS AND RESULTS

2.1 Definition of the KAH 1 stock

The most fundamental requirement for a stock assessment is a definition of the stock to be assessed. For kahawai, our knowledge of genetic exchange between areas, and hence stock structure, is limited. Tagging programmes conducted by Wood et al. (1990) in 1981–84, and Griggs et al. (1998) in 1991, showed that although individuals can undergo migrations over hundreds of miles, most fish remained within 100 miles of their release location. These results are partially an artefact of where fishing effort took place, however, and cannot be considered conclusive. The potential of using otolith microchemistry and meristics to define kahawai stock boundaries has also recently been explored (Smith et al. 2008), but the results were not promising.

This assessment addresses the population in KAH 1, where most observational data have been collected (Figure 1). Migrations to and from KAH 1 were assumed to have little effect on the biomass and composition of the kahawai stock in this area.

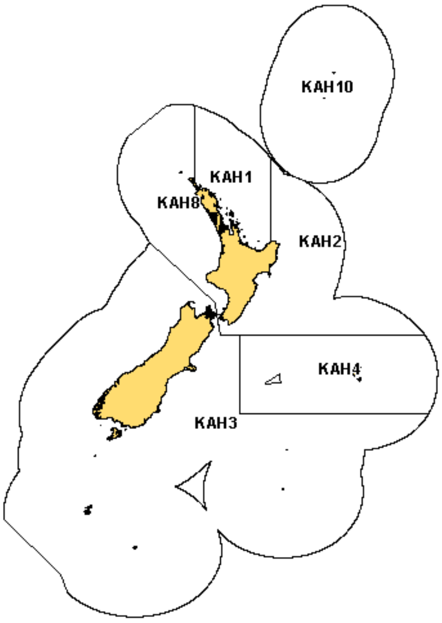

Figure 1: Quota Management Areas for kahawai.

2.2 Model structure

2.2.1 Spatial structure

This stock assessment focused on the KAH 1 stock, yet the observational data available for this area have been collected according to the regional definitions given in Figure 2. The rationale for regional data collection have been that there are clear and consistent differences between the age compositions in each area. For example, annual recreational landings from the Hauraki Gulf are mostly composed of three and four year old fish, whereas a wide range of older age classes are always landed from the Bay of Plenty. These differences cannot be considered as simply an artefact of different selectivities or levels of fishing pressure. There is, nevertheless, good evidence to suggest that there is considerable exchange between all three regions; as inferred from tag recapture data and from interpretation of catch-at-age compositions. The Hauraki Gulf is, for example, a juvenile nursery ground, yet we have little idea of where recruits into this fishery come from, and where these fish go after four years of age. It is also likely that the three regions experience common year class strengths because of this mixing.

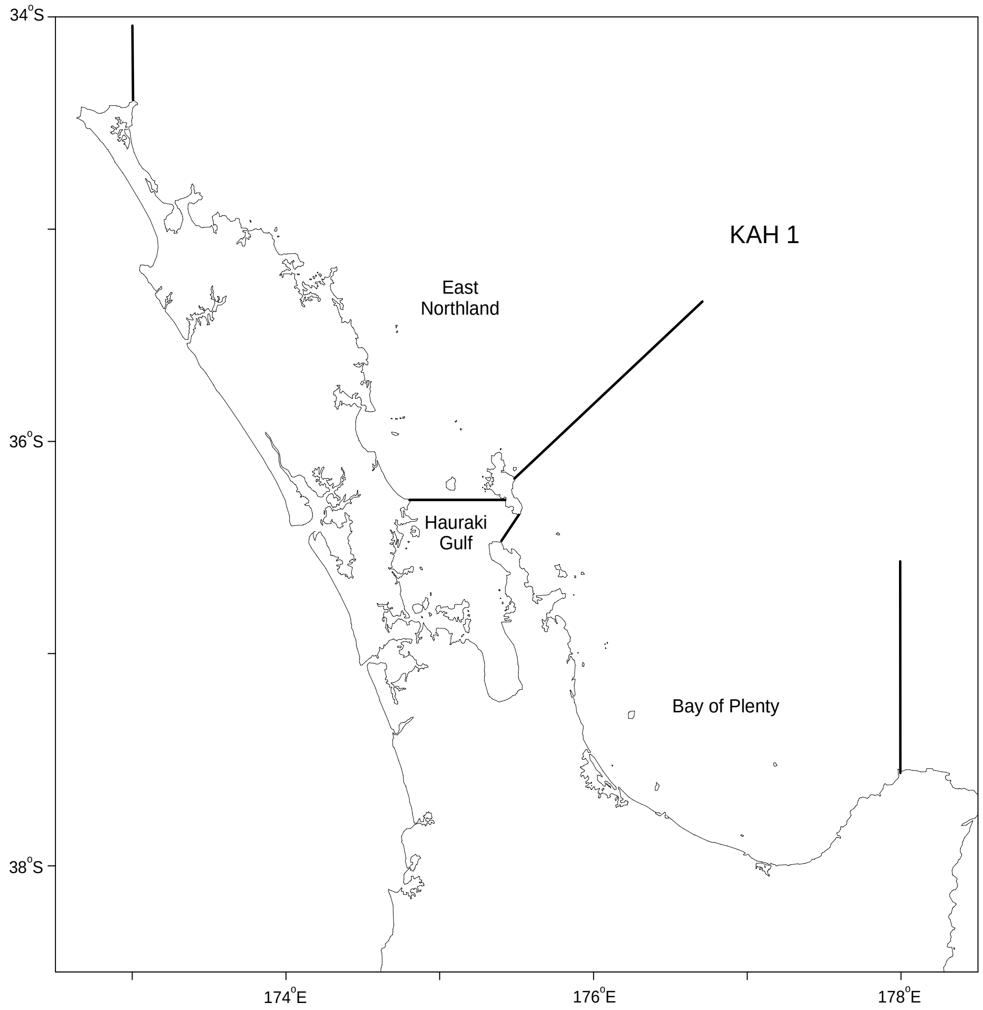

Figure 2: Regions within KAH 1 within which observational data were collected and analysed.

The regional collection of data from a wider KAH 1 population poses a dilemma, however, as the nature and extent of exchange between these regions is unknown, as are their current relative biomasses. There are, therefore, two possible approaches to modelling the KAH 1 stock.

The first option is to partition the model into three interconnected substocks with some allowance for exchange between these populations, possibly allowing for length based migration processes. Common recruitment could be assumed for all three areas, with some simulation of how these recruits are allocated across the three regions. This approach was not considered viable because there were practically no data available (tagging or otherwise) which could be used to estimate length based migration processes. Almost all tagged fish have been released in the Bay of Plenty, telling us nothing about movements from and between East Northland and the Hauraki Gulf. It is also highly likely that the nature and extent of mixing between areas would be highly variable through time, in response to localised densities and short-term oceanographic conditions, which influence such behaviour.

Given these concerns, a second approach was adopted, whereby the impact of each fishery on a common population was determined by its selectivity and associated catch history, regardless of spatial origin. A fishery's selectivity was, therefore, as much a proxy for fish availability as for gear selectivity, to a possibly greater extent then usual.

2.2.2 Biological processes

A single area approach was adopted, and, because of this, the model attempted to estimate changes in stock size and age structure in KAH 1, where the population experiences common year class strengths. Year class strengths were estimated for those recruitment years when they were evident in three or more years of observational catch-at-age data, and were constrained to have a mean of about 1.0 across all fishing years from 1974–75 to 2005–06 (fishing years were defined in the model by their second year; in this case 1975 to 2006). The model began at a lightly exploited equilibrium in 1975, when commercial landings were in the order of only a few hundred tonnes and recreational landings are assumed to be low relative to stock size.

A single annual time step was used in the model, in which ageing was followed by recruitment, maturation, growth, and then mortality (natural and fishing). The relationships between length and age, and length and weight, were assumed to be constant through time (Table 1).

Several sources of uncertainty were explored during the development of this model, and two of these were the values assumed for natural mortality (M) and for the steepness of a stock recruitment relationship (h). Attempts were made to estimate a value for natural mortality, using a normally distributed prior, with a mean of 0.18 and increasing degrees of variance. In all cases, model estimates of M (0.27–0.29) were in the upper range of the associated prior, and were not considered plausible given the high associated estimates of virgin biomass and documented estimates of total mortality (Hartill et al. 2007c). Attempts were also made to model age based natural mortality ogives (using either cosh or double exponential functions) but the resulting mortality rates were considered unrealistically high for most age classes. Two other fixed rates of natural mortality were considered in the final exploration of model uncertainty, 0.12 and 0.24, which the Pelagic Working Group considered to be at the "*outside range of what would be considered plausible values*" (Table 1). The highest of these values (0.24) is close to recent total mortality (Z) estimates of around 0.25 to 0.35, which have been derived from catch curve and Chapman Robson analyses performed on recreational catch-at-age data collected from the Bay of Plenty (Hartill et al. 2007c).

The relationship between kahawai stock size and recruitment is unknown, as no previous estimates of stock size and recruitment strength are available. A Beverton-Holt stock recruitment relationship (h) was assumed in the model. It was not possible to estimate the steepness parameter for this relationship, as there was little contrast in the year class strengths and annual biomasses estimated by the model. In recognition of this uncertainty, two values were considered in a final exploration of uncertainty (Table 1).

Table 1: Fixed parameters used in base model

Parameter	Symbol	Value	Source
Year class strengths (1975–1982, 2002–2006)	YCS	1	
Steepness for Beverton-Holt*	h	0.75, 1.0	
Von Bertalanffy parameters	t_0	-0.10	Hartill et al. (2007c)
	K	0.33	
	$L\infty$	54.3	
Length-weight parameters	a	0.0236	Hartill & Walsh (2005)
	b	2.89	
Natural mortality*	M	0.12, 0.18, 0.24	
Age at maturity		4 years	McKenzie, (unpub. data)

*values considered in the final exploration of likely stock scenarios

The modelled population was not partitioned by sex or maturity status. Age at maturity, which is used to estimate the spawning stock biomass, was inferred from sex and stage data collected from purse seine and single trawl landings collected in the early 1990s (Figure 3; J. McKenzie, NIWA, unpublished data). These data suggest that the onset of maturity may occur at a younger age and length in females. Despite this, almost none of the catch composition data available are structured by sex and, therefore, a common age at maturity of 4 years was assumed.

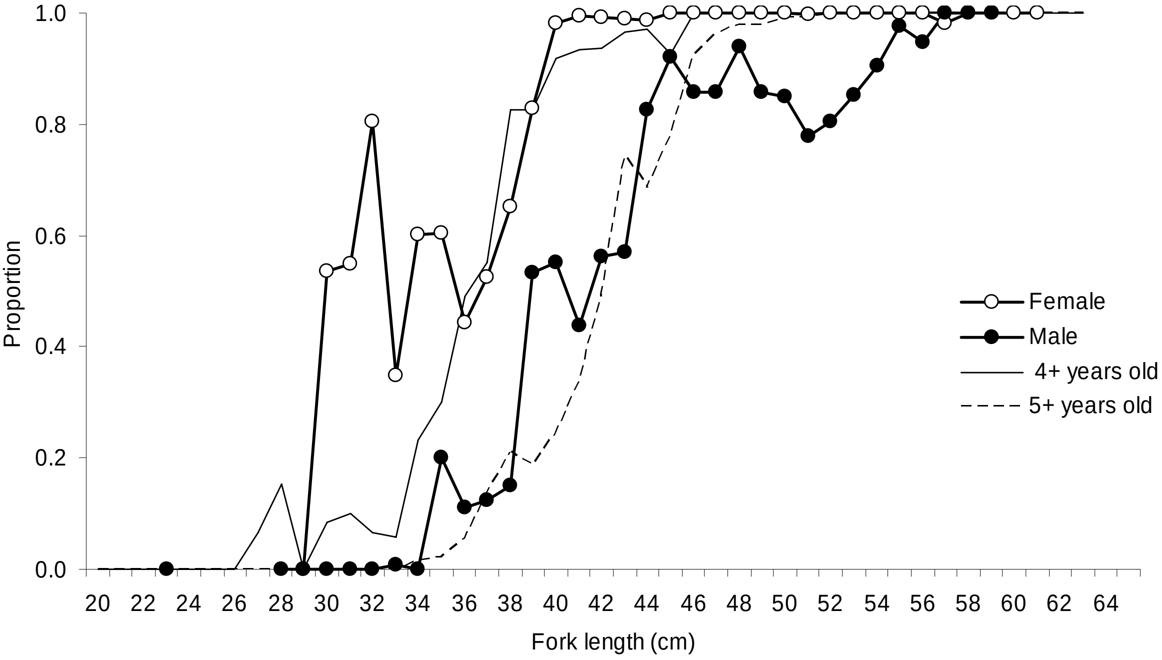

Figure 3: Proportion at length of female and male kahawai with mature reproductive tissue relative to the proportion of kahawai that are 4 or more years old and 5 or more years. Reproductive staging data were collected from Bay of Plenty purse seine and single trawl landings in the early 1990s, and proportions of age-at-length are derived from age at length data collected from recreational landings in the Bay of Plenty between 2000 and 2005.

2.3 Model inputs

2.3.1 Catch histories for commercial fisheries

As stated above, all the observational data used in the model have been collected from three regions within KAH 1: East Northland, the Hauraki Gulf, and the Bay of Plenty (Figure 3). Because observational data were collected at a regional level, regional catch histories were required for each fishery (Table 2). For commercial fisheries the breakdown of catch by area and method is available only from 1989–90 onwards, and catch levels before this were estimated by prorating annual catch totals. For 1982–83 to 1988–89 the reported tonnage of kahawai landed by purse seine was available (which has been attributed to the Bay of Plenty), and the relatively small remainder of the total landed KAH 1 catch was prorated across regions and methods on the basis of the tonnages reported by these fleets in 1989–90. Before 1982–83, annual catch statistics were available only in the form of national catch totals, and catch histories for all regional/method combinations were prorated on the basis of the estimated tonnages landed by these fleets in 1982–83 relative to the national tonnage landed in each year.

Table 2: Commercial catch histories used in the stock assessment by fishing year. PS, purse seine; SN, set net; ST, single trawl; OT, other methods.

	East Northland				Hauraki Gulf				Bay of Plenty				KAH 1
Fishing year	PS	SN	ST	OT	PS	SN	ST	OT	PS	SN	ST	OT	All
1974–75	–	8	1	6	–	27	1	5	12	2	5	2	69
1975–76	–	17	3	13	–	58	2	10	25	4	11	4	146
1976–77	–	33	6	25	–	116	4	21	50	8	21	8	292
1977–78	–	51	9	39	–	176	6	32	77	12	33	12	446
1978–79	–	70	12	53	–	243	9	44	106	16	45	16	614
1979–80	–	74	13	57	–	258	9	47	112	17	48	17	653
1980–81	–	70	12	53	–	244	9	44	106	16	45	16	617
1981–82	–	74	13	56	–	256	9	46	111	17	48	17	647
1982–83	–	112	19	85	–	389	14	70	169	26	72	26	982
1983–84	–	68	12	52	–	237	9	43	1 445	16	44	16	1 941
1984–85	–	87	15	66	–	303	11	55	882	20	56	20	1 517
1985–86	–	56	10	43	–	194	7	35	1 191	13	36	13	1 597
1986–87	–	48	8	36	–	165	6	30	1 544	11	31	11	1 890
1987–88	–	45	8	34	–	157	6	28	3 964	10	29	10	4 292
1988–89	–	72	13	55	–	251	9	45	1 644	17	47	17	2 169
1989–90	1	75	13	57	–	259	9	47	1 698	17	48	17	2 241
1990–91	0	54	10	39	–	189	6	10	1 563	69	65	29	2 035
1991–92	–	68	14	53	3	157	2	21	1 723	65	29	19	2 154
1992–93	199	74	147	93	–	402	14	63	2 326	83	15	53	3 469
1993–94	118	51	19	165	–	278	6	105	1 451	93	55	35	2 377
1994–95	4	103	30	95	–	207	7	73	1 287	67	23	38	1 934
1995–96	1	74	41	71	–	185	4	35	1 368	90	80	39	1 987
1996–97	53	99	63	60	–	120	3	17	989	81	47	34	1 567
1997–98	30	138	40	46	–	144	9	18	682	65	67	22	1 260
1998–99	44	78	28	49	–	110	3	41	1 329	28	115	18	1 843
1999–00	4	74	29	18	–	132	1	25	1 214	31	76	14	1 618
2000–01	34	84	4	27	–	110	–	29	1 359	12	72	15	1 747
2001–02	43	81	5	9	–	195	–	11	949	16	54	37	1 399
2002–03	57	64	12	7	–	173	–	8	551	17	35	29	952
2003–04	52	51	16	11	–	146	–	2	1 311	14	34	24	1 661
2004–05	36	35	11	7	–	101	–	1	905	10	24	16	1 147
2005–06	28	28	9	6	–	80	–	1	713	8	19	13	903

2.3.2 Catch histories for recreational fisheries

The recreational catch history in KAH 1 is unknown. The earliest estimates of the recreational catch in KAH 1 were derived from telephone diary surveys conducted between 1992 and 2001 (Table 3). These estimates were not used in the model as a review of these surveys by a Recreational Technical Working Group in 2003 recommended that

> *"... the harvest estimates from the diary surveys should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and, c) the 2000 and 2001 harvest estimates are implausibly high for many important fisheries."*

Recreational catch estimates for SNA 1, derived from the 2000 and 2001 telephone diary surveys, were considered particularly implausible given our more extensive knowledge of this fishery. Although telephone diary estimates are considered to be biased, it has been suggested that these biases should be universal to all fisheries and hence these surveys can provide information on the relative magnitude of one harvest relative to another (sample size issues notwithstanding). This property is explored in Table 3.

Table 3: Annual recreational harvest estimates for KAH 1 in tonnes. Estimates are also given for the SNA 1 harvest which is understood with greater confidence.

Survey	Survey method	KAH 1	SNA 1	KAH/SNA	Source
1994	Telephone/diary	978	2 813	45 %	Bradford (1997b)
1996	Telephone/diary	952	2 190	43 %	Bradford (1998)
2000	Telephone/diary	2 105	6 297	33 %	Boyd & Reilly (2002)
2001	Telephone/diary	2 161	6 027	36 %	Boyd et al. (2004)
2004–05	Aerial overflight	530	2 419	22 %	Hartill et al. (2007b)

The recreational catch histories used in the model were partially based on more recent estimates derived from aerial overflight surveys, which is the currently preferred survey approach (for the Hauraki Gulf in 2003–04 see Hartill et al. (2007d), and for all of QMA 1 in 2004–05 see Hartill et al. (2007b). One reason for this preference is that most aspects of the harvest were quantified directly by independent observers, whereas telephone diary estimates were largely based on reports of fishing rather than observation.

The aerial overflight method is most suited to estimating the harvest of species when the associated fishing effort is easily and unambiguously observed from an altitude of 500–1000 feet. Observation of kahawai fishing effort is often ambiguous, however, as much of the catch is taken from moving boats and from the shore. This leads to uncertainty surrounding kahawai harvest estimates.

One means of addressing this uncertainty is to consider kahawai harvest estimates relative to those for snapper. Snapper harvest estimates derived from the aerial overflight approach are considered broadly reliable, as most of the entire SNA 1 harvest is taken by fishers from stationary trailer boats which are easily counted from the air and mostly return to boat ramps. In 2004–05 the harvest from KAH 1 was estimated to be 22% of that from SNA 1 (Table 3). The ratio of kahawai to snapper harvest estimates derived from previous telephone diary surveys averaged 37%. If the possibility that the relatively low kahawai estimate from 2004–05 survey of 530 tonnes is not due to declining kahawai catch rates, as the recreational CPUE indices given in Figure 4 suggest, then 37% of the more accepted 2004–05 snapper harvest estimate gives a kahawai harvest estimate of about 892 tonnes.

The current recreational harvest is, therefore, uncertain, but is thought to be in the vicinity of 500–900 tonnes. For modelling purposes, a nominal assumed value of 800 tonnes per annum was used for all years before to 2004–05, as 530 tonnes was considered implausibly low for a long term average. A constant annual catch was used in the model, going back to 1975, as there was some concern that if an assumed trend was used, this trend could influence the model, despite being essentially unknown. Concern was expressed about the sensitivity of the model to an assumed value of 800 tonnes, and a second higher constant tonnage of 1865 tonnes was also used in a range of scenarios. This arbitrary upper bound is equal to the 2004–05 recreational allowance, which was based on the 2000 telephone diary survey estimate less 15%.

Data from three recent surveys of the recreational fishery were used to determine how the constant catch history for KAH 1 was to be allocated across the three regions. These surveys were two telephone diary surveys conducted in 1999–2000 (Boyd & Reilly 2002) and 2000–01 (Boyd et al. 2004), and an aerial overflight survey conducted in 2004–05 (Hartill et al. 2007b). All three surveys suggest very similar catch split proportions, and on the basis of these data, the putative recreational catch history was allocated as follows: East Northland 22%, the Hauraki Gulf 18%, and the Bay of Plenty 60%.

The aerial overflight estimates for the Hauraki Gulf in 2003–04 (Hartill et al. 2007d) and for all three regions in 2004–05 (Hartill et al. 2007b) were used in the model for these years, as they were based on actual observations. Assumed annual tonnages could have been used, as for all previous years, but the influence of such a change would have been minimal given the size of the commercial harvest and the fact that survey based values were used only in the last years of the catch history.

2.3.3 Indices of abundance

Several indices of abundance were available for modelling, but ultimately only some were used (Table 4). Three indices which were used were based on CPUE data collected as part of boat ramp interviews conducted intermittently in KAH 1 since 1991. Separate standardised indices were generated for three regional fisheries: East Northland, Hauraki Gulf, and Bay of Plenty (Hartill & Walsh 2005). Indices were derived from Poisson based generalised linear models of the number of kahawai caught in a trip (including those released) given the time spent fishing and other explanatory variables. Poisson based modelling accommodates a high proportion of zero catches in the data, which often occurs in for recreational fisheries. Boat ramp data suggest that about 80% of the recreational catch is landed (Hartill & Walsh 2005). Levels of dispersion were close to one, supporting the assumption that recreational catch rates generally conformed to a Poisson error structure.

Table 4: Observational data used in the model. All years refer to the second calendar year of the fishing year.

Observational data	Region	Likelihood
Recreational CPUE (1991, 1994, 1996, 2000–2004)	ENLD, HAGU, BPLE	Lognormal
Set net CPUE (1991–2005)	ENLD, HAGU, BPLE	Lognormal
Recreational catch-at-age (2001–2006)	ENLD, HAGU, BPLE	Multinomial
Purse seine catch-at-age (1991–1993, 2005)	ENLD, BPLE (Target only)	Multinomial
Single trawl catch-at-age (1991–1993)	BPLE	Multinomial

Set net CPUE indices were also available for each of the three regions of KAH 1, which were generated as part of the first objective of this programme (McKenzie et al. 2007). Standardised indices of abundance were derived from commercial set net data reported on the CELR system since 1990, although for the Bay of Plenty, there were insufficient data available for modelling for 2003–04 to 2004–05. Annual tonnages from the East Northland and Bay of Plenty set net fisheries were generally less than 100 tonnes, and it is questionable how well these indices describe changes in the abundance of the wider population.

Two indices which were not used were a trawl index from the Bay of Plenty, which was based on a poor measure of fishing effort (McKenzie et al. 2007), and a longer term abundance index based on aerial sightings, which still required further development.

Because six indices of abundance were offered to the model, concern was expressed about how conflicting trends could potentially lead to a flat or misleading biomass trajectory. Recreational catch rates in East Northland increased in the early 1990s, and then declined in recent years, whereas the reverse trend is evident in the set net index (Figure 4). Both of the Hauraki Gulf indices show interannual variability and little trend is apparent. In the Bay of Plenty there is no trend in the recreational index, but a clear decline is evident in the set net index. Sensitivity to index selection was explored in a range of scenarios where either all indices were used, just those derived from recreational CPUE data, or just those derived from set net CPUE. Most concern was expressed about the Bay of Plenty set net CPUE index, which suggested a rapid and marked decline in biomass, which was considered unrealistic.

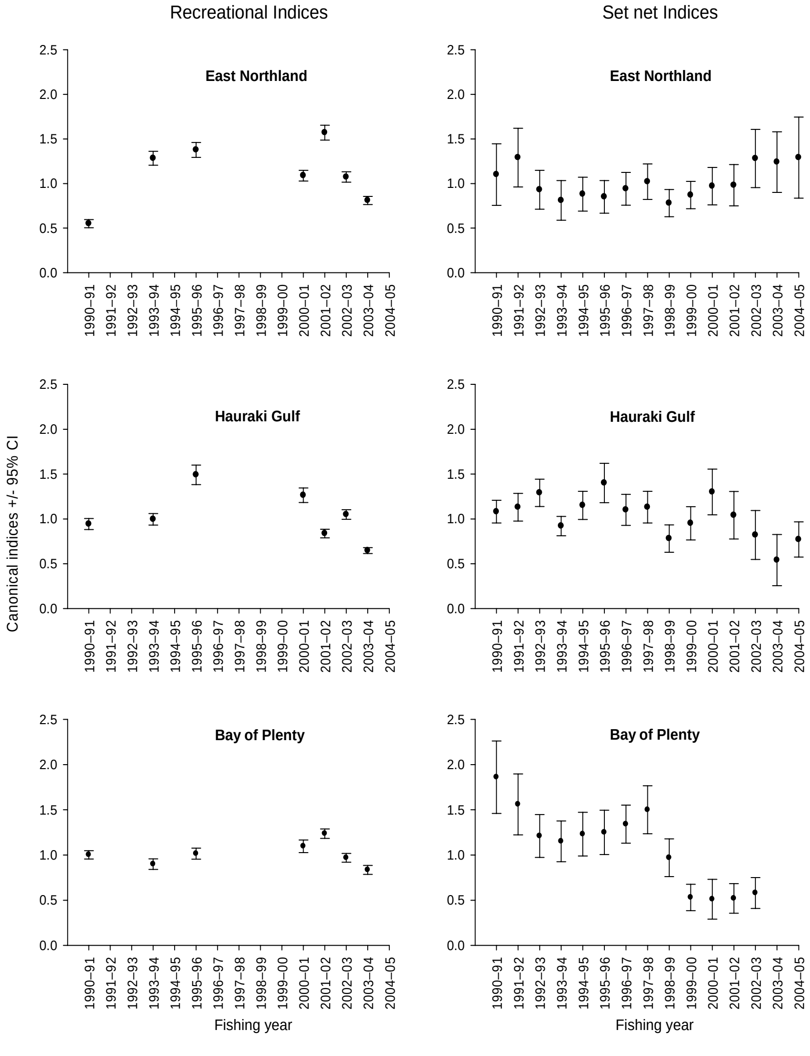

Figure 4: Standardised regional catch rate indices considered in the KAH 1 stock assessment model. Indices derived from recreational fishers using baited hooks and/or jigs since 1991 are given in the left hand panels, and those derived from commercial set net CELR data are given in the right hand panels.

2.3.4 Catch-at-age observations

Catch composition data were available from three types of fishery: recreational, purse seine, and single trawl. The earliest data available from the recreational fishery is catch-at-length data collected during various boat ramp surveys in 1991, 1994, 1996, and 2000 (Bradford 1999, Hartill & Walsh 2005). There were insufficient age-length key data available to convert these data to catch-at-age distributions and they were ultimately dropped from the final model. Dedicated annual boat ramp surveys have been used to collect catch-at-age data from recreational fishers since 2001 (Armiger et al. 2006, Hartill et al. 2007a, 2007c). These data were collected at a regional scale, partially because there appear to be consistent regional differences in population structure, and partially because there is no means of weighting these data together in a meaningful manner. These catch-at-age distributions can be seen in Appendix 1 (East Northland – Figure A6, Hauraki Gulf – Figure A8, the Bay of Plenty – Figure A10)

Catch-at-age data were also collected from the East Northland purse seine fishery in 1993 and 2005, and the Bay of Plenty in the early 1990s and in 2005 (McKenzie, NIWA, unpublished data, Devine 2007) (Appendix Figure 4A). The age distribution derived from landings in the Bay of Plenty in 1993 was ultimately dropped from the model, as over half of the age distribution was composed of three year old fish, which was considered highly atypical, as was the seasonality of the landings sampled in this year. When the 1993 Bay of Plenty purse seine data were included in the model, selectivity parameters hit upper bounds, which were considered unlikely. Removal of the 1993 data allowed the model to estimate a sensible selectivity ogive for the purse seine fishery. A review of the purse seine fishery suggested that the other years for which catch-at-age data were available were broadly representative in a seasonal sense, with most of the catch being taken during the winter. Targeted landings account for a very high proportion of the tonnage landed by the purse seine fleet in any given year.

Single trawl catch-at-age data collected in the early 1990s were also fitted in the model (Hartill & Walsh 2005) (Appendix Figure 4A).

2.3.5 Relative weighting of observational data

For each of these data sets, estimates of process error (c.v.s for lognormal likelihoods and effective sample sizes for multinomial likelihoods) associated with each year's data were generated outside the model. These estimates were included an initial model run that did not include any process error term for the entire data set.

The relative weight of each data set (i.e., across all years combined) was then determined by estimating a process error term for the CPUE data sets within the model, and then, for the catch composition data sets, by iteratively re-estimating an effective sample size process error term outside the model, based on the results of a preceding model run. This iteratively reweighting procedure was repeated until the standard deviations of each data set's residuals were approximately 1.0.

Early model runs suggested that recreational catch composition data dominated the model, and that the Pearson residuals resulting from the fits to these data sets were overly precise (i.e., far less than 1.0). This was addressed by iteratively reducing the effective sample sizes associated with each year, before re-estimating process error terms.

Levels of process error are given in Appendix 2, which relate to the MPD run described in Appendix 1. A range of scenarios were considered in the final exploration of this model (described in Section 2.5) in which levels of process error associated with each catch-at-age data set were held constant. Regardless, the standard deviations of the Pearson residuals were broadly similar in all scenarios.

2.4 Parameter estimation

For reasons given in the discussion, observational data from all three regions of KAH 1 were combined into a single area model which, by necessity, ignores the common spatial origins of each region's catch-at-age data, and their association with regional indices of abundance. Separate catch histories, and where possible selectivity ogives, were therefore employed in an attempt to model the manner in which these fisheries accessed different components of the wider KAH 1 stock.

Selectivities were estimated for all fisheries where catch-at-age data were available (Table 5). There were sufficient data to estimate separate regional selectivities for the recreational fisheries. Double normal ogives were initially estimated for the East Northland and Bay of Plenty fisheries but the right hand limbs were essentially flat, so more parsimonious logistic selectivities were ultimately used. A double normal ogive provided the best fit to the recreational fishery in the Hauraki Gulf, where juvenile three year old fish tend to dominate landings.

There were no data available to estimate selectivity for the set net fisheries, so a fixed double normal ogive was assumed, based on conversations with set net fishers. This ogive peaks at 40 cm, which represents the optimal marketable size for smoked fish. Although annual landings from set net fishers account for only a very small percentage of annual landings, this selectivity was influential in the model as it is used in association with three regional set net CPUE indices. Because this ogive was potentially influential and there were no New Zealand catch sampling data available to estimate set net selectivity, we asked an Australian researcher (John Stewart, New South Wales Department of Primary Industries, who is currently reviewing Australian *Arripis* fisheries) whether he knew of any related overseas studies. No other information appeared to be available.

Table 5: Selectivities used in the model.

Fishery	Type	Parameters
Recreational – East Northland	Logistic	Estimated
Recreational – Hauraki Gulf	Double normal	Estimated
Recreational – Bay of Plenty	Logistic	Estimated
Purse seine	Logistic	Estimated
Single trawl	Logistic	Estimated
Set net	Double normal	a1 40; aL 10; aR 10

Other free parameters estimated by the model were, a virgin level of recruitment, relativity constants for each of the 6 CPUE indices (nuisance parameters), and year class strengths for those years where they were evident in catch-at-age distributions from three or more years (Table 6).

Table 6: Other free parameters used in the model

Parameters	Number	Prior	Bounds
Virgin recruitment	1	Uniform-log	(1E4, 1E8)
Relativity constants	6 (for each CPUE index)	Uniform-log	(1, 1E-9)
YCS (1983–2002)	19	Uniform	(0.01, 20)

2.5 Evaluation of uncertainties in model structure

Four key sources of uncertainty were identified during the development of this model, which were the rate of natural mortality (*M*), the steepness of a stock recruitment relationship (*h*), historical levels of recreational harvest, and the selection of available indices of abundance. None of these uncertainties can be resolved given our current state of knowledge, and it is highly improbable the recreational catch history levels will ever be known. Because of this uncertainty there was no single model which could be considered to be a base or reference model, against which a small number of sensitivities could be considered. Issues of structural uncertainty (process error), therefore, transcended those of statistical uncertainty (observation error), which are usually evaluated using techniques such as Bayesian sampling or bootstrapping.

The approach chosen by the Pelagic Working Group followed that of Kolody et al. (2006) in which the results from a "plausible ensemble" of MPD were considered. This approach explores the potential scope of uncertainty surrounding the model structure. The Working Group identified options for each axis of uncertainty, which were thought to accurately represent a likely range of plausible scenarios (Table 7).

Table 7: Axes of uncertainty and options chosen on grid. N is the number of levels on the axis.

Axis	N	Range
M	3	0.12, 0.18, 0.24,
h	2	0.75, 1.0
Annual recreational catch in KAH 1	2	Constant 800 t, 1865t
Abundance indices	3	All, no set net, no recreational

A further option of a lower constant recreational catch tonnage was considered, but early results suggested that it was unlikely to lead to qualitatively different conclusions, and resources for such analyses were limited.

Model runs were undertaken of all possible combinations of the options identified, producing a "grid" of MPD results. These 36 scenarios were thought to more accurately reflect the true uncertainty in the KAH 1 assessment than would have been apparent from a Bayesian assessment of a narrower range of sensitivities. Time and resources were not available for a fully Bayesian assessment of all 36 scenarios.

2.6 Results

There is insufficient space available to provide diagnostic plots for all 36 model scenarios, although for several scenarios these plots were presented to the Working Group. Diagnostic plots are given here for a scenario where *M* is assumed to be 0.18, the steepness of a Beverton-Holt stock recruitment relationship to be 0.75, the annual recreational harvest to be 800 tonnes, and all indices of abundance are used (Appendix 1).

A grid search of the four axes of uncertainty suggested that the magnitude and manner of their influence on the model differed. The model was largely insensitive to which indices of abundance were offered, which is to be expected given their contradictory nature when comparisons are made across regions. The assumed steepness of a stock recruitment relationship also had only slight influence on estimates of fishing mortality and yield.

The assumed rate of natural mortality had the most influence on the models, although as mentioned previously, the lower value of 0.12 and upper value of 0.24 were regarded as being at the extreme range of plausible values. Lower values of natural mortality resulted in higher levels of estimated fishing mortality, lower yields, and lower current biomass, although there was little contrast in estimates of virgin biomass (Figures 5 and 6, Table 8). Increased levels of natural mortality were offset by estimated selectivity ogives which were shifted to the right, resulting in reduced fishing mortality. The model, therefore, acted as an integrated catch curve, in which the slope of each age distribution's right hand limb was approximated by mediating between an assumed value for natural and a consequential estimate of fishing pressure.

The second most influential axis of uncertainty was that relating to the assumed recreational catch history (Figures 5 and 6, Table 8). The assumed recreational catch history had little influence on the predicted stock status (B_{06}/B_{MSY}), but did affect the estimate of total available yield. Estimates of B_{MSY} as a proportion of B_0 varied across model runs (18.3 to 31.0 % B_0). Lower fractions of B_0 were associated with higher values of steepness.

Based on the scenarios examined, it is likely that current spawning biomass is greater than B_{MSY}, but it is uncertain how far above.

2.7 Yields

A modified yield per recruit analysis (incorporating the effect of the stock recruitment relationship) was carried out for each scenario to calculate the equilibrium yield estimates within each grid cell. It was assumed that the maximum sustainable yield (MSY) occurred at the maximum yield per recruit ($F=F_{max}$). B_{MSY} was defined as the start of the year biomass producing the maximum yield with fixed selectivities for each method and fixed proportional catch splits based on the catch distribution in 2005–06. Results were expressed relative to virgin start-of-year biomass (B_0; which is sensitive to the assumed recreational catch history). The yield per recruit curve and its maximum will vary depending on the allocation of total catch amongst the fisheries, because yield is mediated through the selectivity curves and these differ among the fisheries.

Estimates of MSY(t) derived from various combinations of M and assumed recreational catch history are given in Table 8 and Figure 7. Differences in the range of MSY tonnages associated with the two recreational catch history scenarios (Figure 7) are almost solely due to the size of the associated estimates of B_0. That is, the ratio between MSY and B_0 is approximately constant across the range of recreational harvest estimates. For this reason, each yield estimate is only valid given the recreational catch history used to derive it. The assumed natural mortality rate also influences the yield estimate, both in an absolute sense, and relative to B_0.

Current assumed removals are lower than almost all estimates of deterministic MSY (Table 8). Combining this, and the result that most estimates of B_{06} are well above B_{MSY}, it is unlikely that the stock will decline below B_{MSY} at current assumed catch levels, given the model recruitment assumptions. Estimates of deterministic MSY depend on model assumptions, in particular the assumed rate of natural mortality and time series of recreational catches. When recreational harvests are assumed to have been 800 t per year, median MSY estimates from grid strata range from 2130 to 4007 t. When recreational harvests are assumed to have been 1865 t per year, median MSY estimates from grid strata range from 3042 to 5564 t.

Table 8: Table of model outputs for different values of *M* and assumed recreational catches. Values represent the median of the six model runs in each strata and all biomass values are in terms of spawning biomass.

		B_0 (t)	B_{06} (t)	B_{06}/B_0	B_{06}/B_{MSY}	MSY (t)
	0.12	41 690	11 260	0.27	1.22	2 130
800 t	0.18	38 762	17 582	0.45	1.84	2 822
	0.24	43 216	27 228	0.62	2.12	4 007
	0.12	59 453	14 518	0.24	1.11	3 042
1856 t	0.18	54 614	22 562	0.43	1.78	4 004
	0.24	60 082	35 882	0.59	2.06	5 564

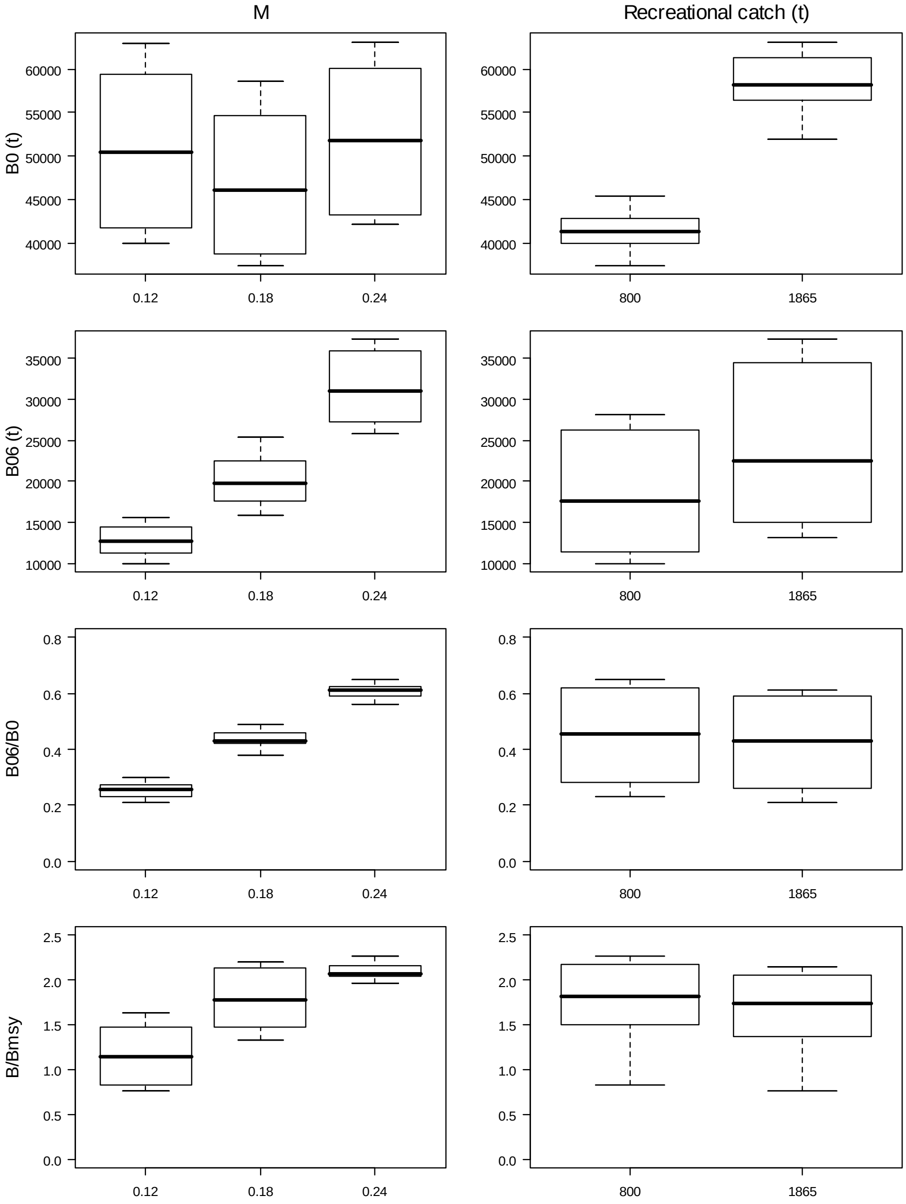

Figure 5: Boxplot showing the distribution of model results for the two key axes in the grid: natural mortality (left) and recreational catches (right). Each boxplot summarises 12 and 18 model runs for natural mortality and recreational catches respectively.

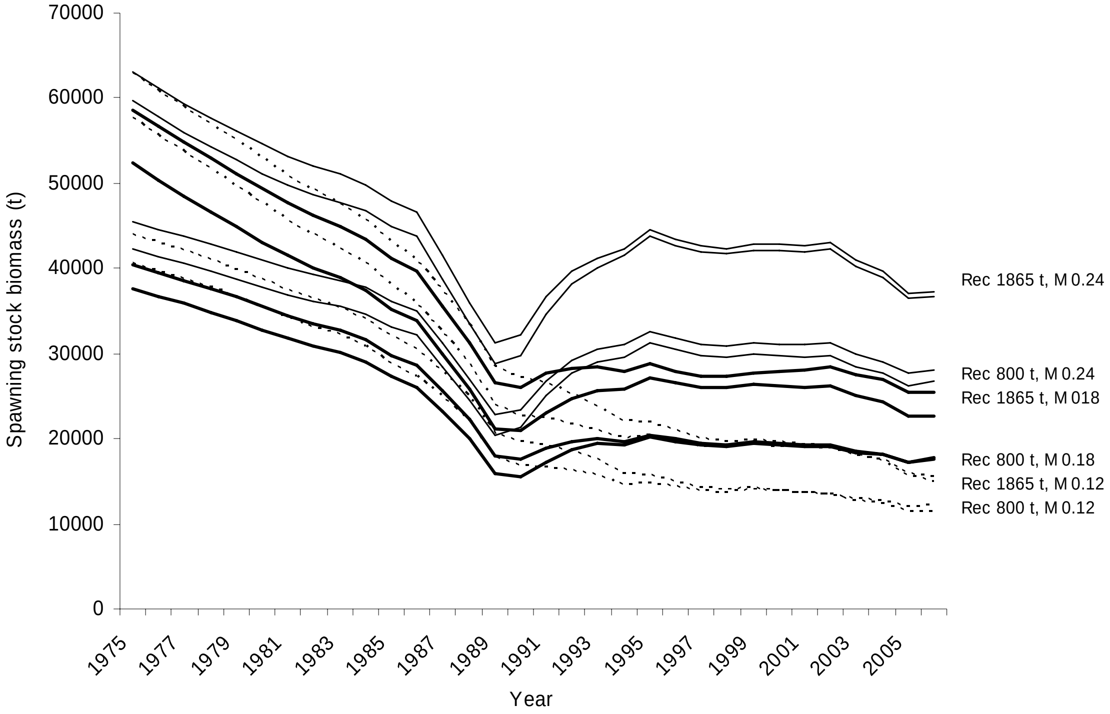

Figure 6: Biomass trajectories for different assumed values for natural mortality (*M*), stock recruitment steepness (*h*) and assumed recreational catch history. For each pair of trajectories, the upper is based on a steepness of 0.75 and the lower an assumed value of 1.0. The model did not appear to be sensitive to the indices of abundance used, and both the set net and recreational indices of abundance are included in these runs.

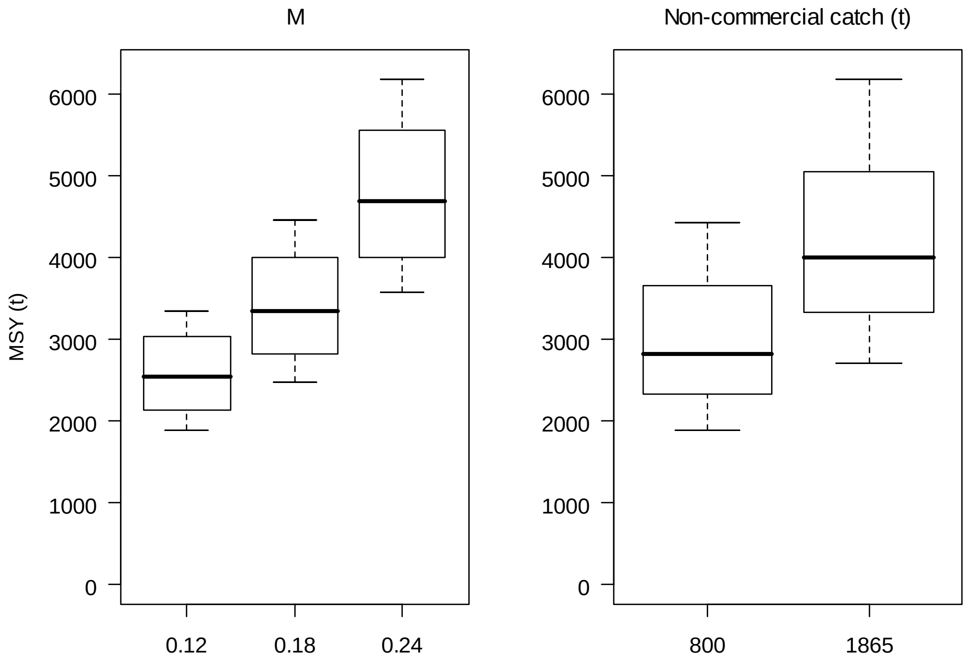

Figure 7: Boxplot showing the distribution of MSY estimates for the two key axes in the grid: natural mortality (left) and recreational catches (right). Each boxplot summarises 12 and 18 model runs for natural mortality and recreational catches respectively.

2.8 Status of the KAH 1 stock

After some deliberation at the 2007 Plenary the following conclusion was reached:

> "*Based on the scenarios examined, it is likely that current spawning biomass is above B_{MSY}, but it is uncertain how far above.*
>
> *Current assumed removals are lower than almost all estimates of deterministic MSY. Combining this with the result that most estimates of current biomass are well above B_{MSY} it is unlikely that the stock will decline below B_{MSY} at current assumed catch levels, given the model recruitment assumptions.*
>
> *The current TAC for KAH 1 is 3315 t with a TACC* ...[of 1075 t]... *and allowances* …[of 2240 tonnes: recreational – 680 t, customary – 495 t, and other sources of non-commercial mortality – 65 t]. *The estimates of deterministic MSY depend on model assumptions, in particular the assumed natural mortality and time series of non-commercial catches. When non-commercial harvests are assumed to have been 800 t per year, median MSY estimates from grid strata range from 2130 to 4007 t. When non-commercial harvests are assumed to have been 1865 t per year, median MSY estimates from grid strata range from 3042 to 5564 t.*"

2.9 Modelling of management options for KAH 1

The recreational catch histories used in the assessment presented to the Plenary, included harvest estimates derived from aerial overflight surveys conducted in 2003–04 and 2004–05 (Hartill et al. 2007d, 2007b). Recreational catch tonnages were held constant in all other years, for which two scenarios were considered; recreational harvests from KAH 1 summing annually to 800 t, and summing to 1865 t. The assumed level of recreational harvest was one of the key sources of uncertainty identified during the assessment.

The aerial overflight survey estimates were set aside when analysing management options for KAH 1, ensuring that there was a clear contrast between the catch splits associated with the 800 t and 1865 t scenarios. Catch splits are used to determine the impact of each fishery on the stock, given their respective selectivities. for KAH 1 assessment, splits were derived from the annual harvest by each fishery from 2002–03 to 2005–06, which previously included the years in which aerial overflight survey estimates were used. The sensitivity of the model to these revised recreational catch histories is shown in Table 9. Natural mortality was assumed to be 0.18 in all of these scenarios, and all CPUE indices available were offered to the model.

Table 9: Sensitivity of modelled quantities to the inclusion (with) and exclusion (without) of aerial overflight estimates of recreational harvest in 2003–04 and 2004–05.

	800 t				1 865 t			
Quantity	h = 0.75		h = 1.0		h = 0.75		h = 1.0	
	with	without	with	without	with	without	with	without
B_0	40 341	40 722	37 636	38 115	58 618	57 095	52 377	52 582
B_{06}	17 618	17 420	17 693	17 598	25 410	23 147	22 611	22 745
B_{06}/B_0	0.44	0.43	0.47	0.46	0.43	0.41	0.43	0.43
B_{MSY}	11 487	11 640	8 206	8 365	16 667	16 194	11 161	9 653
B_{06}/B_{MSY}	1.53	1.50	2.16	2.10	1.52	1.43	2.03	2.36
MSY	2 547	2 569	3 115	3 144	3 698	3 535	4 348	4 305

The switch to a constant catch history which excludes the aerial overflight estimates had little effect on the quantities predicted from the 800 t catch scenarios, but had a more noticeable effect when an annual recreational harvest of 1865 t is considered; especially when it is assumed that there is no stock-recruitment relationship (h = 1.0). Nonetheless, there was little change in the range of values predicted by the ensemble of scenarios considered here. All evaluations of management options presented hereafter are based on constant recreational catch histories, which ignore the aerial overflight harvest estimates.

2.9.1 Evaluation of deterministic and stochastic estimates of yield

The estimates of B_{MSY} given in Table 9 are based on deterministic estimates of MSY (hereafter termed MSY_{DET}), which assume that all processes are in equilibrium. The Harvest Strategy Standard approach currently under consideration, however, allows for process stochasticity, and hence varying stock size, and manages fisheries on the basis of estimates of yield which are thought to be sustainable given an acceptable level of risk.

Two stochastic views of *MSY* are: Maximum Constant Yield (*MCY*); where a constant catch is taken from the fishery, and Maximum Average Yield (*MAY*); where a constant fishing mortality rate is applied to a fishery. Francis (1992) used age based simulations for a range of species to review these two approaches of calculating sustainable yields, and recommended that,

> *Where possible, MCY and CAY should be calculated using simulations similar to those described here* (Francis 1992).

This approach has been implemented in CASAL, and was used here to provide estimates of *MCY* and *MAY* (estimates of Current Average Yield (*CAY*) can also be calculated for any given year) for each of the scenarios considered in Table 9. The catch splits in each of these four scenarios are those discussed in Section 2.9, and hence are the same as those used to derive estimates of MSY_{DET}. The definition of acceptable risk used in these simulations follows the recommendation made by Francis that,

> *In calculations of MCY and CAY, the following definition should be adopted: the risk associated with a level of yield is acceptable if fishing at that level is expected to maintain the spawning biomass above 20% of its mean virgin level at least 90% of the time.*

In CASAL there are two means of generating stochasticity in biomass trajectories, which can be used to evaluate risk: sample based and point based approaches. In the sample based approach a simulation run is done for each of a series of samples drawn from the posterior. This option was not used for this assessment, as the sources of uncertainty discussed in Section 2.5 precluded any Bayesian evaluation of uncertainty. Instead, the point based approach was used, in which a sample of biomass trajectories was generated using the MPD estimate for each parameter, with randomised recruitments drawn from a lognormal distribution with an σ_R of 0.9. The level of stochasticity associated with the point based approach is probably less than that associated with sample based simulations, although the value of σ_R used allows for reasonably high levels of recruitment variability.

Stochastic yield estimates are lower than related deterministic estimates, occurring at higher levels of optimal biomass which are much closer to the predicted biomass in 2006, for any given scenario (Table 10).

Table 10: Estimates of biomass, stock status, and yield for differing combinations of constant annual recreational catch and the assumed steepness of a Beverton Holt stock recruitment relationship.

	800 t		1 865 t	
Quantity	h = 0.75	h = 1.0	h = 0.75	h = 1.0
B_0	40 722	38 115	57 095	52 582
B_{06}	17 420	17 598	23 147	22 745
$B_{MSY(DET)}$	11 640	8 365	16 194	9 653
B_{MAY}	14 152	13 086	19 756	18 169
B_{MCY}	21 095	18 578	31 861	27 800
B_{06}/B_0	0.43	0.46	0.41	0.43
B_{MAY}/B_0	0.35	0.34	0.35	0.35
B_{MCY}/B_0	0.52	0.49	0.56	0.53
$B_{06}/B_{MSY(DET)}$	1.50	2.10	1.43	2.36
B_{06}/B_{MAY}	1.23	1.34	1.17	1.25
B_{06}/B_{MCY}	0.83	0.95	0.73	0.82
MSY_{DET}	2 569	3 144	3 535	4 305
MAY	2 327	2 953	3 306	3 876
MCY	1 784	2 364	2 302	3 084

Most of the disparity in the biological reference points seen in Table 10 is attributable to the assumed level of recreational harvest. The higher 1865 t level of harvest leads to higher estimates of virgin, current, and optimal biomass for all types of sustainable yield. There is far less disparity in the ratios of current to optimal biomass for any given definition of sustainable yield.

The assumed steepness of the stock recruitment relationship had less influence on the disparity in the range of estimates (for either level of recreational harvest). A lower assumed value of 0.75 results in higher estimates of virgin and optimal biomass, but lower estimates of yield. Francis (1992) recommended that:

In teleost population models using the Beverton Holt stock-recruitment relationship a default steepness of 0.75 should be used when there are insufficient data to indicate a different value…

and also concluded that

… it is unsafe to use a default value of 0.95 [and therefore to a greater degree a value of 1.0] for the steepness of the Beverton and Holt stock-recruitment relationship, since this is unlikely to be at the least conservative end of the range of likely values for this parameter.

When viewed deterministically, the assumed steepness of the stock-recruitment relationship does have a bearing on the rate at which surplus production declines with increasing levels of spawning stock biomass (see Figure 8). The difference in these rates is most marked at lower levels of biomass. Estimates of current biomass (in 2006) fall between estimates of B_{MAY} and B_{MCY}

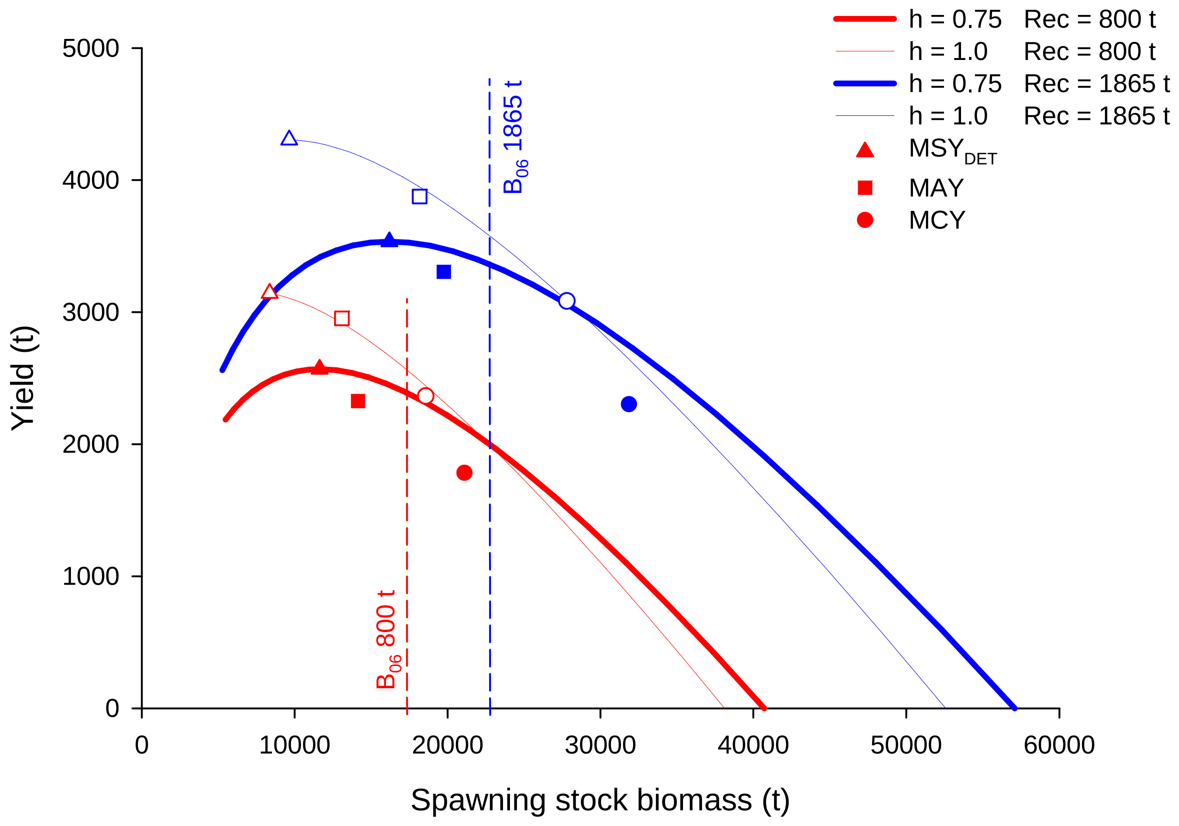

Figure 8: Surplus production curves for differing combinations of constant annual recreational catch and the assumed steepness of a Beverton Holt stock recruitment relationship. Vertical dashed lines denote the average estimate biomass in 2006 for a given level of assumed recreational harvest.

2.9.2 Evaluation of harvest strategies

A series of management strategies was evaluated by deterministically projecting each model forward with different levels of recreational and commercial harvest for 20 years, beginning in 2009 (i.e., for the 2008–09 fishing year). Projections started in 2009 as this is the first year in which any management change could be potentially implemented.

As previously, four scenarios were considered, based on combinations of two levels of historical recreational catch (800 t scenarios, Figure 9a and 1865 t scenarios, Figure 9b) for which two assumed values of Beverton-Holt stock recruitment steepness were considered (0.75 and 1.0). These projections used existing models described previously, which were based on catch histories for 1975 to 2006, and not up until 2008. It is, therefore, assumed that the estimates of sustainable yield and the method catch splits which were used to derive these estimates are still reasonably applicable.

The catches by method for 2006 and 2007 (which were also used for 2008) are given in Table 11 (as provided by G. McGregor, MFish).

Table 11. Catch (kg) by commercial fishing method for 2006 (2005–06 fishing year) and 2007. Landings for each method were further separated into bycatch or target weights, which formed the basis of the 500 t commercial bycatch only TACC scenario projections described below.

	2005–06			2006–07		
Method	Bycatch	Target	Total	Bycatch	Target	Total
Purse seine	319 686	250 013	569 699	222 580	434 051	656 631
Bottom trawl	37 945	0	37 945	24 367	0	24 367
Set net	58 215	103 407	161 622	92 717	118 190	210 907
Longline	54 285	0	54 285	34 166	0	34 166
Pair Trawl	1 618	0	1 618	2 488	0	2 488
Ring net	7 592	63 354	70 945	8 213	81 302	89 515
Danish seine	3 333	0	3 333	3 387	0	3 387
Beach seine	701	2 110	2 811	2 549	6 814	9 363
Trolling	117	320	436	32	1 361	1 394
Hand line	74	100	173	8 893	1 581	10 473
Lobster pot	32	15	47	1	–	1
Pole & line	4	–	4	–	–	–
Diving	2	–	2	7	–	7
Drop line	2	–	2	–	–	–
Drift net	–	–	–	16	–	16
Cod pot	–	–	–	46	–	46
Lampara net	–	–	–	38	–	38
Total	483 606	419 318	902 924	399 501	643 298	1 042 799

Eleven harvest strategies were evaluated for each combination of assumed recreational catch level and stock recruitment steepness. The 11 scenarios were based on selected combinations of 7 levels of commercial catch and 3 levels of recreational catch (Table 12) and the rationales for these scenarios are found in Table 13.

Table 12. Projected harvest scenarios evaluated for each combination of assumed recreational catch level and stock recruitment steepness. The rationale for each scenario is given in Table 13.

Recreational catch 1975–2008 (t)	Steepness	Run	Commercial catch 2009–28 (t)	Recreational catch 2009–28 (t)	B_{28}	B_{28}/B_0
800	0.75	1	0	0	38 984	0.96
		2C	1 075	800	22 409	0.55
		2E	1 075	2007 expl. rates	21 245	0.52
		3C	500	800	27 863	0.68
		3E	500	2007 expl. rates	25 512	0.63
		4	1 585	800 t	16 847	0.41
		5	1 769	2007 expl. rates	15 359	0.38
		6C	968	800	23 480	0.58
		6E	968	2007 expl. rates	22 074	0.54
		7C	860	800	24 524	0.60
		7E	860	2007 expl. rates	22 887	0.56
800	1.0	1	0	0	37 383	0.98
		2C	1 075	800	22 862	0.60
		2E	1 075	2007 expl. rates	21 726	0.57
		3C	500	800	27 465	0.72
		3E	500	2007 expl. rates	25 384	0.67
		4	1 477	800 t	16 982	0.45
		5	1 670	2007 expl. rates	12 461	0.33
		6C	968	800	23 749	0.62
		6E	968	2007 expl. rates	22 426	0.59
		7C	860	800	24 623	0.65
		7E	860	2007 expl. rates	23 118	0.61
1 865	0.75	1	0	0	54 426	0.95
		2C	1 075	1865	27 275	0.48
		2E	1 075	2007 expl. rates	25 718	0.45
		3C	500	1865	33 281	0.58
		3E	500	2007 expl. rates	29 566	0.52
		4	1 739	800 t	22 554	0.40
		5	2 344	2007 expl. rates	21 367	0.37
		6C	968	1865	28 454	0.50
		6E	968	2007 expl. rates	26 460	0.46
		7C	860	1865	29 604	0.52
		7E	860	2007 expl. rates	27 190	0.48
1 865	1.0	1	0	0	51 479	0.98
		2C	1 075	1865	28 103	0.53
		2E	1 075	2007 expl. rates	26 217	0.50
		3C	500	1865	32 969	0.63
		3E	500	2007 expl. rates	29 424	0.56
		4	1 713	800 t	22 196	0.42
		5	2 440	2007 expl. rates	17 826	0.34
		6C	968	1865	29 039	0.55
		6E	968	2007 expl. rates	26 827	0.51
		7C	860	1865	29 962	0.57
		7E	860	2007 expl. rates	27 432	0.52

Table 13. Rationale for evaluated harvest strategies specified in Table 12.

Scenario	Commercial catch
1. No catch	To determine the quickest possible rate of increase of the stock from the current level to determine what it will increase to over a 20 year period from 2008/09.
2. Current TACC	2007 TACC of 1075 t.
3. TACC to cover bycatch only	Estimate the proportion of the commercial catch over the period reported as bycatch over the past three fishing years and reduce the TACC to this amount (~500 t in Table 11).
4. Maintain current biomass	Increase the TACC to a level that will (on average) maintain the stock at the current level. This will be approximated by taking the estimate of current Equilibrium Surplus Production (ESP) from the yield curve for each scenario (see Figure 8). Non-commercial catch should remain unchanged. It is recognised that because the stock is not at equilibrium and that overall fishery selectivity will change as the commercial / non-commercial catch split changes, that the actual biomass that the population converges towards over the projection period will not be the same as predicted from the yield curve.
5. Move towards B_{MSY}	Increase the TACC to a level that will (on average) move the stock towards the B_{MSY} estimate (deterministic). This was approximated by taking the estimate of MSY from the yield curve for each scenario. Non-commercial catch actually declines under this scenario as biomass declines.
6. 10% reduction in TACC	Arbitrary reduction to determine the benefits to the non-commercial sector in reduced commercial catches and changes in the overall value of the fishery.
7. 20% reduction in TACC	Arbitrary reduction to determine the benefits to the non-commercial sector in reduced commercial catches and changes in the overall value of the fishery.

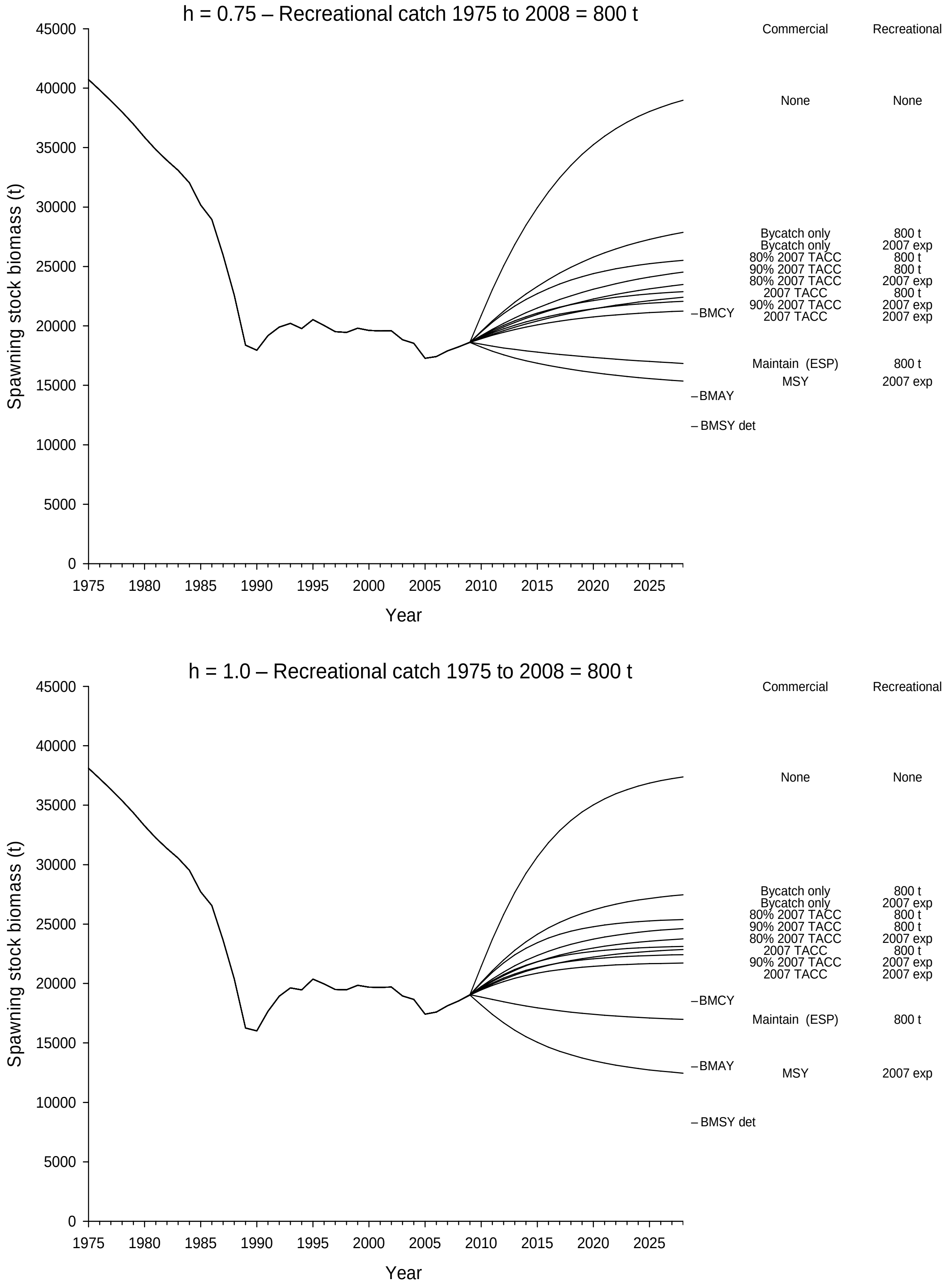

Figure 9a: Deterministic projections of future biomass when the historical recreational catch is assumed to be 800 t per annum, for two values of Beverton Holt stock recruitment steepness (0.75, upper panel and 1.0 lower panel). Different combinations of future commercial and recreational catch are considered in each projection, as defined in Table 12 and as labelled on the right hand side of each panel. Estimates of B_{MCY}, B_{MAY} and deterministic B_{MSY} given in Table 10 are plotted to the right of each series of projections.

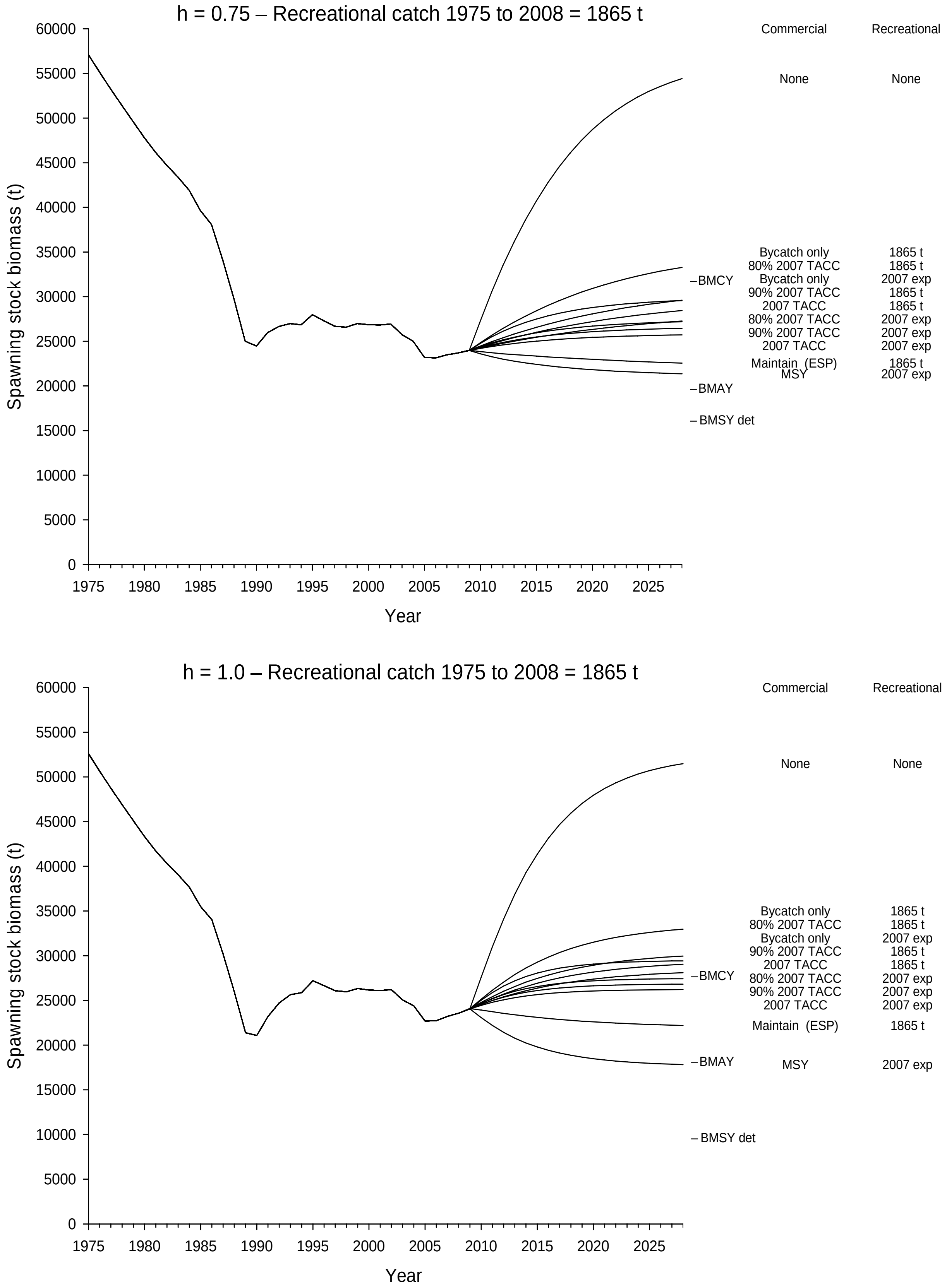

Figure 9b: Deterministic projections of future biomass when the historical recreational catch is assumed to be 1865 t per annum, for two values of Beverton Holt stock recruitment steepness (0.75, upper panel and 1.0 lower panel). Different combinations of future commercial and recreational catch are considered in each projection, as defined in Table 12 and as labelled on the right hand side of each panel. Estimates of B_{MCY}, B_{MAY} and deterministic B_{MSY} given in Table 10 are plotted to the right of each series of projections.

The results for run 4 (Maintain, TACC = ESP less assumed recreational catch) do not maintain the biomass at the 2008 level as initially assumed. This is because the yield curves (see Figure 8) used to determine estimates of ESP, and the current level of biomass used to derive these estimates, were taken from existing model runs where the final year was 2006. Biomass trajectories continued to climb as of 2008, however, and therefore, the ESP_{2006} values are greater than they would be if they were calculated for 2008. Nonetheless, the ESP_{2006} values were used because the purpose of this work was to evaluate harvest strategies based on the 2006 model which had been presented to the 2007 Plenary.

In the original assessment it was argued that a recreational catch history of 1865 t per annum should be considered, as recreational landings in the past could have been higher than at present. The applicability of such a high recreational harvest tonnage in the near future is more questionable, however. Future recreational catch levels are also unknown, but in the immediate future they are likely to reflect recent catch levels. Extensive interviewing at boat ramps over many years has shown that directly observed landings of kahawai in QMA 1 are between 25 and 30% of those seen for snapper (these ratios were also seen in telephone diary estimates). If current and imminent landings of kahawai are assumed to be 1865 tonnes, then either the recreational snapper catch must be far higher than generally accepted (well in excess of the commercial tonnage) or all evidence of kahawai to snapper landing rates must be misleading.

3. KNOWLEDGE GAPS

Although our knowledge of kahawai fisheries and biology has improved over the last decade, this stock assessment has highlighted that there are several key issues which have not been resolved. At least some of these should be addressed before the next the next kahawai stock assessment. These are:

- A better understanding of stock structure, and for KAH 1 at least, some information on exchange rates between subpopulations within management areas. Recent attempts to explore stock structure through otolith microchemistry and meristics suggest that these techniques are not promising. Another approach which is currently being explored is to infer migration rates from tag release and recapture data. Kahawai tagging programmes in the early 1980s and 1990s were of limited value in this regard, as releases were made in only some areas, and these were largely from commercial vessels which interact with kahawai schools in a very non-random fashion. The feasibility of a recreational fishery-based tagging programme is currently being modelled, which partially uses estimates generated from this stock assessment. Recreational fishers interact with a far greater number of schools at a low level of intensity, across a wide spatial range, which could potentially provide a more representative description of movement patterns. Early results suggest, however, that the number of releases required to provide any resolution may be in the order of 10 000 fish released over two years, which is high given the size of the fishery.

- Informative indices of abundance. There are currently two sources of information on changes in abundance, aerial sightings and catch rate data, both of which have their limitations. Aerial sightings data recorded by spotter planes working with commercial purse seine vessels provide the only potential source of information on stock abundance since the early 1980s, when high levels of harvesting would have produced the greatest change in stock biomass. These data were not collected in a scientific manner, however, which is highly problematic. Commercial and recreational catch rate data are also available. Of the commercial fisheries, only the set net data are of any potential use, as these fishers recorded catches on a set by set basis, and measures of effort which give a potentially meaningful measure of catch vulnerability. Set net fishers are, however, increasingly shifting to ring net methods, for which there is no meaningful measure of fishing effort. There is also no meaningful measure of effort for the purse sine fishery, and trawl returns often provide little information on kahawai catch per shot, as it is a minor bycatch species. Recreational catch rate data have been collected intermittently since 1991, but the recent widespread adoption of soft plastic baits by more avid fishers (which cannot be separated out over time) is an issue, as soft plastic fishers tend to have higher catch rates and land larger fish.

- A better description of commercial landings is also required. Since 1993 there has been only one year of catch sampling (mostly from the Bay of Plenty purse seine fishery, in 2005) yet commercial fisheries have accounted for the majority of removals over the last 30 years. A description of the landed length composition form the set net fishery is desirable, as the selectivity ogive currently applied to set net catch rate indices is arbitrary, as there are no data on which to base it.

- Although historical levels of recreational catch will remain unknown, and hence arbitrary, a better understanding of current levels should provide a more realistic picture of the past. Proposed concurrent aerial overflight and telephone diary surveys (or similar) should provide some resolution.

- Despite eight successive years of recreational catch sampling, estimation of annual recruitment strengths remains an issue. Although there is some evidence of consistently apparent strong and weak year classes in the recreational catch-at-age time series, these year class strengths are not as clear as those seen for snapper. One potential avenue which could be explored is to investigate year class catch per unit effort in the Hauraki Gulf. Recreational landings in this region are mostly composed of three year olds, although the strength of this year class changes from year to year. Recreational catch rate data could be used to scale proportional catch-at-age date, and hence provide a better description of year class strength. Although the current model does in fact do this, it also fits to data from East Northland and the Bay of Plenty at the same time, where year class strengths are less apparent.

4. ACKNOWLEDGMENTS

Nick Davies, Jeremy McKenzie, and Shelton Harley have provided much useful guidance with this stock assessment. I also thank Alistair Dunn, Chris Francis, and Any McKenzie who provided useful advice on several aspects of this model. Many useful points were also raised by members of the Pelagic Working Group, especially Paul Starr. Funding for this project, KAH2005/01, was provided by the Ministry of Fisheries.

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Appendix 1: Diagnostic plots from a model run where: *M* is assumed to be 0.18, the steepness of a Beverton-Holt stock recruitment relationship to be 0.75, the annual recreational harvest to be 800 tonnes, and both recreational set net CPUE indices are considered.

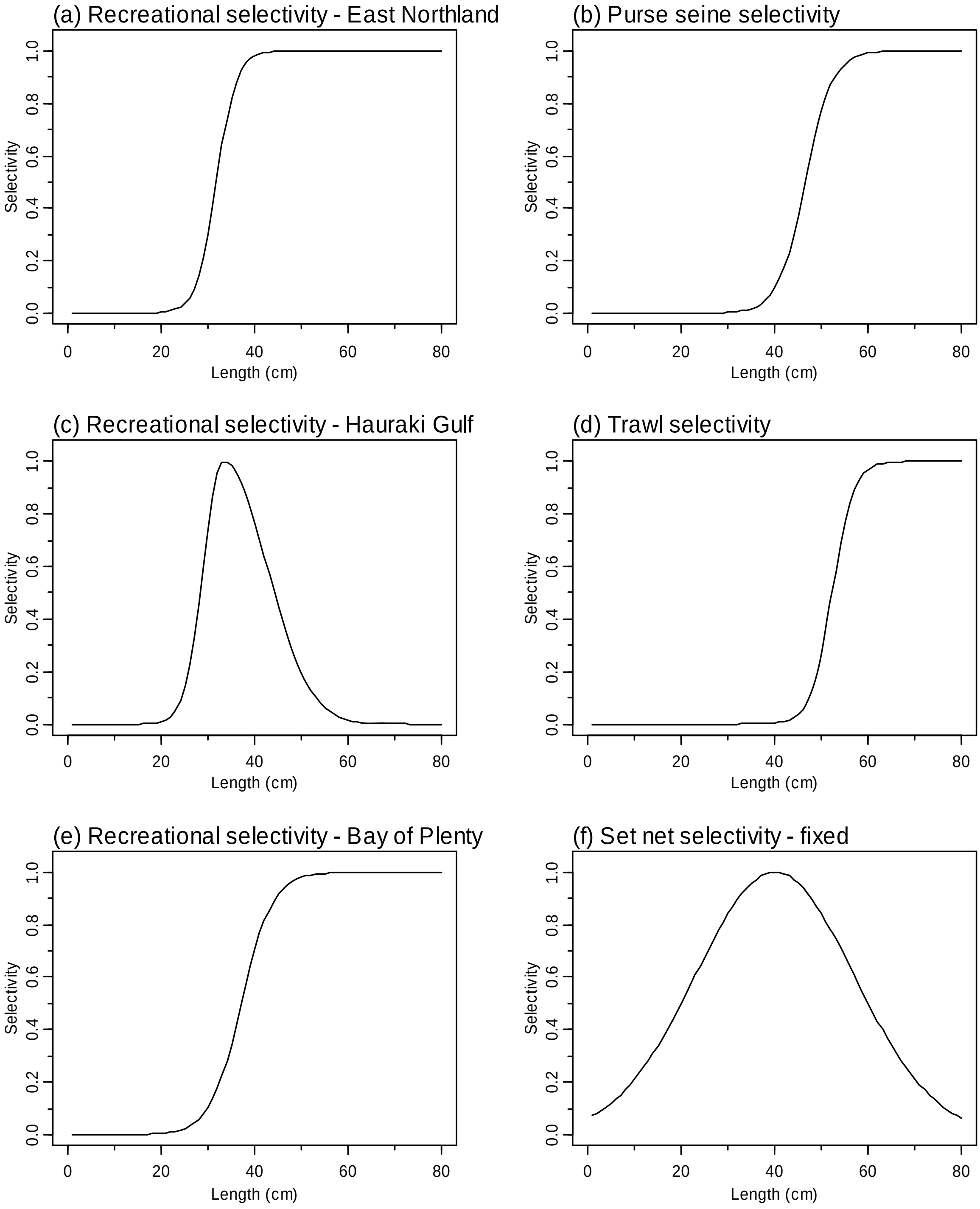

Figure A1: Estimated selectivities.

Appendix 1 – continued:

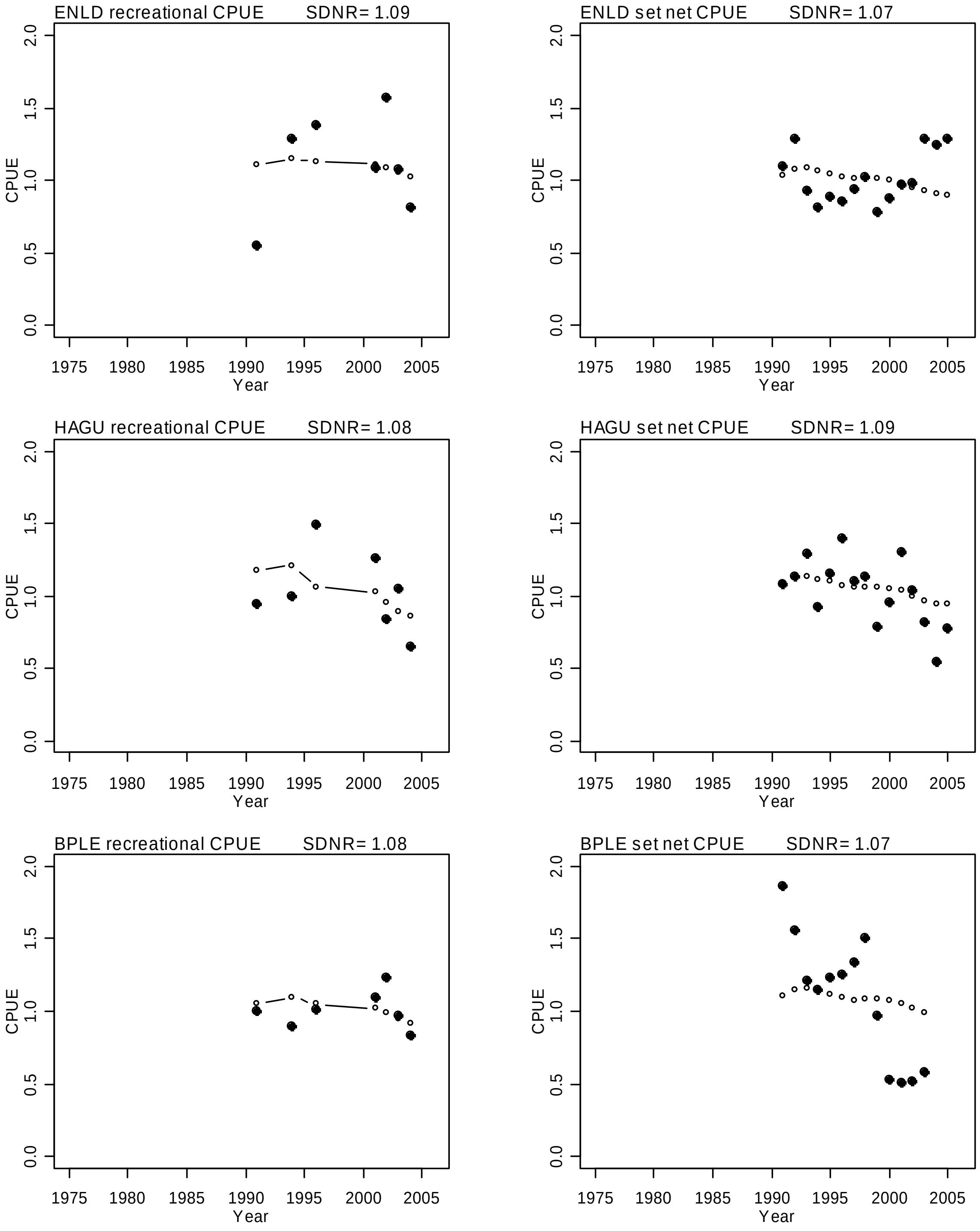

Figure A2: Predicted (dots) and observed (circles) indices of abundance.

Appendix 1 – continued:

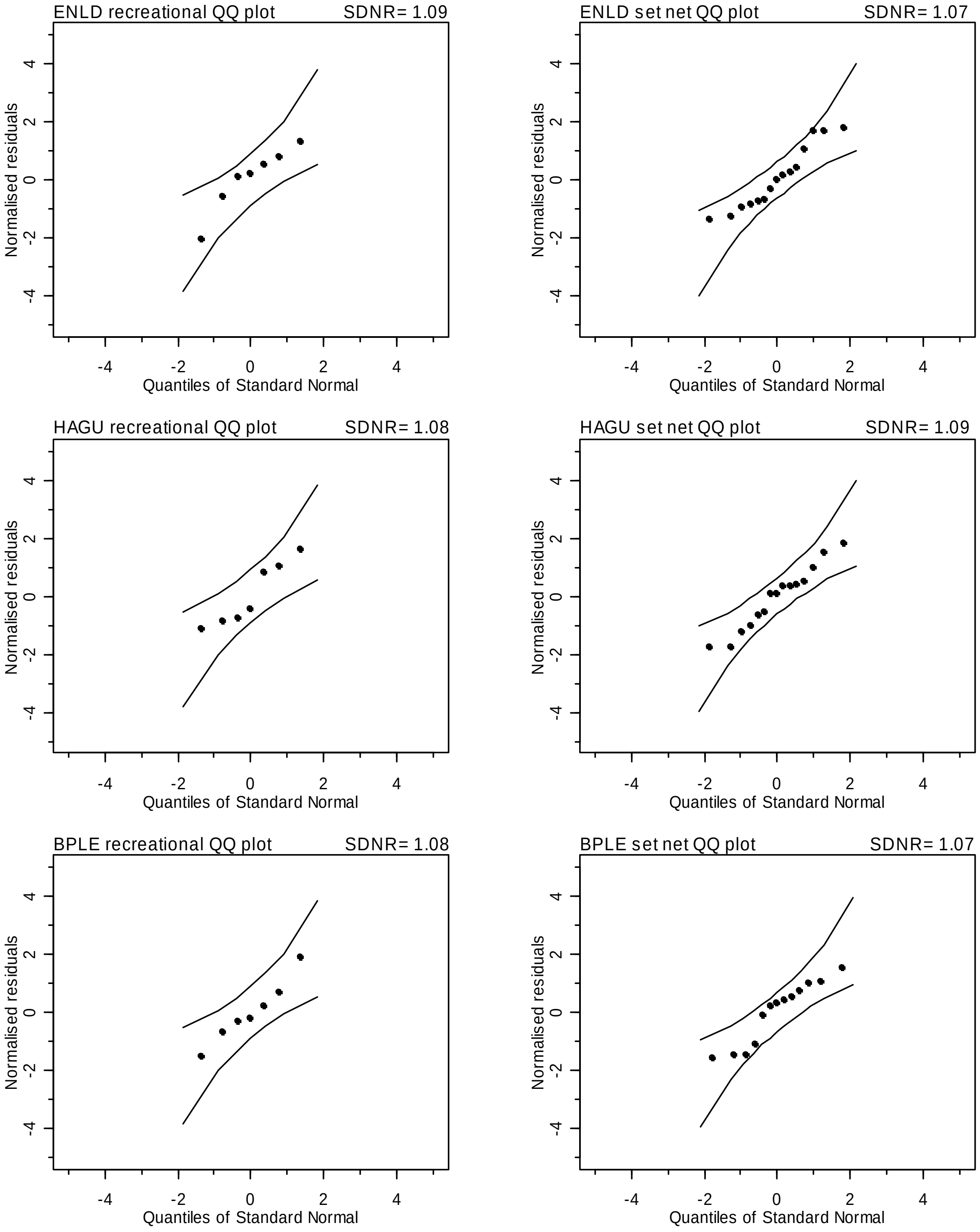

Figure A3: QQ plots of MPD fits to indices of abundance.

Appendix 1 – continued:

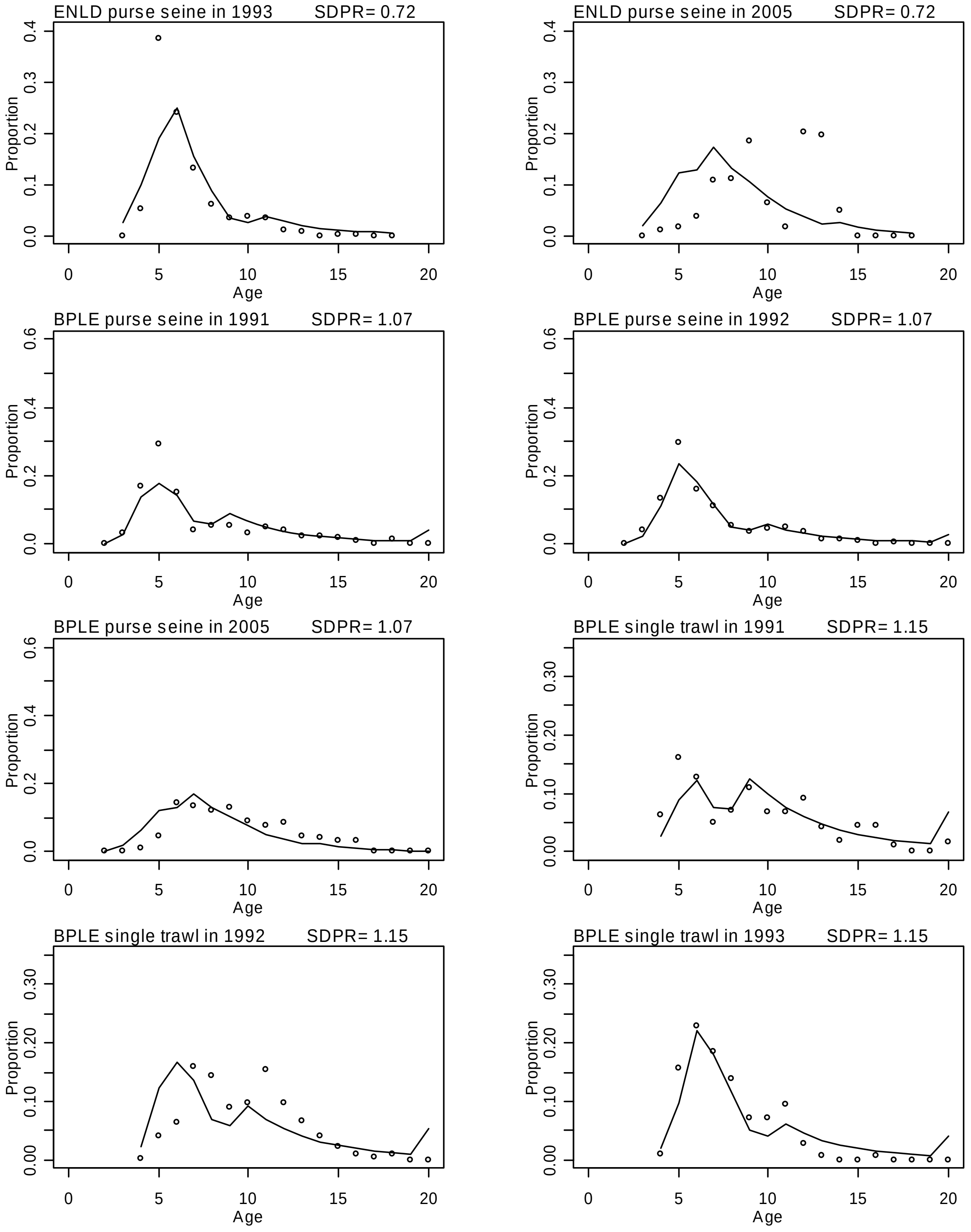

Figure A4: MPD estimates of commercial catch-at-age. The top five panels are purse seine landings and the bottom three panels are for single trawl landings. Observations of catch-at-age are denoted by open circles and lines are used to denote predicted values.

Appendix 1 – continued:

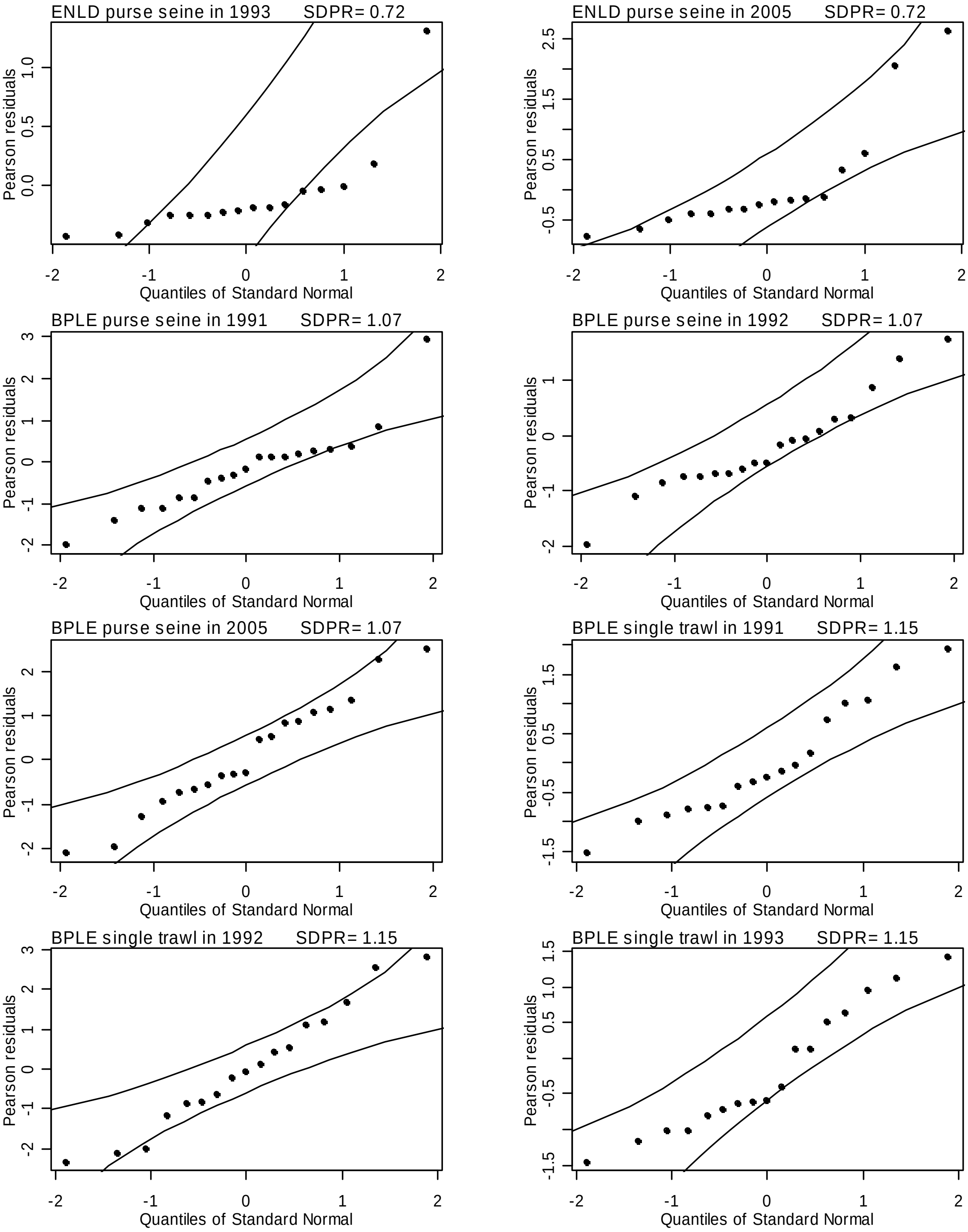

Figure A5: QQ plots of MPD fits to commercial catch-at-age data.

Appendix 1 – continued:

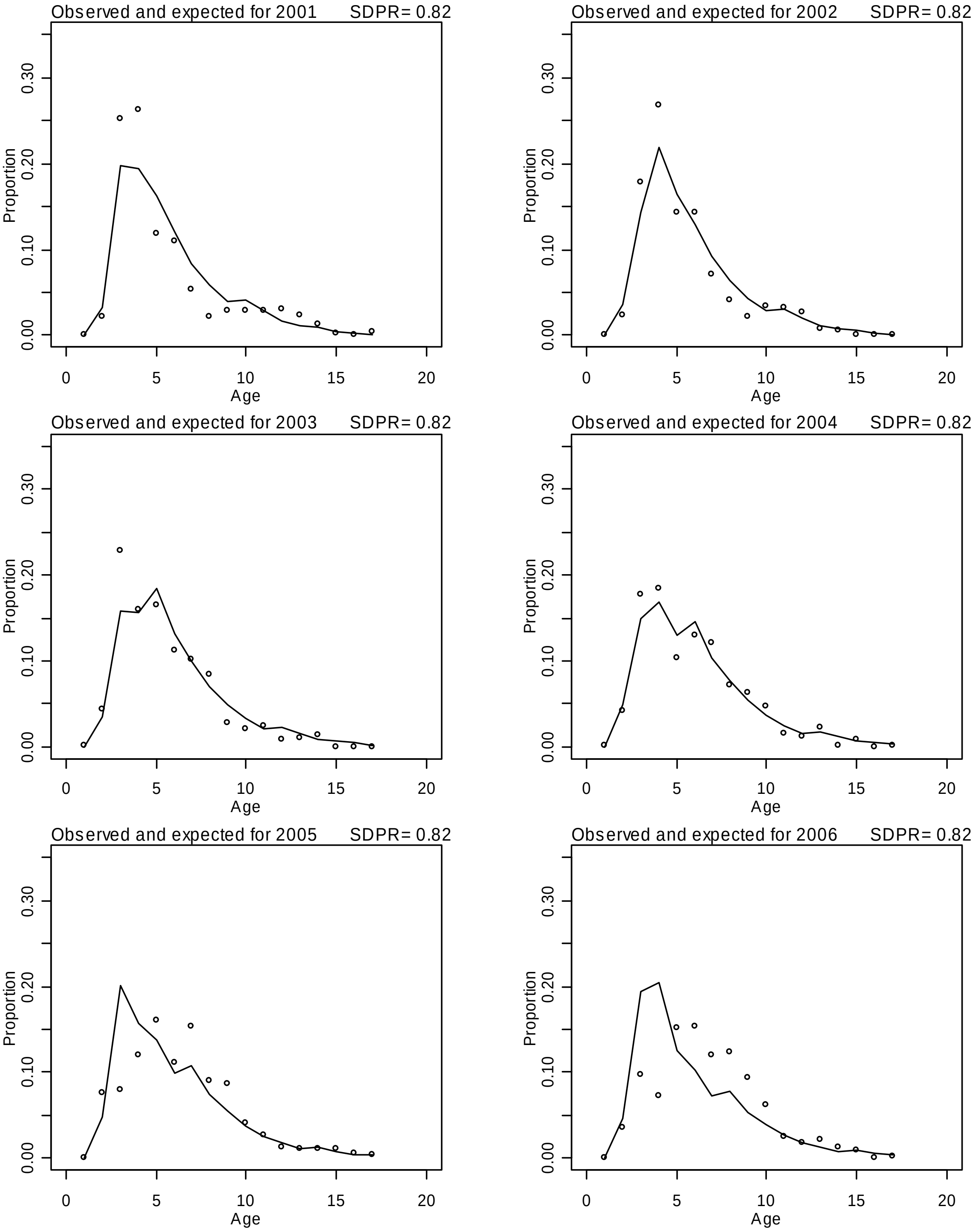

Figure A6: MPD estimates of East Northland recreational catch-at-age composition. Observations of catch-at-age are denoted by open circles and lines are used to denote predicted values.

Appendix 1 – continued:

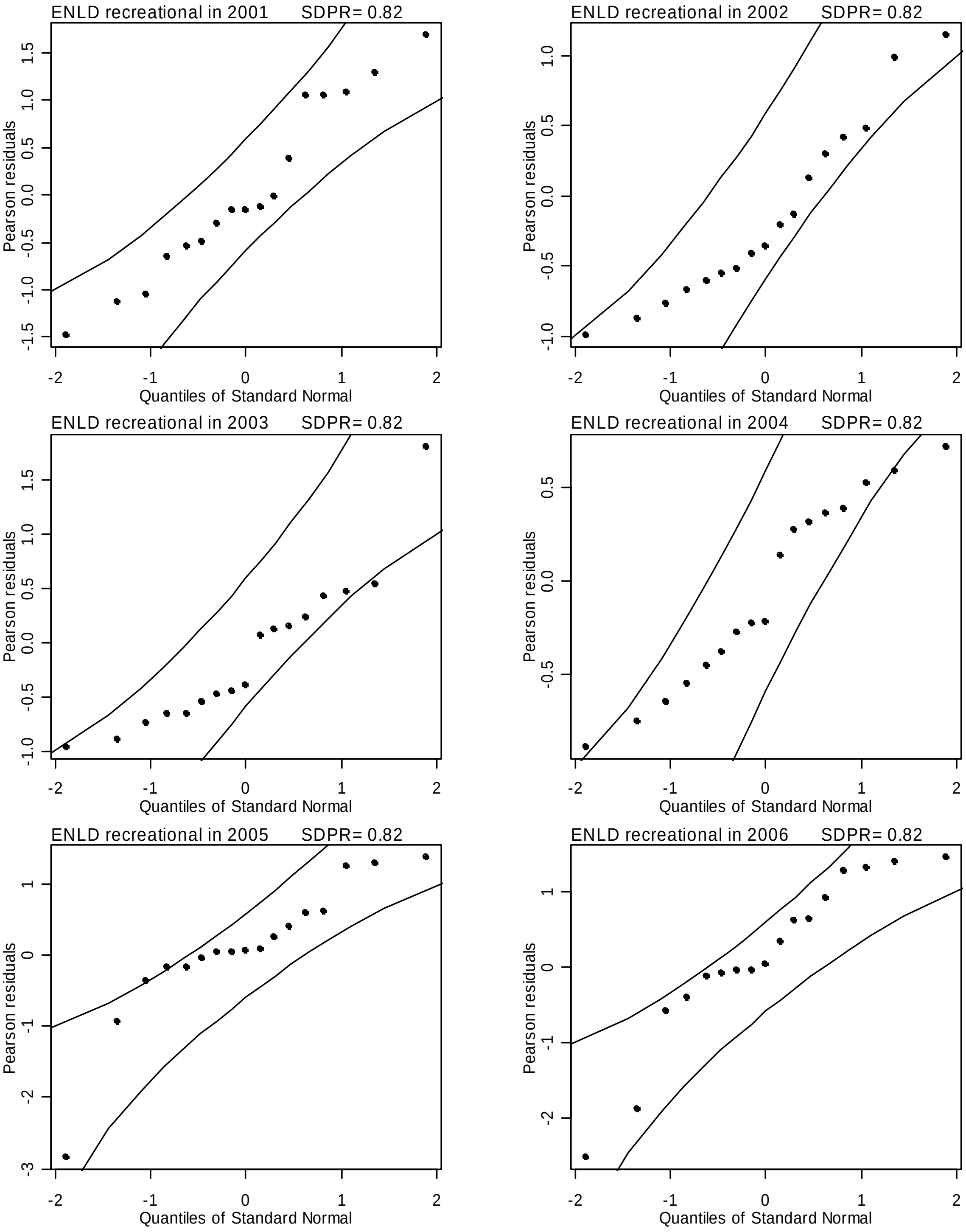

Figure A7: QQ plots of MPD fits to recreational catch-at-age data from East Northland.

Appendix 1 – continued:

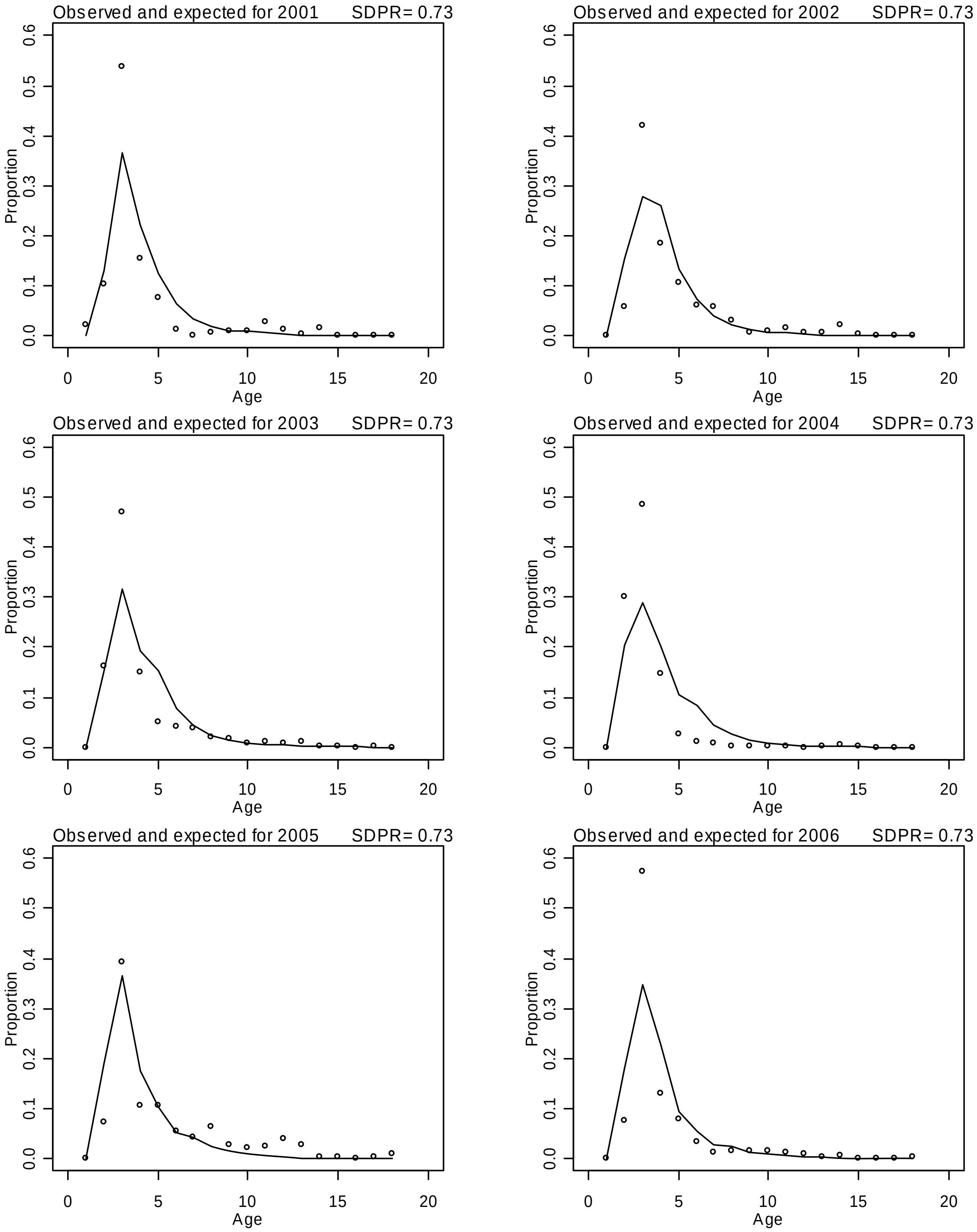

Figure A8: MPD estimates of Hauraki Gulf recreational catch-at-age composition. Observations of catch-at-age are denoted by open circles and lines are used to denote predicted values.

Appendix 1 – continued:

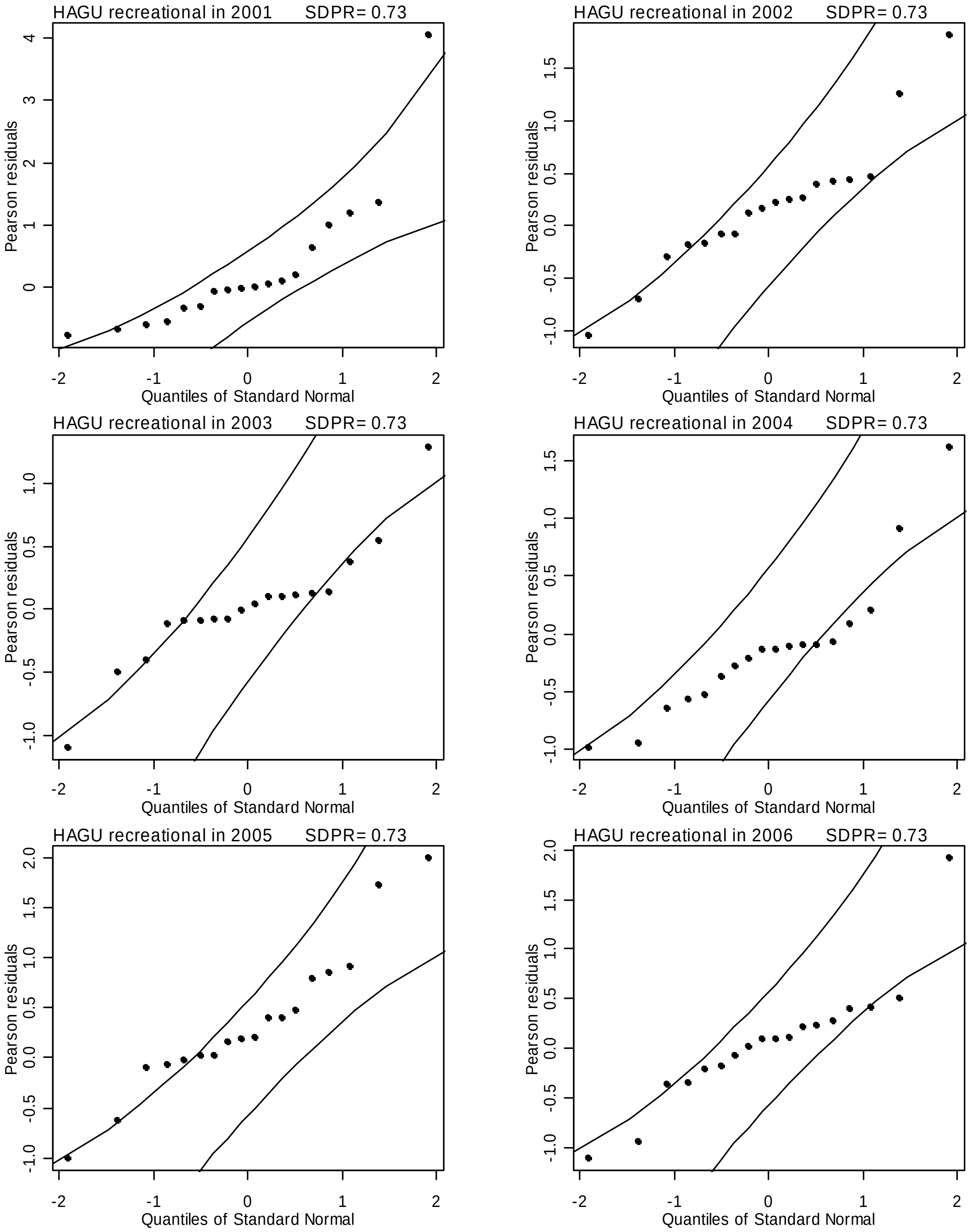

Figure A9: QQ plots of MPD fits to recreational catch-at-age data from the Hauraki Gulf.

Appendix 1 – continued:

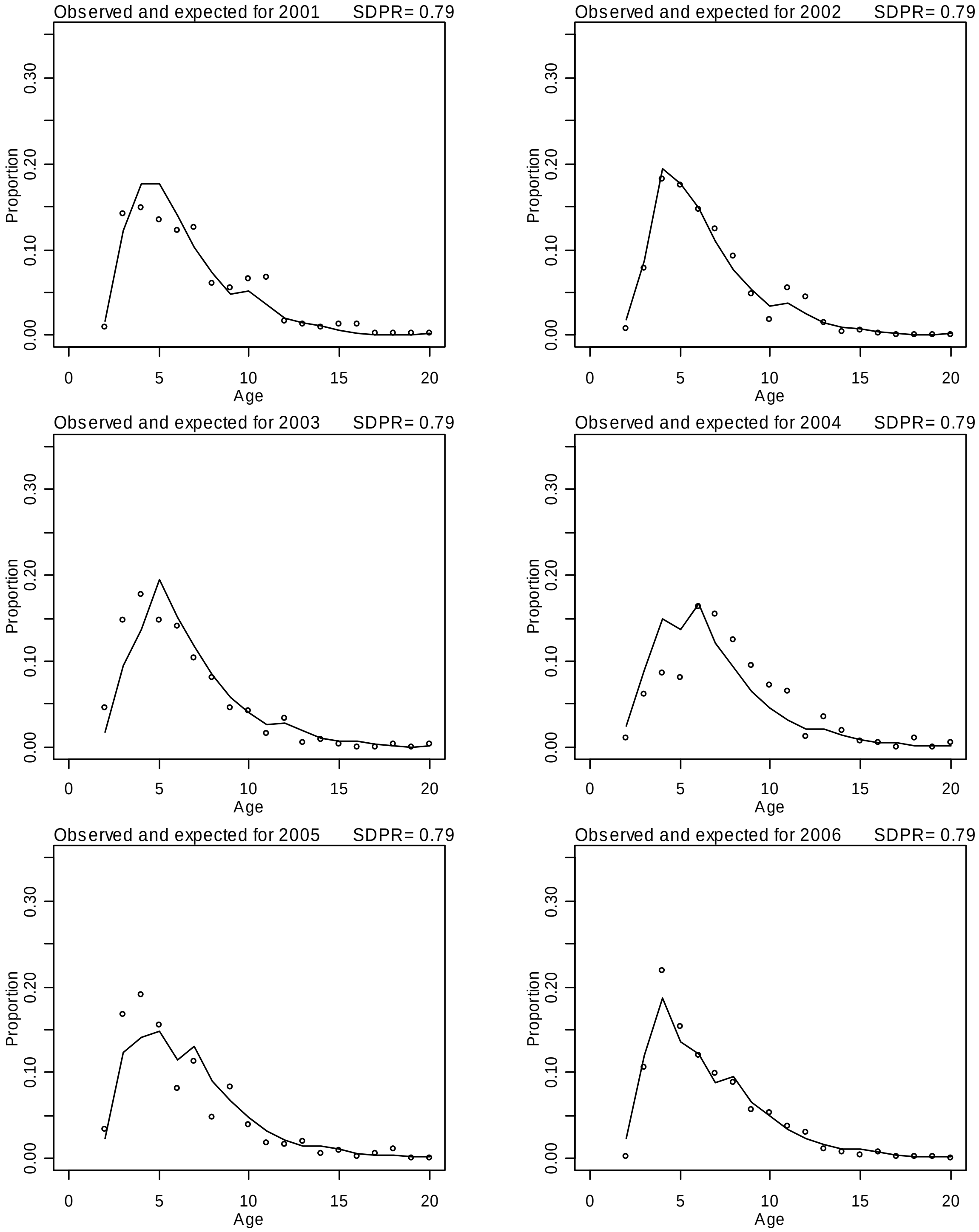

Figure A10: MPD estimates of Bay of plenty recreational catch-at-age composition. Observations of catch-at-age are denoted by open circles and lines are used to denote predicted values.

Appendix 1 – continued:

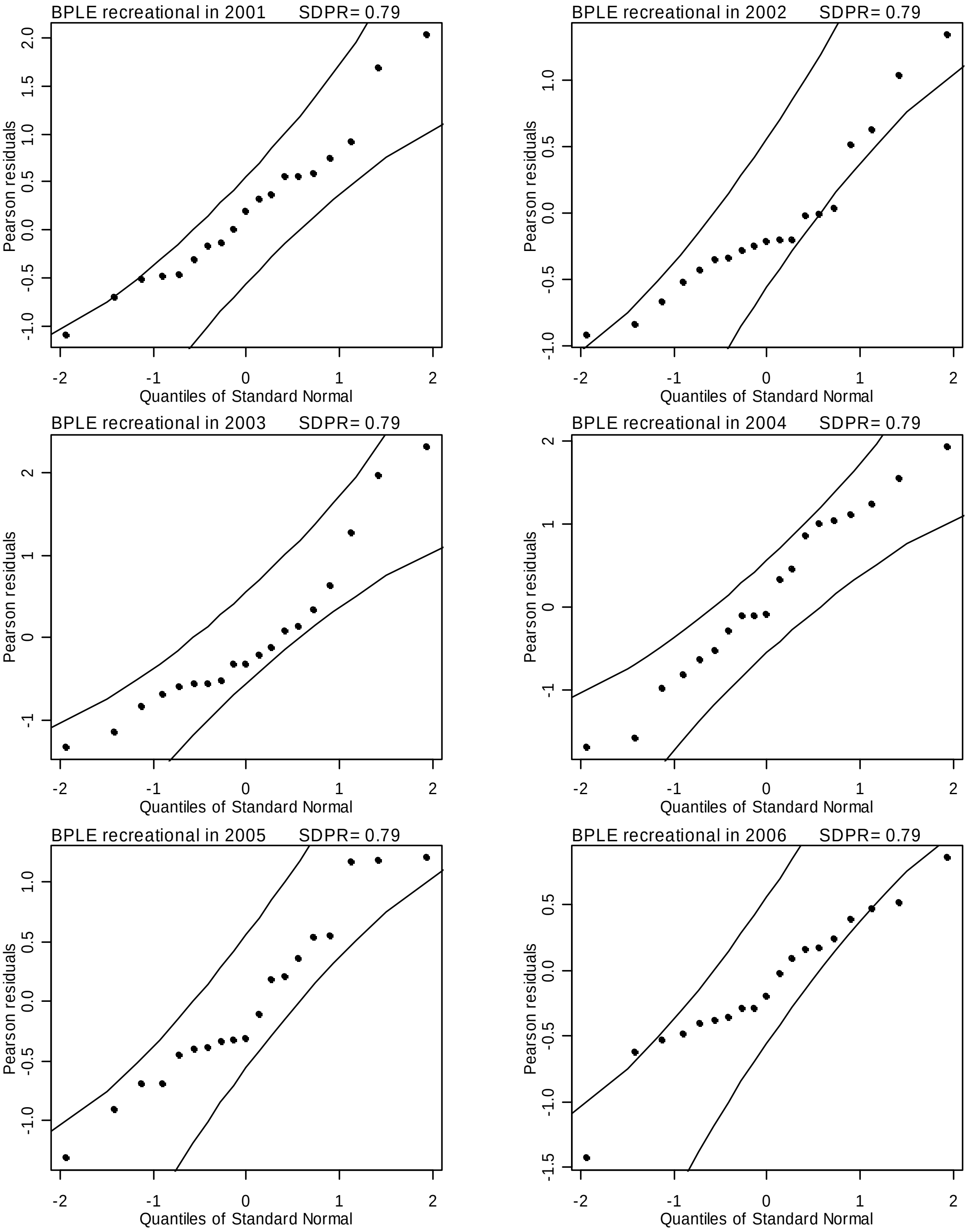

Figure A11: QQ plots of MPD fits to recreational catch-at-age data from the Bay of Plenty.

Appendix 1 – continued:

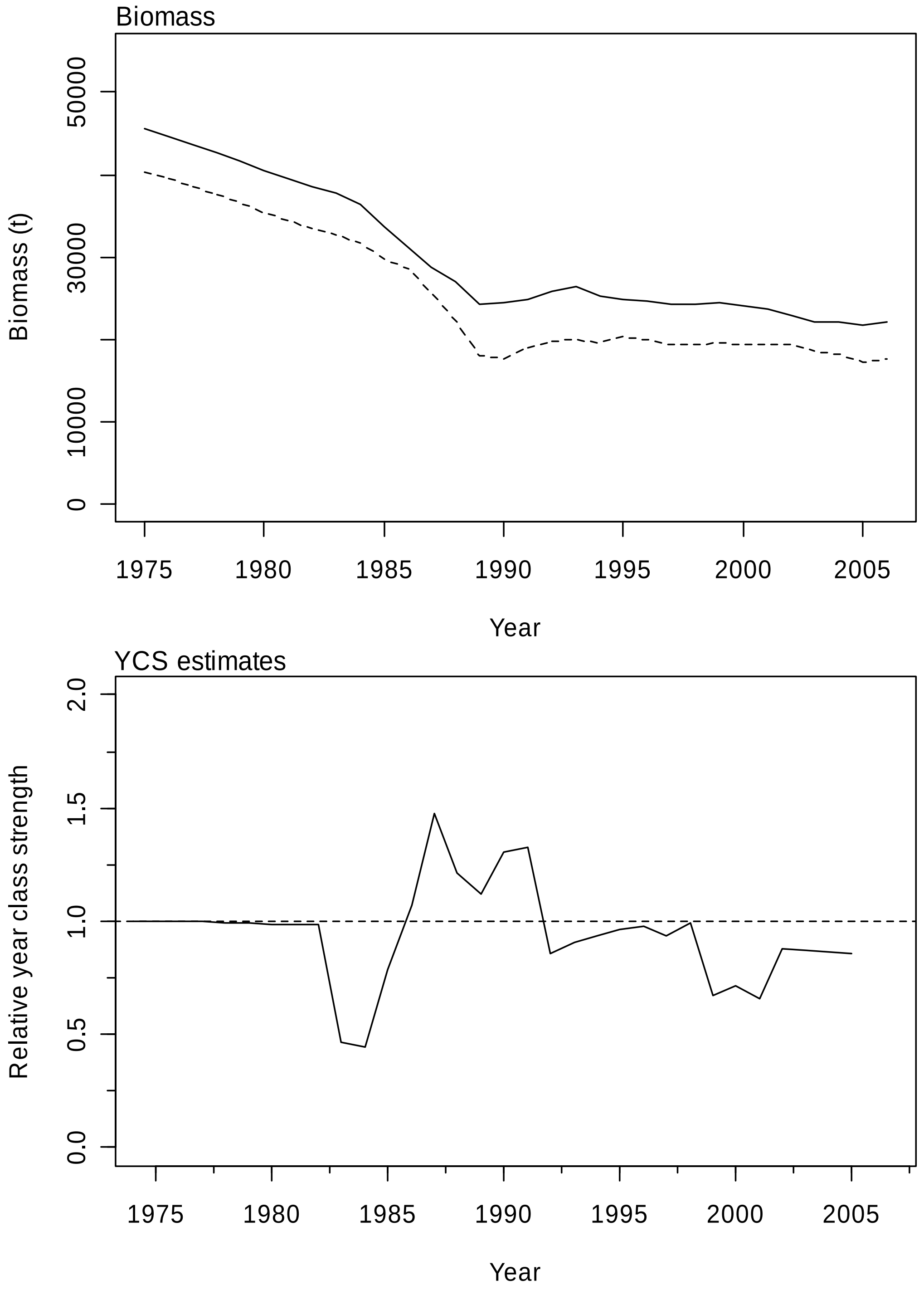

Figure A12: Plots of estimated biomass trajectories (upper panel) and year class strengths (lower panel). In the upper panel the solid line denotes total biomass and the dashed line denotes the spawning stock biomass.

Appendix 2: Levels of process error required to weight each data set to ensure that the standard deviations (SD) of their MPD residuals were approximately 1.0. Error terms associated with indices of abundance are coefficients of variation (with associated standard deviations of normalised residuals) and those associated with the catch-at-age data sets are effective sample sizes (with associated standard deviations of Pearson residuals). The fractions in brackets associated with the recreational catch-at-age data sets describe the extent to which each year's effective sample size was down weighted before the final process error term was estimated for a multi year data set. The values below are for the MPD run described in Appendix 1.

Data set	Observation error	Process error	SD of residuals	Likelihood
Recreational CPUE				
East Northland	0.03–0.04	0.34	1.09	-4.4
Hauraki Gulf	0.03–0.04	0.23	1.08	-6.8
Bay of Plenty	0.02–0.03	0.12	1.08	-11.1
Set net CPUE				
East Northland	0.07–0.18	0.15	1.07	-16.7
Hauraki Gulf	0.08–0.27	0.13	1.09	-18.5
Bay of Plenty	0.08–0.22	0.39	1.07	-5.3
Recreational catch-at-age				
East Northland (1/4)	139–148	243	0.82	149.7
Hauraki Gulf (1/16)	18–34	31	0.73	61.2
Bay of Plenty (1/4)	78–120	–	0.79	165.1
Purse seine catch-at-age				
East Northland	24–763	7	0.72	15.2
Bay of Plenty	202–1053	150	1.07	100.6
Single trawl catch-at-age				
Bay of Plenty	124–382	90	1.15	86.8