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Effect of changing bag limits and minimum legal size on total harvest in SNA 1 and BCO 7

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This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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1. Executive summary

This report addresses Objective 1 of Ministry of Fisheries project REC9702: *To model the effect of changing bag limits and minimum legal size on total harvest of SNA 1 and BCO 7.*

For snapper, data and results are presented for the East Northland and the Hauraki Gulf/ Bay of Plenty substocks of SNA 1. For blue cod, BCO 7, they are presented for the Marlborough Sounds and the area outside the sounds.

The recreational bag size distributions for snapper in SNA 1 and blue cod in BCO 7 are assumed to be negative binomial with variance proportional to the mean as in other recreational fisheries. Several bag size distributions with bag limits are fitted together, with individual means but common variance to mean ratio (shape parameter) and the same non-compliance factor. The parameters are estimated by maximum likelihood. The non-compliance factor (proportion of non-complying fishers amongst those exceeding the bag limit) was estimated to be roughly 50% for both snapper and blue cod. Fishers have to exceed the bag limit before we classify them as compliers or non-compliers. Few fishers exceed the bag limit. For snapper with a bag limit of nine in 1996, 1.1% of fishers interviewed at boat ramps were non-compliers. For blue cod in the Marlborough Sounds, 13.8% of trips recorded by diarists in the 1996 diary survey were non-compliant.

To estimate harvest change with the bag limit change we modified the bag distribution fitted to the observed bag sizes for bags less than the current limit. Estimates are made for 0%, 50%, and 100% compliance factor. Including realistic non-compliance shows that bag limits may be less effective in producing reductions in recreational harvest than expected. If harvest reduction is sought, measures that increase compliance may be equally effective as reducing the bag limit.

Most fishers catch undersize fish and have to decide if they will throw them away and so comply with a minimum legal size (MLS) restriction. Non-compliance with MLS was not estimated, as the size distribution of discarded fish is unknown and cannot be estimated. However, compliance with MLS appears to be high. For example, the lower tail of the snapper size distributions from the boat ramp surveys in 1994 and 1996 moved upwards by about 2 cm when the MLS was increased from 25 cm to 27 cm. The effect of increasing the MLS from current values is shown as a percentage of the total current harvest, but assuming total compliance with the new MLS.

A simple length based model was developed which included the combined effects of a bag limit and an MLS and levels of non-compliance with them. Recreational fishing was modelled as a sequence of actions (catching and keeping or discarding fish) that

lead to the retained harvest. For snapper, current and future recreational harvest was modelled using the length distribution of the fish population predicted in the most recent stock assessment. Change in the level of compliance was modelled. For blue cod, the population size distribution was assumed to be that given by a potting survey in 1996.

Model results are presented as harvest contours for ranges of bag and size limits. The combined modelling of the effects of MLS and bag limits produced different harvests from that of multiplying the separate effects. Substantial change was involved for certain combinations of limits that were some way from the current limits, especially for blue cod.

2. Introduction

2.1 Overview

Boat ramp surveys in the North region in 1991, 1994, and 1996 have measured recreational harvest per trip and size distributions for snapper in SNA 1 (Sylvester 1993, Hartill *et al.* 1998, Bradford 1999). Boat ramp surveys in the Central region from December 1992 to April 1993 and January to December 1996 measured size distributions of blue cod in BCO 7 (Hartill *et al.* 1998). The earlier survey also recorded harvest information but the version of the data currently available to NIWA contains some party harvests. Telephone and diary surveys were conducted in the North region from December 1993 to November 1994, the Central region from December 1992 to November 1993 (Bradford 1996, 1997, Teirney *et al.* 1997, Ryan & Kilner, Ministry of Fisheries, Dunedin, unpubl. data), and nationally in 1996 (Bradford 1998a, 1998b, Bradford *et al.* 1998a, 1998b).

The marine recreational harvest in several important Fishstocks, including SNA 1 and BCO 7, is managed by means of a maximum daily limit (bag limit) and/or a minimum legal size (MLS). Estimates of the change in harvest that would be caused by changes to bag limit or MLS given in the Progress Report for this project were based on the simplest possible assumptions. Total compliance with proposed changes was assumed.

This report addresses Objective 1 of Ministry of Fisheries project REC9702: To model the effect of changing bag limits and minimum legal size on total harvest of SNA 1 and BCO 7. We consider the following.

- The degree of non-compliance with bag limits in SNA 1 and BCO 7.
- The changes in harvest produced by applying a bag limit or MLS separately.
- The combined effect of bag limit and MLS changes in SNA 1 (Hauraki Gulf/Bay of Plenty) and BCO 7 (Marlborough Sounds) on overall harvest, assuming the rates of non-compliance remains the same.
- The combined effect of bag limit and MLS changes on future snapper harvests under various stock size and age structure scenarios.

2.2 Regulations in force in SNA 1 and BCO 7

In SNA 1, MLS was 25 cm and bag limit was 20 fish during the 1991 and 1994 surveys, and 27 cm and 9 fish respectively in 1996. The MLS was increased from 25 to 27 cm from 15 December 1994 and the bag limit reduced from 20 to 15. The bag limit was further reduced from 15 to 9 after 1 October 1995.

For blue cod in the Marlborough Sounds, the MLS was 30 cm and the bag limit 12 fish from 1986 to 1 October 1993, 33 cm and 10 fish respectively to October 1994, and then 28 cm and 6 fish respectively. In BCO 7, but outside the Marlborough Sounds, the MLS was 30 cm and the bag limit was 30 from 1986 to 1 October 1993 and thereafter the MLS was 33 cm and the bag limit 20. The change in regulations in October 1993 during the Central region diary survey has been ignored in this analysis.

3. Data selection

In this report, the data come from the three North region boat ramp surveys held in 1991, 1994, and 1996; the Central region boat ramp survey in 1992–93; the Central region diary survey in 1992–93; the North region diary survey in 1993–94; and the national diary survey in 1996. The recreational data, particularly those from boat ramp surveys, have a complex structure and care is necessary when using them.

The three North region boat ramp surveys had different priorities on their objectives. The sites surveyed were also distributed differently in space and time (Bradford 1999; Todd Sylvester, Ministry of Fisheries, Auckland, unpubl. data). Thus, the data from the three surveys are not strictly comparable. These difficulties were ignored, except that only records from people interviewed who used trailer boats were included. Fish were counted and some were measured. Counts of caught fish included filleted fish, those used as bait, undersized dead fish discarded, and live discards. In the 1991 and 1994 surveys, only live discards of nominally legal sized fish were recorded. By 1996 the number in this category suggests that all discards were included although the instruction to interviewers was still to include only live discards of legal sized fish. The information on discards was not used.

All measured lengths were used after taking the above restrictions into account.

Since we are dealing with mixed species fisheries, a working definition of unsuccessful snapper or blue cod trips was required.

- Trips selected in the North region boat ramp surveys were trips where snapper was caught, or where snapper was the target species, or where the target species was "MIX" and the fishing method was a baited line, or jigging with or without a bait. The snapper that were filleted at sea or used as bait were counted as retained harvest.

- Trips selected in the diary surveys were trips where snapper (blue cod) was caught or where snapper (blue cod) was among the target species. We assume that "catch" was interpreted by diarists as fish that were retained, that is, harvested but some diarists may have recorded retained plus discarded fish as their catch (Bradford 1998a).

- Trips selected in the Central region boat ramp survey were trips on which blue cod (or cod) was caught, or where blue cod (or cod) was a target species, or where the target species was "MIX" for the Waikawa or Okiwi ramps. Fishers using the Nelson ramp were assumed to be mainly fishing for snapper or kahawai, not blue cod. "MIX" was a common target species in this survey.

Harvest size information was not collected in the boat ramp surveys in the Central and South regions in 1996. In the 1992–93 Central region boat ramp survey, some of the harvest sizes are party harvests rather than individual harvests. Whether the harvest was for an individual or a party was recorded and has been used in some analyses (Ryan and Kilner, unpubl. data, Allan Kilner, Ministry of Fisheries, Dunedin, pers. comm), but this information was provided to the recreational database (***rec_data***). Consequently, data from this survey were not used to fit the bag size distributions.

In the recreational database, a trip is defined by fishing method and location, hence a fisher may have more than one trip in a day. The harvests from an individual's trips on a given day were summed to give the daily bag.

For SNA 1, the length and bag data are presented for East Northland and for the Hauraki Gulf and Bay of Plenty combined because these areas are modelled separately in the stock assessments (Figures 1, 2, and 3). The bag size distributions of the diarists have a smaller proportion of zeros than those measured in the boat ramp surveys, but all the bag size distributions have the same general shape (Figure 3).

For BCO 7, the length and bag data are presented for the Marlborough Sounds and for the rest of BCO 7, as different regulatory conditions apply (Figures 4 and 5). There is some uncertainty as to the location of harvests; the available information, including the fishing location indicated by diarists, has been used to assign the harvest to area. The harvests recorded in the Central region diary survey did not include the substantive contribution from South region fishers.

4. Modelling bag size distribution

Following Porch & Fox (1990, 1991), the bag size distributions are assumed to be of a negative binomial form (Appendix 1). This choice is empirical but fits both the large numbers of zero bags and the generally declining distribution of numbers with increasing bag size.

The mean length of snapper measured in the 1996 boat ramp survey remained almost constant as the bag size increased (*see* Figure 2) except that there was an abrupt increase in mean length at the bag limit of 9 and a decrease again in bags greater than 9. This suggests that when fishers exceed the bag limit, they either comply and discard fish (mostly their smaller fish) or they do not comply and discard no fish. People with more than the bag limit, by definition, failed to comply with the bag limit. They may or may not have complied with the MLS. Fishers who complied with the bag limit were modelled as discarding small fish. Those who did not comply with the bag limit were assumed not to discard any fish. These are simple assumptions that are consistent with the data. Figure 2 also shows that there was some non-compliance with the MLS of 27 cm at all bag sizes.

All the bag size distributions for a fishery are fitted at once, using the bag limits in force in each year (Figures 6 and 7). An individual mean is fitted for each distribution; all distributions are assumed to have the same shape (or variance) parameter, V, and proportion of non-compliers, π (Tables 1 and 2). Estimation is by maximum likelihood (Appendix 1). Fishers have to exceed the bag limit before they can become non-compliers. The interpretation of the non-compliance factor is discussed in Section 4.1. The estimated parameters allow us to predict bag distributions for different mean bag sizes before and after discarding.

For snapper in SNA 1, the bag size distributions from East Northland and from the Hauraki Gulf and the Bay of Plenty combined from the three boat ramp surveys and the two diary surveys were fitted at once (*see* Figure 6 and Table 1). It should be remembered that the harvest distributions from the diary survey could be contaminated by some spurious large harvests. For example, diarists might have recorded their catch, that is, harvest plus discards, or they might have recorded party harvests. The fitted distributions show remarkably good fit, up to and including the bag limits, for so few parameters. The tails of non-compliant bags fit less well, but numbers are small. A logarithmic scale was used in Figure 6 to show this lack of fit. The larger sample sizes from the boat ramps carry more weight in the maximum likelihood estimator. The non-compliance factor was estimated to be 48%.

Table 1: Parameters in the fit to bag size distributions in SNA 1. Confidence intervals on V and π are based on likelihood profiles

Region	Survey	Parameter	Estimate	95% confidence interval
East Northland	1996 boat ramp	Mean bag size	2.18	
	1994 boat ramp		1.92	
	1991 boat ramp		1.13	
	1996 diary		3.21	
	1994 diary		3.25	
Hauraki Gulf and Bay of Plenty	1996 boat ramp		2.04	
	1994 boat ramp		2.30	
	1991 boat ramp		1.43	
	1996 diary		3.02	
	1994 diary		3.40	
All	All	Shape (V)	5.47	(5.37,5.57)
		Non-compliance (π)	0.48	(0.44,0.52)

For blue cod in BCO 7, the bag sizes from within the Marlborough Sounds and from the rest of BCO 7 are fitted together. Table 2 gives the parameter estimates using data from the two diary surveys only and using all data. The boat ramp harvest data are contaminated by the presence of some party harvests that cannot be easily identified. The fit to the diary data alone is therefore assumed to give the best parameter estimates (*see* Figure 7). The non-compliance factor was estimated to be 51%. The sample sizes are much smaller for the blue cod than for snapper. Sample sizes from the Central region diary survey are lower than in the national survey partly because no contribution from South region fishers is included.

Table 2: Parameters in the fit to bag size distributions in BCO 7 (as for Table 1). The first set of parameters were used because of the boat ramp data contained some party harvests

Region	Survey	Parameter	Estimate	95% confidence interval
Marlborough Sounds	1996 diary	Mean bag size	5.20	
	1992–93 diary		3.87	
BCO7 outside the	1996 diary		5.86	
Marlborough Sounds	1992–93 diary		6.24	
All	All	Shape (V)	6.29	(5.60,7.10)
		Non-compliance (π)	0.51	(0.43,0.58)
Marlborough Sounds	1996 diary	Mean bag size	6.02	
	1992–93 diary		4.52	
	1992–93 boat ramp		5.07	
BCO7 outside the	1996 diary		6.61	
Marlborough Sounds	1992–93 diary		7.06	
	1992–93 boat ramp		6.48	
All	All	Shape (V)	9.04	
		Non-compliance (π)	0.62	

In what follows we assume that the level of non-compliance with bag limits is 50%, for fishers whose catches exceed them, at all modelled bag limits.

4.1 The non-compliance factor

Fifty percent compliance with a bag limit sounds alarming and, as is shown below, does have serious consequences if extrapolated to much smaller bag limits (Section 5). However the current bag limits are not reached on most trips. For example, in the 1996 boat ramp survey in SNA 1, 1.1% of the fishers interviewed had not complied with the bag limit of 9, and in the 1996 diary survey in the Marlborough Sounds, 13.8% of trips recorded by diarists had not complied with the bag limit of 6. Some of the latter trips may not have been individual harvests.

Figure 8 is included to help visualise what happens. We start with a negative binomial distribution of bag sizes fitted to the snapper bag size distribution from the Hauraki Gulf and Bay of Plenty for the 1996 boat ramp survey. The numbers of trips expressed as a percentage of the total number of trips that did not comply with the bag limit with non-compliance factors of 50% and 75% (25% compliance) are plotted. The percentage of non-compliant trips increases as the bag limit decreases, even though the non-compliance factor was kept constant. For the model data shown in Figure 8 with a non-compliance factor of 50%, 2% of trips would not be compliant with the bag limit of 9, and 18% with a bag limit of 1. For these data, 46% of trips harvest no snapper and 17% harvest one snapper. Similar results will arise for the other cases considered.

Fishers exceeding the bag limit can harvest a large number of fish when the bag limit is small and this can have a large effect on the overall harvest (*see* Section 5).

5. Modelling bag and MLS limits separately

5.1 Changing the bag limit

An unconstrained bag distribution was obtained by applying the parameters fitted for the 1996 snapper boat ramp samples and the 1996 blue cod diary samples without any bag limit. This distribution was used to model the effects of changing the bag limit and non-compliance. The unconstrained bag size distribution fits the observed distribution up to the bag limit and predicts the distribution at higher bag sizes.

It is assumed that any discarding of fish due to the MLS restriction occurs before and independently of any bag limit discarding. To estimate the effect on harvest by weight of bag limit discarding, it is necessary to estimate the mean weight of such discarded fish. Any discarding to comply with a bag limit was assumed to be of "small" fish, until no small fish were left to discard, then to be of large fish. For snapper, small fish were taken to be those less than 30 cm, and for blue cod, less than 33 cm. The mean weights and proportions of small and large fish were estimated from the length frequency distributions. The 1996 boat ramp data were used for snapper in East Northland, and the Hauraki Gulf and Bay of Plenty combined; and 1996 and 1992–93 boat ramp data for blue cod in the Marlborough Sounds. We ignored the small effect that these distributions were measured after discarding. Table 3 contains the mean weights for small and large fish.

Table 3: Mean weights used for small and large fish (w_S and w_L) and proportions of small and large fish (p_S and p_L) in the size distribution

Region	w_S	p_S	w_L	p_L
East Northland	482 g (< 30 cm)	0.293	1 253 g (> 29 cm)	0.707
Hauraki Gulf and Bay of Plenty	486 g (< 30 cm)	0.288	1 021 g (> 29 cm)	0.712
Marlborough Sounds	431 g (< 33 cm)	0.500	764 g (> 32cm)	0.500

Let p_S and p_L be the proportions of small and large fish in the catch before bag limit discarding. Hence

$$p_S + p_L = 1.$$

Let w_S and w_L be the mean weights of small and large fish in the catch before bag limit discarding.

Let N be the total number of fish in the catch before bag limit discarding. Then

$$N = \sum_y y b_y$$

where b_y is the number of bags of size y before bag limit discarding. Then the proportion of fish discarded due to the bag limit,

$$p = \frac{(1-\pi)}{N} \sum_{y>x} (y-x) b_y$$

where x is the bag limit and π is the non-compliance proportion.

Hence the catch before bag limit discarding by number is

$$N$$

and by weight is

$$[p_S w_S + p_L w_L]N .$$

The harvest after bag limit discarding by number is

$$(1\text{-}p)N$$

and by weight is

$$\begin{array}{rl} [(p_S - p)w_S + p_L w_L]N & \text{if } p \le p_S \\ [(p_L + p_S - p)w_L]N & \text{if } p > p_S. \end{array}$$

The reduction in harvest due to the current bag limit is not great for either snapper or blue cod (Figures 9, 10, and 11). The estimated level of bag limit non-compliance is about 50% for both snapper and blue cod. The difference in predicted catch between this and full compliance ($\pi = 0$) is considerable.

5.2 Changing the minimum legal size

It is difficult to estimate the degree of non-compliance with the MLS as we do not know the size distribution of discarded fish. Most fishers will catch small fish and will need to decide whether or not to discard them. Figure 2 shows some non-compliance with the MLS irrespective of bag size. Non-compliance appears to be small. The length frequencies for snapper in 1994 and 1996 in Figure 1 show that when the MLS increased from 25 to 27 cm the left hand tails of the length frequency distributions also moved up roughly 2 cm.

Figures 12 and 13 show estimates of the effect of increasing the MLS. The harvests by weight, assuming total compliance with the MLS, are expressed as a percentage of the (largely compliant) 1996 harvest. Using the relevant length frequency distribution, the MLS is raised 1 cm at a time and the new weight of the harvest is calculated. Lengths recorded by diarists were used for blue cod in the Marlborough Sounds to keep the sample size as large as possible.

6. Modelling bag and MLS limits together

6.1 Model

We develop a length based model which allows the combined effects of an MLS limit and a bag limit to be treated together. This is described in mathematical notation in Appendix 2. Recreational harvest must be modelled in a manner that generates both a length distribution of captured fish and a bag size distribution. We achieve this by modelling recreational fishing as a sequence of steps starting with a catch before any discarding and leading to a retained harvest and a discarded catch. The retained harvest is described by two vectors: the fish size distribution and the bag size distribution. We refer to the discarding in compliance with the MLS as *MLS discarding* and that in compliance with the bag limit as *bag limit discarding*. These are treated as occurring one after the other. The discards are thus described by two vectors: the size distribution of MLS discards and the size distribution of bag limit discards. Fish size distributions within individual bags are not modelled, nor do we consider the survival rate of discarded fish.

Recreational fishing is modelled in a sequence of steps:
1. capture a proportion of each of the length classes according to a known selectivity at length curve and a recreational exploitation rate;
2. discard fish below the MLS (with a level of non-compliance);
3. determine the total number of bags and hence the bag size distribution;
4. determine the number of discarded fish beyond the bag limit (with a level of non-compliance);
5. determine the size distribution of the bag limit discarded catch.

The stock to which the recreational effort is applied is described by a vector of numbers of fish at length, e.g., 2 million at 18 cm, 1.8 million at 19 cm, ... (*see* Figures 14(a) and 20(a)). The initial capture process is determined by a selectivity curve that gives the relative probability of a particular fish in a size class being caught (*see* Figures 14(b) and 20(b)). This curve is scaled by the fishing mortality to give the exploitation rate on each length class. This is then applied to the vector of numbers of fish at length in the population to give the catch at length before discarding.

MLS discarding is modelled by assuming that no fish at the MLS are discarded and that the proportion of fish retained declines by a constant factor, ϕ, the MLS non-compliance factor, for each length class below the MLS. Hence a retained length distribution is obtained. Calling ϕ the MLS non-compliance factor is convenient but perhaps misleading. Our selectivity curves are speculative below 25 cm for snapper and at all lengths for blue cod. Hence we use values of these curves and of ϕ that produce plausible results, but ϕ cannot be used to produce an estimate of the level MLS non-compliance. A cursory examination of Figures 1, 2, and 4 suggests that MLS non-compliance is low.

After MLS discarding, the retained fish are then distributed according to a bag size distribution (ignoring fish size). Fishing effort is measured as the number of bags, i.e. the number of fishing trips undertaken by individual fishers. This is taken to be proportional to the exploitation rate. Given an exploitation rate, the total number of bags is determined and hence the mean bag size. The mean bag size and a constant shape parameter determine the bag size distribution before bag limit discarding, assuming the negative binomial distribution fitted to snapper or blue cod in Section 4.1 above.

This distribution and the non-compliance factor then determine the bags above the limit from which fish are discarded and, hence, the number of fish discarded. Fishers are modelled as being either wholly compliant with the bag limit or wholly non-compliant.

The size distribution of bag limit discarded fish is not modelled bag by bag, but simply by applying a selectivity curve that declines steeply with increasing fish size to all the fish remaining in the catch after MLS discarding. The selectivity curve used is a right hand limb of a normal density function. The "variance" parameter is adjusted until the required number of bag limit discarded fish is achieved. This process of bag limit discarding is more complicated than that used in Section 5.1.

These steps result in a fish size distribution and a bag size distribution of the retained harvest, as well as the size distribution of MLS discards and of bag limit discards. The combined effects on the recreational harvest of varying both the MLS and the bag limit can therefore be predicted in both weight and numbers for a fish population defined by a size distribution.

We produced contour plots of harvests for bag limits 1–20 and size limits 25–35 cm and compared these with the current estimated harvest. We also examined whether the combined modelling of the effects of MLS and bag limit discarding produces different results from that of multiplying the separate effects of MLS and bag limit.

6.2 Results for Hauraki Gulf/Bay of Plenty snapper

The model was applied under scenarios based on the 1998 stock assessment of Hauraki Gulf/Bay of Plenty snapper (Davies *et al.* 1999). Number at length vectors for 1997–98, 2000–01, and 2017–18 were derived from the base case model results. The details of how this was done are not relevant here and are not described. These years were selected because they included the current stock (1997–98), a projected future stock with relatively more small fish (2000–01 contains the strong 1995 and 1996 year classes as 5– and 6–year–olds), and a projected future stock of double the present stock biomass (2017–18). Thus the effects of changes in the MLS and the bag limit under different scenarios could be estimated. The same exploitation rate, and hence the same number of bags, corresponding to the 1996–97 recreational harvest, was applied in each scenario. It was not necessary to model different exploitation rates equivalent to different levels of fishing effort. Under the model, a change in exploitation rate would produce an exactly proportionate change in harvest, since both the size distribution of fish and the distribution of bag sizes would change proportionately. Changes in catchability were also modelled, by doubling and halving the mean number of fish per bag, while keeping constant the number of bags at the 1996–97 level.

The recreational catch selectivity curve was based on relative recapture rates by size for east Northland and Hauraki Gulf in the 1985 tagging programme (Figure 14 (b)). The curve is fitted by eye (with the assistance of a smoother). Below 25 cm the curve is speculative, as fish were not tagged below this size. It is assumed that snapper below

18 cm were not caught. This selectivity curve is assumed fixed for snapper. Table 4 contains the base case values of parameters used in the modelling.

Table 4: Parameters used in the model. Some values have been estimated in earlier sections of this report

	Symbol	Value		Source
		Snapper	Blue cod	
Weight-length $W=aL^b$	a	0.04467	0.0102	Snapper: Paul (1976)
	b	2.793	3.123	Blue cod: Blackwell (1997)
Shape parameter	V	5.47	6.29	This report (above)
MLS non-compliance factor	ϕ	0.25	0.25	This report
Bag limit non-compliance factor	π	0.5	0.5	This report (above)
Minimum size caught	μ	18 cm	18 cm	This report
Exploitation rate for selectivity=1	A	0.066 yr^{-1}	0.18 yr^{-1}	This report
Length for selectivity=1		30 cm	35 cm	This report
Number of bags (thousands)	B	792	71	This report
Current mean bag size	m	3.02	5.20	This report (above)
Current bag limit	ψ	9	6	Regulation
Current minimum legal size (MLS)	λ	27 cm	28 cm	Regulation

Figure 14(a) and (c) show the size distribution calculated for 1997–98 and the estimated size of the resulting harvest (including discards to comply with the current MLS and bag limit). Figure 14(d) compares the modelled size distribution of the harvest in 1996, based on the above parameters, with the recreational harvest measured by the boat ramp survey. The number at length vector for 1995–96 was derived from the 1998 base case stock assessment of Hauraki Gulf/Bay of Plenty snapper (Davies *et al.* 1999). Suitable recreational snapper size data are not available for comparison with the estimated harvest in 1997–98.

Contours of the predicted recreational harvest in 1997–98 under various bag and MLS limits, assuming 50% and 100% compliance with the bag limit, were calculated (Figures 15 and 16). At high bag limits, changing the bag limit has very little effect, and at low bag limits the effect of changing the MLS is small. The particular reduction in recreational harvest could be achieved by reducing the bag limit, by increasing the MLS, or by improving compliance with the bag limit (by greater education or enforcement). Improving compliance with the MLS would have little effect (*see* Figures 14(c) and (d)). Large changes to the harvest would require considerably harsher recreational restrictions.

Contours of the predicted recreational harvest where the population biomass above 25 cm is slightly larger and contains relatively more small fish (2000–01 is 10% larger by weight and contains more 5– and 6–year–olds), do not show noticeable changes in the predicted harvest except at very low bag limits (Figures 17). Contours of the predicted recreational harvest where the population biomass above 25 cm is double that of 1997–98 (2017–18 is 100% larger by weight) show the predicted harvest to be less than double that of 1997–98 (Figures 18). The bag size limit causes a greater reduction in harvest when the mean bag size is greater.

The combined modelling of the effects of MLS and bag limit discarding did not produce different harvests from that of multiplying the separate effects of MLS and bag limit, except when the MLS is substantially increased *and* the bag limit is substantially reduced (Figure 19).

6.3 Blue cod in the Marlborough Sounds

Little modelling of the blue cod stock in the Marlborough Sounds has been undertaken and the available data for such modelling are limited. The stock was assumed to have the size distribution as measured in the 1996 survey (Blackwell 1998) and shown in Figure 20(a). In that survey, most blue cod were caught in pots and a few by line. Here, lengths from both catching methods were used. Lengths less than 17 cm were ignored. The selectivities of the catching methods mean that there are few small fish in the size distribution. We do not know whether these methods have any selectivity against catching larger fish.

The estimated number of blue cod caught in the Marlborough Sounds regulatory area, as given by the 1996 national diary survey, is 267 000 (Bradford, unpubl. data). The mean blue cod weight for BCO 7 was 671 g (Bradford 1998b) which leads to a total of about 180 t. This mean weight may be biased by larger blue cod caught outside the Marlborough Sounds. The mean weight of the stock based on the size distribution (Figure 20(a)) is 437 g. The recreational catch selectivity (Figure 20(b)) was chosen to give reduced catch of fish in the mode of the size distribution, but a mean weight of 671 g was not attained.

Stock size and exploitation rate estimates are not available for blue cod. To apply the model we therefore assumed plausible values. The size distribution (Figure 21(a)) was arbitrarily scaled by 1500. This gave a population above 17 cm of 2.9 million fish. An exploitation rate of 0.18 yr^{-1} then gave a harvest by number of about 267 000 fish, weighing 144 t. The mean bag size estimated for the 1996 diary survey (5.20) was assumed. Table 4 gives the parameters used.

Figure 20(d) shows that larger fish are slightly under-represented. Either large fish are under represented in the population size distribution (Figure 20(a)) or the recreational selectivity should slope upwards to the right. The estimated size distributions of discards cannot be verified.

With the other parameters fixed, the estimated harvests by weight and number are found as MLS and the bag limit are varied (Figure 21). The weight and number of fish given at the current bag limit and MLS are those predicted by the model. These numbers give a mean weight of 545 g. The estimated harvests with bag limit of 12 and MLS of 30 cm (to October 1993) and bag limit of 10 and MLS of 33 cm (1993–94) are indicated. The latter limits would have resulted in a substantial reduction in predicted harvest (assuming that the population was the same). The former limits (in place during most of the 1992–93 diary survey) would have resulted in approximately the same harvest as the current limits.

Figure 22 suggests that bag limit changes have little effect when the MLS is greater than 31 cm as a consequence of the strong modal peak at 30 cm in the assumed population size distribution.

We do not have the information on year class strengths or current biomass of blue cod in the Marlborough Sounds that would enable projection of the recreational harvest to the future.

The combined modelling of the effects of MLS and bag limit discarding produced different harvests from that of multiplying the separate effects, where substantial change in both limits was made (*see* Figure 22).

7. Discussion

We consider in detail the recreational harvests from the snapper stock in the Hauraki Gulf and the Bay of Plenty combined and from the blue cod stock within the Marlborough Sounds.

The negative binomial was empirically chosen to describe the recreational bag size distributions and appears to fit well. The estimated non-compliance level by those whose catches exceeded the limit was considerable but depends somewhat on the validity of the negative binomial in the tail of the distribution. If harvest reduction is sought, measures that increase compliance may be equally as effective as reducing the bag limit. Compliance with MLS restrictions appears reasonable at the levels currently in force.

The model described here allows us to predict the recreational harvest under a bag limit and MLS applied together. The reliability of the predicted harvest will depend on how well we can predict the recreational effort, harvest rate, and size distribution and biomass of the fish population. It also depends on the precision of the bag distribution parameters and the non-compliance factor and the validity of the negative binomial and compliance assumptions. Thus our harvest estimates for the snapper stock are better than for blue cod where the data are fewer.

We know that the number of trips made by recreational fishers and the recreational harvest rates vary from year to year (Bradford 1998c, 1999). Such changes may make larger changes in the recreational harvest than would be predicted from a modest change in bag limit or MLS.

Examination of the data suggests that the frequent changes in BCO 7 regulations and the differences inside and outside the Marlborough Sounds have confused fishers. For example, fishers appear to be complying with a higher MLS in the Sounds than currently in force. However, this could be a consequence of discarding fish up to a few centimetres above the MLS in order to comply with the bag limit.

We have not considered the survival rate of discarded fish. Unless fishers stop fishing when they reach the bag limit or take care to keep their catch alive, many of their discards will be small dead fish that they replace by larger ones. If this is what happens, the benefits to the stock will be less than otherwise. Very low bag limits would result in many discards surviving, being fish smaller than those already in hand. Survival proportions could be calculated for different bag limits under this assumption.

All calculations used the assumption that recreational fisher behaviour does not change if the regulations are changed. For example, the number of trips remains the same and the same levels of non-compliance apply. However, if fishing is primarily for food, fishers may make more trips to maintain their overall harvest if a substantial reduction in bag limit or increase in MLS were imposed. Others may decide to stop fishing if such changes occur.

8. Conclusions

We have provided a model for predicting the combined effect on recreational harvest of a bag limit and an MLS for a given level of exploitation. This includes non-compliance and appears to be better than multiplying the independent effects of MLS and bag limits. The model could be applied under changed assumptions or to other stocks.

9. Acknowledgments

This work was funded by the Ministry of Fisheries in 1997–98 under project REC9702. We thank Allan Kilner and Kevin Sullivan (Ministry of Fisheries) for their useful comments on an earlier version of this report and Mike Beardsell (NIWA) for his editorial comments.

10. References

Blackwell, R. G. 1997: Abundance, size and age composition, and sex ratio of blue cod in the Marlborough Sounds, September 1995. *New Zealand Fisheries Data Report No. 88.* 17 p.

Blackwell, R. G. 1998: Abundance, size and age composition, and yield-per-recruit of blue cod in the Marlborough Sounds, September 1996. *NIWA Technical Report 30.* 47 p.

Bradford, E. 1996: Marine recreational fishing survey in the Ministry of Fisheries North region, 1993–94. *New Zealand Fisheries Data Report No. 80.* 83 p.

Bradford, E. 1997: Estimated recreational catches from Ministry of Fisheries North region marine recreational fishing surveys, 1993–94. New Zealand Fisheries Assessment Research Document 97/7. 16 p.

Bradford, E. 1998a: National marine recreational fishing survey 1996: scaling the diary survey results to give the total recreational harvest. *NIWA Technical Report 17.* 33 p.

Bradford, E. 1998b: Harvest estimates from the 1996 national marine recreational fishing surveys. New Zealand Fisheries Assessment Research Document 98/16. 27 p.

Bradford, E. 1998c: Modelling the recreational snapper harvest in SNA 1. *NIWA Technical Report 26.* 49 p.

Bradford, E. 1999: Comparison of marine recreational harvest rates and fish size distributions. *NIWA Technical Report 48.* 54 p.

Bradford, E., Fisher, D. & Bell, J. 1998a: National marine recreational fishing survey 1996: overview of catch and effort results. *NIWA Technical Report 18.* 55 p.

Bradford, E., Fisher, D. & Bell, J. 1998b: National marine recreational fishing survey 1996: snapper, kahawai, and blue cod length distributions from the boat ramp and diary surveys. *NIWA Technical Report 19.* 49 p.

Davies, N. M., Gilbert, D. J., & McKenzie J. R. 1999: Assessment of the SNA 1 and 8 stocks for the 1998–99 fishing year. Fisheries Assessment Research Document 99/28. 82 p.

Hartill, B., Blackwell, R., & Bradford, E. 1998: Estimation of mean fish weights from recreational catch landed at boat ramps in 1996. *NIWA Technical Report 31.* 40 p.

Johnson, N. L., Kotz, S., & Kemp, A. W. 1992: Univariate discrete distributions. (2nd edition). John Wiley & Sons, New York. 565 p.

Paul, L. J. 1976: A study on age, growth, and population structure of the snapper, *Chrysophrys auratus*, in the Hauraki Gulf, *Fisheries Research Bulletin No. 13.* 62 p.

Porch, C. E. & Fox, W. W. 1990: Simulating the dynamic trends of fisheries regulated by small daily bag limits. *Transactions of the American Fisheries Society 119.* 836–949.

Porch, C. E. & Fox, W. W. 1991: Evaluating the potential effects of a total daily bag limit from the observed frequency distribution of catch per fisher. *American Fisheries Society Symposium 12*: 435–456.

Sylvester, T. 1993: Recreational fisheries catch per unit effort trends in the North region (1990/91). Northern Fisheries Region Internal Report No. 14. 23 p. (Unpublished report held in Ministry of Fisheries North, Auckland.)

Teirney, L. D., Kilner, A. R., Millar, R. B., Bradford, E., & Bell, J. D. 1997: Estimation of recreational harvests from 1991–92 to 1993–94. New Zealand Fisheries Assessment Research Document 97/15. 43 p.

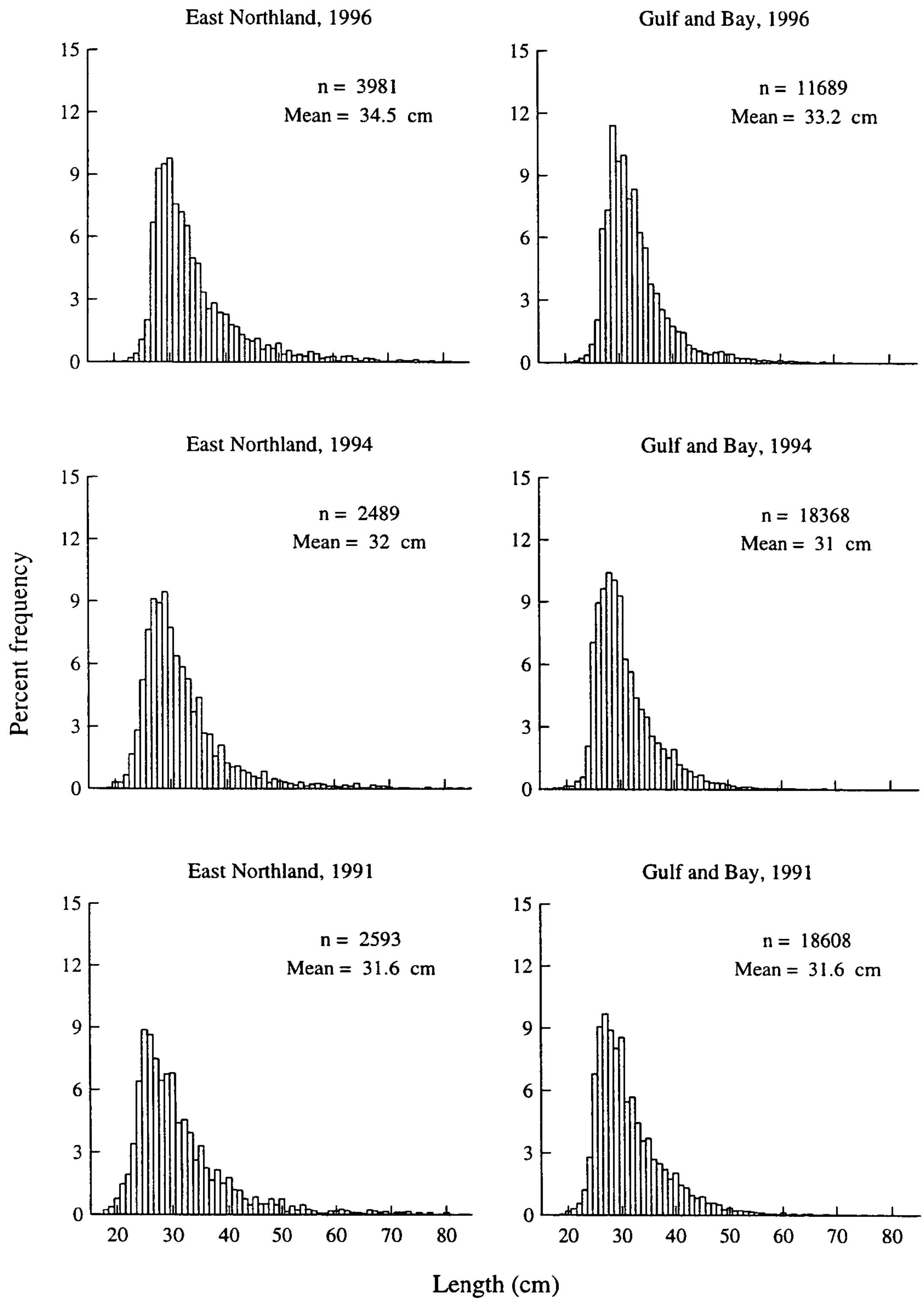


Figure 1: Observed size distributions from the North region boat ramp surveys. Gulf and Bay means Hauraki Gulf and Bay of Plenty.

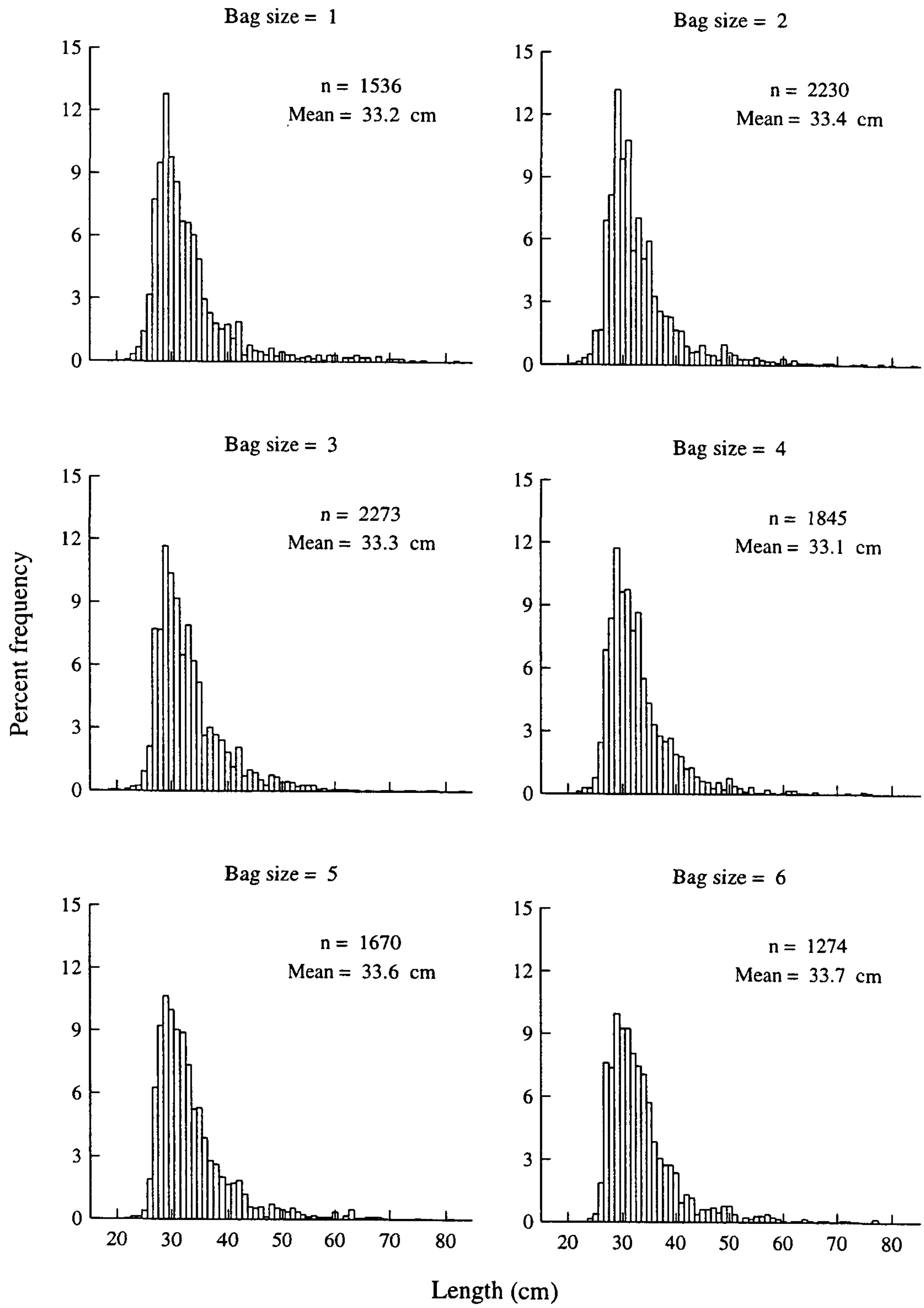
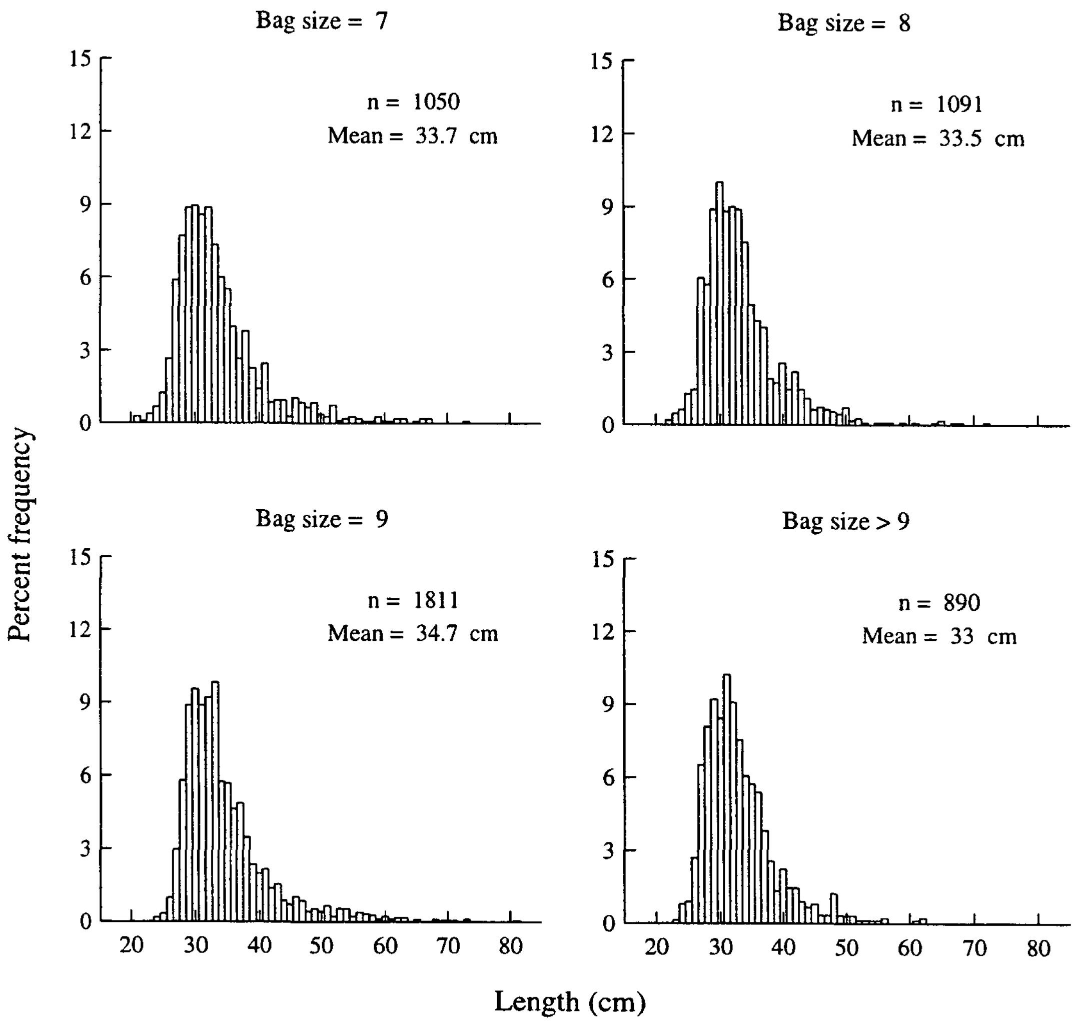


Figure 2: Observed size distributions in SNA 1 from the 1996 boat ramp survey. Distributions are plotted by bag size.



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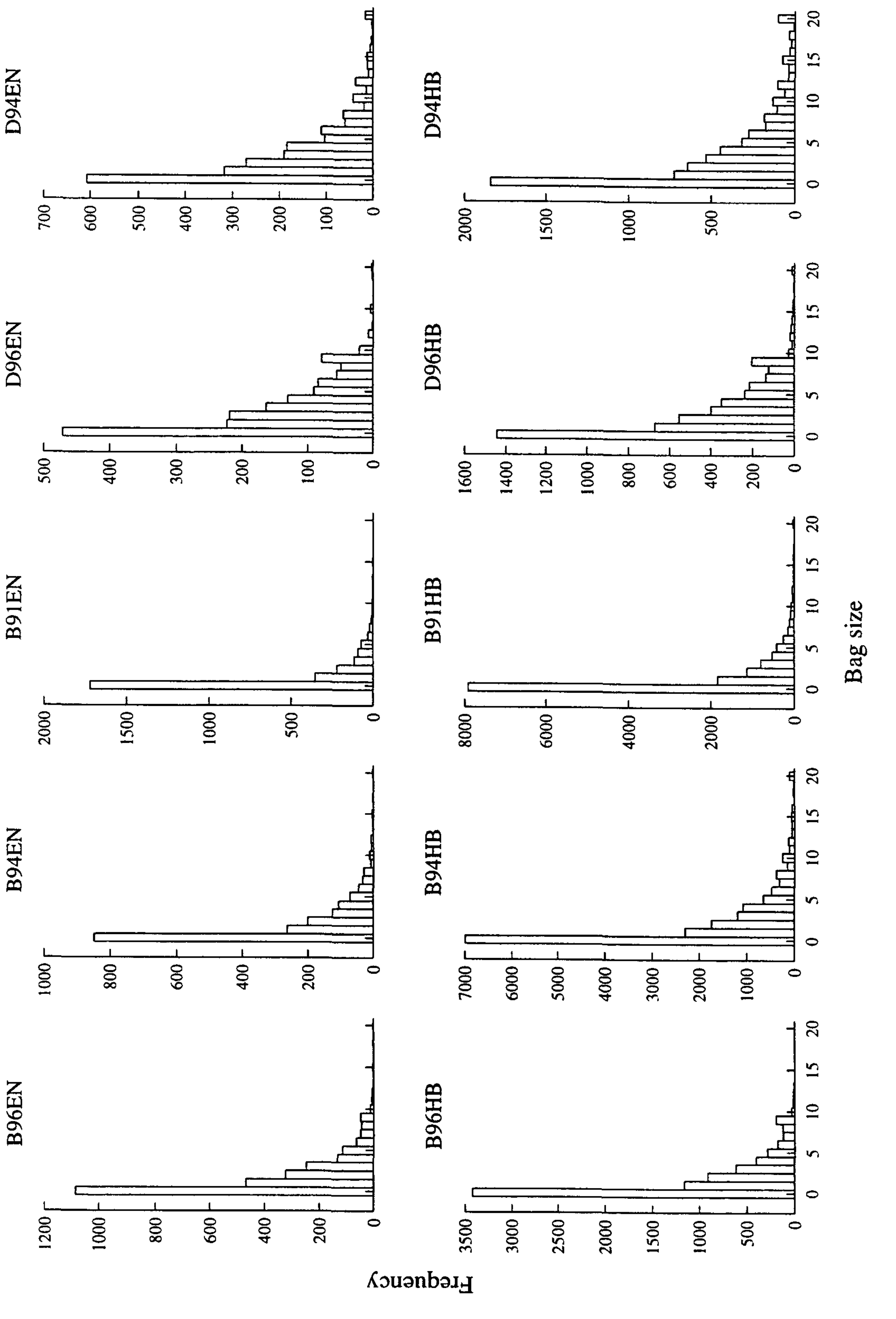

Figure 3: Bag size distributions from boat ramp and diary surveys in the North region. B boat ramp; D, diary; EN, East Northland; HB, Hauraki Gulf and Bay of Plenty; 96, 94, and 91, year of survey.

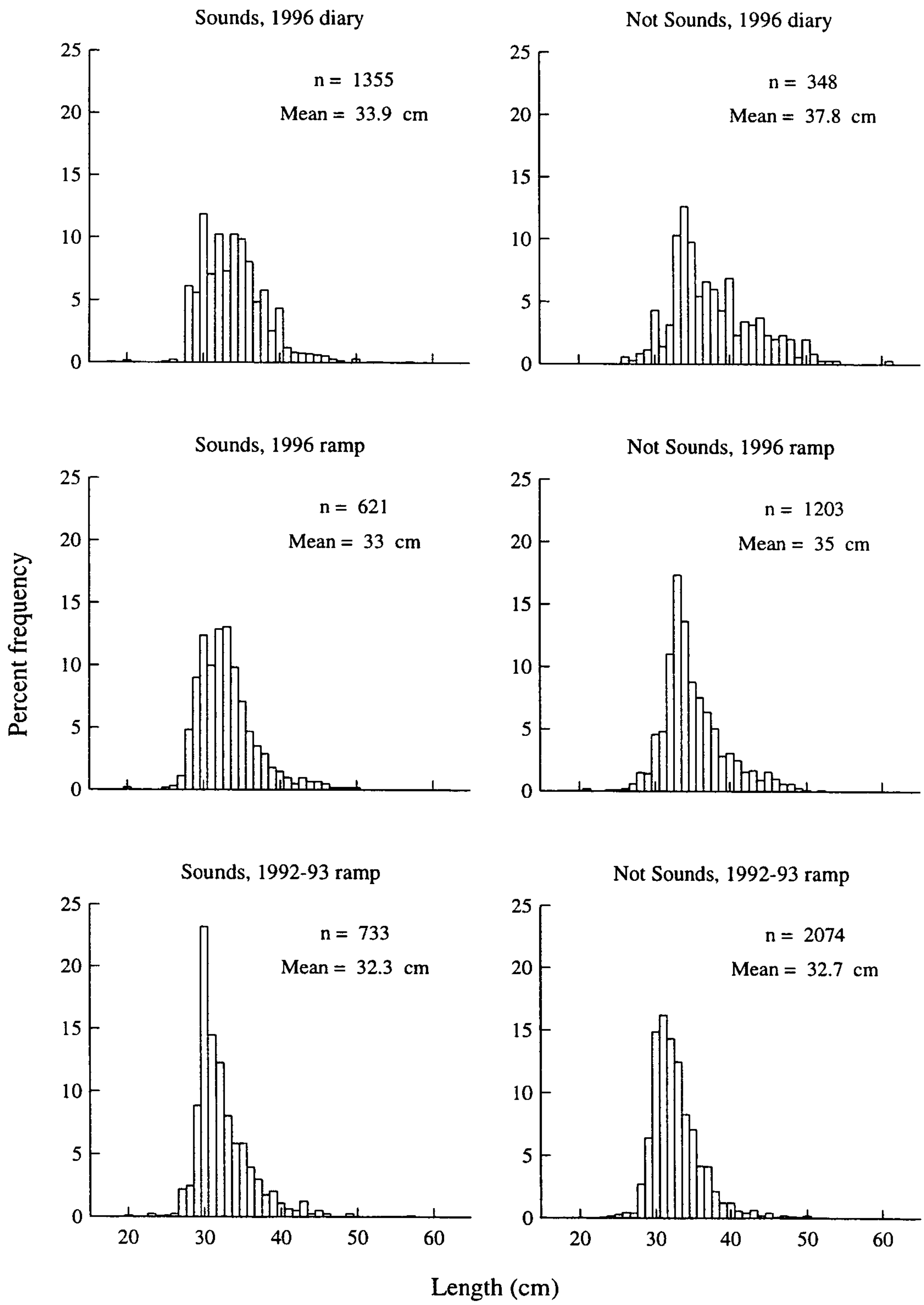

Figure 4: Observed size distributions in BCO 7 from the diary and boat ramp surveys. Sounds means within the Marlborough Sounds, not Sounds means the rest of BCO 7.

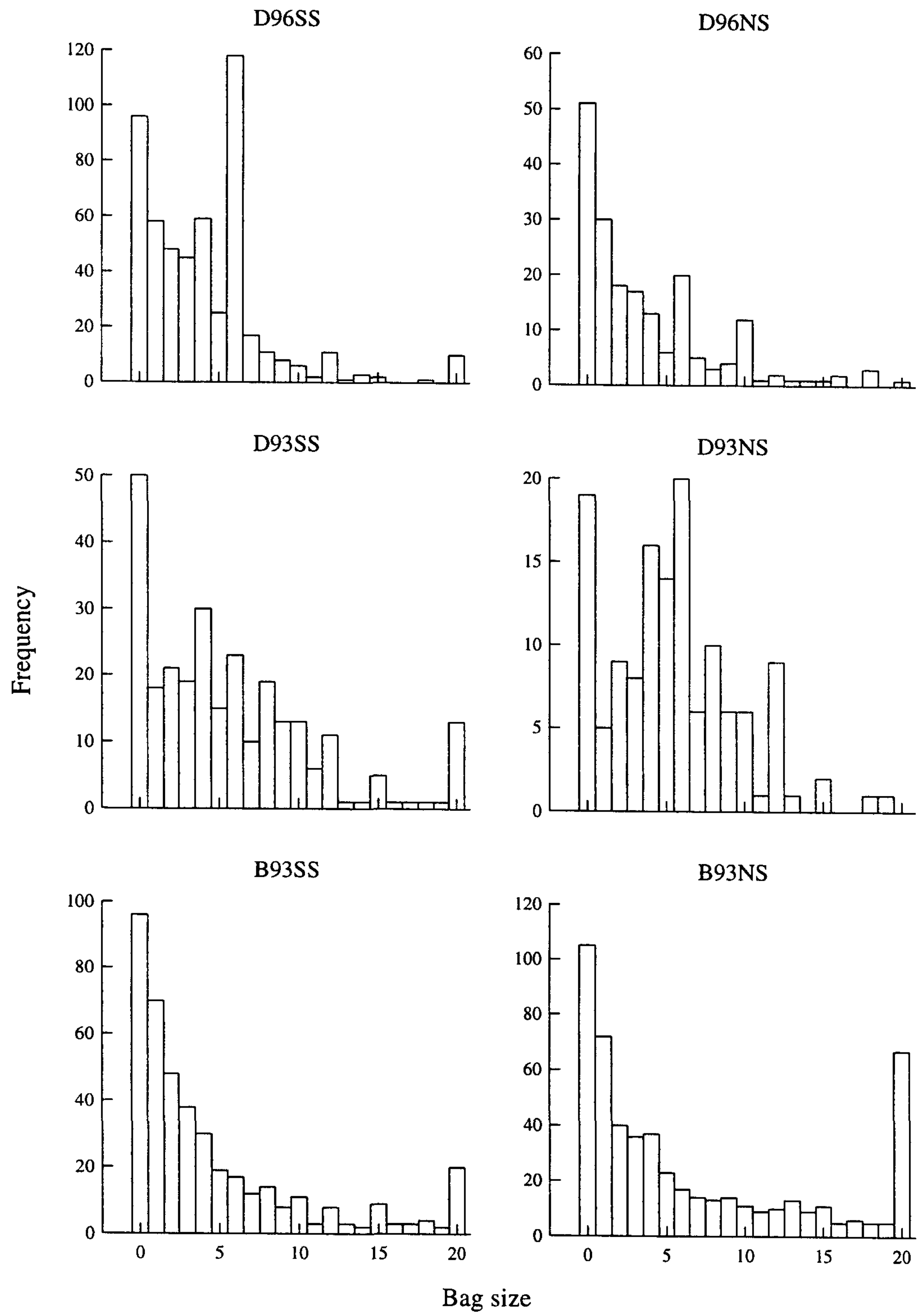

Figure 5: Observed bag size distributions in BCO 7 from diary and boat ramp surveys in the Central region. B, boat ramp; D, diary: SS, Marlborough Sounds; NS, outside the Marlborough Sounds; 96 and 93, year of survey.

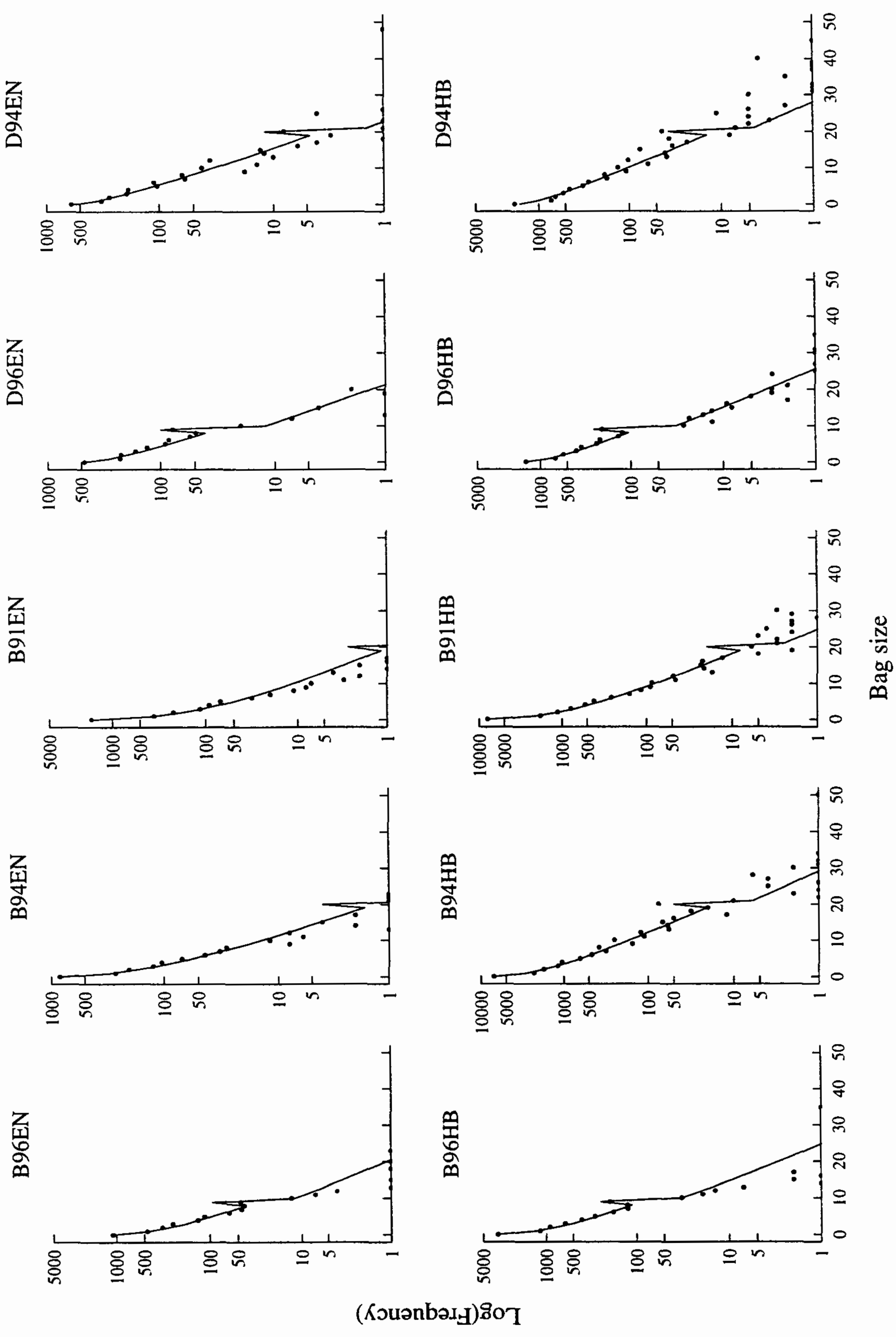

Figure 6: Model fits to the snapper bag data. The log scale is used on the y-axis to emphasise lack of fit.

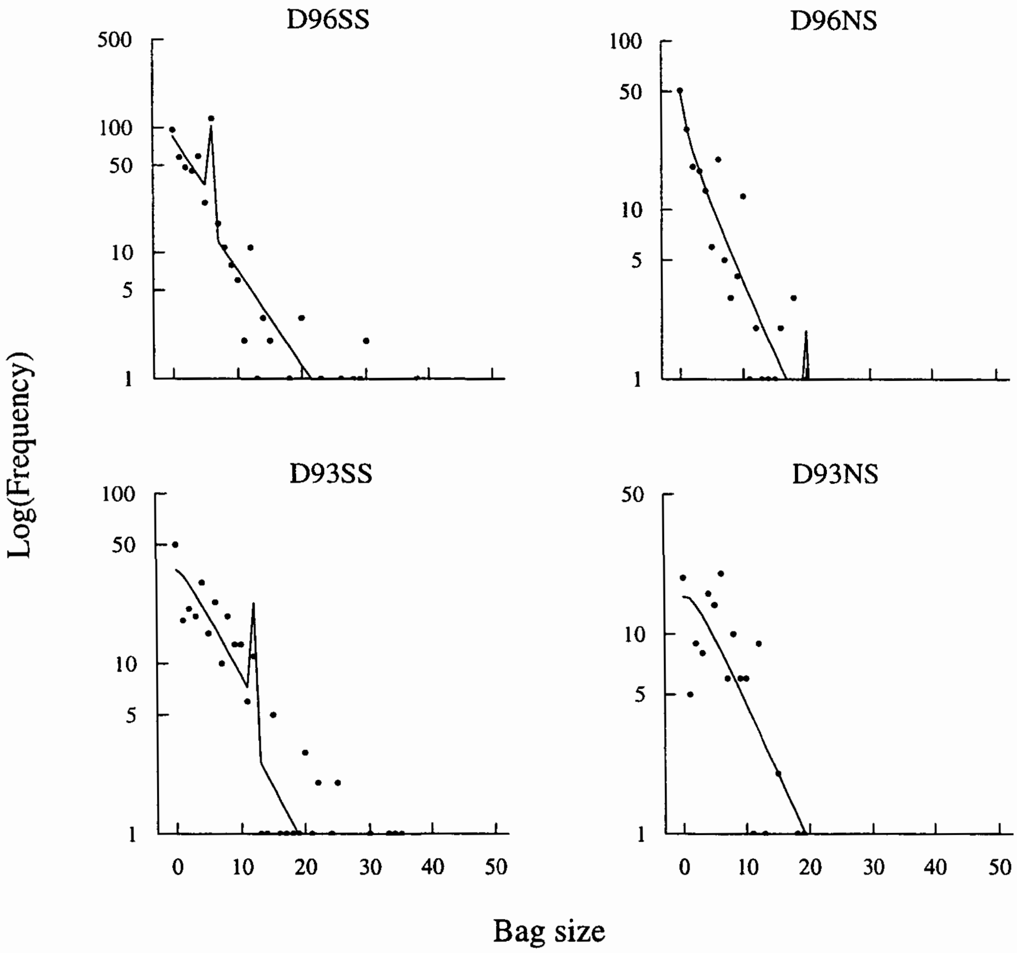

Figure 7: Model fits to the blue cod data. The fit using diary data alone is used. Bag limit was 30 for D93NS.

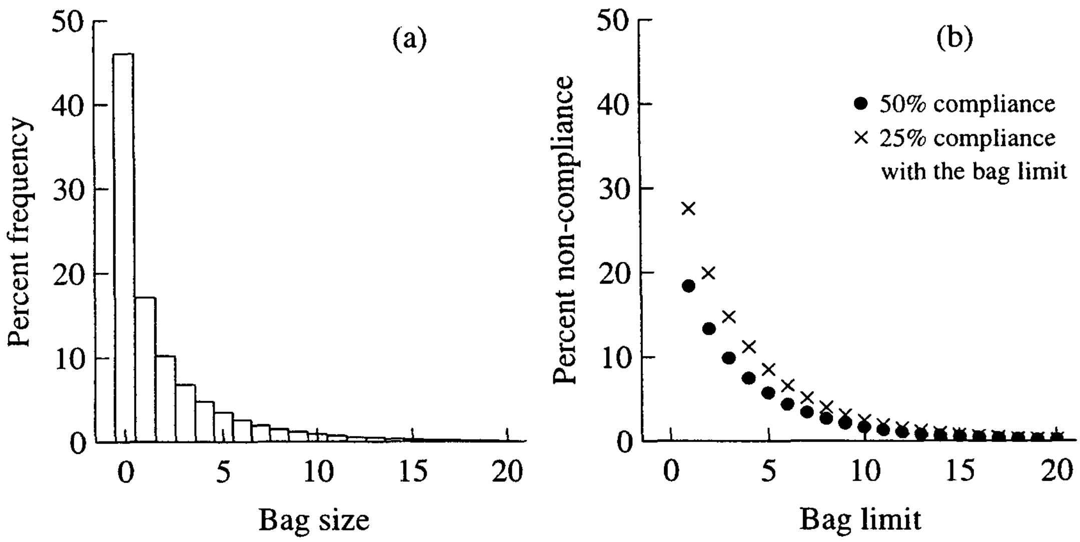

Figure 8: Estimates obtained from the modelled bag size distributions based on snapper counted in the Hauraki Gulf and Bay of Plenty during the 1996 boat ramp survey.
(a) histogram of the model bag size distribution
(b) expected numbers of non-complying trips as a percentage of all trips, plotted for 25 and 50% compliance against the bag limit (× and •).

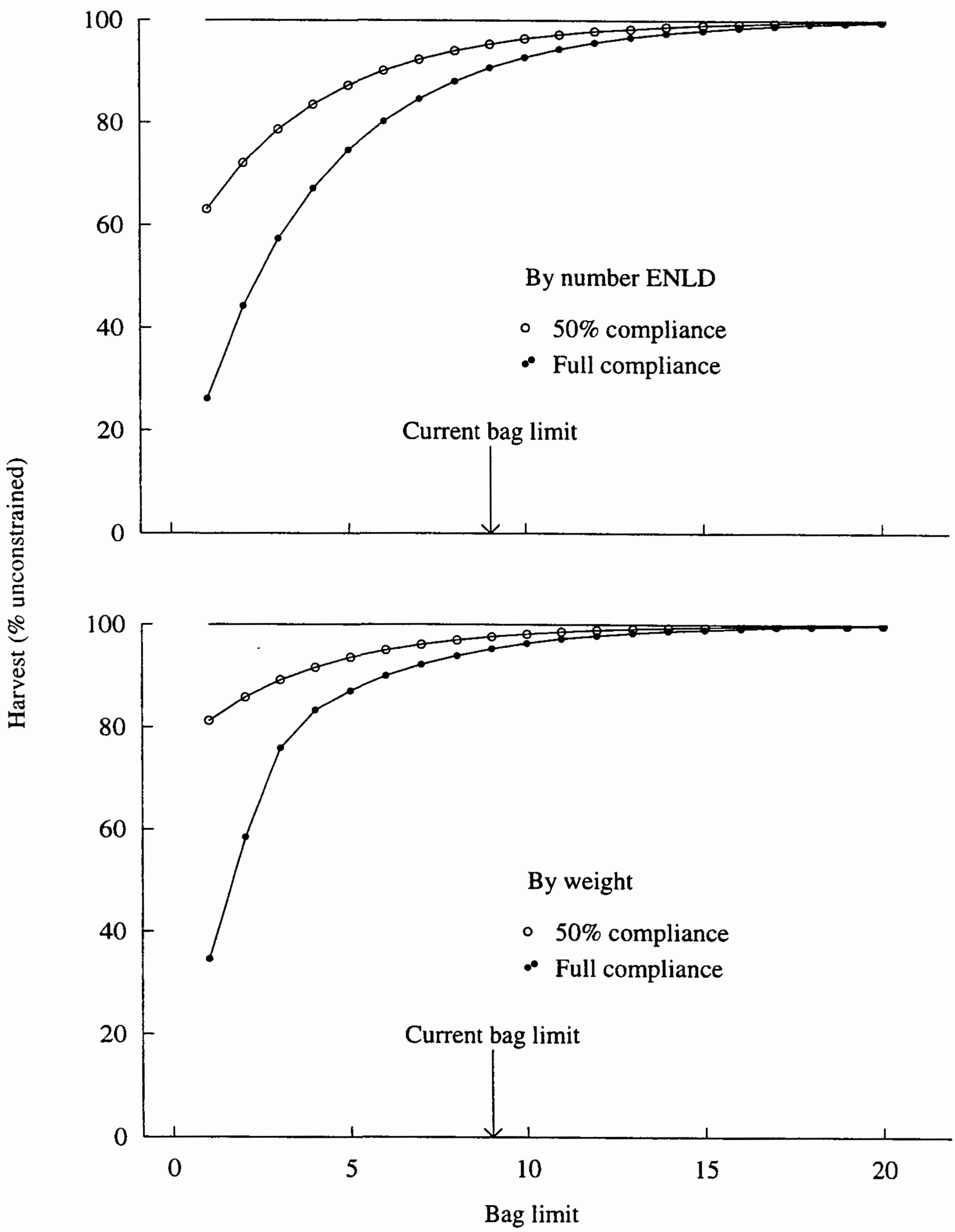

Figure 9: Changing the bag limit in East Northland (ENLD). The plots are by number and by weight. The horizontal line at 100% represents the unconstrained harvest.

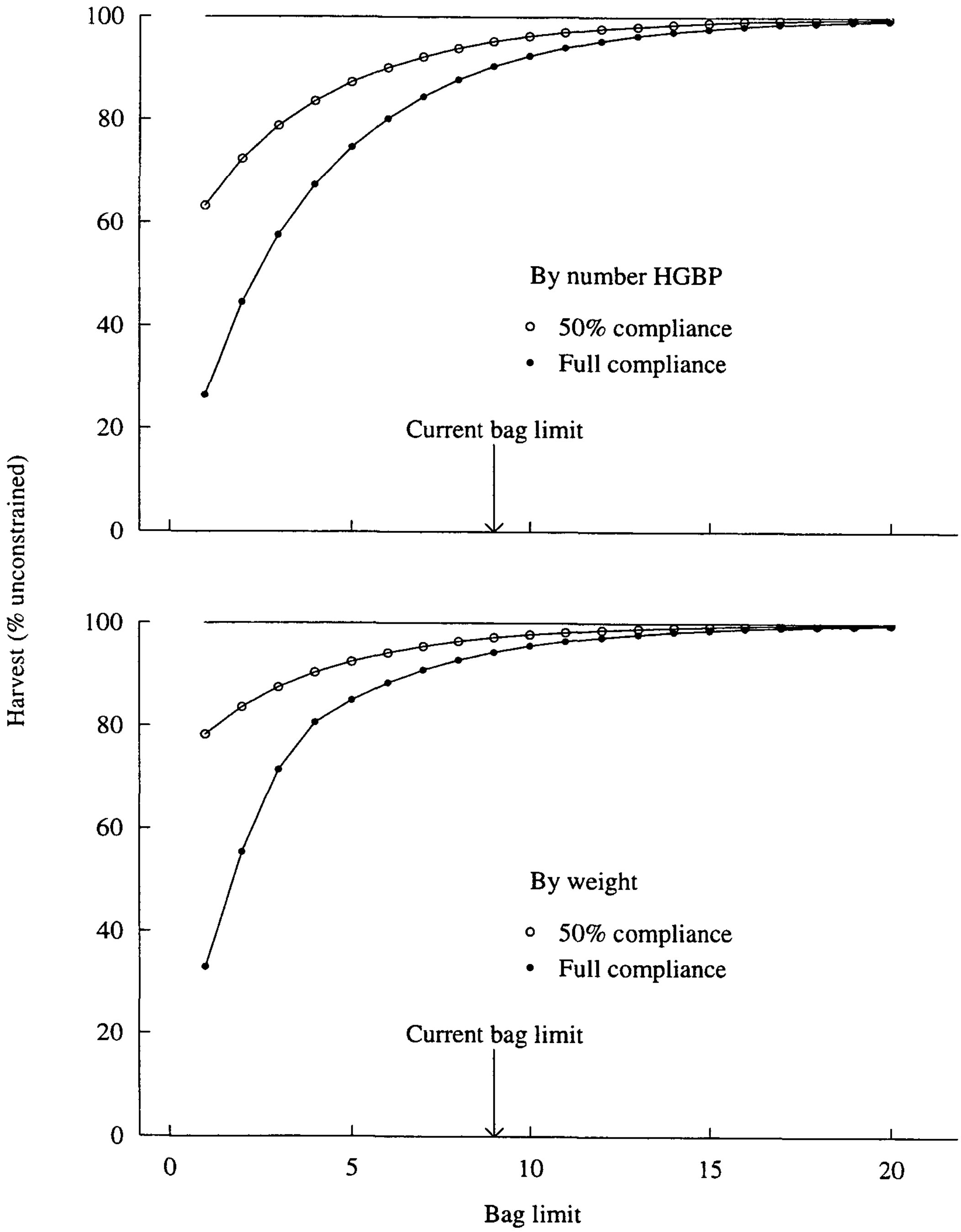

Figure 10: As for Figure 9, based on Hauraki Gulf and Bay of Plenty data (HGBP).

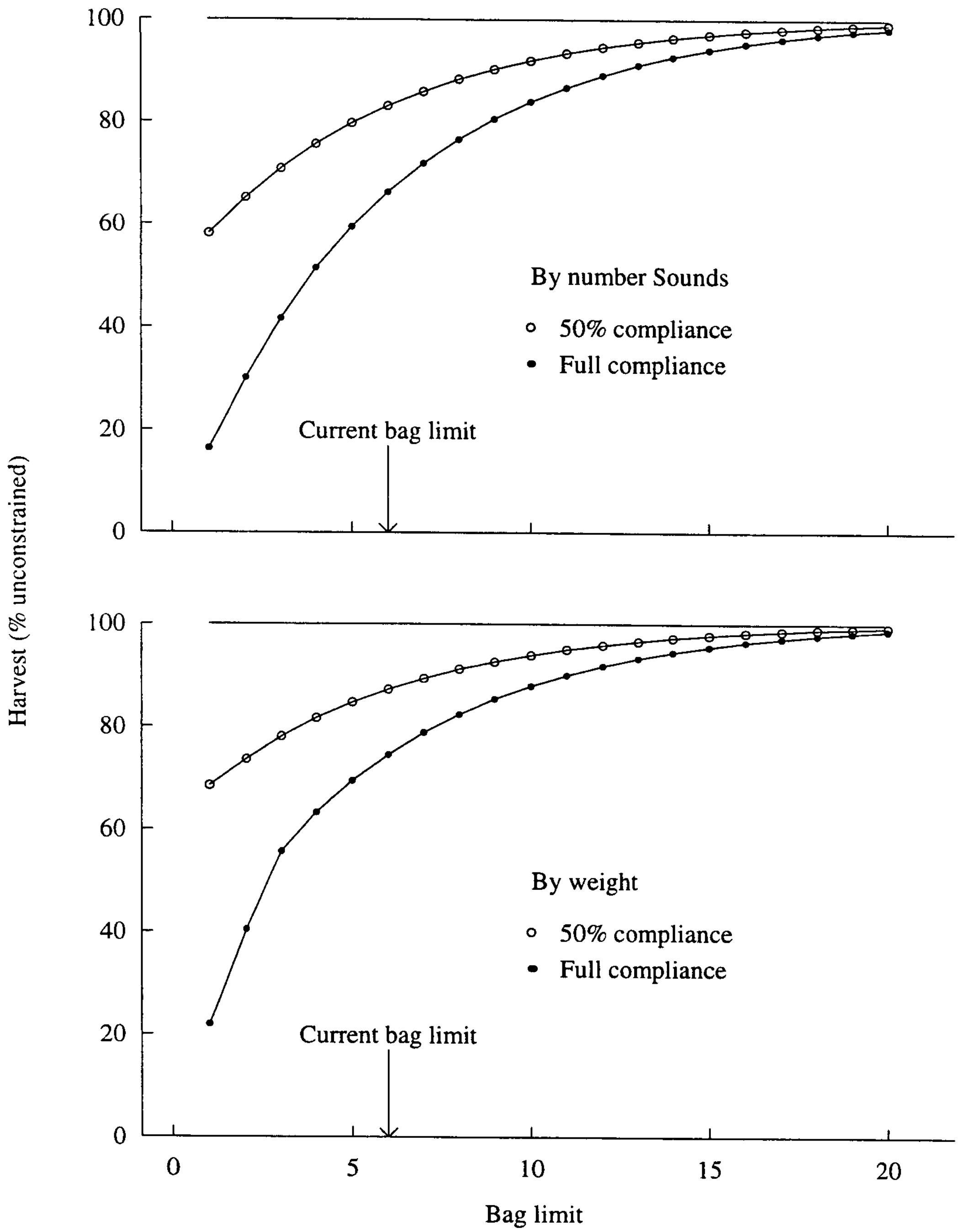

Figure 11: As for Figure 9, but based on Marlborough Sounds diary data (Sounds).

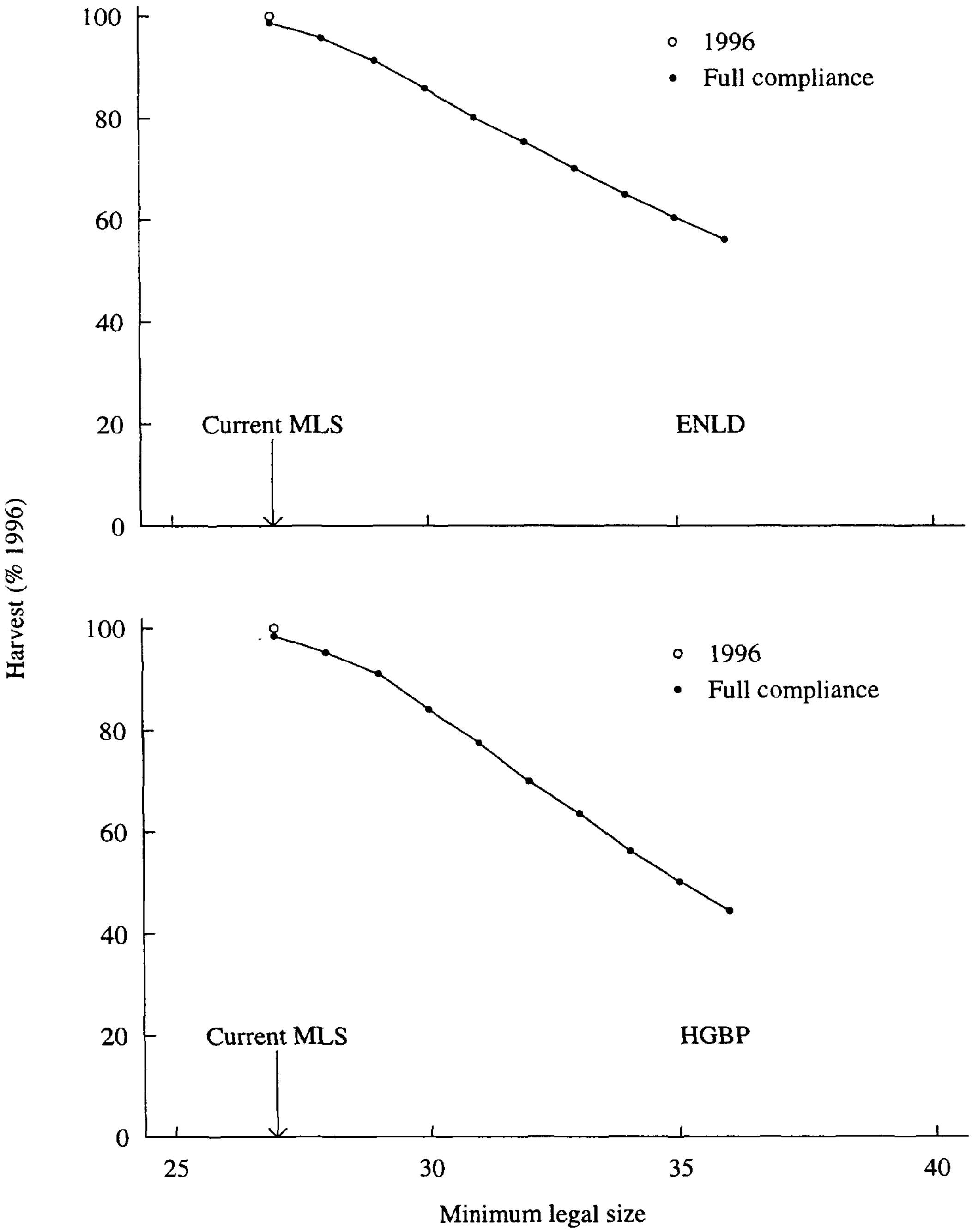

Figure 12: Increasing the minimum legal size from the current value. Points are plotted as percentages of the expected weight from the observed 1996 boat ramp survey size distributions in East Northland (ENLD) and the Hauraki Gulf and Bay of Plenty (HGBP).

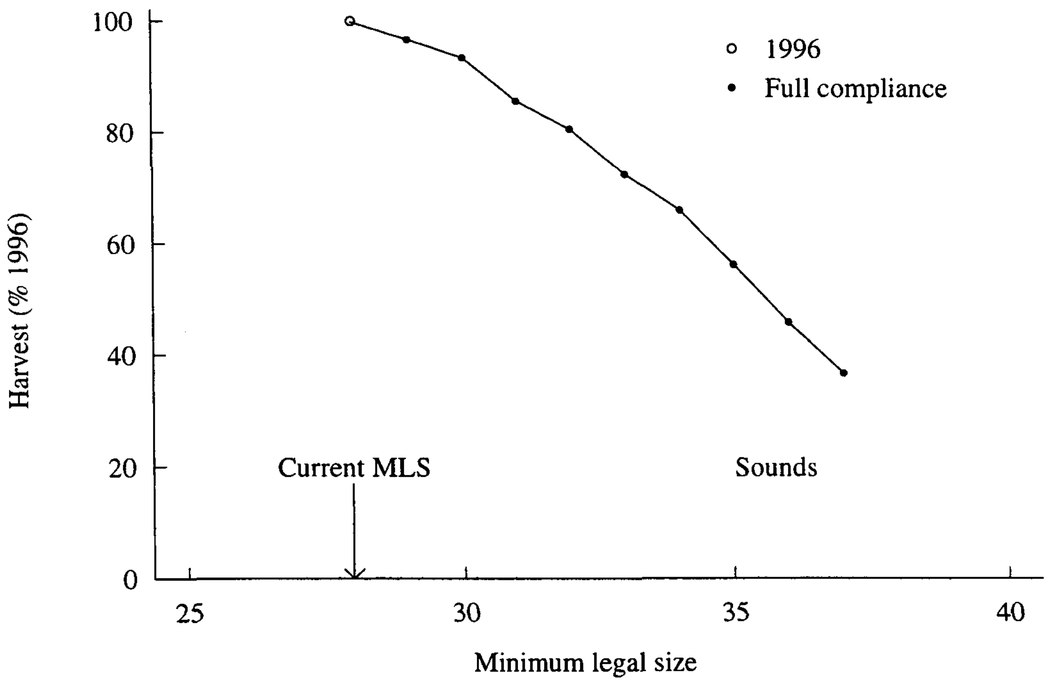

Figure 13: As for Figure 12 except based on the size distribution of blue cod from the Marlborough Sounds as measured by diarists in the 1996 diary survey.

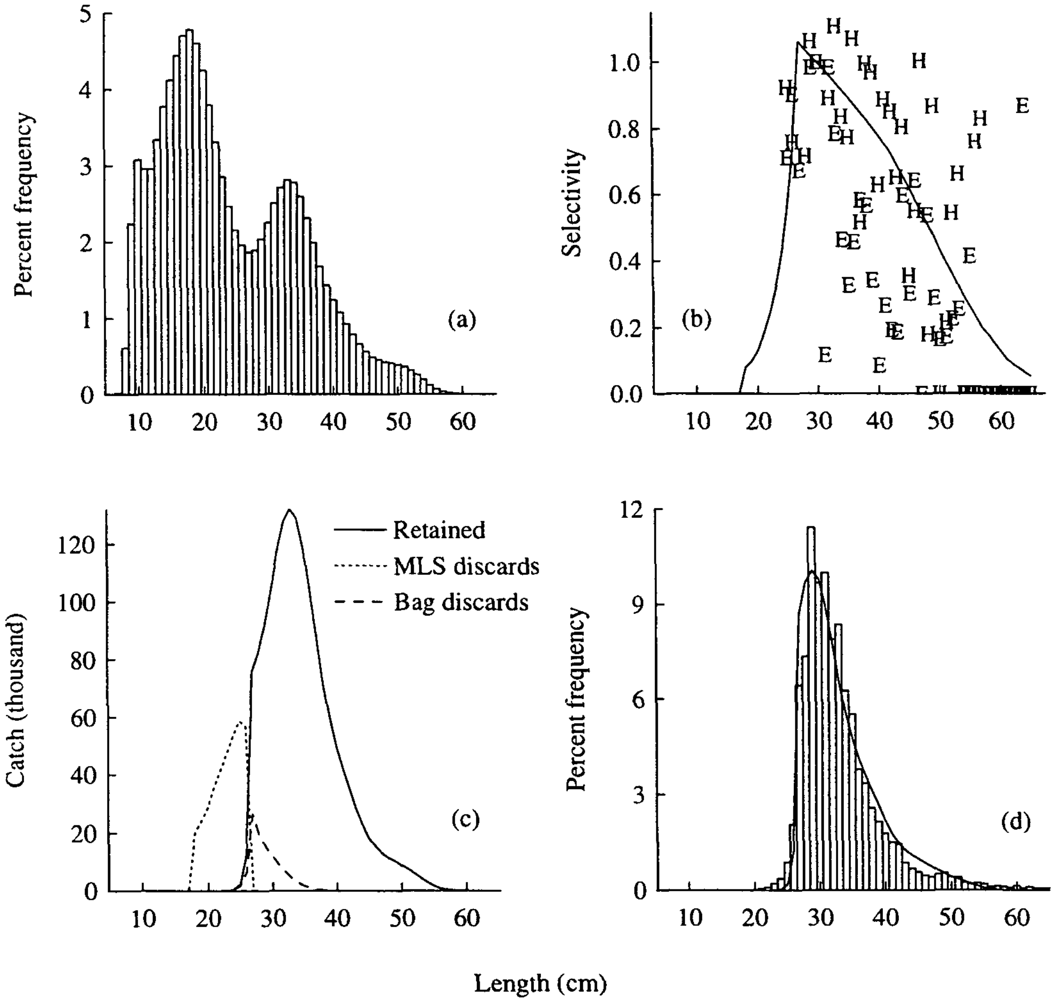

Figure 14: Model inputs and outputs for the recreational snapper catch from the Hauraki Gulf/Bay of Plenty in 1997–98 with bag limit (9) and MLS (27 cm) and 50% non-compliance with the bag limit.

(a) Population size distribution in 1997–98.

(b) Recreational catch selectivity. The plotted points are recapture rates from the 1985 tagging programme for East Northland (E) and Hauraki Gulf (H). Selectivity curve and points are scaled to 1 at 30 cm.

(c) Retained catch at length and discard size distributions from the 1997–98 model.

(d) Modelled 1996 catch (line) and size distribution from the last boat ramp survey (histogram).

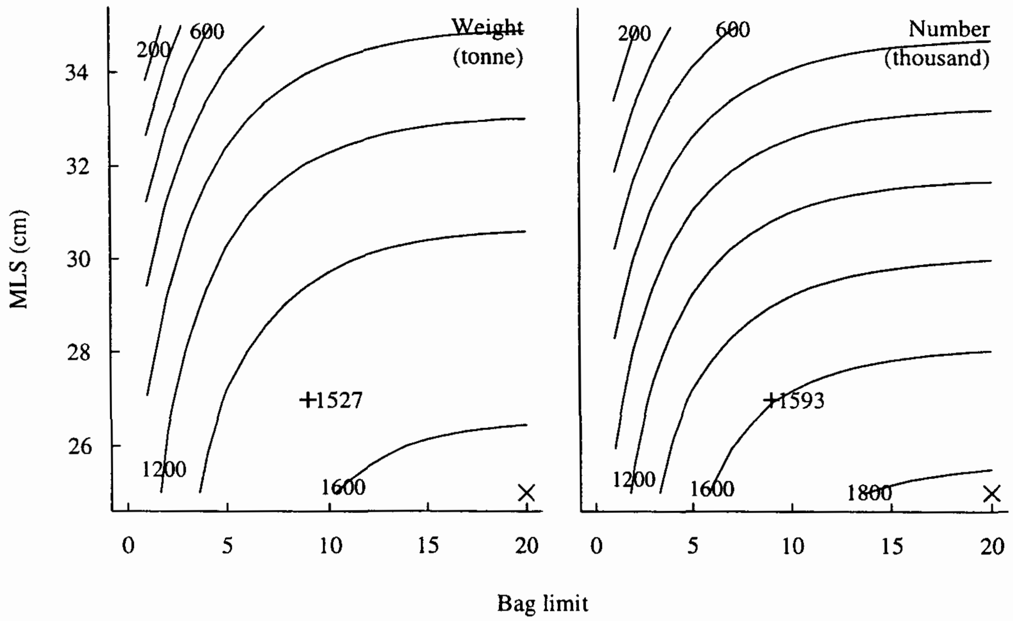

Figure 15: Contours showing predicted recreational catch by weight and number at 50% bag limit compliance for Hauraki Gulf/Bay of Plenty snapper, 1997–98, under various hypothetical bag and MLS limits. The predicted catch corresponding to the current bag (9) and MLS (27) limits is indicated by "+" and at the previous limits (bag 20 and MLS 27) by "×".

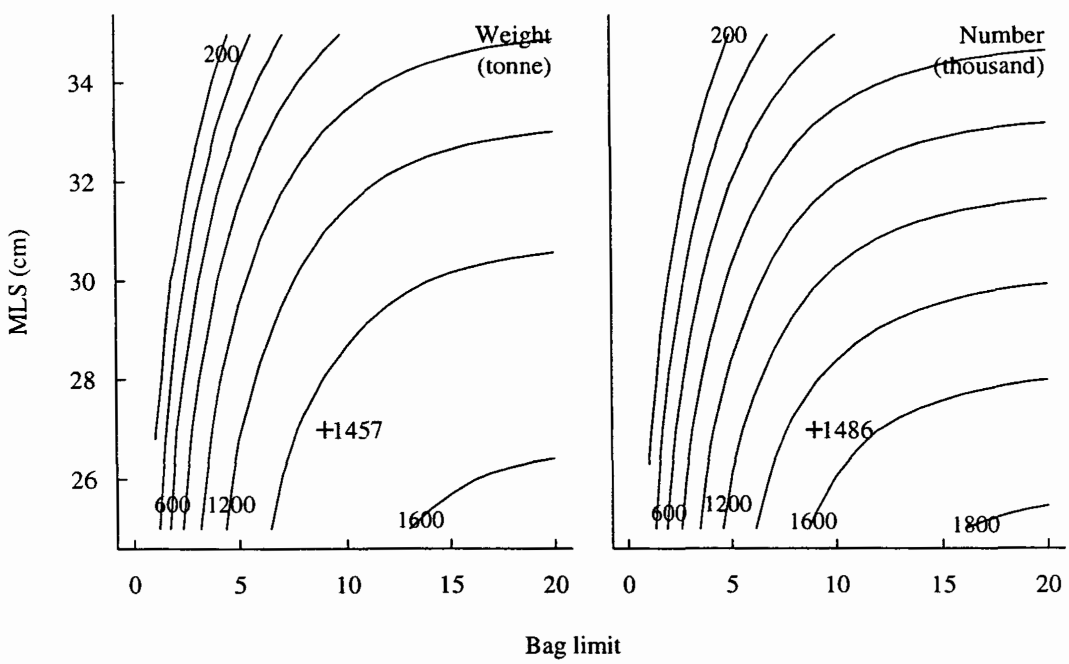

Figure 16: As for Figure 15, but assuming full compliance with the bag limit.

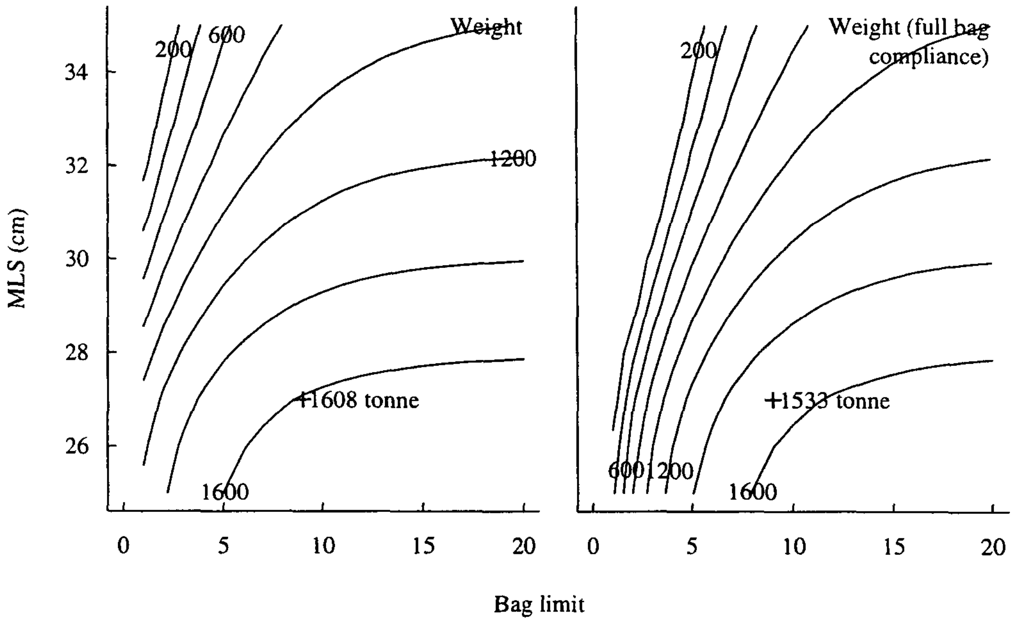

Figure 17: Contours showing predicted recreational catch by weight for Hauraki Gulf/Bay of Plenty snapper, 2000–01, under various hypothetical bag and MLS limits. Predictions for current (50%) and full compliance with the bag limit are shown. The predicted catch corresponding to the current bag and MLS limits is indicated by "+". The 2000–01 stock has a biomass for fish ≥ 25 cm that is 10% higher than 1997–98 and has more 5– and 6–year–olds.

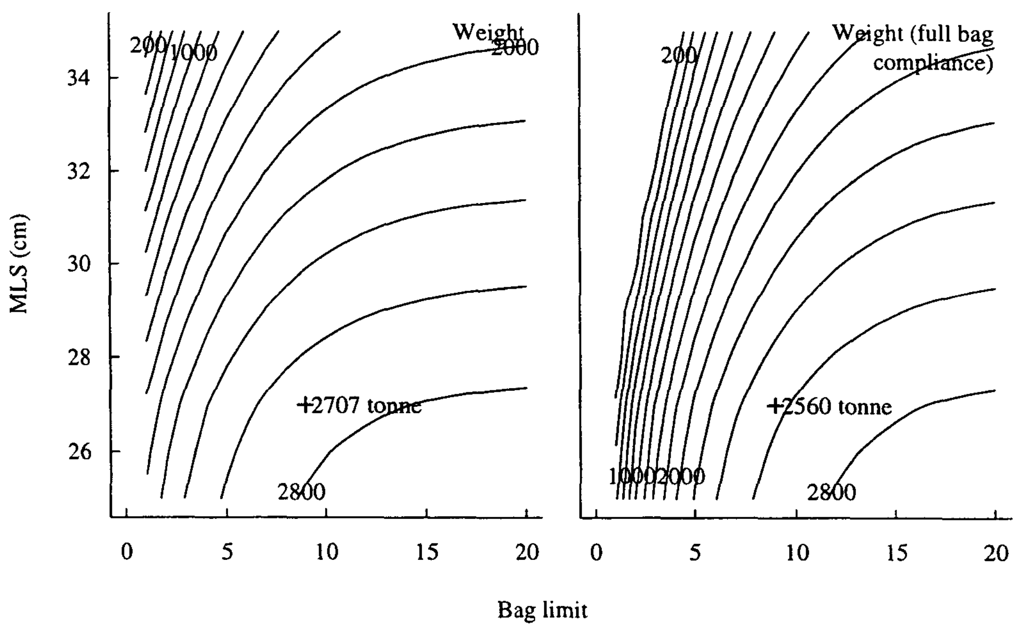

Figure 18: As for Figure 17 except that these estimates are based on a 2017–18 stock that has a biomass for fish ≥ 25 cm that is 100% higher than 1997–98 and has constant year class strength.

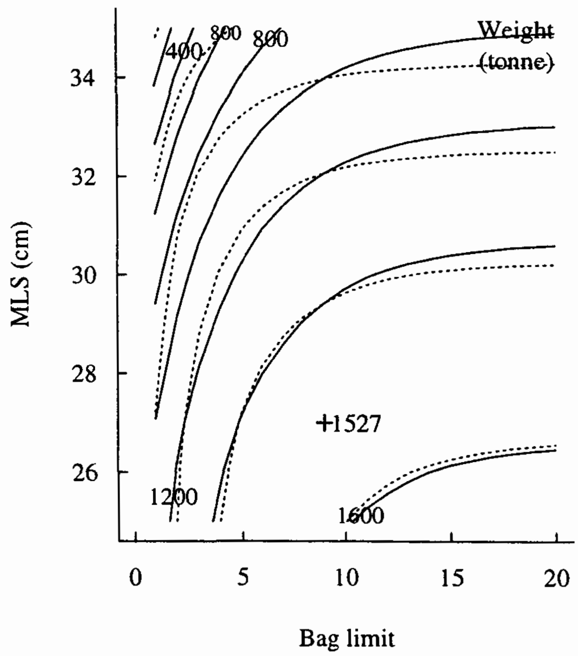

Figure 19: As for Figure 15 (weight). The solid lines show contours estimated when the effects of the bag and MLS limits are modelled together. The dashed lines show contours estimated when the independent effects of MLS and bag limits are multiplied.

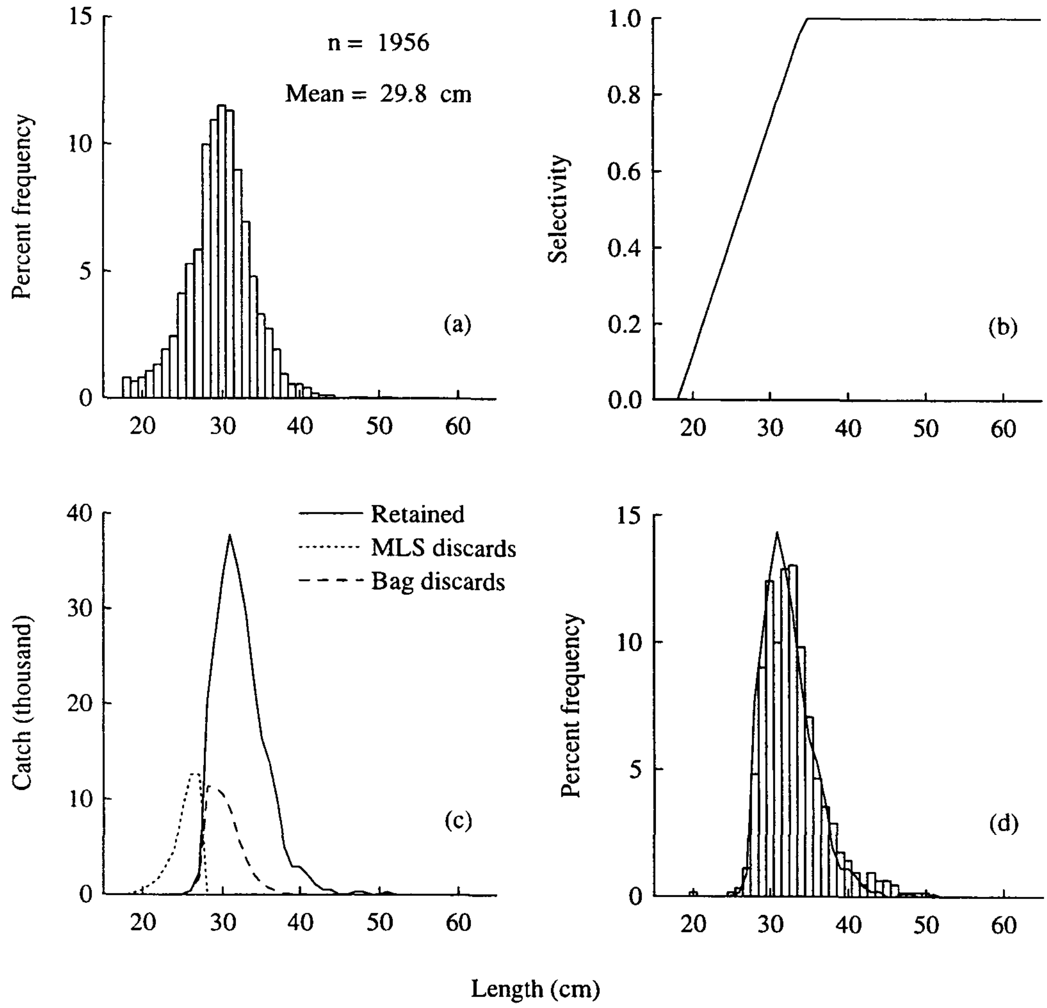

Figure 20: Model inputs and outputs for blue cod in the Marlborough Sounds in 1996 with the current bag limit (6) and MLS (28 cm), and with 50% non-compliance with the daily bag limit.

(a) Assumed population size distribution (Blackwell 1998).

(b) Selectivity at length of the recreational catch (assumed).

(c) Retained catch at length and discard size distributions from the model.

(d) Modelled 1996 catch (line) and size distribution from the last boat ramp survey (histogram).

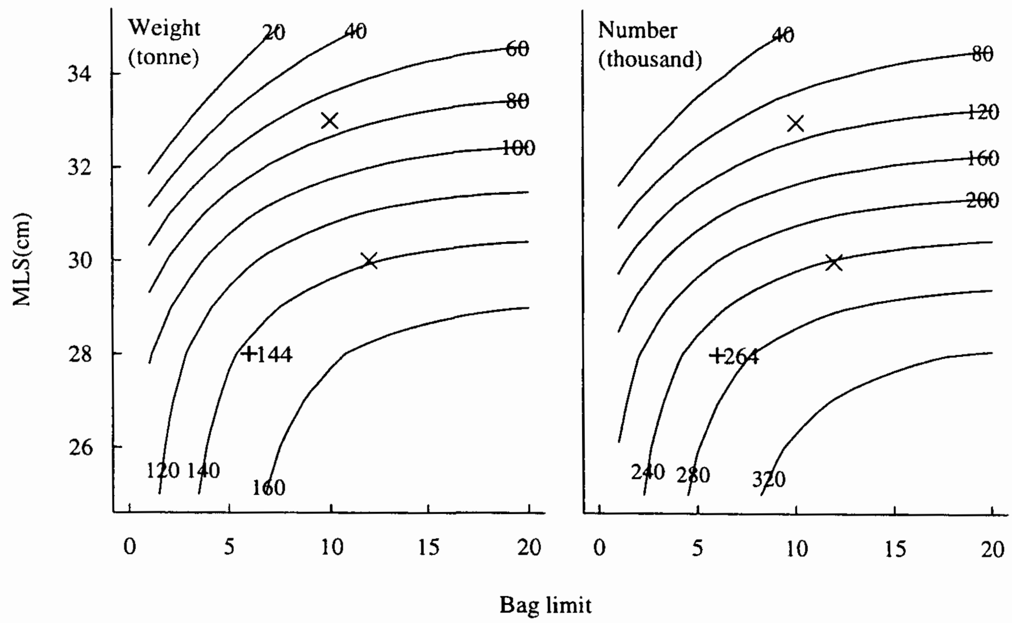

Figure 21: Contours showing predicted recreational catch by weight and number for Marlborough Sounds blue cod, 1996, under various hypothetical bag limits and MLS limits modelled together. The predicted catch corresponding to the current bag (6) and MLS (28 cm) is indicated by "+", and at previous limits by "×".

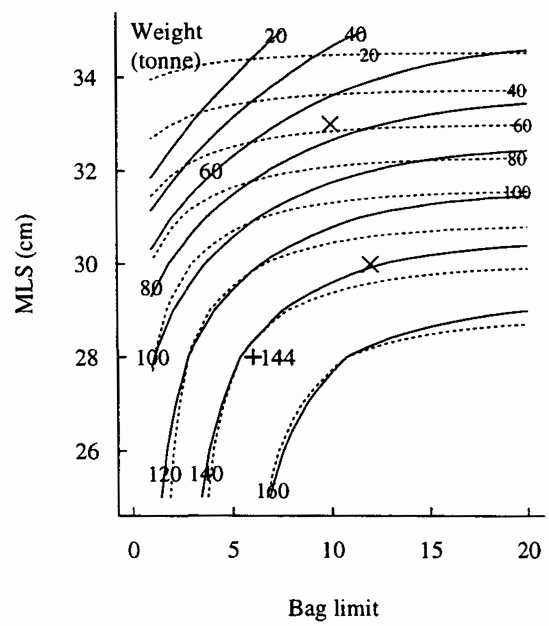

Figure 22: As for Figure 18. The solid lines show contours estimated when the bag and MLS limits are modelled together. The dashed lines show contours estimated when the independent effects of MLS and bag limits are multiplied.

Appendix 1: Negative binomial distribution

Following Porch & Fox (1990, 1991), the negative binomial distribution is used to fit the bag size distribution. Thus each bag size b_x in the distribution is defined as

$$b_x = P[X = x] = \frac{\Gamma(K+x)}{\Gamma(x+1)\Gamma(K)}\left(\frac{m}{m+K}\right)^x\left(1+\frac{m}{K}\right)^{-K}$$

where m is the distribution mean. The other parameter K can be written as

$$K = \frac{m^2}{\sigma^2 - m}$$

where σ^2 is the variance. The above form of the negative binomial distribution allows non-integer values for parameters and thus enables the large number of empty bags to be fitted. Porch & Fox (1990, 1991) gave empirical evidence that the variance is proportional to the mean in bag size distributions. We thus assume that

$$\sigma^2 = Vm \quad \text{and hence}$$

$$K = \frac{m}{V-1} \quad \text{where } K \text{ is required to be real and positive.}$$

We call V the shape parameter.

The two parameters in the negative binomial distribution have been defined in many different ways. The negative binomial can be considered as a mixture of Poisson distributions, such that the expected values of θ of the Poisson distributions vary according to a gamma distribution (Johnson *et al.* 1992).

The modified bag size distribution when a bag limit is imposed at bag size ψ with a non-compliance factor π is assumed to be given by

$$b_x' = \begin{cases} b_x & x < \psi \\ b_\psi + (1-\pi)\sum_{y=\psi+1}^{\infty} b_y & x = \psi \\ \pi b_x & x > \psi \end{cases}$$

Let n_x be the number of bags of size x under bag limit of size ψ and non-compliance factor π. The likelihood, L is

$$L = \prod_{x=0}^{\infty} (b'_x)^{n_x}$$

$$= \prod_{x=0}^{\psi-1} b_x^{n_x} \left[b_\psi + (1-\pi) \sum_{y=\psi+1}^{\infty} by \right]^{n_\psi} \prod_{x=\psi+1}^{\infty} \pi^{n_x} b_x^{n_x}$$

$$= \prod_{x \neq \psi} b_x^{n_x} \pi^{\sum_{x=\psi+1}^{\infty} n_x} \left[b_\psi + (1-\pi) \sum_{y=\psi+1}^{\infty} b_y \right]^{n_\psi}$$

Several bag size distributions can be fitted together using the **S** function ***ms*** to find maximum likelihood estimates of the parameters. An individual mean is fitted for each distribution, but the shape parameter V and the non-compliance factor π are assumed to apply to all the distributions. As the mean catch per trip can vary from year to year, the above set of parameters is parsimonious.

Appendix 2: Recreational catch model

Recreational fishing is modelled by a sequence of actions that leads to a bag size distribution and a size distribution of catch:

1. capture a proportion of each of the length classes according to a known selectivity at length curve and a recreational exploitation rate;
2. discard fish below the MLS (with a level of non-compliance);
3. determine the total number of bags and hence the bag size distribution;
4. determine the number of discarded fish beyond the bag limit (with a level of non-compliance);
5. determine the size distribution of the bag limit discarded catch.

Let $\{n_l : l = 1,\ldots 80\}$ be the distribution of numbers at length in the population (start of year) and $\{s_l : l = 1,\ldots 80\}$ be the selectivity at length of the recreational catch. s_{30} is arbitrarily set to 1 (for snapper). The number of fish caught at length, l,

$$c_l = As_l n_l,$$

where A is the exploitation rate.

After MLS discarding the number of fish remaining in the catch, at length, l,

$$c'_l = \begin{cases} \phi^{\lambda - l} c_l & l < \lambda \\ c_l & l \geq \lambda \end{cases}$$

where ϕ is a fixed parameter less than 1 and λ is the MLS.

The number of bags,

$$B = fA$$

where f is a parameter that is fixed provided catchability is constant. Hence mean bag size,

$$m = \frac{\sum_l c_l'}{B}$$

The mean bag size, m, shape parameter, V, and non-compliance parameter, π, determine the bag size distribution given above in Appendix 1. The total number of bag limit discarded fish is

$$(1-\pi)\sum_{x=\psi+1}^{\infty}(xb_x - \psi)$$

where b_x is the number of bags of size x before bag limit discarding, ψ is the bag limit and summation is over bag sizes for which at least one bag occurs. Fishers are modelled as being either wholly compliant with the bag limit or wholly non-compliant. The number of fish of length, l, remaining after bag limit discarding

$$c_l'' = \left(1 - e^{-\frac{(l-\mu)^2}{\theta}}\right)c_l'$$

where the parameter μ was fixed at 18 cm, the size below which virtually no recreational catch is taken, and the parameter, θ was adjusted for each year's catch until

$$\sum_l (c_l' - c_l'') = (1-\pi)\sum_{x=\psi+1}^{\infty}(xb_x - \psi)$$