The spatial and temporal age structure of bluenose (*Hyperoglyphe antarctica*) commercial catches from Fishstock BNS 1

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EXECUTIVE SUMMARY

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This report describes an investigation of the age structure, and associated estimates of instantaneous mortality, of the bluenose (*Hyperoglyphe antarctica*) catch taken by the line fishery in parts of Fishstock BNS 1. The work aimed to determine if evidence of the large declines in abundance seen in CPUE can also be seen in the age structure of the commercial catch sampled over an 8-year period, and at different locations sampled contemporaneously. The locations sampled were in southeastern Bay of Plenty (around White Island), and on two distinct fishing grounds in Statistical Areas 004 and 008.

Instantaneous total mortality (*Z*) was estimated using two methods: the Chapman-Robson estimator, and the slope of the right-hand limb of the catch curve. A comparison of the Chapman-Robson estimates of *Z* showed no significant differences between the three areas sampled contemporaneously, or over an 8 year period in the southeastern Bay of Plenty. A similar conclusion was drawn from the analysis of the catch curve slopes. If bluenose stocks have declined markedly in the last 20 years then it appears likely that behavioural factors influencing the availability of fish to the fishing method are influencing estimates of *Z* in a way that hides any true trends in population age structures. Based on a likely assumed range for instantaneous natural mortality (*M*) and the estimated range of *Z*, instantaneous fishing mortality would have been lower than *M*, an unexpected result given the recent strong declines in bluenose CPUE. It was concluded that the obtained estimates of *Z* were underestimates, and likely reasons for this bias are discussed.

There was no information in the data that usefully enhanced our knowledge of stock structure of bluenose in BNS 1 or elsewhere.

Maturity ogives were fitted to data from aged staged bluenose. Estimates of the age at 50% maturity were about 15 and 17 years for males and females, respectively. It appears likely that about 60–70% of the BNS 1 line fishery catch is comprised of pre-reproductive fish.

1. INTRODUCTION

Similar declining trends for several bluenose Fishstocks (Starr et al. 2008) suggested that standardised CPUE was indexing abundance and that New Zealand bluenose may comprise a single stock. The work presented here aimed to determine if evidence of the large declines in abundance seen in CPUE can also be seen in the age structure of the commercial catch. This report describes catch-at-age distributions for bluenose, and the associated estimates of instantaneous mortality, from various samples over time and space in Fishstock BNS 1. It fulfils the reporting requirements for Objectives 1, 2, and 3 of Project BNS2008-01 "Age structure of bluenose", funded by the Ministry of Fisheries. The overall objective is:

1. to determine the stock status of bluenose (*Hyperoglyphe antarctica*) by investigating the spatial and temporal age structure of the New Zealand bluenose commercial catches.

Specific objectives are:

1. to design a sampling programme to investigate age structure in the bluenose commercial catches, using existing otolith collections held by SeaFIC and MFish;
2. to investigate stock structure by determining the age structure of the bluenose catches across areas;
3. to assess fishing mortality rates by comparing the age structure of bluenose catches over time.

2. METHODS

2.1 Otolith inventory

Large numbers of bluenose otoliths have been collected from various areas around the New Zealand EEZ since 1979, although the vast majority have been obtained since the mid 1990s. The otoliths are held by SeaFIC (collected as part of the AMP monitoring programme) and NIWA (collected by observers, or during market sampling programmes). All otoliths were catalogued to identify (as accurately as possible): collection date, location, fishing method, fishing depth, fish length, sex, and maturity stage. Derivation of these data was straightforward for the SeaFIC and observer samples, simply involving data extraction from existing databases. Deriving data for the market samples (all from BNS 2) was not as straightforward because the otoliths were obtained at point of landing, so could not be associated with individual set or tow data. The locations of all otoliths from the 1979–80 and 1984–87 samples are known to the level of geographic feature, e.g., Palliser Bank, Tuaheni High, Paoanui Ridge (Horn & Massey 1989). The market samples from 1996 to 2001 can be associated with a trip only. The relevant CELR or TCEPR reports from each sampled trip were examined to determine the smallest sampling area that could be attributed to the trip catch, i.e., geographic feature, statistical area, Fishstock.

The completed catalogue of otolith data by sampling date and location was used to select the most appropriate fish to age for the analyses required under objectives 2 and 3. Although data from all areas were catalogued, the additional work under this project aimed to investigate bluenose from Fishstock BNS 1 as this fishery had the longest history and fishing location was recorded for each sample. The intention was to define three subareas or features in BNS 1 that had been consistently fished by bottom longline, contributed significantly to the landings from this Fishstock, and had been comprehensively sampled (for length, sex, and otoliths) in at least some years. Hence, samples from these areas would theoretically be reflective of the fishery or the population. Approximately contemporaneous otolith samples were selected from each of these three areas (to enable the 'across-area' comparison), plus two additional samples were selected from one of the areas (to enable the 'across-time' comparison).

The proposed experimental design was presented to the Southern Inshore Fisheries Assessment Working Group for approval before the start of the ageing work.

2.2 Fish ageing

Horn et al. (2008 and unpublished) used the bomb-chronometer method of Kalish (1993) to validate a method to age bluenose by counting zones in thin-sectioned otoliths. The new ageing protocol for bluenose was described in detail by Horn et al. (2008), and was used here to age all fish. Briefly, the method relies on an examination of the sulcal region of the otolith at high magnification (×80), and counts all distinct dark zones, even if they appear to merge with other zones some distance from the sulcus.

A sample of 600 otoliths from around White Island in the Bay of Plenty in 2000–01was used to determine sample sizes necessary to achieve estimate age-frequency distributions with mean weighted c.v.s of about 30%. The resulting age data were then used to simulate the likely precision (c.v.) of *Z* estimates obtained from samples of 200, 400, or 600 age data points. Hence, an "ideal" size was estimated for the other four samples to be aged.

2.3 Data analysis

Catch-at-age distributions for each sample were calculated by constructing age-length keys separately for each sex and applying them to the scaled length-frequency data (derived from the SeaFIC logbook scheme from the relevant subarea and year) using software developed specifically for this task by NIWA (Bull & Dunn 2002).

Estimates of instantaneous total mortality (*Z*) were derived for each sample using the Chapman-Robson estimator (Chapman & Robson 1960) and regression of the right-hand limb of the catch curve (Ricker 1975, Dunn et al. 1999). The Chapman-Robson estimator is:

$$Z = \log_e\left(\frac{1 + a - 1/n}{a}\right)$$

where *a* is the mean age above recruitment age and *n* is the sample size. For this estimator, age at recruitment (*R*) should be the age at which 100% of fish are vulnerable to the sampling method (rather than the often used age at 50% recruitment). A 95% confidence interval around this estimator is $\pm 2*\sqrt{\text{var}}$, where $\text{var} = (1-e^{-Z})^2/(ne^{-Z})$.

Z can also be estimated from minus the slope of the right hand limb (i.e., points where age is *R* or older) of the relationship between age and the natural logarithm of the frequency of fish in that age class (Ricker 1975). The regression model used here set *R* at 16 years, and used only data from fish aged 16–30 years as older fish pre-dating the fishery would have been exposed to different mortality regimes during their lives. A 95% confidence interval around this estimator was taken as ± 2*SE of the slope.

The structure of the age-frequency distributions and the estimates of *Z* were compared between times and subareas.

Maturity ogives were derived for bluenose, separately by sex, using data from all gonad staged fish that were aged during this study, and had been caught from January to May (i.e., the likely spawning season, as defined by Starr et al. (2008)). Stage 1 fish were classified as immature. Fish with gonad stages 2–5 (i.e., maturing, mature, ripe, spent) were classified as mature. Proportions of mature fish by age class were calculated, and logistic ogives were fitted to the data using the equation:

$$f(x) = 1 \Big/ \left[1 + 19^{(a_{50} - x)/a_{to95}}\right]$$

This ogive takes values 0.5 at $x=a_{50}$ and 0.95 at $x=a_{50}+a_{to95}$.

3. RESULTS

3.1 Available otoliths

About 32 000 bluenose otoliths had been inventoried on the SeaFIC and MFish databases up to the end of the 2007–08 fishing year. Approximate otolith numbers were: SeaFIC logbook, 14 000; MFish observer, 8600; market samples, 9000; trawl surveys, 120. The most accurate location of capture was determined for each otolith; these ranged from very general (i.e., FMA) to precise (i.e., latitude and longitude). All otoliths collected by observers and during trawl surveys could be precisely located. Market sample otoliths could, at best, be located to a specific geographic feature, but this was reliant on all tows or sets during a trip occurring on a single ground. Most trips sampled on shore had fished on more than one ground, often spread over more than one statistical area, so the otoliths could only be located very generally.

A summary of available MFish otoliths (i.e., observer, market, or survey samples) is given in Table 1. Most of the FMA 2 otoliths collected up to 2000–01 were from market samples; most of the remaining otoliths from other FMAs and years were collected by observers. Observer sampling was most concentrated in FMA 7 (west coast South Island) where bluenose occur as an occasional bycatch in the hoki target trawl fishery.

Table 1: Numbers of bluenose otoliths available, by FMA and fishing year, from market sampling, observer sampling, and trawl survey sampling.

Fishing year	FMA 1 AKE	FMA 2 CEE	FMA 3 SEC	FMA 4 SOE	FMA 5 SOU	FMA 6 SUB	FMA 7 CHA	FMA 9 AKW
1978–79	0	73	0	0	0	0	0	0
1979–80	0	195	0	0	0	0	0	0
1984–85	0	290	0	0	0	0	0	0
1985–86	0	2 158	0	0	0	0	0	0
1986–87	0	200	0	0	0	0	0	0
1991–92	0	0	0	0	17	0	0	0
1992–93	0	12	0	5	25	0	9	0
1993–94	0	29	0	0	3	0	24	0
1994–95	17	322	11	3	1	0	266	0
1995–96	29	47	42	10	68	2	178	0
1996–97	21	746	0	11	0	0	358	0
1997–98	11	475	40	30	48	1	662	0
1998–99	5	1 172	121	8	34	0	590	0
1999–2000	55	1 421	102	17	144	4	447	20
2000–01	0	1 322	199	67	107	0	149	0
2001–02	6	134	16	7	48	0	94	9
2002–03	7	38	12	16	25	2	64	43
2003–04	38	5	7	39	29	0	114	55
2004–05	19	11	9	51	33	0	109	7
2005–06	69	2	0	7	67	3	208	1
2006–07	3	13	0	5	21	0	104	10
2007–08	5	5	0	1	0	0	13	0

Clearly, most FMAs were sampled inadequately to provide any useful catch-at-age information. While FMA 7 has high totals in some years, the Working Group considered it unlikely that bluenose caught sporadically as a trawl bycatch would represent any part of the population in a consistent way. FMA 2 was well sampled in several years. However, most of these otoliths were derived from market samples, for which location was often not well defined. Examination of the CELR or TCEPR reports associated with each sampled trip enabled those that had fished only one ground to be identified. Table 2 shows the numbers of otoliths from market samples that can be attributed to distinct geographic features (Figure 1). It is apparent that only the Palliser Bank in 1985–86 has a sample size that is likely to be useful for any catch-at-age analysis. These fish were sampled several times throughout the year from a trawl fishery targeting alfonsino and bluenose (Horn & Massey 1989).

Table 2: Numbers of bluenose otoliths available from market samples in Fishstock BNS 2, where the distinct geographic location of the otoliths is known.

Fishing year	Koutuni Ridge	Tuaheni High	Paoanui Ridge	Madden Canyon	Kaiwhata Bank	Palliser Bank	Cook Strait
1979–80	172	0	0	0	0	0	0
1984–85	0	60	0	43	0	173	0
1985–86	0	226	322	0	0	1610	0
1986–87	0	0	0	0	0	200	0
1996–97	0	0	0	120	57	0	97
1997–98	0	0	0	22	70	0	165
1998–99	0	0	0	0	42	0	140
1999–00	0	0	50	101	50	150	50
2000–01	50	0	35	50	0	200	50

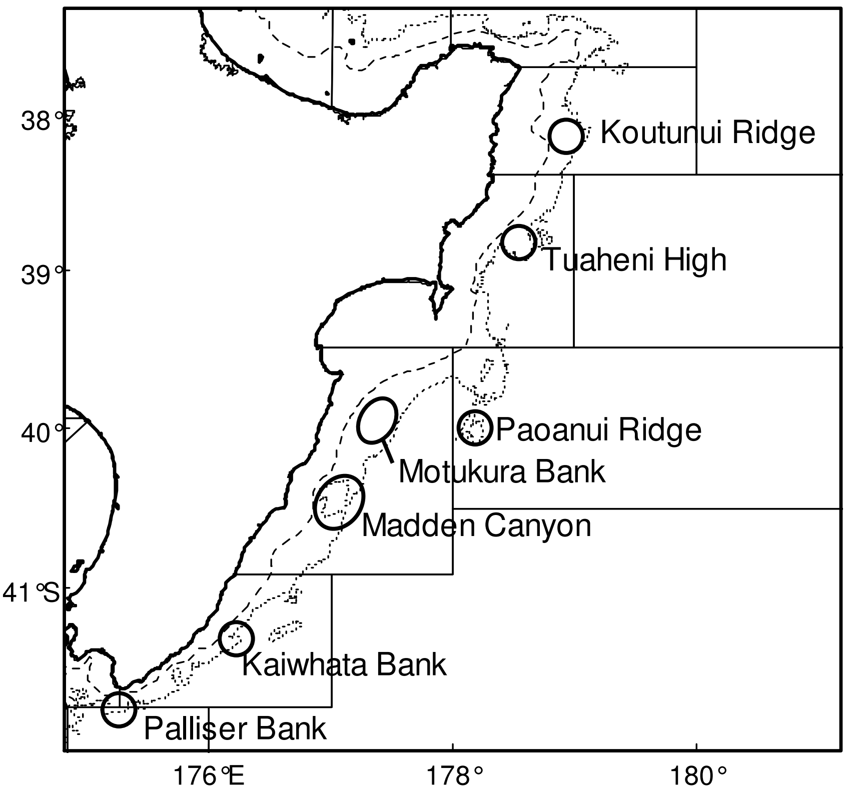

Figure 1: Geographical features (denoted by circles or ovals) in FMA 2 where bluenose has been targeted (by either line or trawl). The 200 m and 1000 m contours are shown as dashed lines. The unbroken lines are statistical area boundaries.

All otoliths collected under the SeaFIC logbook programme could be located at least to statistical area, with most recorded to latitude and longitude. All otoliths were collected from the bluenose target line fishery. The SeaFIC sampling has been concentrated in FMA 1 (Statistical Areas 001–010) and to the southeast of the Chatham Islands (FMA 4, Statistical Area 051), although small samples are also available from FMAs 2, 3, 4, 8, and 9. Inventoried numbers of otoliths from frequently sampled areas are listed in Table 3. It is clear that the Bay of Plenty (Areas 009 and 010) and north-east of Great Barrier Island (Area 004) are the most comprehensively sampled areas.

Table 3: Numbers of bluenose otoliths inventoried from SeaFIC logbook samples in Fishstock BNS 1 and at the Chatham Islands, by statistical area.

	Statistical Area					
Fishing yr	002	004	008	009	010	051
1995–96	0	254	0	0	0	0
1996–97	0	0	5	90	107	0
1997–98	0	23	55	291	266	365
1998–99	92	49	172	339	317	0
1999–2000	215	359	177	848	465	69
2000–01	56	259	208	870	628	110
2001–02	14	221	110	364	331	189
2002–03	30	30	77	392	278	181
2003–04	0	10	69	506	325	108
2004–05	0	137	113	229	215	0
2005–06	0	274	49	530	74	0
2006–07	0	210	20	0	0	0

It was considered likely that many of the SeaFIC logbook programme samples could be associated with precisely defined features within the statistical areas. Consequently, locations of sampled sets were plotted (Figure 2). Several distinct concentrations of set positions were apparent. In the Bay of Plenty there was extensive fishing around White Island in an area that crossed the boundary between Statistical Areas 009 and 010 ("southeast Bay of Plenty", see large circle in Figure 2). There were two other concentrations in Area 009, one to the northwest of White Island ("north Bay of Plenty"), and the other further to the west near Mayor Island ("west Bay of Plenty"). There was one distinct fishing ground in Area 008. In Area 004 there was a band of fishing positions along the shelf edge, although fishing tended to be more concentrated at the southeastern end (see oval in Figure 2).

3.2 Sample selection

The planned work required that five samples be aged: three from the same area, but distributed over time, and two from other areas, but approximately contemporaneous with one of the samples from the first area. It was clear that the southeast Bay of Plenty was the only area that would provide three reasonable sized otolith samples spread throughout the sampling period (Table 4). It was also apparent that there were three other areas available as candidates for the "between-area" comparisons, i.e., Area 004 from 1999 to 2001, Area 008 from 1998 to 2001, and western Bay of Plenty from 1999 to 2001 (see Table 4). The Inshore Working Group selected the Area 004 and 008 samples for analysis. The final sample structure is shown in Table 4; it was expected that the minimum number of age data points per sample would be about 500.

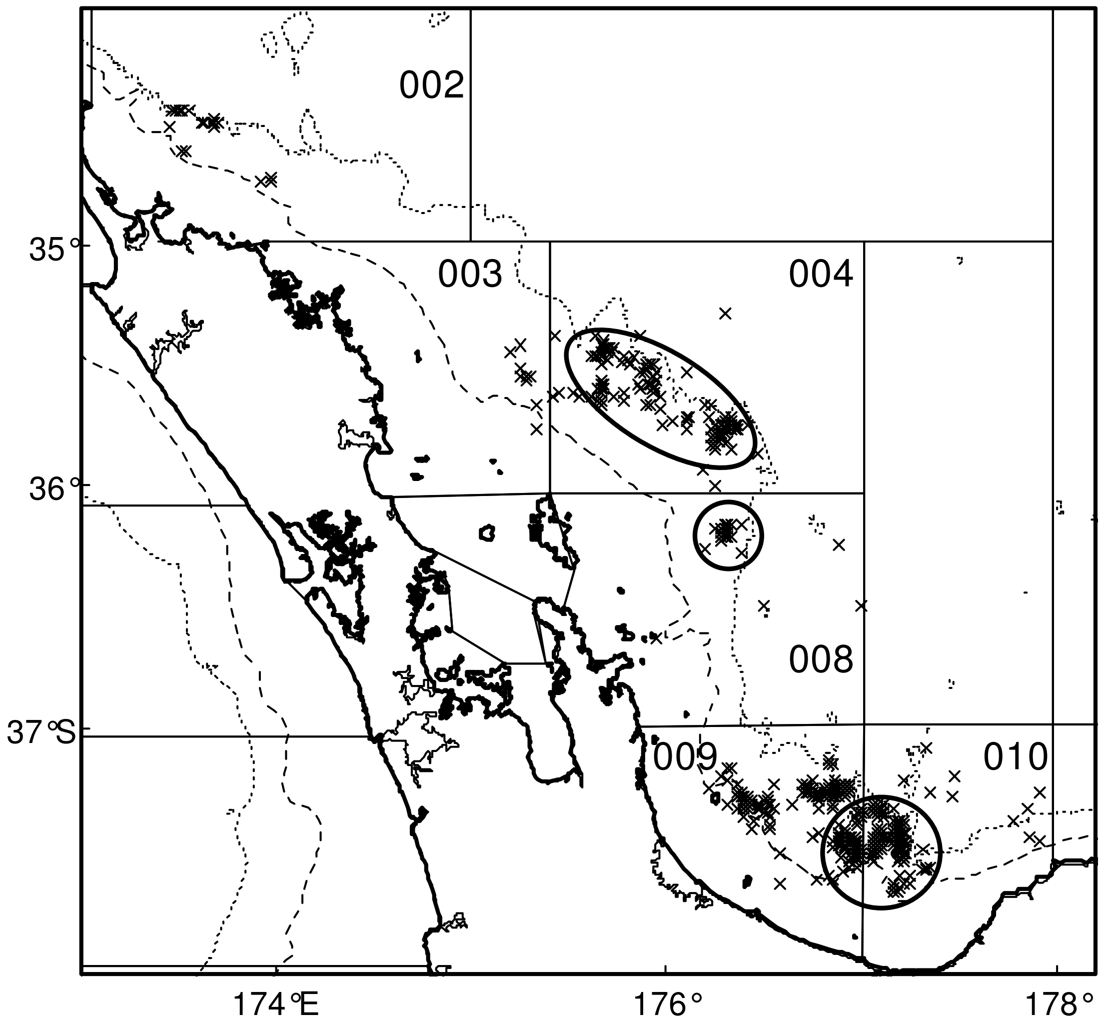

Figure 2: Locations of sets (denoted by ×) sampled by the SeaFIC logbook programme in Statistical Areas 002–004 and 008–010. Note that each × can represent one or more sets. The 200 m and 1000 m depth contours are shown as dashed lines. Oval and circles show the locations of areas sampled for age.

Table 4: Numbers of inventoried bluenose otoliths in SeaFIC logbook samples from the three areas illustrated in Figure 2, as well as from the "north" and "west" fishing grounds in Bay of Plenty. Boxes show where otoliths from one or more years were combined to create a sample.

Fishing year	Area 004	Area 008	Bay of Plenty North	Bay of Plenty West	Bay of Plenty Southeast
1996–97	0	1	20	21	146
1997–98	21	50	62	91	351
1998–99	49	152	57	123	461
1999–00	321	177	225	226	782
2000–01	229	168	175	345	606
2001–02	141	70	80	89	435
2002–03	10	47	80	60	423
2003–04	0	69	90	219	445
2004–05	97	103	10	120	294
2005–06	234	9	196	100	204

3.3 Determining ideal sample size

A total of 606 otoliths was available from the area around White Island (i.e., southeast Bay of Plenty) from 2000–01. All these otoliths were prepared and read, and a subsample of 212 was re-read one month later by the same reader. The index of average percentage error (IAPE, Beamish & Fournier 1981) for the within-reader comparison was 2.7% (Horn et al. unpublished results). The estimated catch-at-age distribution was produced using the first set of readings, and the Chapman-Robson estimate of *Z* (with c.v.s and 95% confidence intervals) was calculated.

The estimated catch-at-age distribution, and estimates of *Z* using different values of age at full recruitment (*R*) are shown in Figure 3. It was apparent that an *R* of 16 years was most applicable for this sample (i.e., *Z* stabilised at about *R* = 16). This produced a *Z* of 0.160. The curve overlaid on the catch-at-age distribution is the expected number of fish at age, from age 16 upwards, assuming *Z* = 0.16; the curve fits the observed data very well (see Figure 3).

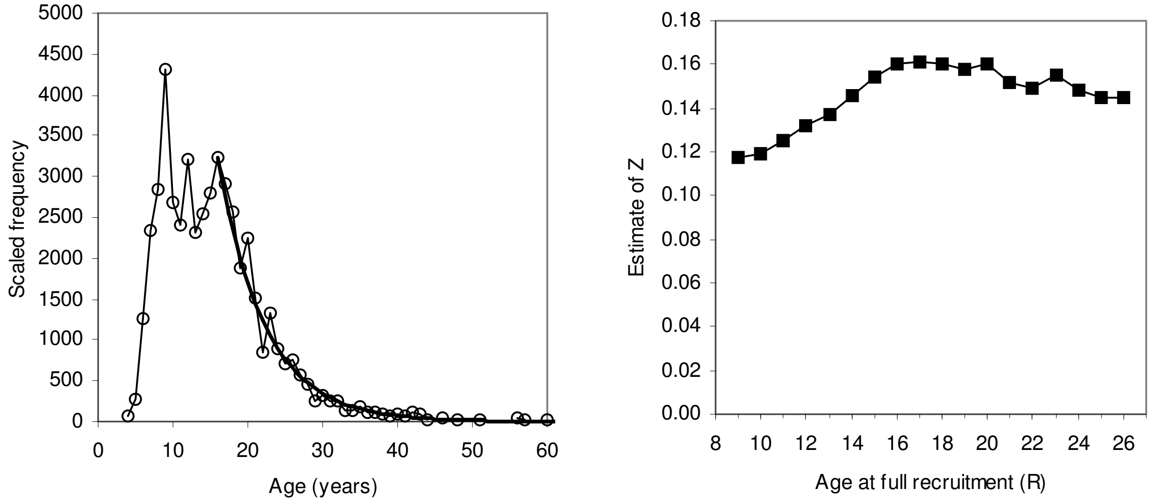

Figure 3: Estimated catch-at-age distribution, and estimates of *Z* for a range of *R* values, for the 2000–01 southeast Bay of Plenty sample.

The estimate of *Z* using all available data (i.e., 606 age-at-length points) was 0.160, with a 95% CI of 0.128–0.206, and a c.v. of 12.2%.

Simulations were run to examine the variability of the estimated *Z* using samples where *N* was 200, 400, or 600 age-at-length data points. Nine simulations were run for each *N*. The age data sets used were selected randomly with replacement from the available set of 606 points. The resulting *Z* estimates and their 95% confidence intervals are shown in Figure 4. The mean and range of the c.v.s for each simulation group are as follows:

200 age data	14.3% (13.7–15.0)
400 age data	13.1% (12.7–13.4)
600 age data	11.9% (11.8–12.5)

It is clear that 200 data points are insufficient to produce a sufficiently precise *Z* (the range from the nine simulations is 0.152–0.181), while 600 data points clearly is sufficient (0.159–0.162). The simulations using 400 data points had a range from 0.150 to 0.167. It is probably desirable that the range be narrower than this as the aims of this work include looking for differences in *Z* over time and space. Consequently, it was concluded that a sample of about 500 age points (and certainly no fewer than 400) should be used in each estimation of *Z*.

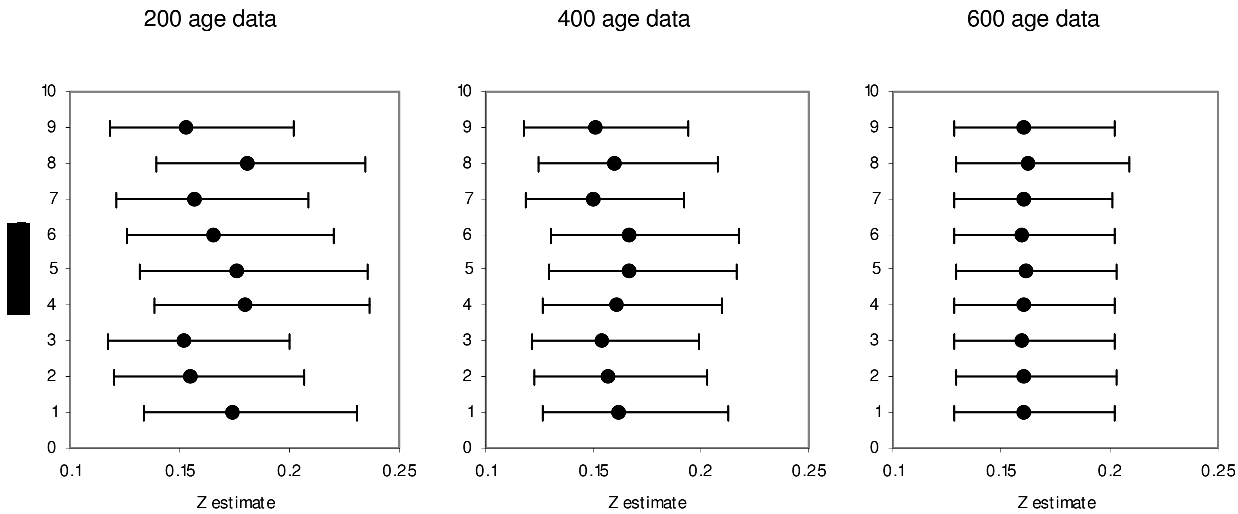

Figure 4: Estimates of *Z* (with 95% confidence bounds) from data simulations using samples sizes of 200, 400, or 600 age data points.

3.4 Estimation of Z using the Chapman-Robson method

As many otoliths as possible from the samples identified in Table 4 were extracted from archives, prepared, and aged. The actual numbers of otoliths successfully aged from each sample (Table 5) were less than those expected to be available (see Table 4) owing to the duplication of some fish in the otolith inventory, an inability to find some inventoried otoliths, some otoliths being too damaged to enable successful preparation, and an inability to satisfactorily age some preparations. However, all samples comprised at least 433 age data.

Table 5: Numbers of measured and successfully aged bluenose in the five samples, and the resulting c.v.s (MWCV, mean weighted across all age classes) for the estimated catch-at-age distributions.

Sample	Number of lengths	Number of ages	Catch-at-age MWCV
SE Bay of Plenty 1996–97 and 1997–98	515	460	0.32
SE Bay of Plenty 2000–01	816	606	0.29
SE Bay of Plenty 2004–05 and 2005–06	501	454	0.37
Area 004 1999–2000 and 2000–01	500	461	0.33
Area 008 1998–99 to 2000–01	462	433	0.34

3.4.1 Between-area comparison of *Z*

Chapman-Robson estimates of *Z* for a series of *R* values from the three separate areas all sampled around 2000 are shown in Figure 5. *Z* appears to stabilise at an *R* of about 16 years for the southeast Bay of Plenty sample, but *R* could be much lower for the two more northern grounds. However, there is significant overlap in *Z* estimates from all grounds at all *R* values, and consequently no apparent significant differences in *Z* (or *F*) between grounds.

Scaled age-frequency distributions by area are shown in Figure 6. The fitted curves of expected numbers-at-age are the best fits to the raw data derived by trialling all *R* values from the age at maximum frequency (R_{max}) to R_{max}+7. The best *R* values are: Area 004, 12 years; Area 008, 9 years; southeast Bay of Plenty, 16 years.

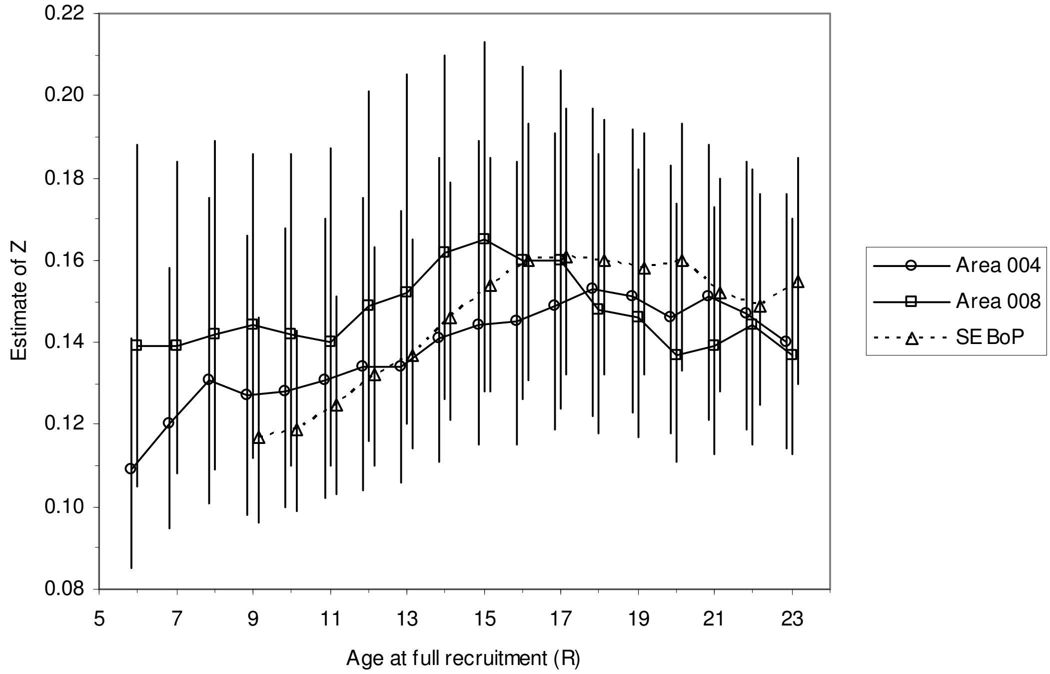

Figure 5: Chapman-Robson estimates of *Z* (with 95% confidence intervals) for a range of *R* values, for three areas all sampled around 2000.

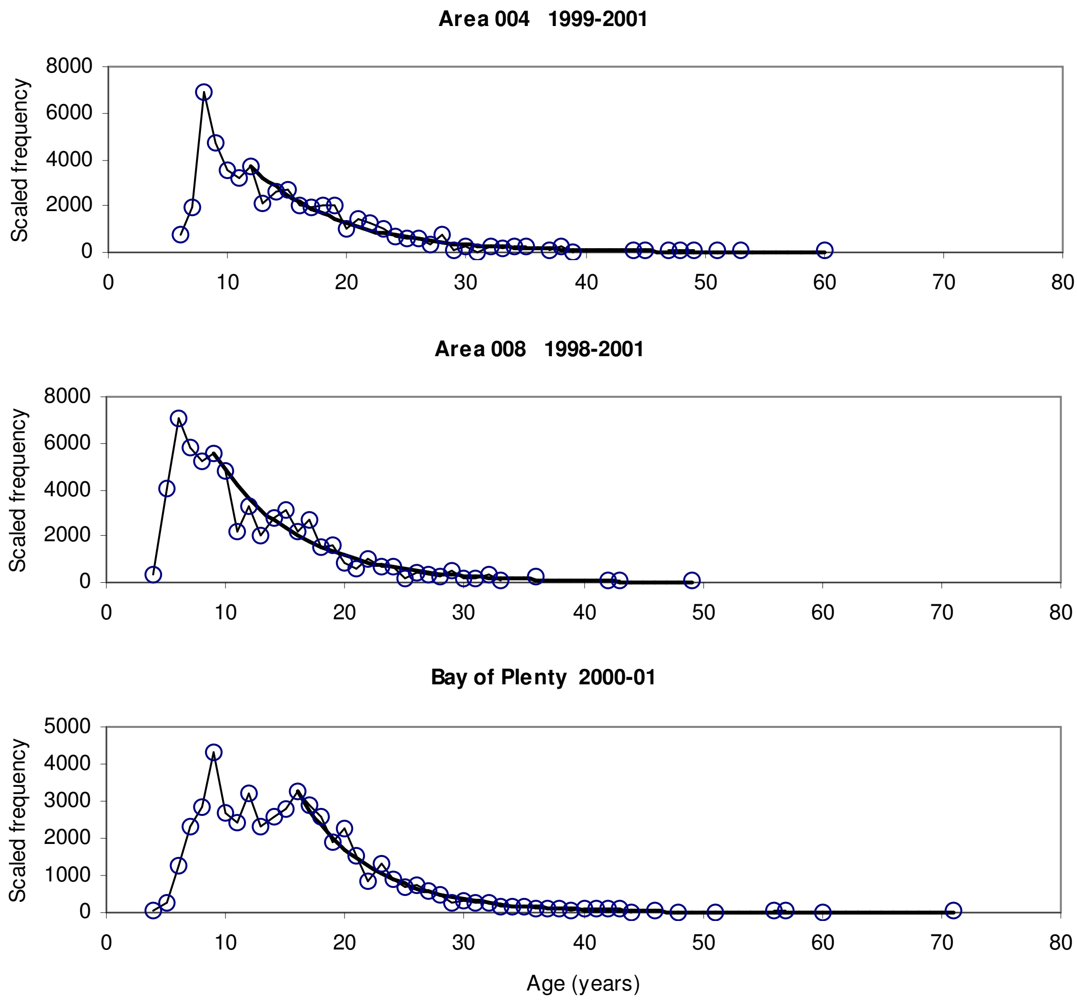

Figure 6: Scaled age-frequency distributions (sexes combined), with best fit expected numbers-at-age curves, for three areas all sampled around 2000.

3.4.2 Between-year comparison of *Z*

Chapman-Robson estimates of *Z* for a series of *R* values from the three southeastern Bay of Plenty samples collected at different times are shown in Figure 7. An *R* of about 16 years appears to be most likely for these samples. It is apparent that where *R* ranges from 14 to 17, the point estimates of *Z* decrease over time. However, there is significant overlap in *Z* estimates for all years at all *R* values, and consequently no apparent differences in *Z* (or *F*) between years.

Scaled age-frequency distributions for the three southeast Bay of Plenty samples are shown in Figure 8. The fitted curves of expected numbers-at-age are the best fits to the raw data derived by trialling all *R* values from the age at maximum frequency (R_{max}) to R_{max}+7. The best *R* values are: 1996–98, 15 years; 2000–01, 16 years; 2004–06, 14 years.

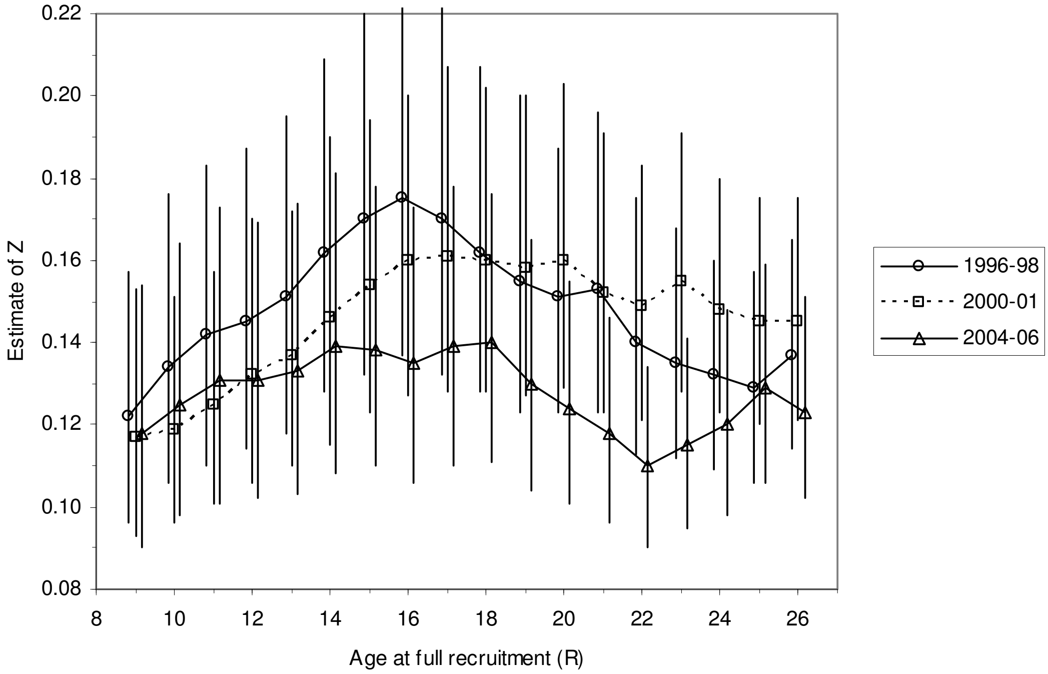

Figure 7: Chapman-Robson estimates of *Z* for a range of *R* values, for the southeast Bay of Plenty area, sampled at three different times.

It is apparent from Figure 2 that there is spatial structure of fishing effort within the area in the Bay of Plenty chosen for the between-year analysis. Ideally, the sampling structure would be similar between the three time periods. To examine this we split the sampled area into five subareas based on clusters of points, and determined the number of otoliths aged from each subarea and time (Figure 9). Sampling was relatively consistent between years in all areas, except that 11% of the otoliths from 2000–01 were collected from an area southeast of White Island that was not sampled in either the earlier or later periods.

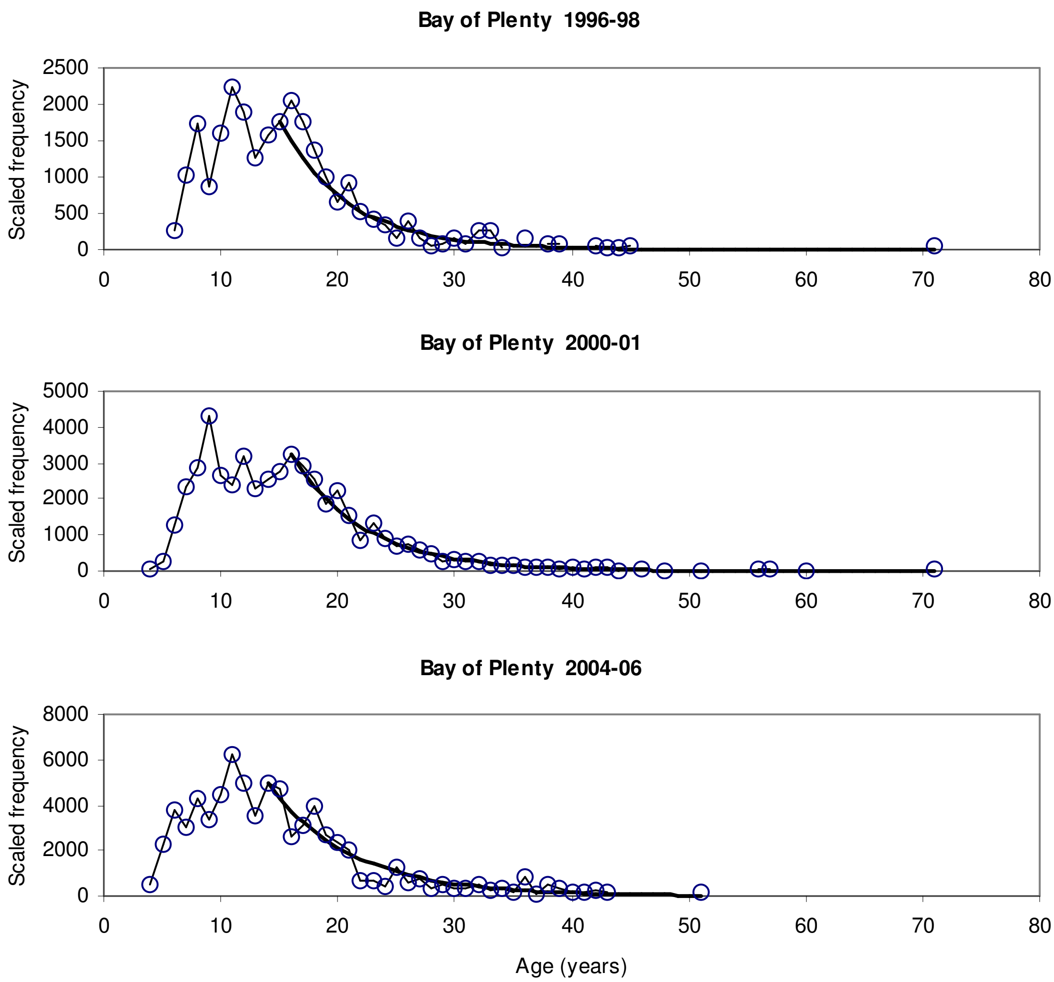

Figure 8: Scaled age-frequency distributions (sexes combined), with best fit expected numbers-at-age curves, for three samples collected over time from the southeastern Bay of Plenty.

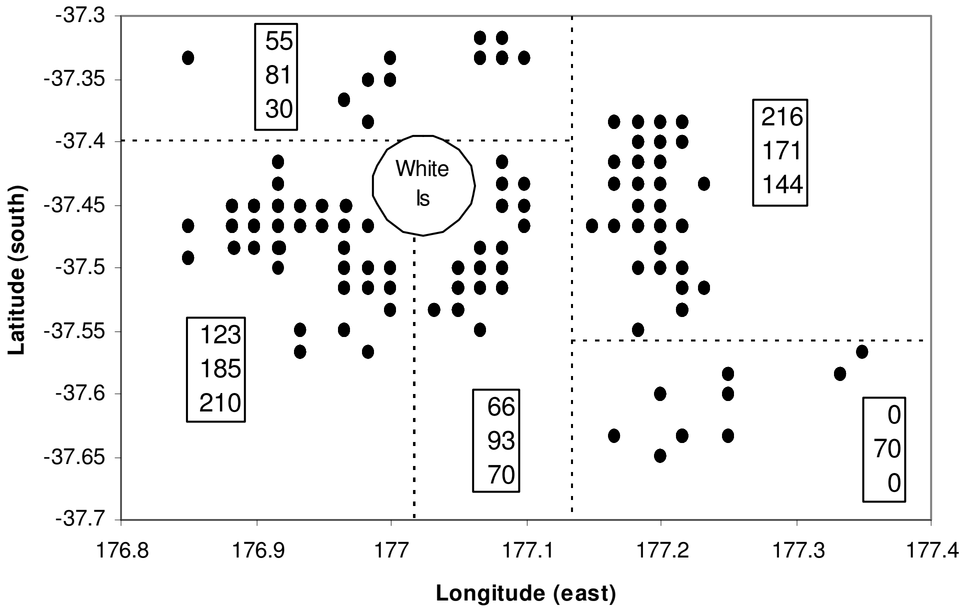

Figure 9: Distribution of sampled sets (dots) in the Bay of Plenty sampling area. Broken lines denote subarea boundaries. Numbers of aged otoliths, by subarea and time, are listed in the text boxes: top number, 1996–98; middle number, 2000–01; bottom number, 2004–06.

3.5 Estimation of *Z* using the slope of the catch curve

Total instantaneous mortality (*Z*) was estimated for the five aged bluenose samples using the slope of the right hand limb of the catch curve where fish were aged from 16 to 30 years. The plots of frequency against age, and the regression lines fitted to these data, are shown in Figure 10. Estimates of *Z* (i.e., the slopes of the regression lines) with 95% confidence intervals are listed in Table 6, with Chapman-Robson estimates given for comparison.

Table 6: Estimates of total instantaneous mortality (*Z*) derived from the slope of the right-hand limb of the catch curve (using data from fish aged 16–30 years), and using the Chapman-Robson estimator (with *R* = 16 for all samples)

Sample	Catch curve slope		Chapman-Robson estimator		
	Z	95% CI	*Z*	90% CI	95% CI
SE Bay of Plenty 1996–97 and 1997–98	0.232	0.183–0.281	0.175	0.141–0.218	0.137–0.227
SE Bay of Plenty 2000–01	0.175	0.152–0.198	0.160	0.131–0.193	0.127–0.200
SE Bay of Plenty 2004–05 and 2005–06	0.170	0.121–0.219	0.135	0.110–0.164	0.106–0.173
Area 004 1999–2000 and 2000–01	0.167	0.121–0.213	0.145	0.120–0.177	0.115–0.184
Area 008 1998–99 to 2000–01	0.162	0.114–0.210	0.160	0.130–0.197	0.126–0.207

A between-year comparison shows that the three catch curve estimates of *Z* from the southeast Bay of Plenty samples all have overlapping 95% confidence intervals (i.e., 0.183–0.198). A trend of reducing *Z* over time is apparent. A similar trend is apparent in the Chapman-Robson (CR) estimates, but the CR values are generally lower than comparable catch curve values (see Table 6). [Note that the CR estimates presented here all use *R* = 16 years, and incorporate all data from fish aged 16 years and over.] The three CR estimates also have overlapping 95% confidence intervals (i.e., 0.137–0.173), but this interval of overlap does not coincide with that for the three catch curve estimates. However, there is reasonable overlap of the 95% confidence intervals for the three CR estimates and the latter two catch curve estimates (i.e., 0.152–0.173).

A between-area comparison shows that the catch curve estimates of *Z* from three areas sampled approximately contemporaneously all have overlapping 95% confidence intervals (i.e., 0.152–0.198) (see Table 6). The CR values are consistently lower than the comparable catch curve values, but there is still a reasonable overlap of the 95% confidence intervals for the three CR and three catch curve estimates (i.e., 0.152–0.184).

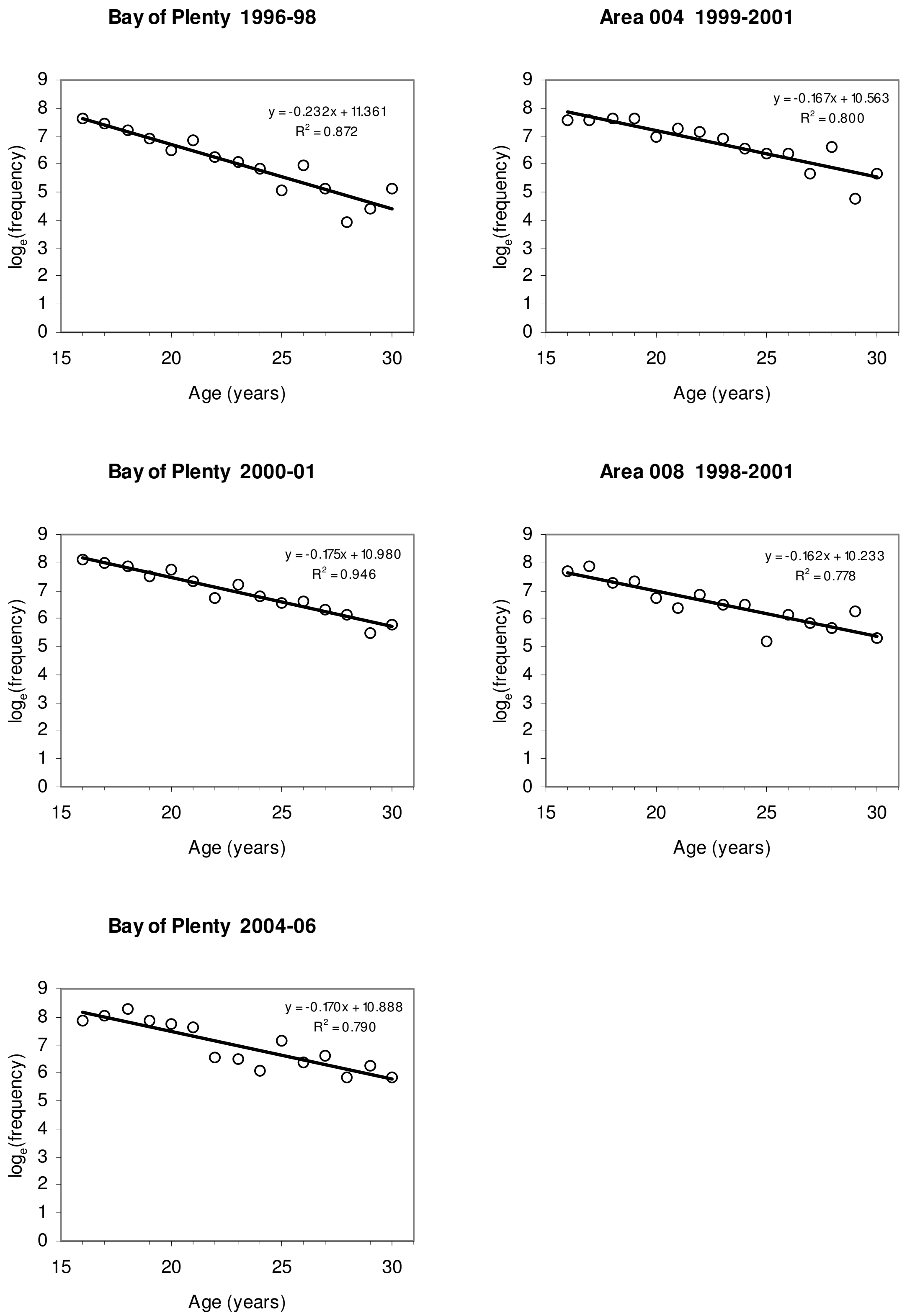

Figure 10: Estimated frequency at age (for ages 16 to 30 only) for five bluenose samples, with fitted linear regressions.

3.6 Estimation of maturity ogives

Proportions of male and female bluenose mature at age are shown in Figure 11. The number of aged and staged male fish (*n* = 531) was more than double that for females (*n* = 234). Consequently, female data were grouped in 2-year bins before the ogives were fitted, e.g., 8 and 9 year old fish were grouped in a new 8.5 year class. The male data are well fitted by a logistic curve, indicating 50% maturity at age 15.1 years. Female data were not as well fitted; the ogive appears to be less steep than that for males, and is indicative of an age at 50% maturity of 16.7 years.

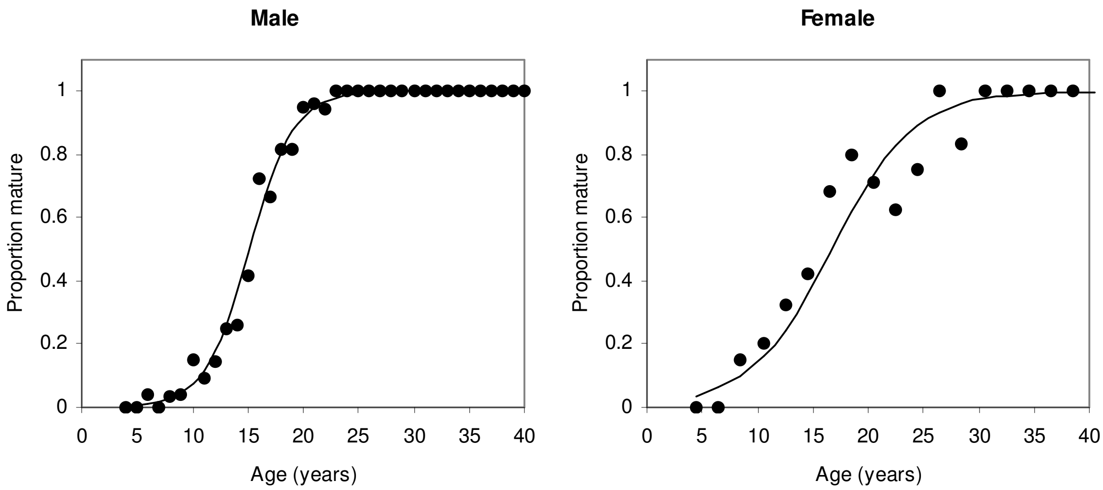

Figure 11: Proportions of fish mature at age, and estimated maturity ogives, by sex, for bluenose from BNS 1.

3.7 Stock structure

To determine whether the available data provided any information on stock structure of bluenose in BNS 1 we estimated proportion-at-age distributions by year, and looked for patterns of strong and weak year classes within and between sampled areas.

For the Bay of Plenty samples, there was an indication that the 1981 year class was relatively strong in four out of the five samples (Figure 12). The 1998 year class may be weak, although it was recorded in only the two most recent samples. However, for some years the data are contradictory, e.g., the 1988 year class manifests as both strong and weak. The 1979 year class in the Area 004 sample, and the 1982 and 1979 year classes in the Area 008 samples could be interpreted as being relatively strong (Figures 13 and 14). However, there were no year classes that were consistently strong or consistently weak between areas.

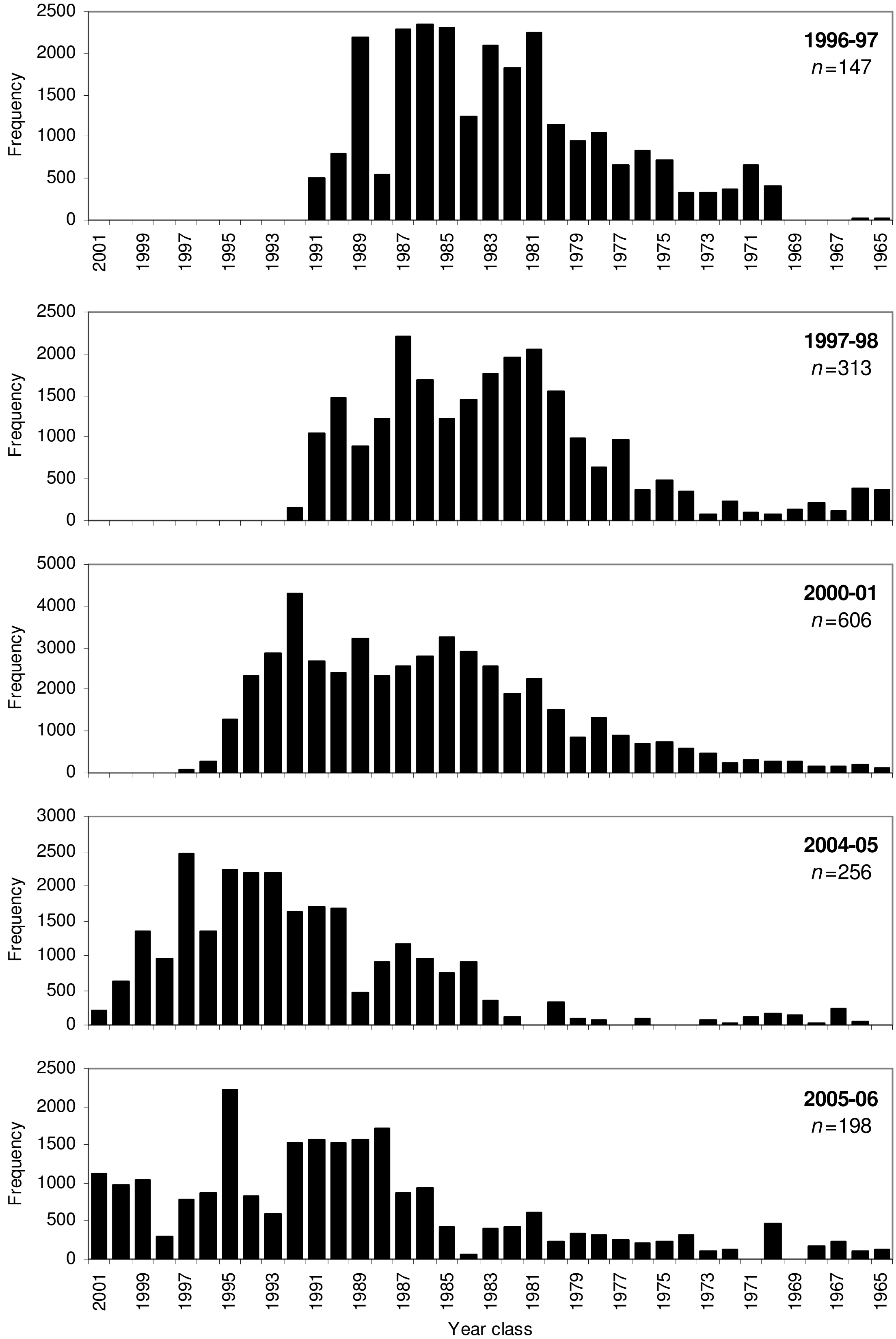

Figure 12: Scaled age-frequency distributions (sexes combined) by fishing year for the area sampled in the Bay of Plenty. *n*, number of successfully aged fish.

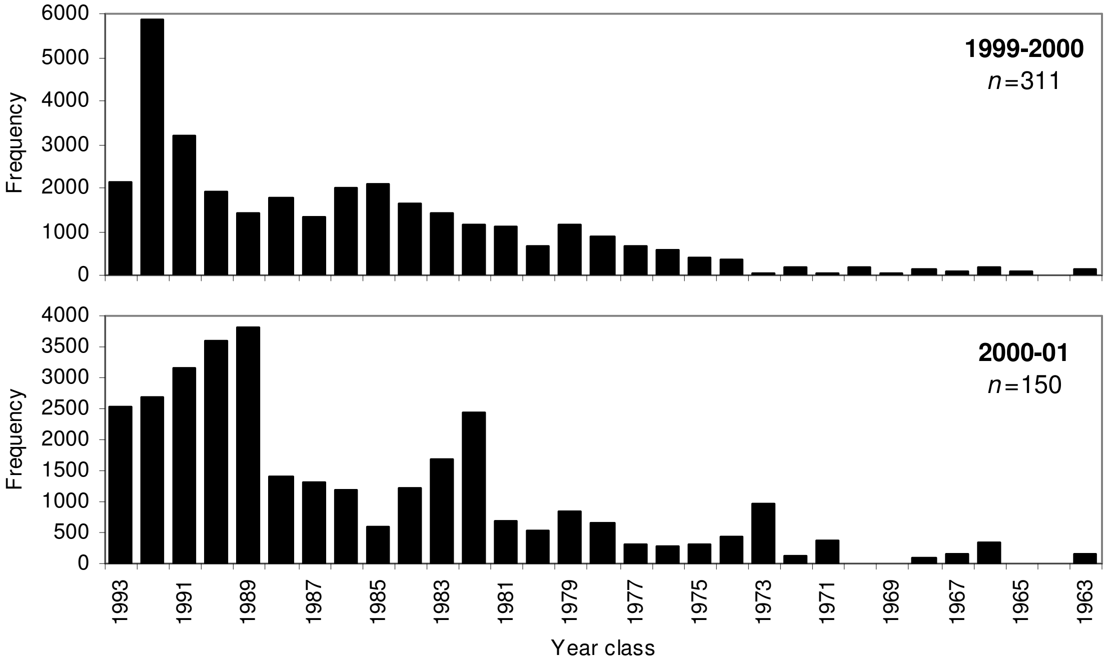

Figure 13: Scaled age-frequency distributions (sexes combined) by fishing year for the samples from Statistical Area 004. *n*, number of successfully aged fish.

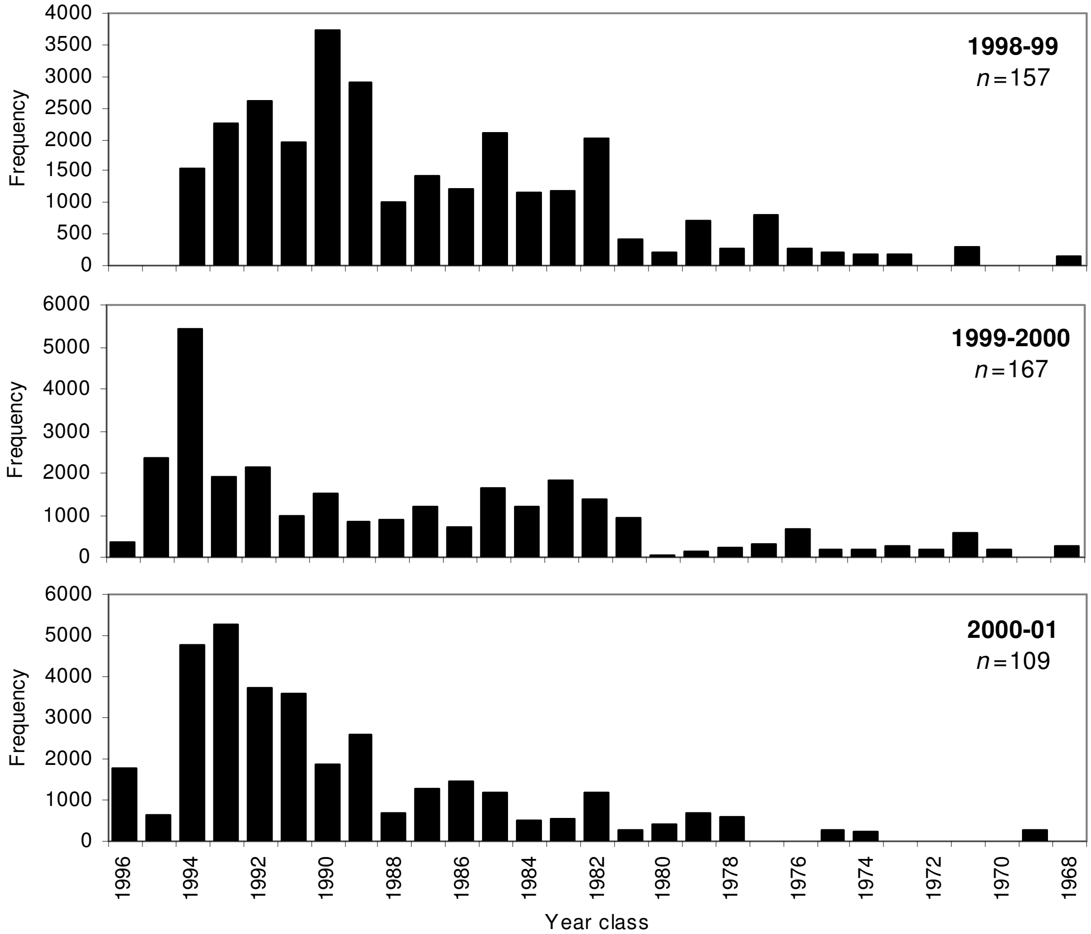

Figure 14: Scaled age-frequency distributions (sexes combined) by fishing year for the samples from Statistical Area 008. *n*, number of successfully aged fish.

4. DISCUSSION

Starr et al. (2008) presented CPUE analyses indicating large declines in abundance of bluenose (*Hyperoglyphe antarctica*) primarily in the Bay of Plenty and off east Northland, but also in other areas, since the early 1990s. The current work aimed to determine if evidence of such a decline could also be seen in the age structure of the commercial bluenose catch from those areas by examining catch-at-age distributions, and the associated estimates of total instantaneous mortality (*Z*), from various samples over time and space. Existing otolith collections held by SeaFIC and MFish were summarised by capture date and location, resulting in the identification of five samples that could be used to test for differences in *Z* at one location (i.e., around White Island in the southeast Bay of Plenty) over an 8-year period, and at three different locations all sampled at about the same time (i.e., around 2000–2001).

A preliminary study using the southeast Bay of Plenty 2000–01 sample indicated that a collection of about 500 otoliths (and certainly no fewer than 400) was likely to produce a reasonably stable and precise estimate of *Z* (i.e., with a c.v. of about 12–13%). However, even when using 600 data points, a c.v. of 11–12% might still be expected, and the 95% confidence bounds would still be reasonably wide (e.g., ranging from about 0.13 to 0.20 around a point estimate of 0.16).

In four of the five samples analysed it was necessary to combine data from more than one year to produce sufficiently large sample sizes (i.e., 400–500 otoliths). Combining data from more than one year to estimate *Z* was deemed to be acceptable for long lived species such as bluenose (C. Francis, NIWA, pers. comm.). In the example given above (Bay of Plenty, 2000–01), year classes from 1985 back to about 1950 are used to estimate *Z*. If the 2001–02 data were also incorporated in this analysis, then information essentially from the same year classes (now 1986 to about 1950) would be used. Consequently, using two, or even three consecutive years of data to produce a single estimate of *Z* is not seen as a problem. Combining data from several years could only become a problem when testing for changes in *Z* over time, as a trend could be blurred. However, in the current work, the samples used for comparisons over time never required the combination of more than two year's data (see Table 5).

A comparison of the Chapman-Robson estimates of *Z* showed no apparent differences between the three areas sampled contemporaneously, or over an 8 year period in the southeastern Bay of Plenty. Similar conclusions were drawn from the analysis of the slopes of the right-hand limb of the catch curves. Both analyses showed a (non-significant) trend of decreasing *Z* over time in southeastern Bay of Plenty, which would not be expected given the increasing fishing pressure. If we assume that bluenose stocks have declined markedly in the last 15–20 years (Starr et al. 2008), then it appears likely that behavioural factors influencing the availability of fish to the fishing method are influencing estimates of *Z* in a way that hides any true trends in population age structures.

From all the samples analysed, Z appears most likely to be in the range 0.13–0.17. If we assume that 1% of an unfished bluenose population live to between 30 and 50 years, then, using Hoenig's (1983) method, instantaneous natural mortality (*M*) would be in the range 0.09–0.15. If the true *M* is within this range, and the true *Z* is between 0.13 and 0.17, then this implies that instantaneous fishing mortality (*F*) has been less than *M*, perhaps significantly so. This result would be unexpected given recent strong declines in bluenose CPUE and the dramatic increase in targeting beginning in the mid 1980s. Note, however, that the true *M* for bluenose could be even lower than 0.09 given that the maximum recorded age is 71 years and that old bluenose may be poorly sampled by the line fishery (see below).

There are at least two possible explanations as to why the obtained estimates of *Z* may not reflect true mortality rates. First, the fishing grounds sampled might not represent closed populations, with large or old fish sometimes migrating onto the fishing grounds from other areas. Tagging studies indicate that bluenose are capable of migrating large distances (Horn 2003), and fisher experience indicates that the mean size of fish and catch rates on a feature may change radically from one day to the next. If some of the older fish are often not available to the fishery then this would result in over-estimates of true *Z*. However, movement of older fish onto the fishing grounds from other areas would result in under-estimates of *Z*.

Second, older fish within the populations sampled have not been exposed to current rates of *F* for the period they have been fully recruited to the fishery. An important assumption of the Chapman-Robson and catch curve methods is that all age classes used in the calculation of *Z* have been exposed to the same rate of fishing mortality. In situations where older fish were exposed to lower rates of fishing mortality when they were younger, these methods will underestimate *Z*. Given that bluenose age structure used in the present study included fish up to 71 years old, that fishing effort for bluenose intensified in the mid 1980s, and that the samples were collected between 1996 and 2006, the mixed fishing mortality experience by older age classes during their full recruited life-spans would have negatively biased estimates of *Z*. Excluding age classes that were fully recruited to the fishery before 1985 from calculations of Z should eliminate this negative bias.

The analysis of the catch curves using only fish aged 16 to 30 years would have gone some way to remove the bias described in the previous paragraph. Indeed, the estimates of *Z* from this analysis were generally higher than those derived from the Chapman-Robson method (see Table 6). However, the results and trends derived from both *Z* estimation methods were similar, so the likelihood that the fisheries do not exploit the whole bluenose population remains strong. Besides migration by large or old fish away from the main fishing grounds, there are other possible complications that could result in uneven vulnerability across a population, e.g., localised depletion on a feature (bluenose fishers, pers. comm.), schooling by size (author's unpublished data), different size structures on different geographical features (Horn & Massey 1989), and a positive correlation between fish size and preferred depth (Paul et al. 2004).

Estimates of the age at 50% maturity were about 15 years for male, and 17 years for female bluenose. Age at 100% maturity appears to be just over 20 years for males and just under 30 years for females. However, the female maturity ogive is relatively data poor and not well defined. There are also factors that could bias the ogives both up and down. Although fish with stage 2 (maturing) gonads were classified as mature, some of these may never have spawned, thus biasing the age at maturity down. However, some relatively old fish with stage 1 (immature gonads) may have simply had resting or regressed gonads at the time of sampling (rather than never having spawned), thus biasing the age at maturity up. But based on the derived ogives it appears that about 60% of the bluenose line catch from southeastern Bay of Plenty and about 70% of the catch from the northern grounds (Areas 004 and 008) is pre-reproductive fish.

Information from this analysis did not usefully enhance our knowledge of bluenose stock structure. When the catch-at-age distributions were estimated for individual years and compared, there were no clear patterns of strong or weak year classes between years, either within or between sampled areas. However, while strong and weak year classes probably exist, the relatively small sample sizes in most years, and the difficulty in ageing these fish, will certainly have reduced the chances that such characteristics could be identified in the current analysis. Given the known ability of bluenose to move long distances in relatively short times (Horn 2003) it is considered unlikely that bluenose from any one of the three areas sampled would constitute a stock separate to those on the other two areas.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Beamish, R.J.; Fournier, D.A. (1981). A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences 38*: 982–983.

Bull, B.; Dunn, A. (2002). Catch-at-age: User manual v1.06.2002/09/12. NIWA Internal Report 114. 23 p. (Unpublished report held in NIWA library, Wellington.)

Chapman, D.G.; Robson, D.S. (1960). The analysis of a catch curve. *Biometrics 16*: 354–368.

Dunn, A.; Francis, R.I.C.C.; Doonan, I.J. (1999). The sensitivity of some catch curve estimators of mortality to stochastic noise, error, and selectivity. New Zealand Fisheries Assessment Research Document 99/5. 23 p. (Unpublished report held in NIWA library, Wellington.)

Hoenig, J.M. (1983). Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin 82*: 898–902.

Horn, P.L. (2003). Stock structure of bluenose (*Hyperoglyphe antarctica*) off the north-east coast of New Zealand based on the results of a detachable hook tagging programme. *New Zealand Journal of Marine and Freshwater Research 37*: 623–631.

Horn, P.L.; Massey, B.R. (1989). Biology and abundance of alfonsino and bluenose off the lower east coast North Island, New Zealand. *New Zealand Fisheries Technical Report 15*. 32 p.

Horn, P.L.; Neil, H.L.; Marriott, P.M.; Paul, L.J.; Francis, C. (2008). Age validation for bluenose (*Hyperoglyphe antarctica*) using the bomb chronometer method of radiocarbon ageing, and comments on the inferred life history of this species. Final Research Report for Ministry of Fisheries Research Project BNS2005-01. 36 p. (Unpublished report available from MFish, Wellington.)

Kalish, J.M. (1993). Pre- and post-bomb radiocarbon in fish otoliths. *Earth and Planetary Science Letters 114*: 549–554.

Paul, L.J.; Sparks, R.J.; Neil, H.J.; Horn, P.L. (2004). Maximum ages for bluenose (*Hyperoglyphe antarctica*) and rubyfish (*Plagiogeneion rubiginosum*) determined by the bomb chronometer method of radiocarbon ageing, and comments on the inferred life history of these species. Final Research Report for Ministry of Fisheries Project INS2000/02. (Unpublished report available from MFish, Wellington.)

Ricker, W.E. (1975). Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board, Canada 191*. 382 p.

Starr, P.J.; Kendrick, T.H.; Bentley, N.; Lydon, G.J. (2008). 2008 Review of the BNS 1 adaptive management programme. AMP-WG-2008/11. 105 p. (Unpublished report available from the NZ Seafood Industry Council, Wellington.)