Compilation and evaluation of the Western Zone (Region A) weight-grade data

Report for PIRSA Fisheries and Abalone Management SA

S. Mayfield

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EXECUTIVE SUMMARY

1. This is the first report to compile and evaluate the weight-grade data for the South Australian Western Zone (WZ) abalone fishery.
2. The objectives of the report were to (1) assess the quality of the weight-grade data; (2) compile the data and evaluate their suitability for aiding assessments of the fishery; and (3) determine whether the weight-grade data could replace the catch-length-frequency data as a measure of the length structure of the commercial catch.
3. The blacklip abalone weight-grade data are inaccurate and unreliable. Data for greenlip abalone are more consistently and accurately collected. These data provide a reliable estimate of the distribution of each daily catch of greenlip, by each licence, into each grade. Data are available for ~70% of the greenlip catch since 1979.
4. Greenlip abalone weight-grade data are suitable for aiding stock assessments of this species in the WZ. However, interpreting these data is complicated by a range of factors and is reliant on catch length-frequency data. This result re-affirms the need for an appropriate catch-length-frequency sampling program for this fishery.
5. Weight-grade data could also be used to estimate the number of greenlip harvested and, in turn, their mean meat weight. This would provide another direct measure of resource extraction.
6. The consistency with which greenlip harvested from both Regions A and B in the WZ suggests that high resolution, greenlip weight-grade data could substantially aid the assessment of these fisheries.
7. There was no evidence of a correlation between the weight-grade data and the catch length-frequency data. The absence of strong, predictable relationships between these data sets suggests that the use of the weight-grade data as a measure of the length structure of the commercial catch is problematic and inappropriate.
8. A key disadvantage of the weight-grade data is its low resolution. This problem could be overcome by increasing the resolution of the grading system or obtaining individual greenlip abalone weights from a representative sub-sample of the graded catch.

1. INTRODUCTION

The South Australian abalone fishery (SAAF) began in the early 1960's. Consistent with fisheries elsewhere, management arrangements for the fishery have evolved since its inception. These changes include the sub-division of the fishery into three Zones (Western, Central and Southern) in 1971 (see Nobes *et al*. 2004). The Western Zone (WZ), which has 23 licence holders, extends between the Western Australia/South Australia border and Meridian 136°30'E. This Zone was subdivided into Region A (Meridian 133°50.8'E to Meridian 136°30'E) and Region B in 1985.

Annual, total allowable commercial catches (TACCs) were introduced for greenlip and blacklip abalone (hereafter referred to as greenlip and blacklip, respectively) in Region A in 1985, and amended to the calendar year fishing season from 1989 (Nobes *et al.* 2004). Quotas are issued and decremented in meat weight. The TACC for greenlip in Region A remained unchanged from 1989 to 2005 (69 t meat weight; ~207 t whole weight). From 2006, the greenlip TACC was increased to 75.9 t meat weight and has remained unchanged at that level. Similarly, the TACC for blacklip in Region A (97.75 t meat weight; ~293.25 t whole weight) has stayed relatively stable since 1989. Minimum legal lengths (MLL) of 130 and 145 mm shell length (SL) apply for blacklip and greenlip, respectively. In addition, because fishers can "shuck" at sea (*i.e*. separate the abalone meats from the shell and viscera), there are also minimum meat weights for both greenlip (140 g) and blacklip (113 g) in this Zone. Both species can be harvested on the same day.

The management of fish stocks and fisheries depends on reliable stock assessments (Hilborn & Walters 1992; Rice 1999). Current scientific assessments of the abalone stocks in Region A are based on a balance of information and data from a range of sources (see Chick *et al*. 2009). These include data provided by commercial fishers (*e.g.* catch and effort and catch-sampling data) and collected by SARDI (*e.g.* biological and fishery-independent survey data), and outputs from numerical modelling (*e.g*. egg-per-recruit analyses and developing integrated models).

An important component of the assessment process for this fishery is the use of length-frequency data to determine temporal changes in the length structure of the commercial catch through time. This approach is consistent with stock assessments of abalone elsewhere, including New South Wales (Andrew & Chen 1997), Tasmania (Tarbath *et al*. 2008), New Zealand (*e.g.* Breen & Kim 2005) and those of other

invertebrate species that are difficult to age, including lobsters (Walker & Bentley 2002; Haist *et al*. 2005).

Commercial-catch, length-frequency data are available from Region A for both greenlip (1979 – 1982 & 1999 – 2008) and blacklip (1999 – 2008; see Chick *et al*. 2009). In addition to these data, the commercial abalone catch in this Zone has been separated by the processing factories into three weight grades since ~1979. These weight grades are loosely based on the number of abalone per pound. With the exception of 2002 (Mayfield *et al*. 2002), these commercial weight-grade data (hereafter referred to as weight-grade data) have not been used in scientific assessments of the fishery. This is primarily because of the low resolution of these data, the apparent temporal and spatial variability in the relationship between shell length and meat weight, and the loss of weight (termed "bleeding"; Gorfine 2001) by shucked abalone meats that is influenced by a wide range of factors, most notably the elapsed time between shucking and weighing (Gorfine 2001; Rodda & Mayfield 2002).

Directors of Abalone Management SA (AMSA), the industry-based management company for the SAAF, recently questioned the usefulness of the commercial-catch, length-frequency data (hereafter referred to as catch length-frequency data) for stock assessment of the South Australian abalone fisheries. They queried whether the current commercial catch-sampling program in the WZ could be terminated, and be replaced by the use of the weight-grade data. This approach would require that the weight-grade data represent a suitable surrogate for the catch-length-frequency data, and that patterns in the weight-grade data, through time, can be interpreted and used to inform assessment of the fishery.

The primary objectives of this report were to (1) assess the quality of the weight-grade data; (2) compile the data and evaluate their suitability for aiding assessments of the fishery; and (3) determine whether the weight-grade data could replace the catch-length-frequency data as a measure of the length structure of the commercial catch. This last objective was the most complex and required assessment of the relationships between meat-weight and shell-length, and between paired weight-grade and catch-length-frequency data.

2. METHODS

2.1 Data sources

Three sources of data were used to obtain the information and undertake the analyses presented in this report. They were the (1) commercial catch and effort, (2) commercial catch sampling, and (3) fishery-independent, morphological data.

Commercial catch and effort data for the abalone fishery in Region A have been collected since 1968. One major change was made to the data-collection system in 1978, when the sub zones and fishing blocks were replaced with smaller spatial units termed fishing areas (FA) and map codes. For each fishing day a research logbook must be completed and then submitted to SARDI at the end of each month. The logbook provides information on the date of fishing, the FA, the total catch landed and, in general, the weight of each abalone grade (see Section 2.2 below) comprising that total catch. The data are entered into an Oracle database, validated and stored (see Knight *et al*. 2009). Weight-grade data from January 1979 to December 2002 in the current database do not have explicit weight-grade headers (*e.g.* 1-2; 2-3; refer to Table 1 and Section 3.1). These data have categorical headers (*e.g.* GL1, GL2) and are, despite retrospective cross-checking of a sub-sample, considered less reliable than data from January 2003.

Catch length-frequency data are available for greenlip and blacklip from Region A between 1999 and 2008. Prior to 1 July 2005, these data were obtained from samples provided to SARDI from commercial fishers. Since July 2005 the Abalone Industry Association of SA Inc. have provided these data, which are obtained by the commercial fishers, to SARDI. Information on the date of fishing, FA, licence number and species are available for each set of individual shell lengths (SL, mm).

Morphological data for greenlip were collected by SARDI from Flinders Island and Searcy Bay (November 1999), Hotspot (May 1999), Price Island (June 1999) and The Gap (June 1999 and January 2000). Data collected included sampling date, species, sampling site, the sex, SL, whole weight (g), meat weight (g) and 24-hr bled meat weight (BMW, g) for each abalone sampled. The latter measurement reflects the “bleeding” of abalone meats during the typical time period between shucking at sea and “weighing off” to subsequent processing undertaken at the processing factories (Gorfine 2001). This measure was obtained using the same methods as the commercial fishers apply to their daily catches.

2.2 Quality of the weight-grade data

Four abalone processing factories collectively process >95% of the abalone harvested from Region A. Three of these – Western Abalone Processors Pty Ltd (WAP), Streaky Bay Marine Products (SBMP) and Abalone Down Under (ADU) – account for the catch from ~22 of the 23 licence holders (~96%). Information on the protocols and procedures for processing the abalone catches, including the weights defining the three weight-grade categories, was obtained by interviewing staff (WAP: Jim George & Hayden Myers; ADU: Gary White) during site visits conducted in April 2009. Catch processing was observed at the same time at WAP. The same data were collected by telephone from SBMP (Damon Edmunds) in May 2009. The information provided by WAP, SBMP and ADU was used to evaluate the quality of the weight-grade data and to undertake the analyses on greenlip outlined in Sections 2.4 and 2.6 below. Similar analyses were not undertaken for blacklip due to the lack of high-quality, weight-grade data for that species.

2.3 Representation of the weight-grade data to the fishery and catch

The logbook data supplied by the commercial fishers were used to determine the degree to which the weight-grade data were representative of both the catch and the fishery in Region A. To do that, the percentage of the daily and the total catches (for which weight-grade data were available) and the number of commercial fishers providing these data, were calculated. Analyses were undertaken separately for each species. The percentage of the daily catches for which weight-grade data were available for each species was only determined from those daily records where the catch of that species on that day was not reported as zero. The percentages of weight-grade data for the daily and total catches were highly correlated ($r^2 > 0.99$). Only total catch data are presented.

2.4 Spatial and temporal patterns in the weight-grade data

The logbook data supplied by the commercial fishers were used to determine the spatial and temporal patterns in the weight-grade data from 1979 to 2008. This was achieved by calculating the percentage contributed by each of the three weight-grade categories to their combined weight, across a range of spatial and temporal scales. Analyses were undertaken separately for each species.

Temporal trends in the weight-grade data from both species were determined for the whole of Region A and six key FA. For greenlip, the key fishing areas were FA 8, 9, 14 and 18, while for blacklip they were FA 4, 9, 11 and 14 (see Chick *et al*. 2009). Subsequently, finer temporal-scale patterns were determined for greenlip. These included the monthly proportions of each weight-grade from 2003 to 2008 for Region A and in 2004, 2006 and 2008 for FA 8, 9, 14 and 18. Similarly, inter-annual trends, within months, were determined from January to June for Region A and from January to April for FA 8, 9, 14 and 18. These time periods were selected because most (>75%) of the greenlip catch is harvested by June each year (SARDI, unpublished data), and because weight-grade data prior to 2003 are considered less reliable.

2.5 Relationships between shell length and bled meat weight

The fishery-independent, morphological data were used to evaluate the relationships between SL and BMW. Limitations in the data available required that data from all sites and sampling times (see Section 2.1 above) were used to determine relationships between SL and BMW for male and female greenlip. Subsequently, as there was no significant difference in this relationship between males and females ($Z = 0.85$, $p > 0.05$; Zar 1984) data from Hotspot, Price Island and The Gap, collected within a 2-week period in autumn 1999, were used to evaluate the effect of sampling location on the SL-BMW relationship. In all cases, the strengths of the relationships were determined using simple linear correlation. The correlation coefficients (r) among sampling locations were compared using a χ^2 test following transformation of r to a z value (after Zar 1984). Distributions of potential BMW values within seven 5-mm shell length classes (145 – 149; 150 – 154; …..>175 mm SL) were determined. Potential SL distributions from greenlip meats in each of the three weight-grade categories (Grade 1: ≥ 230 g; Grade 2: 150 – 229 g; Grade 3: 140 – 149 g; see Table 1) were similarly derived. The median, maximum, minimum, upper 75th and lower 25th quantiles of each distribution were extracted.

2.6 Relationships between weight-grade and length-frequency data

Relationships between weight-grade and length-frequency data were determined by pairing data on the proportions of each grade of greenlip in the commercial catch obtained from the logbooks, with commercial length-frequency data that were obtained on the same fishing day. Three unique identifiers (date, licence number and fishing location) were used to align the data sets. Any datasets that were imperfectly

matched (~20%) were discarded. The percentage contributed by each of the three weight-grade categories to their combined weight was determined for each paired sample. Thereafter, the mean SL for each paired sample was determined from the length-frequency data.

The strengths of the relationships between the percentage of Grade 1 greenlip in the commercial catch and mean SL were determined using simple linear correlation. These analyses were undertaken for all paired samples in Region A from 2004 to 2008 and from 2005 to 2008 separately. The relationship between the percentage of Grade 3 greenlip in the commercial catch and mean SL in Region A was also determined using data from 2004 to 2008. The numbers of paired data sets at finer spatial and temporal scales were limited. However, data from FA 9 and mapcodes 9A and 9D during summer 2007 and from mapcode 9B during January 2007 were used to evaluate the effect of fishing location on these relationships.

2.7 Estimates of the number and mean weight of abalone harvested

Estimates of the maximum number of greenlip harvested and their minimum mean weight were derived from data on the proportions of each grade of greenlip in the commercial catch that was obtained from the logbooks. This required four steps: (1) the percentage contributed by each of the three weight-grade categories to their combined weight was calculated; (2) the proportion of each weight grade was multiplied by the total catch (graded and ungraded) to provide an estimate of the total weight harvested within each weight-grade category; (3) the weight harvested within each grade category was divided by the minimum meat-weight limit for that grade (Grade 1: 230 g; Grade 2: 150 g; Grade 3: 140 g; see Table 1); and (4) the number of abalone harvested within each grade category was summed.

Minimum mean weight was estimated by dividing the total catch by the estimated maximum number of abalone harvested. Temporal trends in the numbers of abalone harvested, and their minimum mean weight, were determined for the whole of Region A and FA 9 and 18.

3. RESULTS

3.1 Quality of the weight-grade data

Discussions with representatives from three of the four processing factories in the WZ identified subtle differences among the factories' processing procedures, and distinct differences between the methods by which weight-grade data were obtained for greenlip and blacklip. Although each factory uses three meat-weight grades based crudely on the number of abalone per pound, each factory used slightly different weight categories for each species (Table 1), but similar grade categories for both greenlip and blacklip. For the largest processing factory, WAP, the three grades are termed 1-3 (Grade 1; ≥ 230 g), 2-3 (Grade 2; 160 – 229 g; also periodically called 1-3) and 3-5 (Grade 3; <160 g). The greatest difference among factories was 10 g. There is no information to suggest the catch processed by the remaining factory is dissimilar to that at WAP, SBMP and ADU.

Table 1. Commercial abalone meat-weight grade categories (g) used by the principal processing factories in the WZ. The values used in this report are also shown.

Abalone grade	Western Abalone Processors	Abalone Down Under	Streaky Bay Marine Products	Default for this report
Grade 1 (1-2)	≥ 230	≥ 225	≥ 230	≥ 230
Grade 2 (2-3)	160 – 229	150 – 224	150 – 229	150 – 229
Grade 3 (3-5)	<160	<150	<150	<150

Greenlip and blacklip are processed differently at the three factories. For greenlip, at each of the three factories, the whole catch from each licence holder is graded separately with every individual greenlip assigned a grade. The different grades are then weighed separately. This provides a reliable estimate of the distribution of each daily catch of greenlip, by each licence, into each grade. However, for blacklip, the same level of rigour is seldom applied. At WAP, the whole daily blacklip catch from each licence holder is weighed. Thereafter, estimates of the proportions of that catch that would fall into the three grade categories are made visually, through cursory examination of the catch in a crate. The weight of blacklip in each grade is then determined by multiplying the weight of the total catch by the proportion of that catch in each grade. At ADU and SBMP, the blacklip catches are not graded, with the exception of the small (<5%) amount that is sold frozen, rather than canned; those blacklip sold frozen are graded to the standards that are applied to greenlip.

Consequently, estimates of the distribution of each daily catch of blacklip, by each licence, into each grade are much less reliable than those for greenlip

3.2 Representation of the weight-grade data to the fishery and catch

Weight-grade data were available for both greenlip and blacklip from 1979 to 2008, with the exception of 1997, 1998 and 1999 (Figure 1). For greenlip, commercial weight-grade data were available from 1979 for ~70% of the total catch (range: 0% in 1997, 1998 and 1999 to 95.9% in 1981). Notably, the percentage of the total catch for which commercial, weight-grade data were available has declined from ~80% between 1979 and 1996 to ~70% since 2001. On average, data were available from ~75% of the 23 licence holders. However, the number of licence holders for which data were available was lower in the period from 2001 to 2008 (18.3), when compared to that from 1979 to 1996 (20.4). Similar patterns were also evident for blacklip, although the percent graded is consistently ~15% lower than for greenlip (Figure 1).

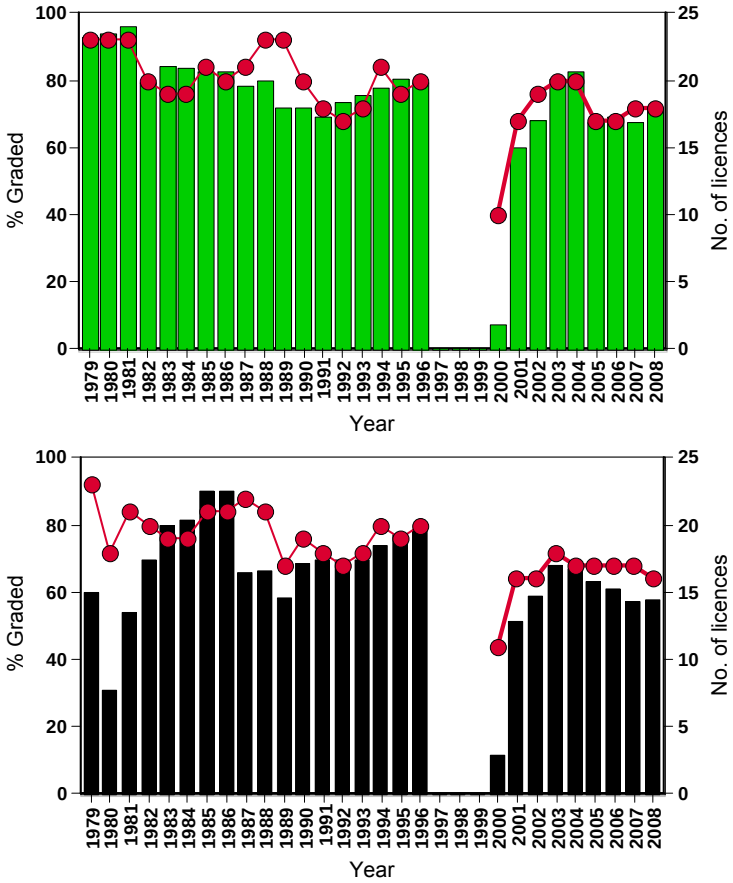

Figure 1. Percentage (bars) of the total catch of (top) greenlip and (bottom) blacklip for which commercial weight-grade data were available between 1979 and 2008. The number of licences for which commercial weight-grade data were available is also shown (lines; maximum = 23).

3.3 Spatial and temporal patterns in the weight-grade data

3.3.1 Greenlip

The percentage of Grade 1 greenlip in the commercial catch from Region A has increased significantly since 1980 (Linear Regression (LR): r^2 = 0.78; df = 24; p < 0.01; Figure 2). The percentages of both Grade 2 and Grade 3 greenlip have decreased significantly over the same time period (LR's: r^2 = 0.59; df = 24; p < 0.01 and r^2 = 0.77; df = 24; p < 0.01, respectively).

Further, because Grade 3 greenlip have comprised <20% of the commercial catch since 1979, the percentages of Grade 1 and Grade 2 greenlip are essentially the mirror image of each other. As there is no evidence of a seasonal shift in fishing effort towards those months during which recovery rates are highest (SARDI unpublished data), these data suggest that the average weight of greenlip in the commercial catch has been gradually increasing over the past 30 years, or that there has been an increased market demand for larger greenlip. In contrast to this general trend, the percentage of Grade 1 greenlip has declined since 2005. In 2008, it was 61.7%, the lowest since 2004 (58.5%).

Similar temporal patterns were also observed in FA 9 and 18 (Figure 3). In FA 9, the percentage of Grade 1 greenlip in the commercial catch increased significantly from 1982 to 2006 (LR: r^2 = 0.58; df = 22; P < 0.01; Figure 3) before decreasing sharply between 2006 (65.0%) and 2008 (41.7%) to the lowest level since 1993. Percentages of Grade 2 and Grade 3 greenlip have both increased substantially over the last two years. As for the whole of Region A, these data suggest that the average weight of greenlip in the commercial catch from FA 9 gradually increased prior to 2006, it has decreased substantially.

There is little evidence of a reduction in the percentage of Grade 1 greenlip being harvested from FA 18. Consequently, it is likely that the average weight of greenlip harvested from this area has been increasing since 1979. In FA 14, Grade 1 and Grade 2 greenlip contributed similar levels to the catch between 1979 and 1996, they diverged (Figure 3). Since 2000, Grade 1 abalone have dominated the catch from this FA. The catch from FA 8 was dominated by Grade 2 greenlip from 1981 to 2000, the catch has generally been dominated by Grade 1 greenlip.

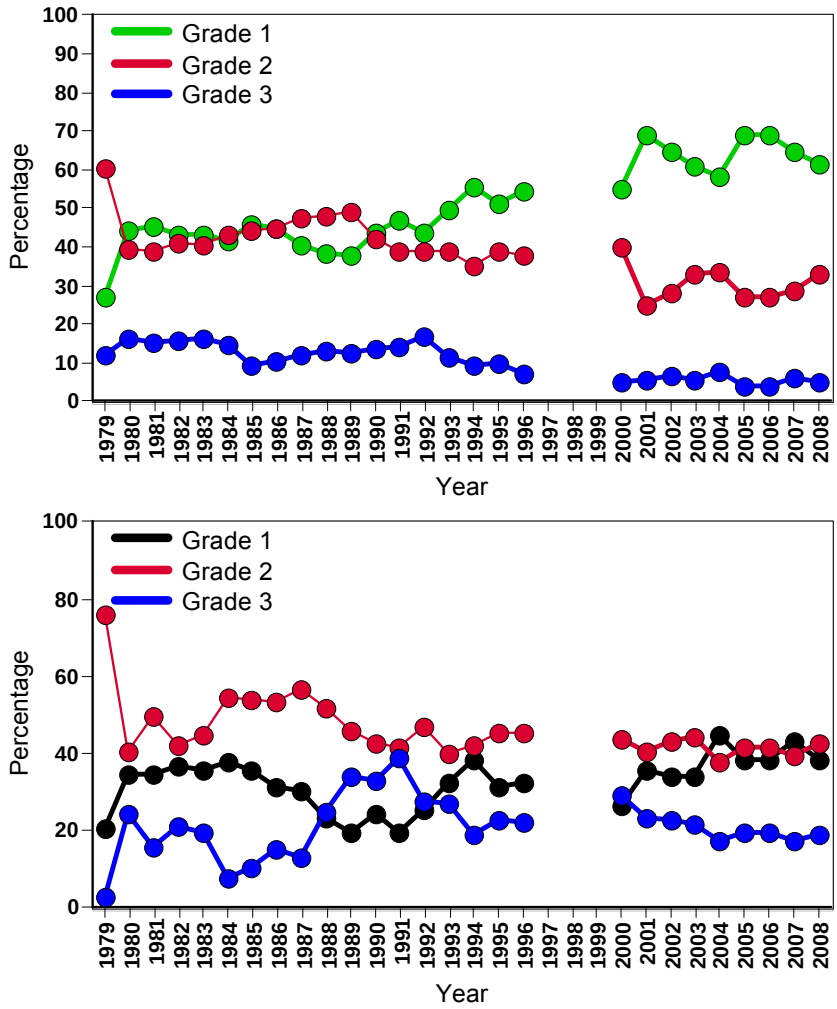

Figure 2. Percentage of Grade 1, Grade 2 and Grade 3 (a) greenlip and (b) blacklip in the commercial catch between 1979 and 2008. No data were available for 1997, 1998 or 1999. Data from 1979 to 2002 are considered less reliable than those from 2003.

There are several strong seasonal patterns evident in the weight-grade data from 2003 (Figure 4). Firstly, the percentage of Grade 1 greenlip in the catch tended to increase through summer, with a peak in autumn and gradually decrease through winter and spring. This pattern was most evident from 2005 to 2008, but also occurred in 2003 and 2004. Secondly, the percentage of Grade 2 greenlip tended to be low during summer and autumn, but increased markedly during winter and spring. However, despite this increase, the percentage of Grade 2 greenlip seldom exceeded that of Grade 1 greenlip in the catch. Thirdly, Grade 3 greenlip rarely comprised > 20 % of the proportion of the graded catch. The exceptions were August 2003, December 2006 and October 2007. Although the absence of data complicated interpretation, similar patterns to these were generally evident for each of the current principal FA (Figure 5).

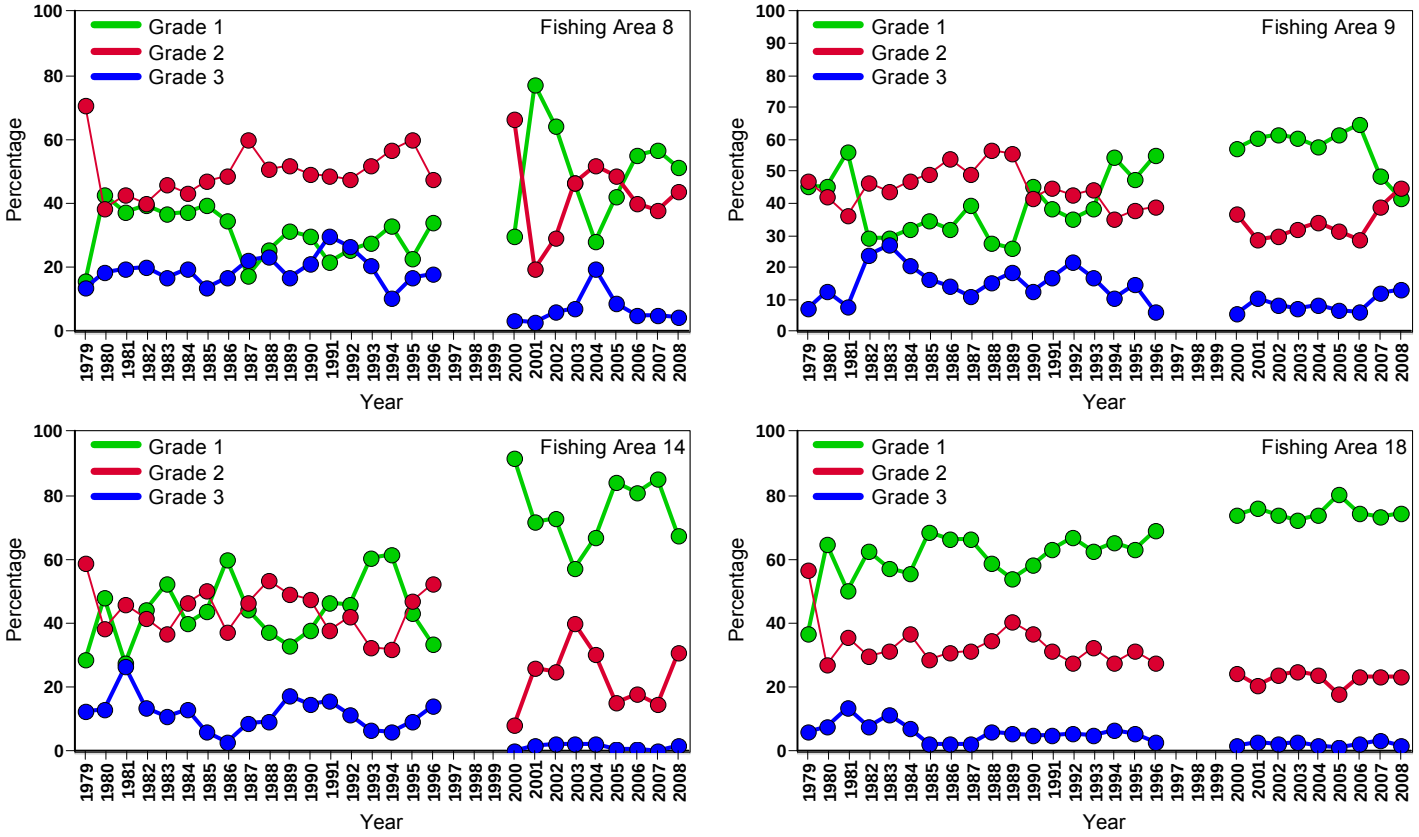

Figure 3. Percentage of Grade 1, Grade 2 and Grade 3 greenlip in the commercial catch from FA 8, 9, 14 and 18 between 1979 and 2008. No data were available for 1997, 1998 or 1999. Data from 1979 to 2002 are considered less reliable than those from 2003.

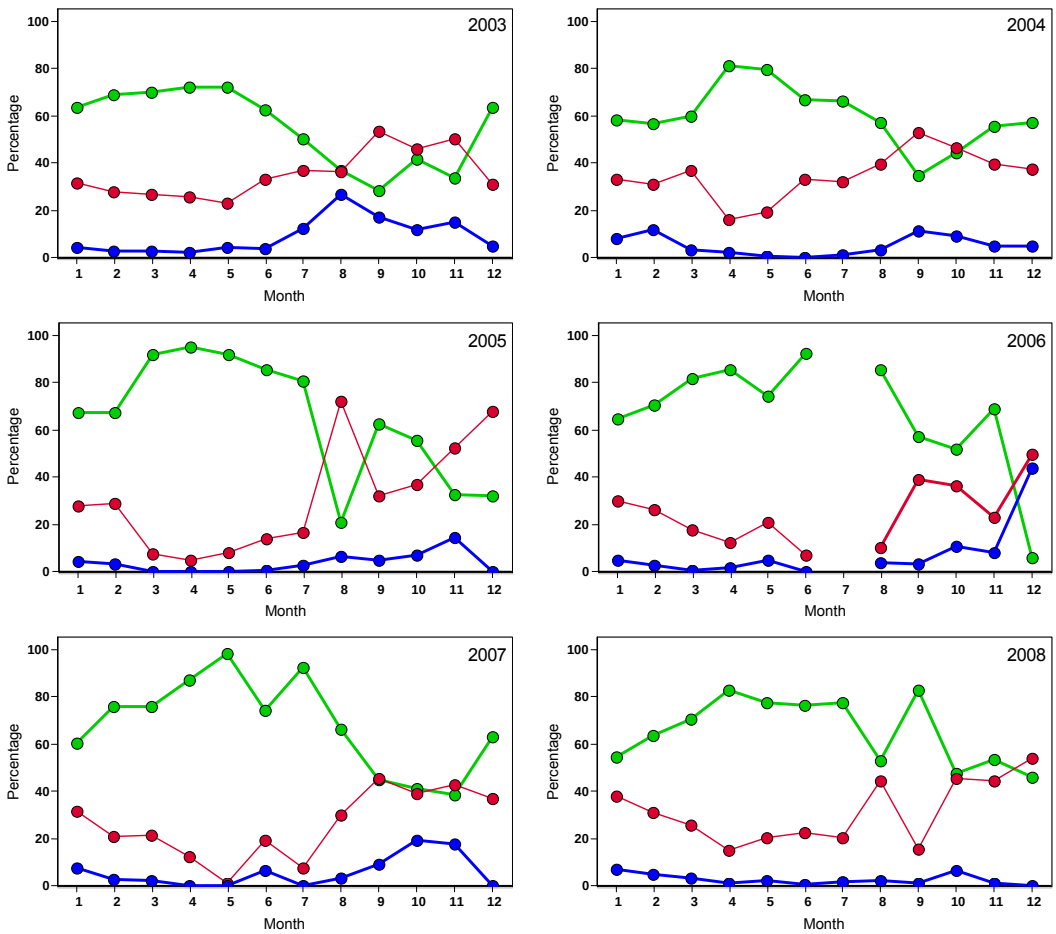

Figure 4. Percentage of Grade 1 (green lines), Grade 2 (red lines) and Grade 3 (blue lines) greenlip, by month, in the commercial catch from Region A from 2003 to 2008.

Inter-annual patterns (*i.e.* within months, across years; Figure 6), were not as marked as those for the seasonal effects described above. The most obvious were the decreases in the percentages of Grade 1 greenlip caught in January and May since 2005, matched by the percentage increase of Grade 2 greenlip caught over the same time period. Reductions in the percentages of Grade 1 greenlip harvested were not evident in April, May or June.

Interpreting the patterns for the principal FA was more complicated (Figure 7). Few clear patterns were evident for FA 9 and 14 between January and April. In FA 9, the percentage of Grade 1 greenlip in January was stable between 2003 and 2006, it has reduced sharply. The percentage of Grade 2 greenlip has increased rapidly since 2006. Patterns in February, March and April were inconclusive. Following a long period of consistent grade percentages, the percentage of Grade 1 greenlip reduced substantially between 2007 and 2008 during February, March and April in FA 18.

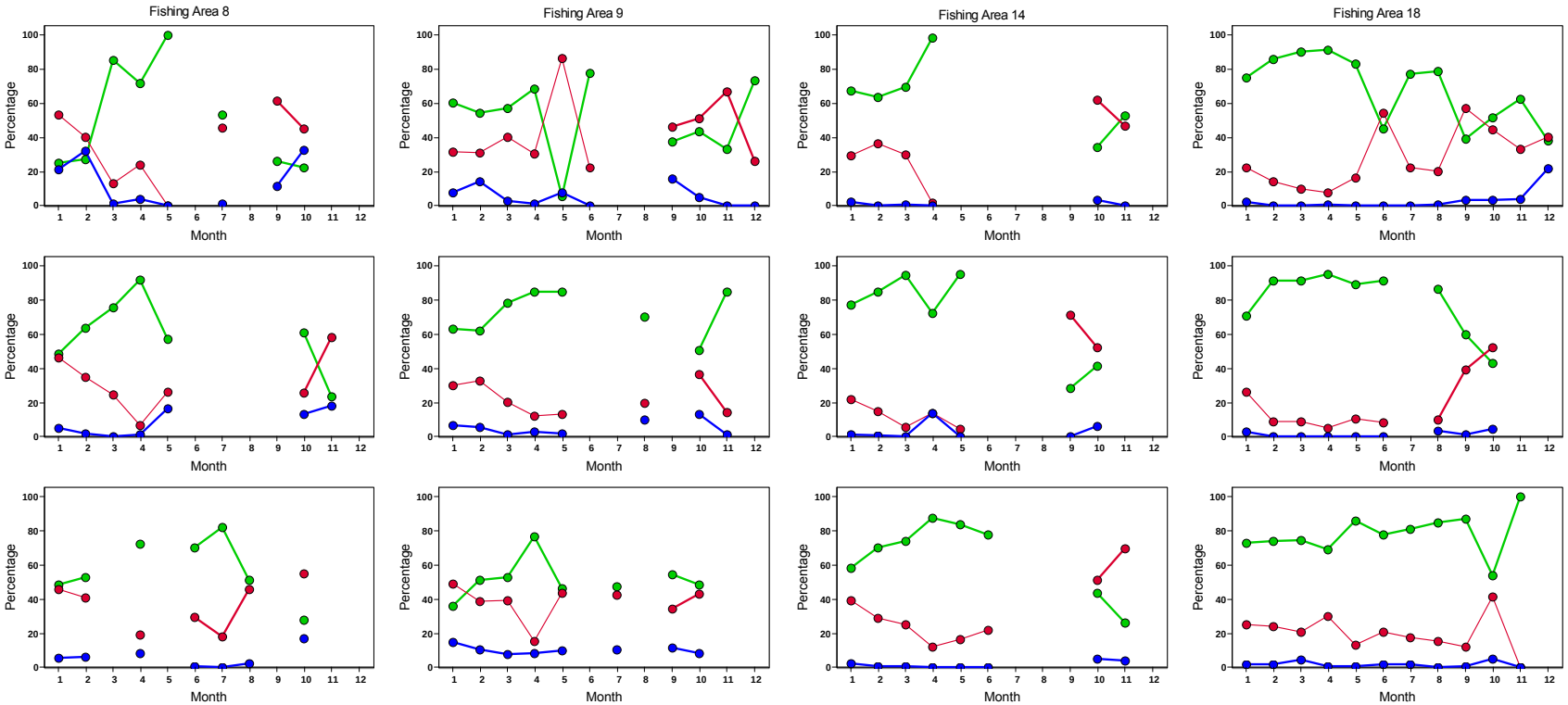

Figure 5. Percentage of Grade 1 (green lines), Grade 2 (red lines) and Grade 3 (blue lines) greenlip, by month, in the commercial catch from FA 8, 9, 14 and 18 during (top) 2004, (middle) 2006 and (bottom) 2008.

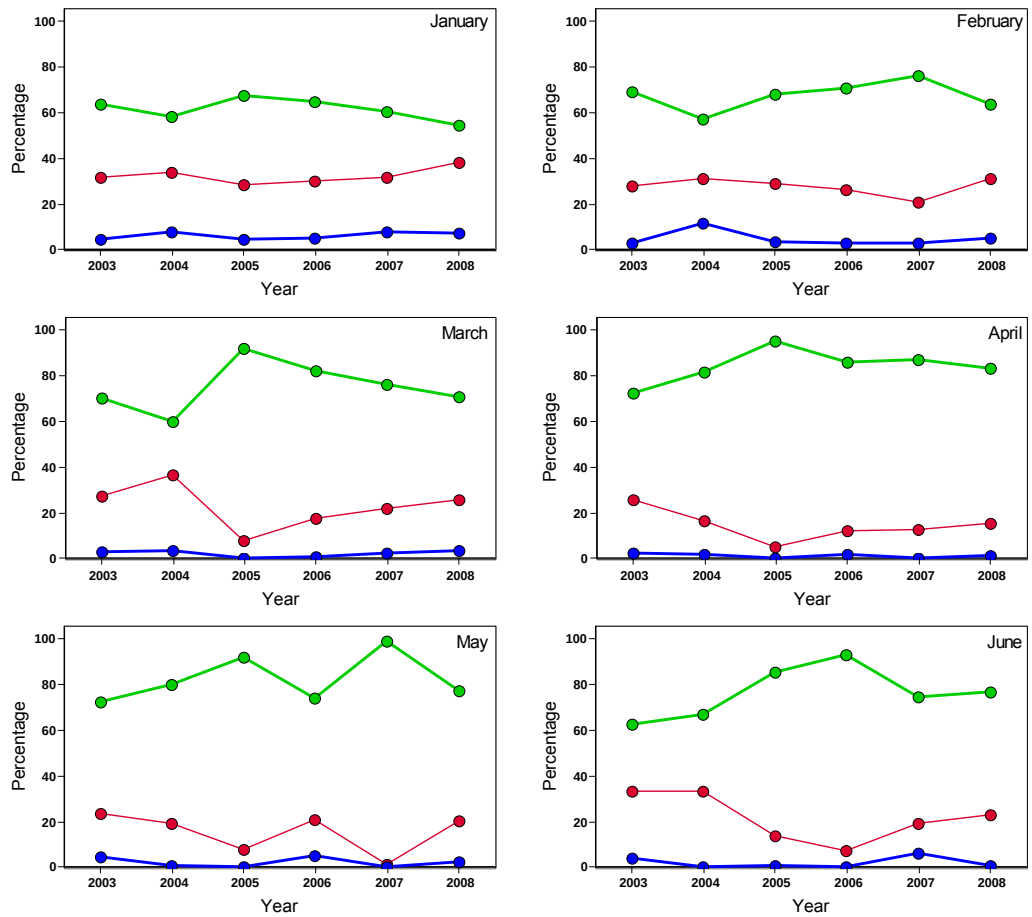

Figure 6. Percentage of Grade 1 (green lines), Grade 2 (red lines) and Grade 3 (blue lines) greenlip in the commercial catch from Region A in January, February, March, April, May and June between 2003 and 2008.

3.3.2 Blacklip

Interpreting the patterns for blacklip is more complicated than for greenlip, and is strongly influenced by the quality of the data. Grade 2 blacklip have dominated the commercial catch from Region A since 1979, with the exceptions of 2004 and 2007 (Figure 2). However, the proportion of Grade 1 blacklip in the catch has been increasing since 1988, to the extent that the commercial catch now comprises approximately equal proportions of these two grade categories. Since 2000, the proportion of each grade in the commercial blacklip catch has generally been consistent (~ 40% for each of Grades 1 and 2; ~ 20% for Grade 3). Similar patterns to these were also evident for FA 9 and 11 (Figure 8). However, increases in the proportion of Grade 1 blacklip in the catch in recent years were less evident for FA 4 and 14. In both these FA, the proportions of each grade comprising the commercial catch have been generally more consistent through time.

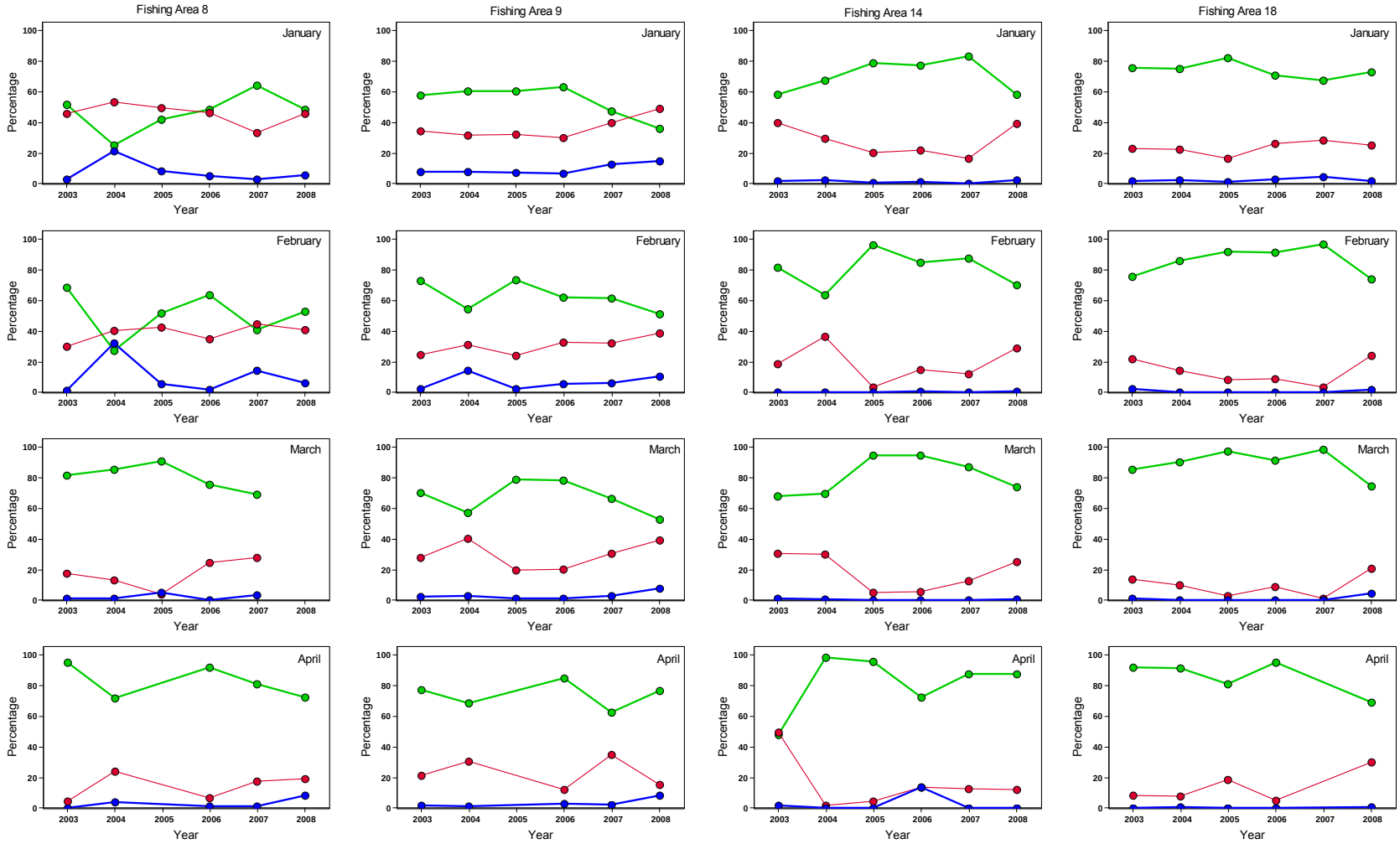

Figure 7. Percentage of Grade 1 (green lines), Grade 2 (red lines) and Grade 3 (blue lines) greenlip in the commercial catch from FA 8, 9, 14 and 18 in January, February, March and April between 2003 and 2008.

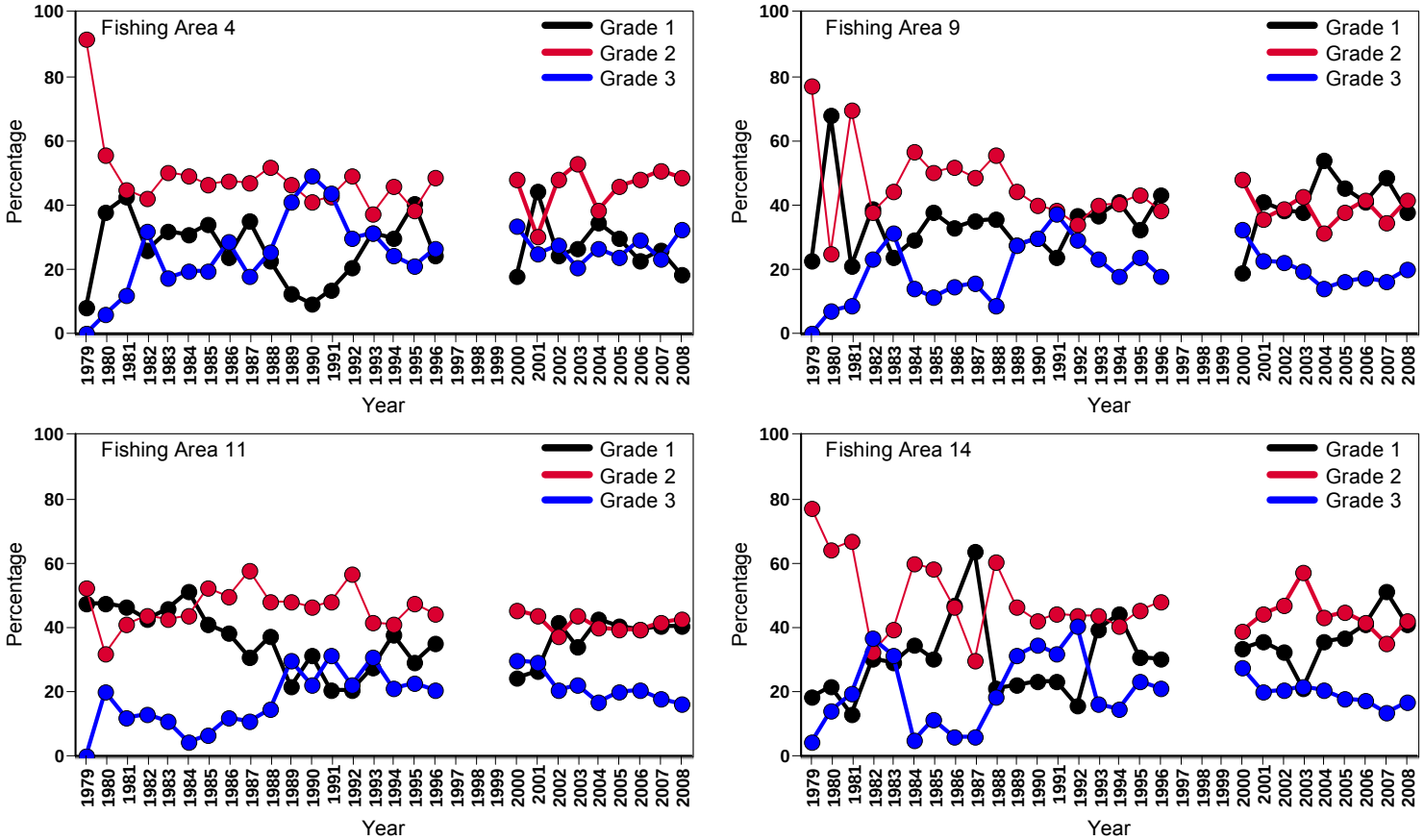

Figure 8. Percentage of Grade 1, Grade 2 and Grade 3 blacklip in the commercial catch from FA 4, 9, 11 and 14 between 1979 and 2008. No data were available for 1997, 1998 or 1999. Data from 1979 to 2002 are considered less reliable than those from 2003.

3.4 Relationships between shell length and bled meat weight

There was a strong, positive correlation between shell length and bled meat weight for greenlip in Region A (Figure 9; Table 2) with no clear separation between male and female greenlip, and no significant differences among sampling locations ($\chi^2 = 3.47$, $p > 0.05$). Nevertheless, the relationships were improved when two potential confounding factors (*i.e.* season and sampling location) were taken into account (Figure 9; Table 2). Despite the strength of these relationships, a large proportion of the data were distributed within a narrow meat-weight range (100 – 150 g) that spanned a broad range of shell lengths (145 – 175 mm SL). Consequently, a single meat-weight value could be obtained from greenlip with a wide range of shell lengths and, similarly, a range of meat-weight values could be obtained from greenlip with the same shell length (Figure 9). This resulted in a broad range and considerable overlap of both (1) potential BMW values within narrow (5 mm) shell-length classes, and (2) potential greenlip lengths within each of the three weight-grade categories (Figure 10).

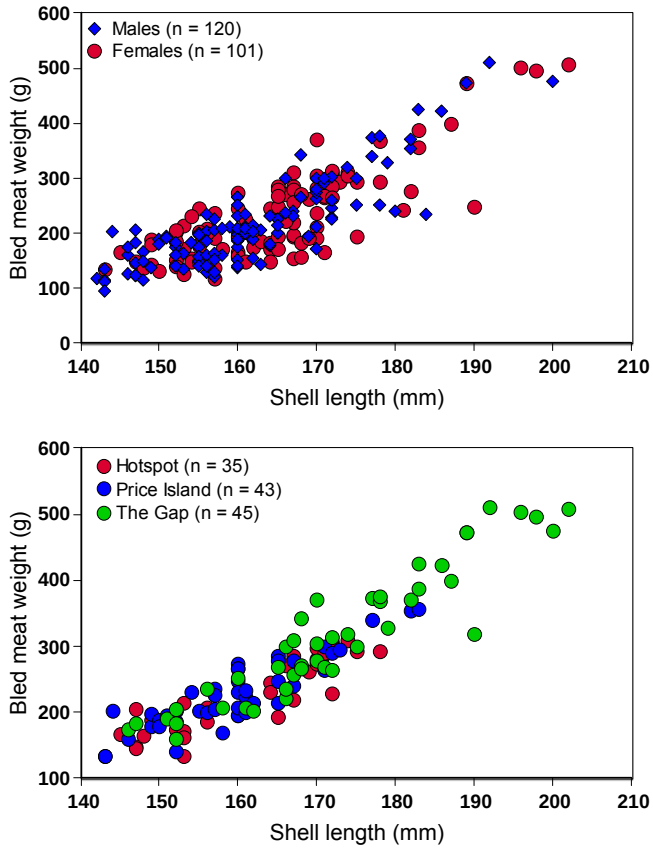

Figure 9. Relationships between shell length (mm) and meat weight (g) for (top) male and female greenlip (sites combined) and (bottom) greenlip sampled from Hotspot, Price Island and The Gap (males and females combined) during autumn 1999.

Table 2. Sex, correlation index (r^2), sample size (n) and *P* value from the relationships between shell length (mm) and bled meat weight (g) for greenlip sampled from Region A.

Sample site	Date	Sex	r^2	n	*P*
Region A	May 1999-Jan 2000	Male	0.72	120	<0.05
Region A	May 1999-Jan 2000	Female	0.66	101	<0.05
Hotspot	May 1999	All	0.81	35	<0.05
Price Island	June 1999	All	0.77	43	<0.05
The Gap	June 1999	All	0.88	45	<0.05

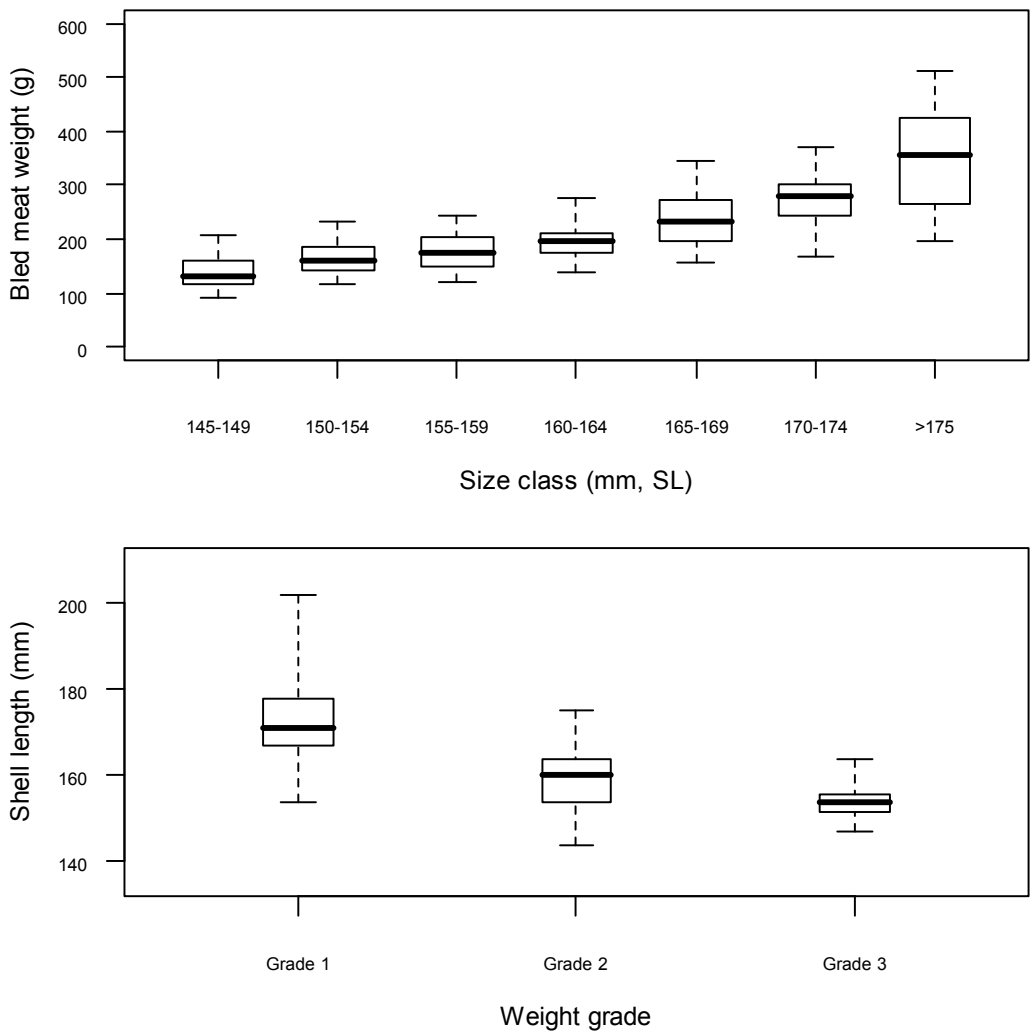

Figure 10. Box and whisker plots showing the distribution of (top) potential bled meat values within 5 mm shell length classes and (bottom) potential shell length values from each of the three weight-grade categories. The whiskers show the minimum and maximum values of the data, the upper (75th) and lower (25th) quantiles of the data are shown as the top and bottom lines of the box and the median is dark line within the box.

3.5 Relationships between weight-grade and length-frequency data

Although the slopes of several correlations between paired samples of mean shell length and the proportions of Grade 1 or Grade 3 greenlip in the commercial catch were significantly different from zero, the relationships were generally weak (Figure 11; Table 3). The relationships between these two variables were also seldom improved when the two principal confounding factors, season and location, were taken into account (Figure 12; Table 3). Stemming from the problems outlined above (*i.e.* a single bled-meat-weight value could be obtained from greenlip with a wide range of shell lengths and its converse), the correlation index (r^2), which reflects the amount of variability in mean shell length accounted for by the proportion of Grade 1 greenlip in the commercial catch, did not exceed 0.3 (Table 3). This indicates that there is little evidence of a relationship between mean shell length and the proportion of Grade 1 greenlip in the commercial catch. The lack of strong correlations between these two sets of data suggests that the use of weight-grade data as a surrogate for the length-frequency data is problematic.

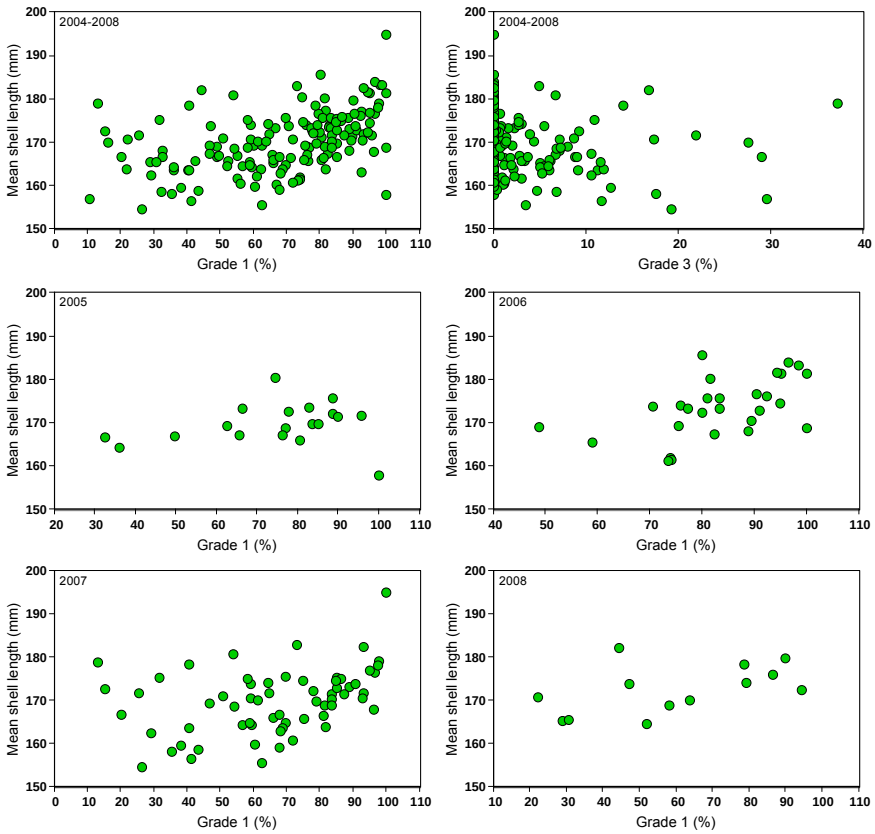

Figure 11. Relationships between paired mean shell length (mm) and the proportion of Grade 1 greenlip in the commercial catch from 2004 – 2008 (combined), and for 2005, 2006, 2007 and 2008 separately. The relationship between paired mean shell length (mm) and the proportion of Grade 3 greenlip in the commercial catch from 2004 – 2008 (combined) is also shown.

Table 3. Grade, correlation index (r^2), sample size (n) and *P* value from the relationships between paired samples of mean shell length and the proportions of graded greenlip in the commercial catch. NS indicates the relationship was not statistically significant.

Location	Year	Grade	r^2	n	*P*
Region A	2004-2008	Grade 1	0.20	154	<0.05
Region A	2004-2008	Grade 3	0.04	154	<0.05
Region A	2005	Grade 1	0.04	19	NS
Region A	2006	Grade 1	0.29	28	<0.05
Region A	2007	Grade 1	0.14	63	<0.05
Region A	2008	Grade 1	0.25	13	NS
FA 9	Summer 2007	Grade 1	0.01	27	NS
Mapcode 9A	Summer 2007	Grade 1	0.28	8	NS
Mapcode 9D	Summer 2007	Grade 1	0.23	6	NS
Mapcode 9B	January 2007	Grade 1	0.92	4	<0.05

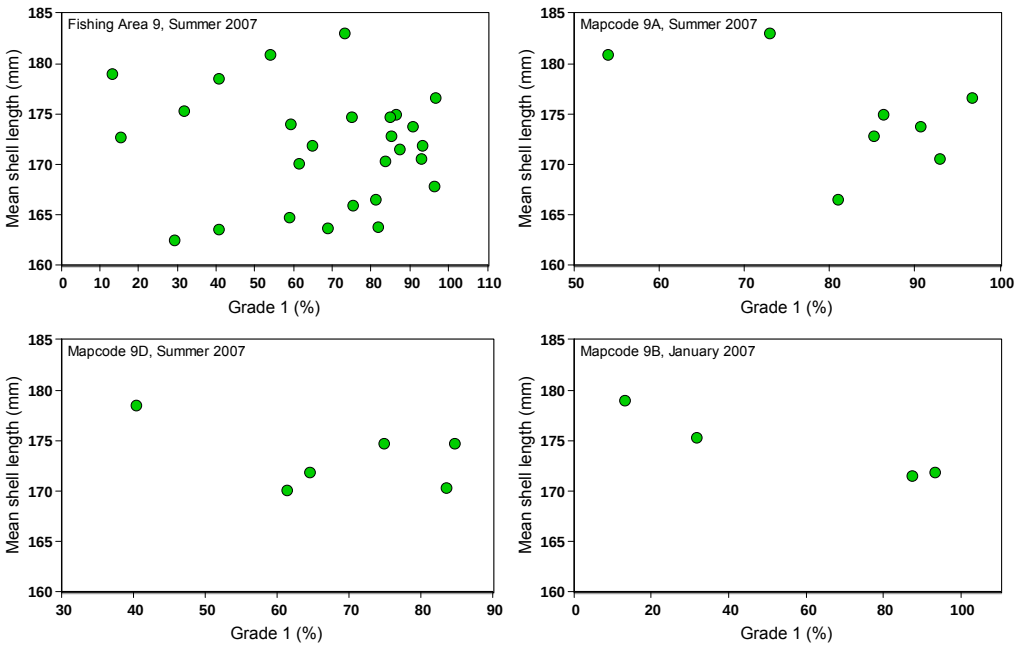

Figure 12. Relationships between paired mean shell length (mm) and the proportion of Grade 1 greenlip in the commercial catch from FA 9 and Mapcodes 9A and 9D in Summer 2007, and from Mapcode 9B in January 2007.

3.6 Estimates of the number and mean weight of abalone harvested

There was a strong relationship between total catch and the estimated maximum number of greenlip harvested between 1979 and 2008 in region A (Figure 13). The number of abalone harvested has generally been increasing over the last decade. This trend was likely driven by a combination of the increase in TACC from 2006 and the reduction in minimum mean weight of the catch (Figure 13), that, in turn, was underpinned by the decreases in the proportion of Grade 1 greenlip in the commercial catch over recent years (see Figure 2). Although there was also a strong relationship between catch and number in FA 9 and 18 (Figure 14), the temporal patterns were different from those observed across Region A. Notably, in FA 9, catch by number, catch by weight and the minimum mean weight of greenlip harvested have all decreased sharply to the lowest levels in ~15 years. In contrast, the estimated mean weight of greenlip harvested from FA 18 has been relatively stable since 2000.

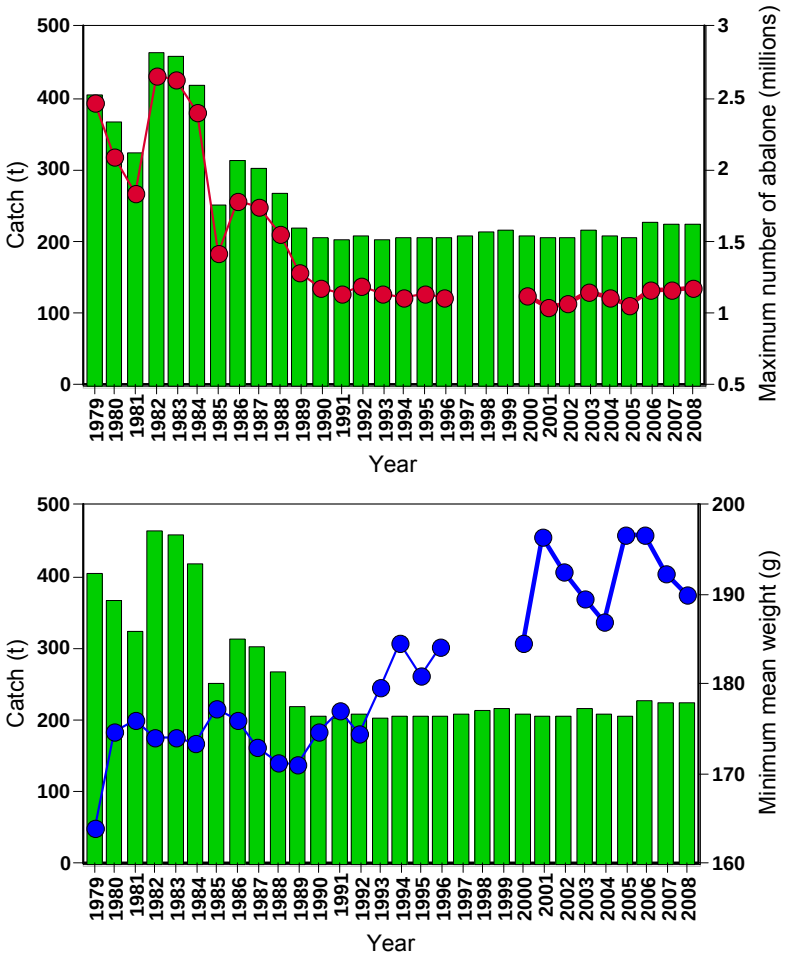

Figure 13. Total catch (bars, top and bottom), maximum number (red line, top) and minimum mean weight (blue line, bottom) of greenlip in Region A estimated from the weight-grade data between 1979 and 2008.

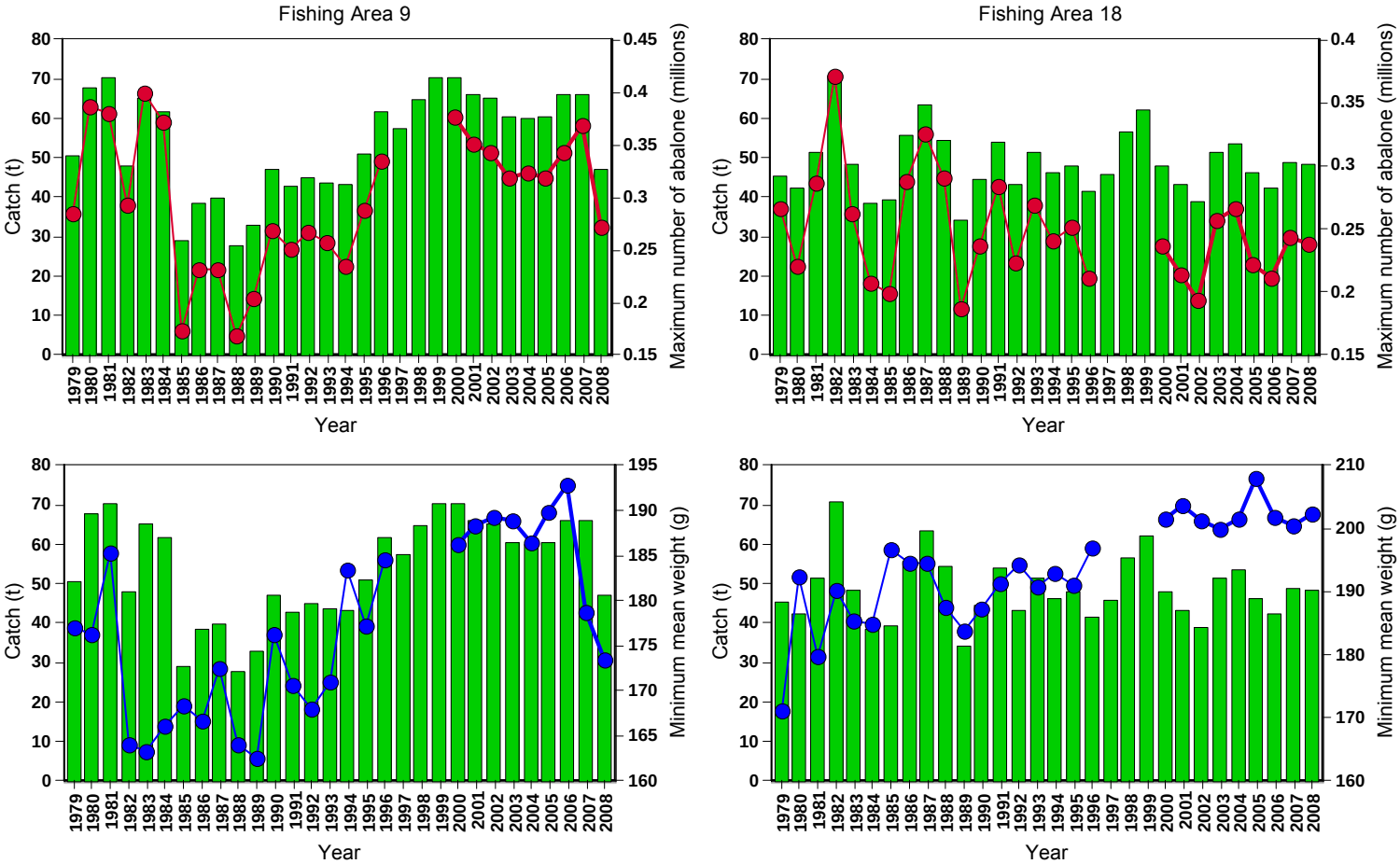

Figure 14. Total catch (bars, top and bottom), maximum number (red lines, top) and minimum mean weight (blue lines, bottom) of greenlip in FA 9 and 18 estimated from the weight-grade data between 1979 and 2008.

4. DISCUSSION

This is the first report to compile and evaluate the weight-grade data for the WZ abalone fishery. The three most important findings were that the (1) quality of the weight-grade data for greenlip substantially exceeded that for blacklip; (2) greenlip weight-grade data are suitable for aiding stock assessments of this species in the WZ – both in their own right and following conversion to a mean greenlip weight; and (3) use of weight-grade data to replace the catch length-frequency data as a measure of the length structure of the commercial catch is inappropriate.

4.1 Quality of the weight-grade data

There were large differences in the quality of the weight-grade data between the two harvested species. Notably, for blacklip, about half the catch is only “graded” through the superficial, visual inspection of the catch in a crate. Most of the remainder, with the exception of a small volume that is sold frozen, remains ungraded. This approach means that the current blacklip weight-grade data are inaccurate. Consequently, while these data should not be used for assessment of the blacklip fishery, more precise collection of data could aid future assessments. In contrast, data for greenlip are more accurately and rigorously collected. These data have also been obtained in a consistent manner for >20 years. Despite subtle differences in the weight ranges of the same grade among the different processing factories, at each factory the whole greenlip catch from each licence holder is graded and then weighed separately. This methodology provides a reliable estimate of the distribution of each daily catch of greenlip, by each licence, into each grade. Importantly, weight-grade data were available for ~70% of the greenlip catch since 1979. Although current proportions of the total catch for which weight-grade data were available are lower than in previous years, these data are more representative of the fishery and the catch than the catch length-frequency data (Chick *et al*. 2009).

One disadvantage of the weight-grade data is its low resolution. This problem arises because there are only three grades, and Grades 1 and 2 span a broad range of individual meat-weight values. In future years, this problem could be overcome by either increasing the resolution of the grading system or obtaining the individual greenlip weights from the entire catch or a representative sub-sample of the graded catch. Implementation of the latter approach could include consideration of investment in automated weighing and grading systems into the processing facilities. Nevertheless, despite this current disadvantage, the manner in which these data are

obtained, and high degree to which they appear representative of the fishery suggest that the weight-grade data can aid in assessment of the greenlip stocks in the WZ.

4.2 Use of the weight-grade data to aid fishery assessment

The weight-grade data have the potential to aid assessment of the greenlip stocks in the WZ in two ways. Firstly, the weight-grade data could be used, as they were here, to estimate the maximum number of greenlip harvested and, in turn, their minimum mean weight. In concert with total catch, estimates of the number of individuals harvested provide another, direct measure of resource extraction. This information is rare in abalone fisheries. However, while the current data permit estimation of the maximum number of greenlip harvested, their low resolution prevents estimation of more usful, alternative counts (*e.g.* estimated actual number). Improving the estimate of mean weight, and hence the estimates of total number, could provide informative indicators for the fishery and significantly improve any future stock assessment modelling (Mc Garvey *et al*. 1997, 2005; McGarvey & Matthews 2001). As described earlier, this problem could be overcome by weighing a representative sub-sample of individual greenlip from the catch throughout the fishing year.

Secondly, the weight-grade data provide a direct measure of the proportions of the catch within each of the three grades. While these data can be aggregated up to the scale of the Region A fishery, they are probably more usefully employed at smaller spatial scales, that better represent the scales of abalone populations (Prince 2005; Saunders & Mayfield 2008). However, interpreting temporal trends in these data is complicated by a range of factors, including the potential targeting of larger, legal-sized greenlip, variable recovery weights and seasonal effects. Interpretation is also made difficult by the absence of robust catch-sampling data. For example, in FA 9, the percentage of Grade 1 greenlip has decreased sharply since 2006, to the lowest level since 1993. That reduction was driven by decreases in the percentage of Grade 1 greenlip from January to March. These data suggest that (1) fishers have targeted smaller, legal-sized greenlip; (2) the mean size and/or weight of greenlip in the commercial catch has decreased; (3) recovery rates have reduced in recent years; and/or (4) a combination of these factors has resulted in the observed trends. Data from commercial catch sampling suggest that the mean length of greenlip in the commercial catch has increased over recent years. Similarly, fishery-independent surveys in FA 9 indicate no change in the mean length of legal-sized greenlip (Chick *et al*. 2009). In combination with recent market demand for larger greenlip (Jim

George, WAP, personal communication), these length data suggest that the most plausible biological reasons for the observed reduction in the percentage of Grade 1 greenlip from FA 9 are declines in the mean weight (possibly through the harvest of 'flat' rather than 'dome' shelled abalone) and recovery rate. While it is known that recovery rates vary seasonally and spatially (Rodda & Mayfield 2002), the biological and/or environmental drivers for variability are poorly understood. Nevertheless, distinguishing among these plausible reasons was important because the observed decline has had "ripple" effects into existing fishery Performance Indicators, such as catch-per-unit-effort and mean daily catch (see Nobes *et al*. 2004), that have been observed in this FA since 2006 (Chick *et al*. 2009). Notably, this analysis highlights the necessity of robust, representative, catch-sampling data – especially given the absence of a relationship between the weight-grade and shell-length data.

4.3 Use of the weight-grade data as a measure of length structure

Replacement of the current commercial catch-sampling program in the WZ with the use of the weight-grade data for stock assessment would require the weight-grade data to be an appropriate surrogate for the catch length-frequency data. The analyses undertaken in this report provide no evidence of a functional, strong relationship between these two variables. The correlation index, which reflects the amount of variability in mean shell length accounted for by the proportion of Grade 1 greenlip in the commercial catch, was very low (and <0.3) in all of the examples considered. Notably, the relationships between these two variables were rarely improved when the two principal confounding factors, season and location, were taken into account. This problem extended to the smallest spatial and shortest temporal scales considered. The absence of strong, predictable relationships between these two data sets suggests that the use of the current weight-grade data as a measure of the length structure of the commercial catch is inappropriate.

There are at least two reasons for the poor relationships between these data sets. Firstly, shell length and bled-meat weight are not highly correlated. Although the strength of these relationships did improve when considered at finer spatial and temporal scales, a large proportion of the data were distributed within a narrow meat-weight range that spanned a broad range of shell lengths. Thus, a range of meat-weight values could be obtained from greenlip with the same shell length and a single meat-weight value could be obtained from greenlip with a wide range of shell lengths. Secondly, the weight-grade categories are coarse. Consequently, there was

a broad range and considerable overlap of potential greenlip lengths within each of the three weight-grade categories. This analysis was based on all available morphological data that included the confounding influences of sampling time and location. While improvement in these relationships with these factors removed suggests the importance of obtaining these relationships across numerous locations and seasons, the lack of a strong relationship between shell length and weight-grade data indicates that any improvement observed is likely to be minimal.

4.4 Summary, conclusions and future research needs

Evidence presented in this report suggests the blacklip weight-grade data are inaccurate and unreliable and should not be used for assessment of the blacklip fishery. However, the high quality of the weight-grade data for greenlip, in conjunction with the high degree to which it represents the catch and fishery, suggest these data are suitable for aiding stock assessments of this species in the WZ. Trends in the weight-grade data can be interpreted, and/or converted into estimates of the number of greenlip harvested and their associated mean weight. The consistency with which greenlip harvested from both Regions A and B in the WZ are processed suggests that the greenlip weight-grade data may also be useful for assessment of the stocks in Region B.

Interpreting trends in the weight-grade data appears heavily reliant on robust, catch length-frequency data. In association with the finding that greenlip weight-grade data are not a suitable replacement to the catch length-frequency data as a measure of the length structure of the commercial catch, this emphasises the need for an appropriate catch-sampling program for this fishery (Andrew 1996; Andrew & Chen 1997). Measures from the length structure of the commercial catch suggest the current sampling program is insufficient to provide accurate and precise estimates to quantify biologically significant temporal changes in these measures, and development of a representative sampling regime remains a high priority (Chick *et al*. 2009). This approach would allow the weight-grade data to be used in conjunction with data on the length-frequency distribution of the catch to aid stock assessment.

Overcoming the low resolution of the weight-grade data would be advantageous. This could be most easily achieved by obtaining the individual greenlip weights from a representative sub-sample of the graded catch. Implementation of this approach could include consideration of automated weighing and grading systems.

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