Accuracy of at-sea commercial size grading of tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in the Australian northern prawn fishery

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The size-frequency distribution of the commercial catch is often used as the basis of fisheries stock assessments (Pauly and Morgan, 1987; Gulland and Rosenberg, 1992) because most dynamic processes of populations (growth, survival, recruitment) are reflected in changes in this distribution. The data are generally collected, often at great expense, by sampling the catch at landing sites and markets, or onboard fishing vessels.

Size-frequency distributions of prawns (*Penaeus esculentus* and *P. semisulcatus*) can also be obtained from fish processors, who grade landings by size. These data are easier and cheaper to obtain than research samples, but unfortunately they are also considered less accurate and lack spatial information. However, they have been used in stock assessment of prawns in Kuwait (Jones and van Zalinge, 1981) and Malaysia (Simpson and Kong, 1978).

It is often difficult to relate size data obtained from a processor to time and place of capture of the prawns, but this is not the case when the product is packed onboard, as in Australia's northern prawn fishery (NPF).

Trawler operators in the NPF have voluntarily recorded size composition since 1985, when provision for this was made in operators' daily logbooks (between 30% and 45% of the tiger prawn catch reported in the logbooks contain size information). These books are therefore the most comprehensive source of information on the spatial and temporal size distribution of the commercial catch of the NPF. Present assessments of the fishery are based on deterministic growth and deterministic seasonal recruitment patterns (Wang and Die, 1996) and do not use size-structured data. If available, these data would help relax the assumption of deterministic recruitment and improve current stock assessments of the NPF.

Before the size data recorded in the logbooks can be used, however, the accuracy of size grading at sea needs to be assessed. This paper examines the accuracy of grading tiger prawns, by using data collected from a private firm, A. Raptis and Sons, that operates a large modern processing factory that regularly assesses the onboard grading of product purchased from NPF trawler operators.

Although the work presented here relates specifically to the NPF, the practice of onboard size grading is widespread in other fisheries around the world. Therefore our methods have potential application to other fisheries.

Methods

At-sea commercial grading procedures

Prawns landed from the NPF are size-graded at sea because both the demand and price structure differ for prawns of different sizes. Commercial sizes are based on the number of prawns of the same size per unit of weight (per pound), and the sizes are then grouped in a range to constitute a commercial grade. For example, "9 to 12 grade" means prawns in a range of sizes individually equivalent to between 9 and 12 per pound.

The size grades (especially for the larger sizes) used for tiger prawns are often more precise than those used for other species, and the grades selected by fishermen at sea vary with operator, pack size, and target market. For this project we examined the data for the two pack sizes that were most commonly used during 1993 and 1994: small packs (3 kg) and large, variable weight (12–15 kg) packs.

Small packs Since the early 1990s, the use of accurate digital scales on many vessels has improved the accuracy of procedures for packing prawns into 3-kg or smaller packs, as well as into more conventional larger packs. The sensitivity of

these digital scales also makes it possible to pack in more precise grades of prawns.

Prawns for these small packs are initially sorted by eye by experienced crew, and many are verified by individual weighing. Those prawns that fall outside a particular size grade are removed and the remainder are graded according to corresponding count-per-unit-of-weight tables.

Large packs   Prawns for onboard grading into the large packs are sorted by eye into groups of about the same size (occasionally by counting the number into a unit of weight [often a pound measured on analogue scales] and grouping them accordingly). Very large and very small prawns are removed and regraded.

Quality control assessment in the factory—source of data for analysis

A. Raptis and Sons process tiger prawns caught by their own large fleet of trawlers working in the NPF, as well as prawns purchased from other fishermen operating in the same area. The company randomly checks the quality of the packs entering its factory, including the accuracy of the grading.

Packs for quality-control assessment were selected at random for every vessel and from all consignments entering the factory. All packs were clearly marked with the vessel's name, the prawn species group, the grade of the prawns, and the date caught.

The selected samples were thawed individually. For the small packs, net weight was recorded, and size grading was checked by counting all prawns from each pack and averaging the count. Large and small prawns that did not fit the grade category were selected by eye, weighed, and graded individually, and the percentage by weight and the true grade of these prawns were recorded along with the percentage of those correctly graded.

With the large packs, a variable 2.5–3 kilogram sample of prawns was randomly taken from each pack, counted, and checked as above. The percentage by weight and the true grade of incorrectly graded prawns in the sample were recorded.

Categorical analysis

The results of all factory quality-control checks on both the small and large packs between mid-1993 and the end of 1994 were examined. Over this time, samples from 51 of the 127 boats that fished different areas in the NPF had been taken. We split the data into three time periods to find out whether the accuracy of grading early in the year differed from grading

Table 1

Commercial size grades (*) used in grading and quality-control assessments of tiger prawns for two different pack sizes. Also shown are the ranges of carapace lengths (mm) for each size grade.

Grade (prawn count (per lb)	Carapace length (mm)	Small pack	Large pack	Quality control
Under 6	>46	*	*	*
6 to 8	46–42	*	*	*
Under 10	>39		*	
9 to 12	41–36	*	*	*
10 to 15	38–33		*	
13 to 15	35–33	*	*	*
16 to 20	32–30	*	*	*
10 to 20	38–30		*	
Over 20	<29	*		
21 to 25	29–28		*	
26 to 30	27–26		*	
21 to 30	29–26		*	*

that took place later in the year when smaller prawns recruited to the fishery. Period one was from July to December 1993, period two from January to June 1994, and period three from July to December 1994.

Data from the large packs, where the grades used were not the same as those for the small packs, were omitted from the analysis because they could not be compared directly. The commonly used size grades for both pack sizes are shown in Table 1, as well as the equivalent carapace length of the prawns.

The number of prawns (n) contained in the small packs was recovered by converting the net weight of the pack to pounds (weight in kilograms divided by 0.45359), and then by multiplying by the count-per-pound derived from the quality-control inspection. The number of misgraded prawns (r) in the small packs was estimated by multiplying the number of prawns in the sample by the percentage misgraded in that pack. The numbers misgraded for each period and each size grade were analyzed by fitting binary regression models by means of iterative weighted least squares. The number of misgraded prawns was assumed to have a binomial distribution:

$$Pr = \binom{n}{r}\pi^r(1-\pi)^{n-r}, \qquad (r=0,\ 1...n)$$

with P(misgraded) $= \pi$ and P(correctly graded) $= 1 - \pi$. The probability π was modelled in terms of the log-odds or logistic transformation ($\log(\pi/(1 - \pi))$). The computed deviance statistic, approximately distributed as chi-squared, was used in goodness-of-fit tests.

It was not possible to recover the total number of prawns in the large packs because the variable sample weight (between 2.5 and 3 kilograms) was not recorded in the Raptis database. Therefore estimates of the number of misgraded prawns were derived only for the samples and not for the whole pack. Because these samples were randomly chosen, it was possible to assume that the assessment of grading accuracy was representative of the grading accuracy for the whole pack.

For the large pack samples, the proportion misgraded had a mean (Eq. 1) and variance (Eq. 2) over the different samples

$$\text{Mean} = \pi \qquad (1)$$

and

$$Variance = E\left(\frac{\pi(1-\pi)}{n}\right), \qquad (2)$$

where π = the misgrading probability; and
n = the sample size.

Because the weight range of the samples was small, it was possible to estimate the expected reciprocal sample size

$$\left(E\left(\frac{1}{n}\right)\right)$$

(Eq. 4) by integrating over the sample weight range (assumed for mathematical convience to be uniformly distributed between 2.5 kg and 3 kg) (Eq. 3):

$$E\left(\frac{1}{n}\right) = \int_{2.5}^{3} \frac{0.45359}{\rho w} 2\, dw \qquad (3)$$

$$= \left(\frac{0.45359 \times 2 \times \ln(3/2.5)}{\rho}\right) \qquad (4)$$

where ρ = count per pound;
0.45359 kg = 1 lb; and
w = sample weight.

The relationship between Equations 1 and 2 here is the same as that for the binomial distribution; therefore the data were analyzed by fitting binomial regression models.

The size of misgraded prawns was examined to determine whether misgrading was a result of including small prawns in large grades or vice versa. The number of size grades in which misgrading occurred was also assessed.

Results

Small packs

Of the 21,443 tiger prawns in 293 small packs that were assessed, an estimated 1937 (9%) prawns in 229 packs were misgraded. There were significant changes in the proportion misgraded with both period of catch and size grade, with higher proportions of misgraded prawns in the small size grades (Table 2; Fig. 1A). Overall, grading accuracy tended to increase over the 18 months examined (Fig. 1A).

The size of the misgraded prawns over the different grades did not show a consistent pattern, but generally larger prawn grade packs tended to contain smaller prawns (Fig. 1A). The proportion of misgraded prawns that should have been in smaller grades, however, was

1 not constant over all size grades within each period of catch (Table 3; Fig. 1A);
2 not the same for each size grade over the three periods examined (Table 4; Fig. 1A).

Of the misgraded prawns, 99% were size-graded either one grade larger or one grade smaller. Only grades 9 to 12 and 16 to 20 contained prawns misgraded by as much as two size grades, with no more than 2% so misgraded. Because there was no larger grade, prawns misgraded in the under 6 size, were graded as 6 to 8.
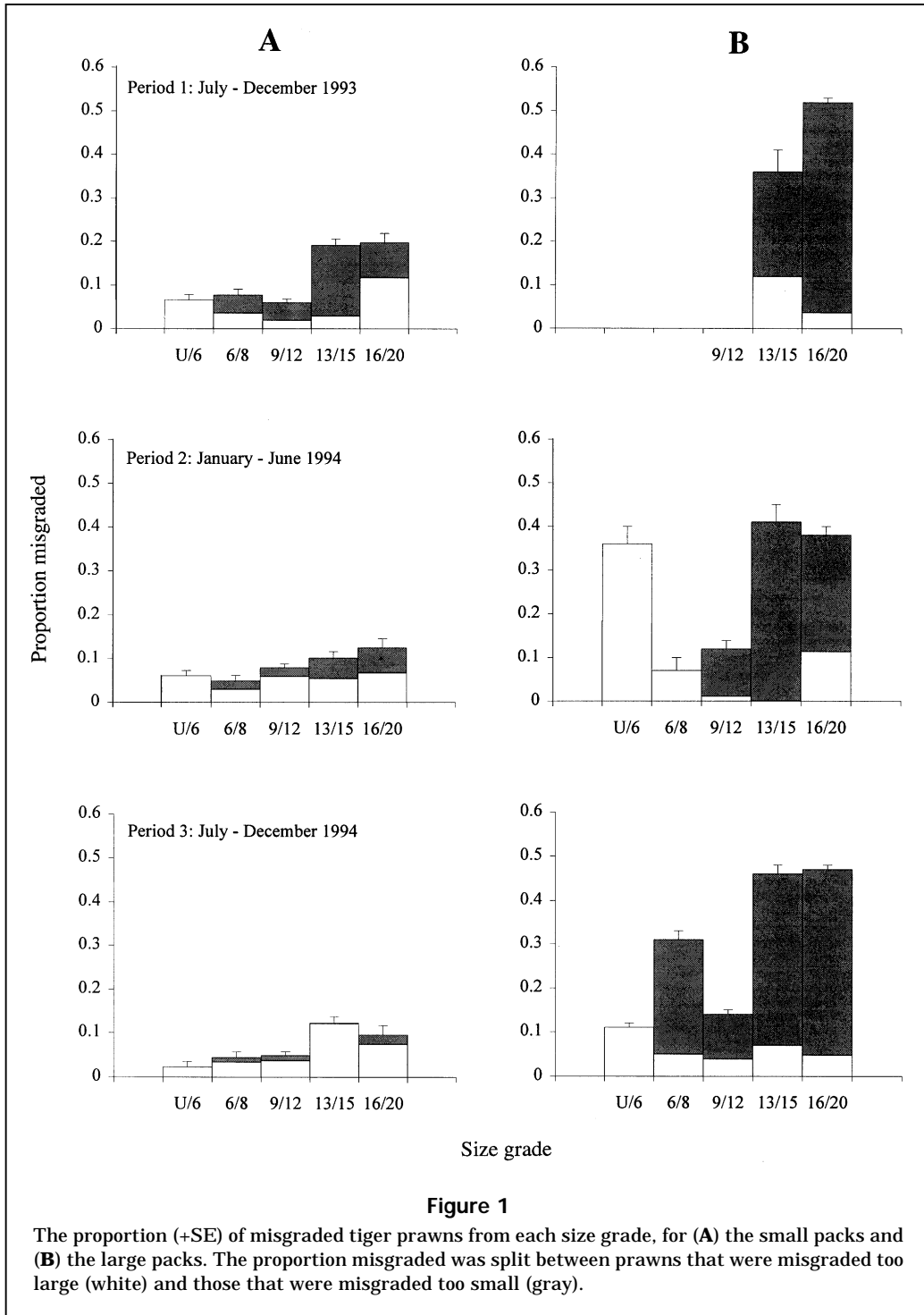
If the proportion of prawns graded size i by fishermen at-sea that were actually size j (i, j=1 for under 6, 2 for 6 to 8, 3 for 9 to 12, 4 for 13 to 15, 5 for 16 to 20, and 6 for over 20 prawns per pound) obtained from the sample data are denoted by θ_{ij}, then the proportions, p_i, of all prawns graded as size i at-sea can be adjusted with the equation:

$$\sum_{i=1}^{5} p_i \theta_{ij} \qquad (5)$$

to give a corrected grade size distribution (j=1, 2, …, 6). Shown in Table 5 are the corrected distributions compared with at-sea grading for the small packs. The adjustments can be seen to be quite modest, and the at-sea gradings provide a reliable assessment of the size distribution.

Large packs

Samples containing an estimated 8210 tiger prawns from 124 large packs were assessed. Of these samples, an estimated 2914 (35%) prawns from 107 packs were misgraded. Again, there were significant

Figure 1

The proportion (+SE) of misgraded tiger prawns from each size grade, for (**A**) the small packs and (**B**) the large packs. The proportion misgraded was split between prawns that were misgraded too large (white) and those that were misgraded too small (gray).

changes in the proportion misgraded with period of catch and size grade, with significant differences in the proportion misgraded with period of catch, and generally higher proportions of the smaller size grades misgraded (Table 2; Fig. 1B).

There was a tendency for smaller-prawn grade packs to contain larger prawns (Fig. 1B). The pro-

portion of misgraded prawns that should have been in a larger-size grade, however, was

1   not constant over all size grades, within any one period of catch (Table 3; Fig. 1B);
2   not the same for each size grade, over the three periods examined (Table 4; Fig. 1B).

Table 2
Binomial model fits for each period of catch (1: July–December 1993, 2: January–June 1994, and 3: July–December 1994) and pack-size combination. (a, b, c) denote groups of size grades with no significant differences in the proportion of misgraded prawns.

Pack size	Time period	Size grade					χ^2	df	P
		Under 6	6 to 8	9 to 12	13 to 15	16 to 20			
Small		a	a	a					
	1				b	b	1.517	3	0.68
		a	a						
	2			b			0.476	1	0.52
					c	c			
		a							
	3		b	b			3.244	2	0.20
					c	c			
Large				a					
	1				b		[1]		
						c			
			a	a					
	2	b			b	b	2.695	3	0.44
			a	a					
	3		b				2.892	2	0.24
					c	c			

[1] Zero degrees of freedom.

Table 3
Chi-squared statistics for the constant model of misgraded prawn size in each period of catch (1: July–December 1993, 2: January–June 1994, and 3: July–December 1994), for both small and large packs. * $P < 0.0001$

Period	Small pack	Large pack
1	45.088 *	17.963 *
2	45.916 *	55.701 *
3	32.915 *	83.060 *

Table 4
Chi-squared statistics for the constant model of misgraded prawn size in each size grade for both small and large packs. * $P < 0.0001$, ** $P = 0.13$, *** $P = 0.03$.

Size grade	Small pack	Large pack
6 to 8	4.1494 **	14.408 *
9 to 12	33.271 *	4.7639 ***
13 to 15	220.58 *	27.039 *
16 to 20	16.159 *	106.83 *

Of the prawns misgraded, 92% were sized either one grade larger or smaller. Of those misgraded in the 16 to 20 grade, 11% were misgraded by as much as two grades, whereas less than 2% were so misgraded for the other size grades.

The misgrading proportions can again be used in Equation 5 to obtain the at-sea grade-size distribution for these large packs. Shown in Table 5 are these corrected distributions compared with at-sea gradings; here the adjustments can be seen to be more substantial than those for the small packs, particularly for the smaller grades 13 to 15 and 16 to 20 prawns per pound, owing to the tendency of the fishermen to classify the prawns to smaller size grades.

Discussion

Our analysis indicates that small prawns are graded less accurately than large ones. Given that the length

Table 5

Size-grade distributions, expressed as proportions, from grading at sea and adjusted according to Equation 5.

Size grade	Period 1 (July–December 1993)		Period 2 (January–June 1994)		Period 3 (July–December 1994)	
	at-sea	adjusted	at-sea	adjusted	at-sea	adjusted
Small packs						
Under 6	0.15	0.14	0.012	0.015	0.098	0.097
6 to 8	0.16	0.17	0.19	0.19	0.11	0.11
9 to 12	0.30	0.33	0.31	0.30	0.32	0.30
13 to 15	0.26	0.23	0.28	0.28	0.24	0.23
16 to 20	0.13	0.11	0.21	0.20	0.24	0.24
Over 20	0	0.015	0	0.014	0	0.018
Large variable packs						
Under 6	—	—	0.11	0.071	0.12	0.15
6 to 8	—	—	0.059	0.11	0.17	0.15
9 to 12	0.079	0.12	0.12	0.16	0.22	0.28
13 to 15	0.055	0.43	0.10	0.22	0.14	0.21
16 to 20	0.87	0.42	0.61	0.38	0.36	0.20
Over 20	0	0.030	0	0.069	0	0.017

range corresponding to the small commercial grades is narrow (Table 1), it is perhaps not surprising that small prawns tend to be misgraded more frequently. Alternatively the grading of small prawns may be less accurate because they are less valuable than large prawns and therefore less time is spent on grading each individual.

In small packs, misgraded prawns were generally graded into larger categories, whereas in large packs, those misgraded were generally placed into smaller categories.

Incorrectly graded prawns from both pack sizes, however, tend to be incorrectly graded by only one size category, so that all prawns were graded to within three and six millimeters carapace length of their corresponding size grade.

The high proportion of landings graded and the accuracy of some of this grading suggest that size information contained in the NPF logbooks could be valuable for stock assessment. Most prawns sold in small (3-kg) packs have been accurately graded by fishermen, and these gradings could be used as a reasonable measure of the length-frequency distribution of the prawns. However, prawns sold in larger (12–15 kg) packs are graded less accurately, especially for the smaller grade sizes, and it is recommended that data from quality inspections be used to correct fishermen's grade-size distribution.

Although the work outlined in this paper was done for the Australian northern prawn fishery, similar analyses using similar methods could be carried out for other fisheries if comparable data on size gradings were available.

Acknowledgments

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