New Zealand Fisheries Assessment Research Document 97/29

Calculation of the recruited biomass of orange roughy on the northwest Chatham Rise using the 1996 Graveyard Hill egg survey (TAN9608)

R. I. C. C. Francis, M. R. Clark, and P. J. Grimes
NIWA
PO Box 14901
Wellington

December 1997
Ministry of Fisheries, Wellington

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N.Z. Fisheries Assessment Research Document 97/29. 18 p.

1 Executive Summary

In voyage TAN9608, *Tangaroa* carried out stratified random trawl and plankton (egg) surveys on the northwest Chatham Rise between 10 June and 12 July 1996 with the aim of estimating the biomass of recruited orange roughy in this area. The trawl survey covered a wide area (178 E – 178.5 W, 700 – 1300 m) but the plankton survey was restricted to the only known spawning ground in this area, near the Graveyard hill (42° 45.7′ S, 179° 59.4′ W).

From the trawl survey (and additional data from an earlier survey in the area) the ratio (by weight) of recruited (SL ≥ 32 cm) fish to spawning females, S, was estimated to be 2.29 (*c.v.* 10%).

From fecundity and gonad stage data it was estimated that, during the plankton survey, the rate of decline of fecundity of spawning females, D, was 799 eggs kg^{-1} day^{-1} (*c.v.* 12%).

From the plankton survey the daily production of eggs, N_0, was estimated to be 17 billion per day.

Biomass estimates of 21 000 t (for spawning females) and 49 000 t (for recruited fish) were calculated from the above values. It was not possible to estimate *c.v.*s for these estimates.

2 Introduction

This document describes the estimation of the recruited biomass of orange roughy on the northwest Chatham Rise using the daily fecundity reduction method (Lo *et al.* 1992, 1993) as modified by Zeldis *et al.* (1997a). Recruited biomass, B_{rec}, is estimated using the formula

$$B_{rec} = B_{spf} S = \frac{N_0}{1000D} S$$

where B_{spf} = biomass of spawning females (t)
N_0 = daily egg production (eggs day^{-1})
D = mean daily fecundity (eggs kg^{-1} day^{-1}) for spawning fish
S is an estimate of the ratio B_{rec}/B_{spf}, and
the factor 1000 converts kilograms to tonnes.

The primary data used in the analysis were collected on voyage TAN9608 on the northwest Chatham Rise between 10 June and 12 July 1996 (Clark 1996, Grimes 1996). On this voyage, two stratified random surveys were carried out: a trawl survey of the area between 178 E and 178.5 W and 700 m to 1300 m (12–21 June), and a plankton survey of the spawning area near the Graveyard Hill (42° 45.7′ S, 179° 59.4′ W) (20 June – 11 July). Gonad stage data and fecundity samples were collected during the trawl survey, and also from some trawling during the plankton survey.

Thus the voyage resulted in three distinct data sets, each associated with one of the above parameters:

- random trawl survey data (S)
- fecundity and gonad stage data (D)
- plankton survey data (N_0)

The analyses of these data sets are described in Sections 3, 4, and 5 below.

It was also intended to apply the annual egg production method (Saville 1964) but the data proved inadequate. However, the estimation of some parameters needed for this method (date of start and end of spawning and initial fecundity) is described below in the appropriate sections.

3 Estimation of S

The ratio S is used to convert the biomass of females spawning at the Graveyard to that of all recruited fish (SL ≥ 32 cm) in the northwest Chatham Rise. Thus it allows for recruited females that did not spawn, and females that did but were under 32 cm (very few), as well as the sex ratio.

For the purposes of this analysis, the northwest Chatham Rise stock area is taken as being approximated by the area covered by the 1994 trawl survey (TAN9406), i.e., between 750 and 1500 m depth and between 175 E and 177.5 W (note, the latter longitude is the western boundary of the spawning box). However the 1996 trawl survey (TAN9608) covered a much smaller area (Figure 1). For this reason S was calculated by taking the ratio calculated from the 1996 data, S_1, and scaling this up to the whole area using two ratios calculated from the 1994 survey (S_2, S_3): $S = S_1 \times (S_2/S_3)$.

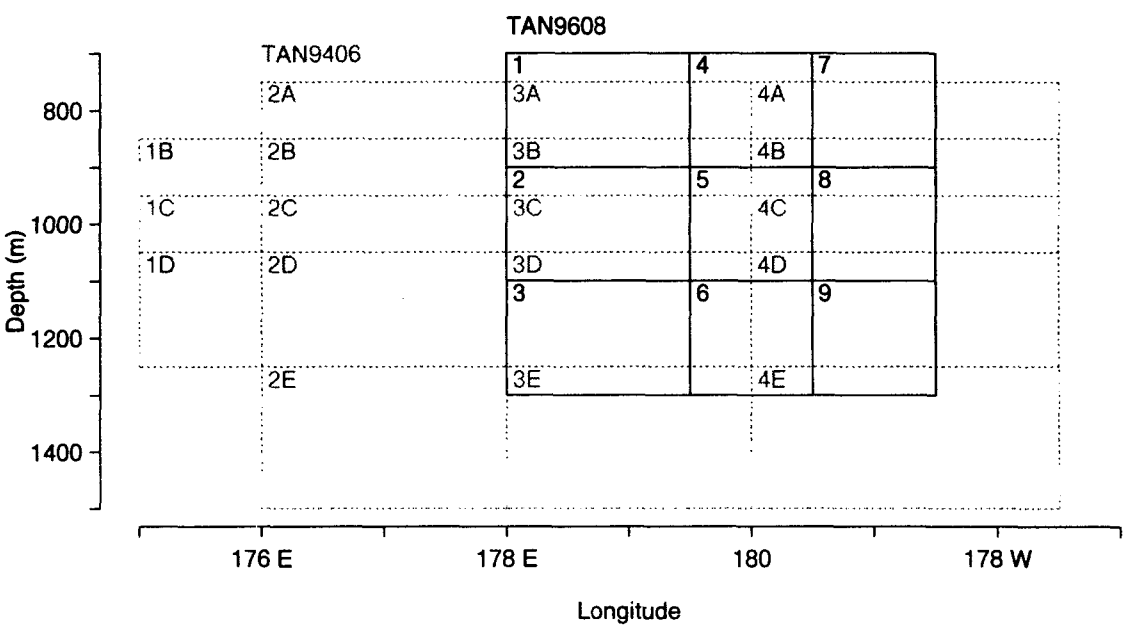

Figure 1. Stratum boundaries for two surveys on the northwest Chatham Rise: TAN9608 (solid lines), and TAN9406 (broken lines). Hill strata (all near longitude 180) are not shown. Note that eastern boundary of TAN9406 strata is the western boundary of the 'spawning box'.

The estimates, and the data used in calculating them, are shown in Table 1. The method of calculation followed Zeldis *et al.* (1997a).

Table 1: Estimates of S, the ratio (by weight) of recruited fish over spawning females

Quantity	Data	Value	*c.v.* (%)
S_1	All TAN9608	2.01	10
S_2	All TAN9406	2.22	5
S_3	TAN9406 strata approximating those in TAN9608*	1.95	5
S	$S = S_1 \times (S_2/S_3)$	2.29	10

* strata 3A–3D, 4A–4D, plus hill strata (*see* Figure 1).

4. Fecundity and Gonad Stage Data

These data came from a series of 16 trawls on Graveyard Hill carried out during the trawl and plankton surveys of TAN9608, plus one trawl (on 14 July) on a subsequent voyage (TAN9609). At each tow a random sample of fish was sexed and staged macroscopically. In all but one tow ovaries were taken from a subsample of the staged fish for estimation of fecundity and histological analysis.

Fecundity and gonad stage data were also gathered from trawls away from Graveyard Hill, but these data were not used in the present analysis.

4.1 Start and End of Spawning

To develop annual egg production biomass estimates it is necessary to define dates for the start and end of spawning. This was done as for the East Cape survey (Zeldis *et al.* 1997b): June 15 (start of spawning) was estimated to be the day at which the proportion ovulated first exceeded 0.05; July 8 (end of spawning) was the estimated date at which the proportion spent reached 0.95 (Figure 2).

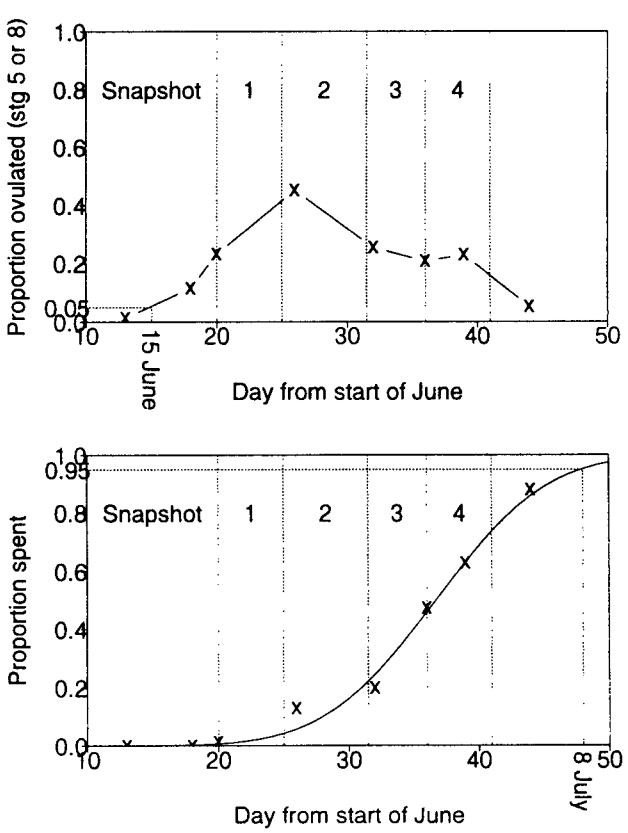

Figure 2: Illustration of the calculation of the dates at start (15 June) and end (8 July) of spawning (see text for details). The line in the lower panel is a probit function fitted to the data.

4.2 Turnover

After the 1995 plankton surveys at East Cape and Ritchie Bank (Zeldis *et al.* 1997b), a comparison of trends in the percentage of running ripe females suggested that turnover had occurred in both Ritchie Bank surveys (1993 and 1995), but not at East Cape. It was inferred that, on the Ritchie Bank, spent females had left the survey area before all spawning had finished, leading to a very high percentage of running ripe females at the end of both these surveys. At East Cape, in contrast, the percentage of running ripe females peaked at about 50 and then declined as the percentage spent increased.

The pattern in the Graveyard survey was similar to that at East Cape (Figure 3). Thus it is concluded that there was no significant turnover in the 1996 survey.

One reason suggested for there being turnover on the Ritchie Bank but not at East Cape was that there was commercial fishing activity during both Ritchie Bank surveys but not during the East Cape survey. Such activity may have encouraged spent fish to leave the area earlier than they would otherwise have done. It is noteworthy that there was almost no commercial fishing at the Graveyard during the 1996 survey.

To correct the Ritchie Bank survey biomass estimates for turnover it was assumed that the mean active time (MAT, the average time females spend in the active stages 4, 5, or 8) in this area was the same as at East Cape (i.e., 18.6 d). (The MAT was estimated as the time between the date when half of spawning females were stage 3 and that when half were stage 6 [i.e., spent]). With this assumption, it was estimated that spent females left the survey area about 1.6 d after becoming spent. We now have a second estimate of MAT from the Graveyard survey: 25.7 d (Figure 4).

4.3 Correction of Fecundity Counts using Chorion Counts

In preparation for orange roughy fecundity counts a weighed sample (between 5 and 6 g) was taken from each pair of ovaries and soaked in KOH to free the eggs from the matrix. The freed eggs were then filtered through a 0.7 mm sieve to remove matrix fragments and small oocytes (stages 1 and 2). What remained on the sieve was then stained and counted.

For a small sample (n = 43) of ovaries, the material that passed through the sieve was retained and examined. Sometimes this material contained a large number of chorions ("egg shells"). It is assumed that each chorion corresponds to an egg that should have been counted but was not. Very approximate counts were made of these chorions. These ranged from 0 to 3000 (mean 639). The "incidence" of chorions [(chorion count)/(chorion count + egg count) expressed as a percentage] ranged from 0 to 65% (mean 21%).

There are two possible reasons for the presence of these chorions. Excessive soaking in KOH could have caused some eggs to rupture and the chorions from the ruptured eggs could have passed through the sieve. Also, if spraying (to wash debris through the sieve) was too vigorous this could have been a contributory factor.

Ovary preparation and counting was done by two readers and there was a marked between-reader difference in the counts and incidences of chorions (Table 2). This suggests that there could be a slight negative bias (about 1%) in counts from reader 2 and a much larger negative bias for reader 1 (at least for ovaries of stages 3 and 4). However, these data contain no information about likely bias in counts by reader 1 for stage 5 or 8 ovaries.

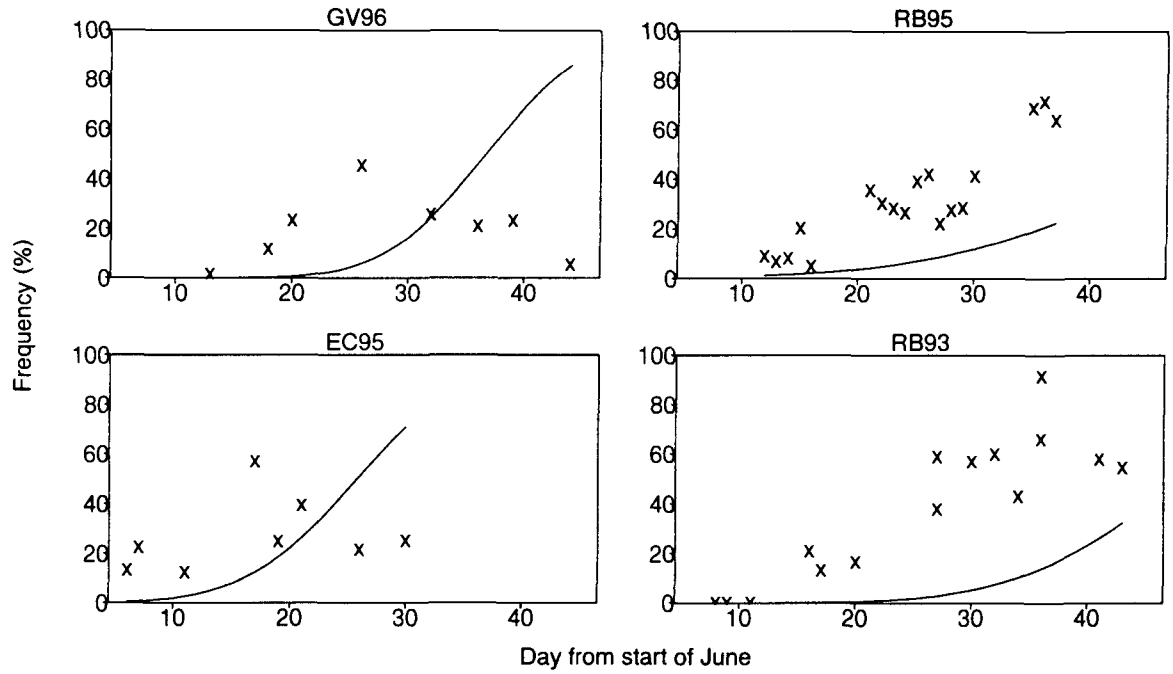

Figure 3: Between-survey comparison of trends in the percent running ripe ('x'), showing how the two Ritchie Bank surveys differ from the present survey and that at East Cape in 1995. The lines are probit functions fitted to percent spent. (All frequencies are for females only).

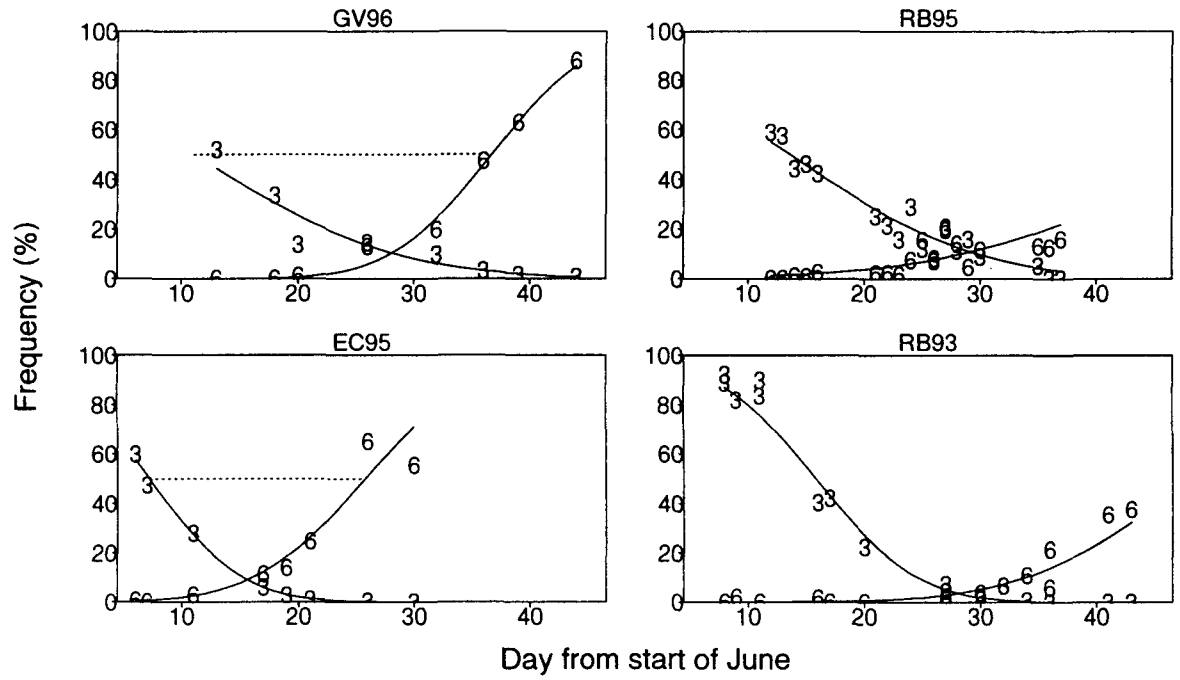

Figure 4: Comparison of turnover data for four orange roughy egg surveys. Plotting symbols show percent frequency of females of stages 3 and 6 for each day that samples were available. Smooth curves are fitted to these data using the turnover model of Zeldis et al. (1997b). For the two surveys for which it is believed that no turnover took place the mean active time is the length of the dotted line (see text for details).

Table 2: Mean count and incidence of chorions by reader and ovary stage. Incidence is the chorion count as a percentage of (chorion count + egg count). n = sample size, '–' = zero sample size

	Reader 1			Reader 2		
Stage	Count	Incidence	n	Count	Incidence	n
3	965	28	21	24	1.8	7
4	777	33	9	8	0.5	4
5	–	–	0	10	2.0	2
All	909	29	30	17	1.4	13

There is also a marked between-reader difference in the median egg counts calculated over all ovaries that were counted (Table 3). Ovaries were assigned to readers more or less at random so, in the absence of bias in the counts (or if the bias was the same for both readers), the expected ratio of the median counts is 1. A ratio greater than 1 is consistent with a small negative bias for reader 2 and a larger negative bias for reader 1.

Table 3: Median count (eggs per gram of sample) and sample size (in parentheses), by reader and stage, for all ovaries that were counted

Stage	Median count(sample size)		Ratio(2/1)
	Reader 1	Reader 2	
3	323 (74)	394 (73)	1.22
4	129 (76)	210 (126)	1.63
5	88 (33)	112 (52)	1.27
8	86 (7)	118 (25)	1.37

Statistical tests were devised to answer two questions about the ratios in Table 3. The first question was, "how likely is it that these ratios differ from 1 solely by chance?" (because reader 2 happened to be assigned ovaries with more eggs). A (1-sided) randomisation test found that the ratio was significantly greater than 1 for stage 3 ($P = 0.007$) and stage 4 ($P < 0.001$) but not for stages 5 or 8. The second question was, "assuming that these ratios differ from 1 because of a between-reader difference in bias, is there any evidence that the true ratio differs by ovary stage?". Bootstrap distributions for the ratio at each stage showed no such evidence (Figure 5). If we assume that this ratio is independent of stage then our best estimate of the ratio is the weighted average of the ratios in Table 3, where the weights are the inverses of the variances of the bootstrap distributions in Figure 5. This estimate is 1.306.

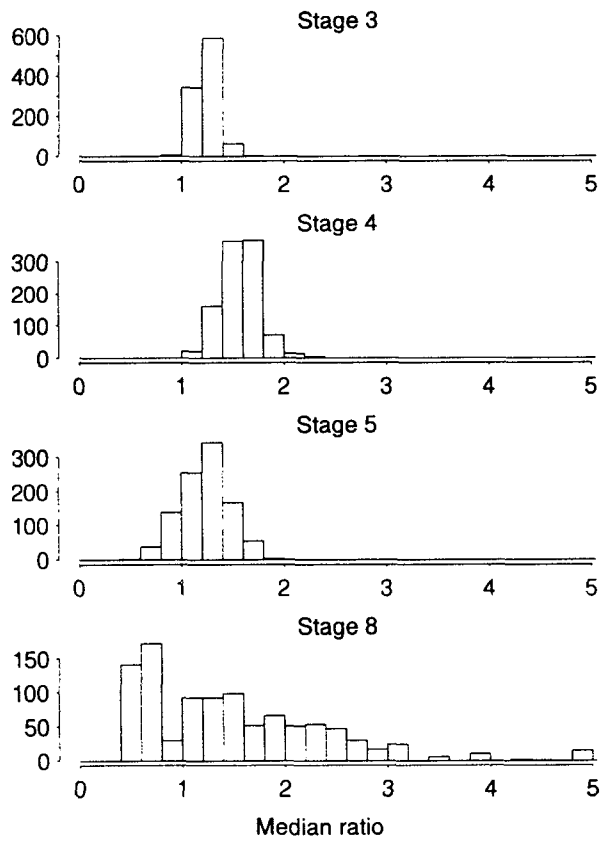

Figure 5: Bootstrap distributions for the ratios in Table 3

On the basis of these results it was decided to use the following procedure to "correct" all fecundity counts. For reader 2, multiply all counts by 1.01 [=1/(1-0.014), where 0.014 is the overall incidence for reader 2 in Table 2]. For reader 1, multiply all counts by 1.32 [=1.306/(1-0.014)].

4.4 Atresia

Histological slides from 196 ovaries were examined for evidence of atresia. In most slides no atretic eggs were found and, overall, less than 1% of eggs were atretic. Thus it was decided there was no need to correct fecundity counts for atresia. (In counting atretic eggs, those with diameter less than 0.7 mm were ignored because they would have passed through the sieve and thus not been counted).

4.5 Pre-Spawning Fecundity

Pre-spawning fecundity is needed for the annual egg production method. The estimated values were markedly lower at Graveyard than for previous surveys, although only one tow was available for the present survey (Table 4).

Table 4: Mean fecundity of stage 3 females early in the spawning season (standard errors in parentheses). Calculated from 5 tows before 12 June for Ritchie Bank 1993; 13 tows before 17 June for 1995 Ritchie Bank; 7 tows before 12 June for East Cape; and 1 tow before 15 June 1996 for Graveyard)

Survey	Total fecundity ('000 eggs/female)		Relative fecundity ('000 eggs/kg)	
Ritchie Bank 1993	53.9	(2.4)	30.7	(1.0)
Ritchie Bank 1995	61.2	(3.1)	32.9	(1.6)
East Cape 1995	44.0	(2.0)	26.5	(1.0)
Graveyard 1996	34.6	(4.1)	22.1	(2.3)

4.6 Daily Fecundity Reduction

Fecundity of the spawning population (as measured by the average number of eggs per kilogram of spawning females) declines during the spawning season as fish develop and release their eggs. The daily fecundity reduction, D (eggs kg^{-1} day^{-1}), was estimated (following Zeldis *et al.*1997a) as minus the slope of the solid line in Figure 6.

The base case estimate of D (799 eggs kg^{-1} day^{-1}, *c.v.* = 12%) was based on the corrected fecundities (*see* Section 4.3). A similar estimate (780 eggs kg^{-1} day^{-1}, *c.v.* = 13%) was obtained when the calculation was restricted to uncorrected counts from reader 2. The estimate using uncorrected counts from both readers was 11% less than the base case value (712 eggs kg^{-1} day^{-1}).

Note that a correction applied to all fecundity counts produces exactly the same effect on D (i.e., a 10% increase in counts produces a 10% increase in D)

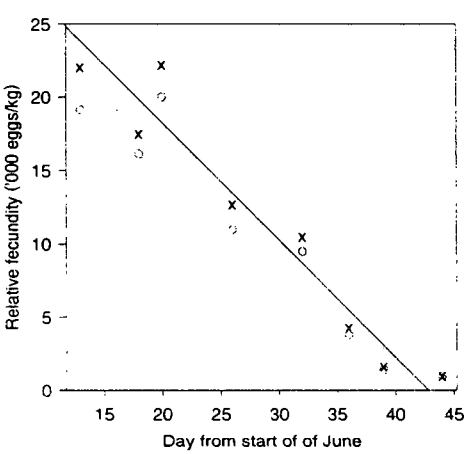

Figure 6: Illustration of estimation of the daily fecundity reduction, D. Each plotted point represents the mean relative fecundity for fish sampled on a particular day ('x' = corrected fecundities; 'o' = uncorrected fecundities). The lines are fitted using a linear regression in which each point is weighted by the size of the gonad stage sample. D is minus the slope of the line.

5. Estimation of Daily Planktonic Egg Production

5.1 Survey Design

The plankton survey consisted of four separate surveys (or snapshots), the first of which was very much a pilot survey. A key issue with these snapshots was to define survey boundaries that are wide enough so as to encompass all spawning activity and the resulting plume of eggs (carried away from the immediate spawning area by water currents) but not so wide that many plankton tows caught no eggs. For this reason, the area covered by the survey, and its stratification, was different for each snapshot as the water currents (and our knowledge of them) changed (Figure 7).

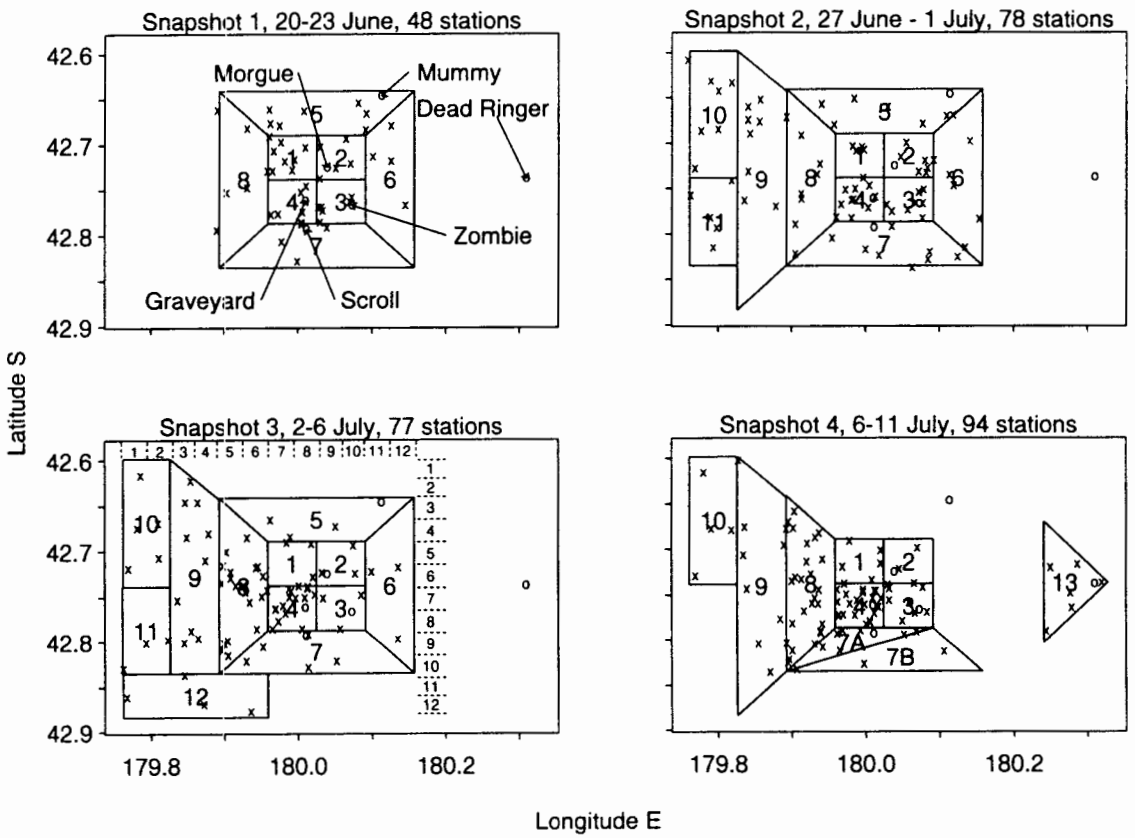

Figure 7: Stratum boundaries and plankton station positions (x) for the four "snapshots" making up the plankton survey. The positions of major hills are marked as 'o'. Also shown, on the lower left panel, are the edges of the 12 latitudinal and 12 longitudinal strips used in investigating the advection of eggs (*see* Section 5.5). Strata 1–4 are squares with sides about 5.4 km.

5.2 Egg Development and Upward Migration

For all the stages of development used in this analysis, orange roughy eggs are positively buoyant. The rate at which they develop, and rise through the water column, depends on the water temperature. The thermal history model of Zeldis *et al.* (1995) and the depth-temperature relationship measured during the survey were used to calculate the age and depth range for each egg stage (Table 5). For this purpose, all spawning was considered to take place at 850 m. For stages 16–25, eggs were assumed to be distributed throughout the mixing layer, which extended from the surface down to 145 m.

As in earlier egg surveys, some young eggs (younger than stage 8) were damaged in the net and

so were not able to be assigned to individual stages. However, it was possible to assign these to one of two composite stages: A (stages 0–3) or B (stages 4–7).

Table 5: Calculated minima and maxima of age (h) and depth (m) for each egg stage, and for the composite stages, A and B. Stage 0 is unfertilised eggs

Stage	Minage	Maxage	Maxdepth	Mindepth
A (0–3)	0	11	850	708.9
B (4–7)	11	21.5	708.9	568.1
0	0	1.8	850	828.7
1	0	5	850	787.3
2	5	8	787.3	747.4
3	8	11	747.4	708.9
4	11	13.8	708.9	671.7
5	13.8	16.4	671.7	635.9
6	16.4	19	635.9	601.4
7	19	21.5	601.4	568.1
8	21.5	23.8	568.1	536
9	23.8	26	536	505.1
10	26	28.2	505.1	475.4
11	28.2	33.2	475.4	404.3
12	33.2	40.2	404.3	303.2
13	40.2	45.9	303.2	215.7
14	45.9	50.8	215.7	139.2
15	50.8	55.1	139.2	70.8
16	55.1	59.3	145	0
17	59.3	63.5	145	0
18	63.5	67.7	145	0
19	67.7	72	145	0
20	72	76.2	145	0
21	76.2	80.4	145	0
22	80.4	84.6	145	0
23	84.6	93.8	145	0
24	93.8	103.1	145	0
25	103.1	112.3	145	0

5.3 Standardisation of Egg Counts

The standardisation from egg counts to egg density (eggs m^{-2}) used the formula

(egg density) = (egg count) x (correction factor).

The correction factor takes into account the mouth area of the net and the volume of water filtered by it. It was necessary to calculate a separate correction factor for each egg stage at each plankton station because the volume of water filtered varied a) from station to station (primarily because of variation in vessel drift during hauling), and b), by depth for each station (mostly because the net path during hauling was not straight). The correction factor for a given egg stage at a given station was calculated as

correction factor = (layer thickness)/(volume filtered in layer)

where "layer" refers to the depth range in which that egg stage is found (*see* Table 5).

The volume filtered within a layer was calculated by multiplying the flow (f_{ij} in m) by the net mouth area (2 m^2). The calculation of flow varied according to the data available and was carried out as following.

1. For snapshots 2–4, depth, time, and water flow were recorded at 10 s intervals on a datalogger mounted in the mouth of the net. Interpolation was used to calculate the flow, f_{ij} (m), and time spent, t_{ij} (s) in the depth layer for egg stage i at station j (flow was averaged over two flow meters).

2. For stations 101–112 (the first 12 stations in snapshot 1) the datalogger recorded only flow and time. However, the Scanmar sensor was mounted on the net, and the shipboard readout from this was used to record the time at 50 m depth intervals during hauling. f_{ij} and t_{ij} were calculated by interpolation from these two sources. The ratio f_{ij}/t_{ij} for the stations considered so far ranged from about 0.4 to 1.6, with a mean value of 1.01, corresponding well with the target hauling rate of 1 m.s^{-1} (Figure 8A).

From these data, the following regression equation was used to relate the flow rate, f_{ij}/t_{ij}, to w_j (the recorded wind speed at station j), and d_i (the mean depth of the ith depth layer)

$$f_{ij}/t_{ij} = 1.07 - 2.10\text{x}10^{-4} d_i + 5.15\text{x}10^{-3} w_j$$

Residuals from this regression are symmetrical with standard deviation 0.17 (Figure 8B).

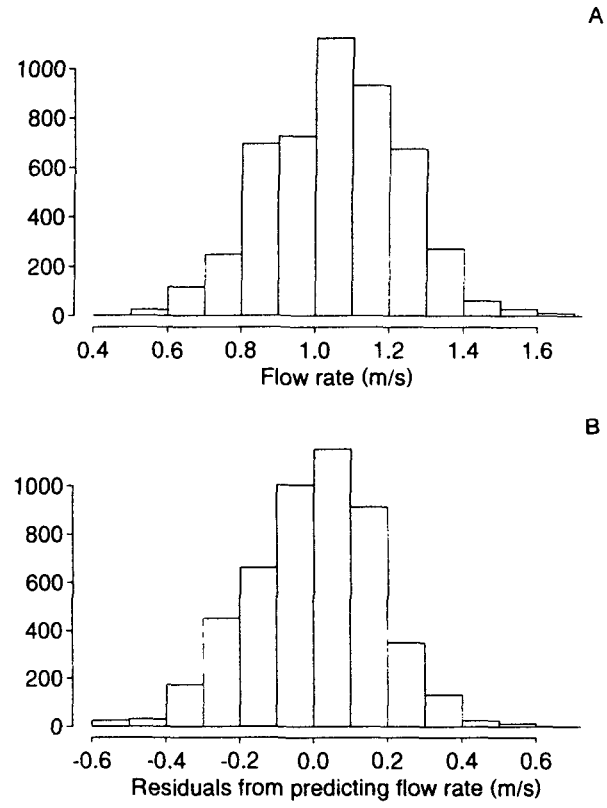

Figure 8: A, Histogram of flow rates during hauling for all plankton stations where the datalogger was used. B, Residuals from the regression estimating flow rate as a function of depth and wind speed (see text for details).

3. At the remaining stations in snapshot 1, only Scanmar data (times at 50 m intervals during hauling) were available. From these data the t_{ij} were calculated. The above regression was used to estimate f_{ij}/t_{ij} from d_i and w_j, and then f_{ij} was calculated as the product of t_{ij} and the estimated f_{ij}/t_{ij}.

This was the first New Zealand orange roughy egg survey which used a datalogger mounted on the plankton net. In earlier surveys the calculation of correction factors involved inferring the water flow and path of the net from ship position data (Zeldis et al. 1997a,b). Thus it is of interest to compare the present correction factors with those from the earlier surveys. In all

interest to compare the present correction factors with those from the earlier surveys. In all surveys the correction factors generally declined as the eggs rose through the water column because of curvature in the net path during hauling. However, the values calculated for the current survey declined more slowly than did those from earlier surveys (Figure 9A). Note that there is considerable between-station variability in correction factors for the same egg stage (Figure 9B).

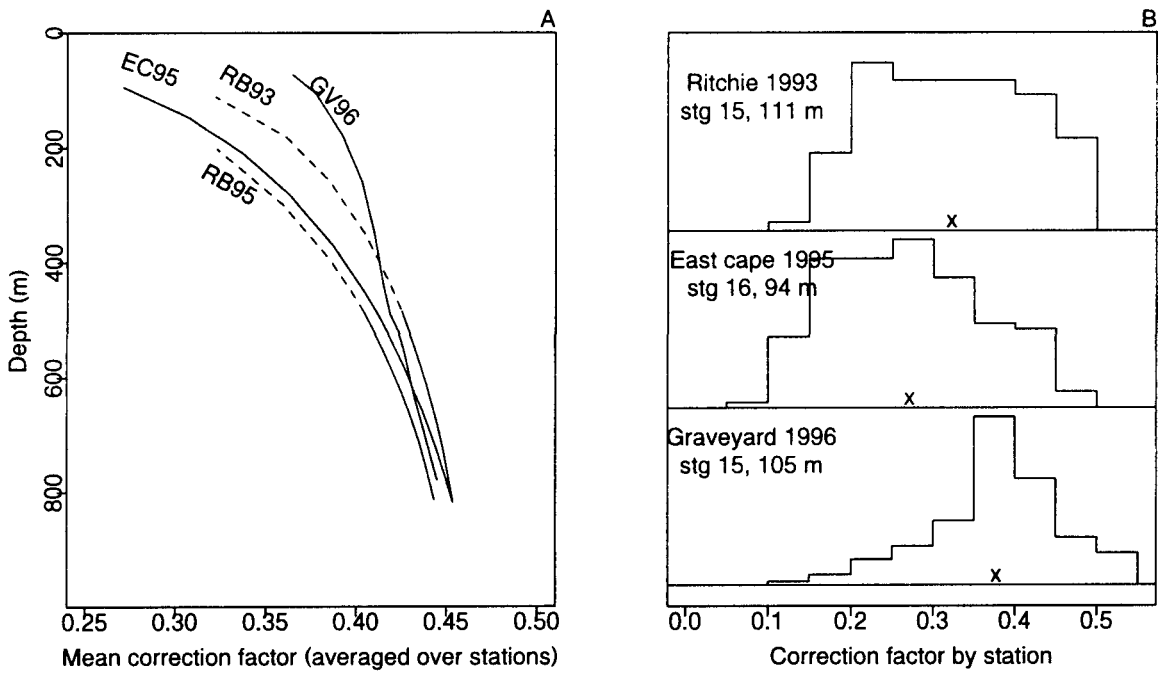

Figure 9: Between-survey comparison of the correction factors that convert plankton egg counts at stage to egg densities. A, Mean correction factor vs depth (correction factors were calculated for each egg stage; the depth plotted for each egg stage is the mean of the depth layer associated with that depth). For the earlier surveys the broken lines indicate egg stages not included in the estimation of biomass. B, Histograms of correction factors estimated for one egg stage from each of three surveys to give an idea of the between-station variability. The stages were chosen so that the mean depths were approximately equal. 'x' marks the mean value for that stage in that survey (corresponding to the top points in the corresponding curves in panel A).

5.4 Calculation of Egg Abundance by Stage

The calculation of egg abundance by stage from egg densities is precisely analogous to the estimation of (absolute) biomass from catch rates in a stratified random trawl survey. Thus,

$$E_{ij} = 10^6 \sum_k \left(A_k D_{ijk} \right)$$

$$c.v.\left(E_{ij}\right) = \frac{10^6 \left[\sum_k \left(A_k^2 V_{ijk} / n_{jk} \right) \right]^{0.5}}{E_{ij}}$$

where E_{ij} is the estimated abundance (number) of eggs of stage i in the survey area in snapshot j, D_{ijk} and V_{ijk} are the mean and variance of the density (eggs/m^2) of eggs of stage i in stratum k during snapshot j, A_k is the area of stratum k (km^2), n_{jk} is the number of stations in stratum k in snapshot j, and the factor 10^6 converts square kilometres to square metres.

5.5 Advection of Eggs

In this section we determine which egg stages should be omitted from the estimation of daily egg production. We show that the great majority of the spawning activity occurred on or near Graveyard Hill (in stratum 4, Figure 7) and eggs were carried westward (approximately) from there by water currents. This advection eventually carried eggs outside the survey area. Thus, eggs past a certain stage would be under-represented in the survey and so should be omitted from further analysis.

For most of the survey virtually all stage A eggs were caught in stratum 4 (Figure 10). Late in snapshot 3 there was one large catch on the west side of Morgue in stratum 2 (station 373); in snapshot 4 there was one large catch on the west side of Zombie in stratum 3 (station 420) and another in stratum 7A, near the boundary with stratum 4 (station 479). This suggests that the great majority of spawning took place in the inner four strata (1–4), and much of that in stratum 4.

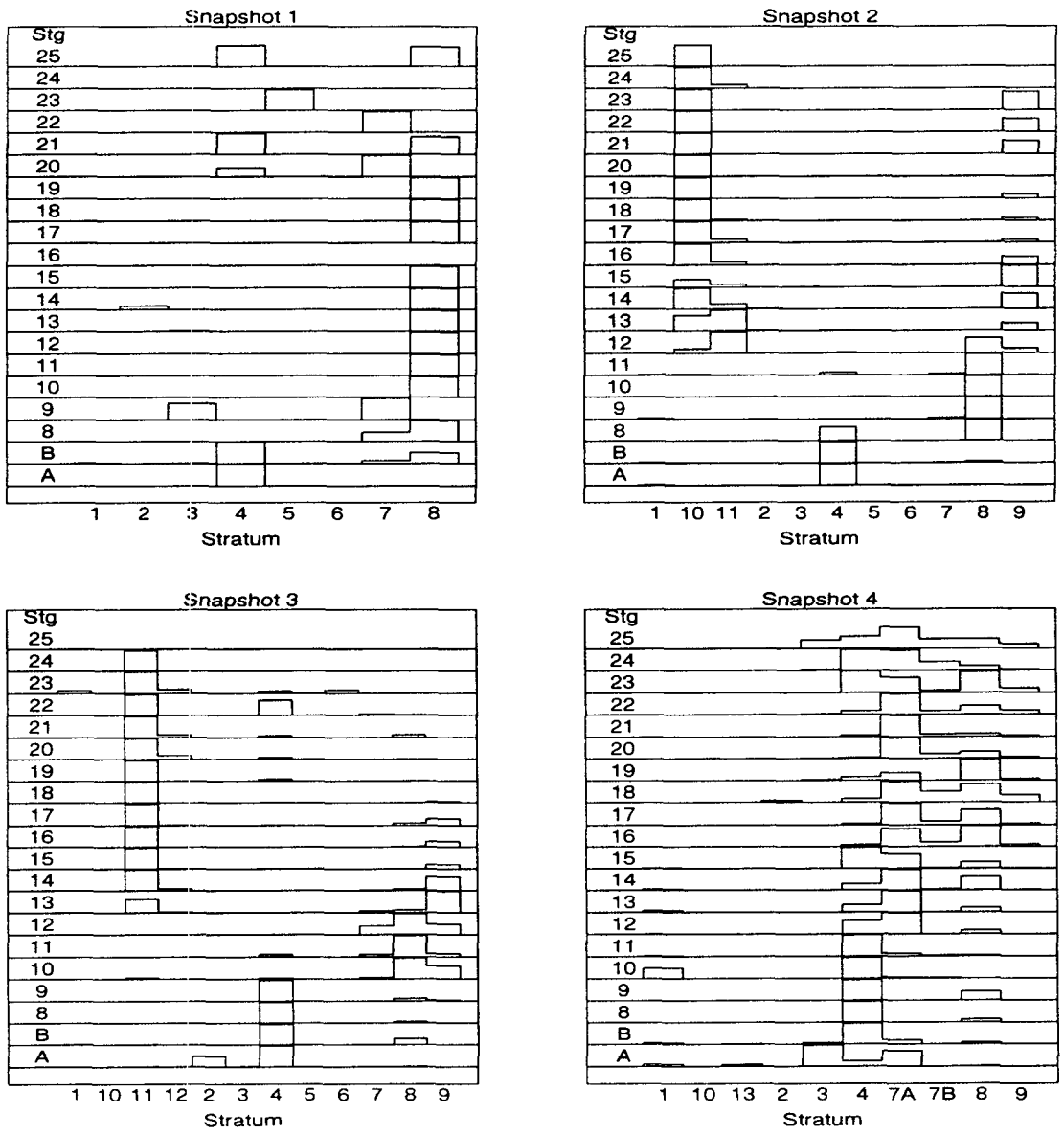

Figure 10: Histograms of egg density by snapshot, stratum, and egg stage.

To study the advection of the eggs the survey area (omitting stratum 13, which is considered below) was divided into a 12 x 12 grid defined by 12 latitudinal and 12 longitudinal strips (shown in Figure 7, lower left panel). For each egg stage and snapshot, mean egg density was calculated for each latitudinal and longitudinal strip, and for each of the 144 cells in the grid. The centroid for each egg stage and snapshot was calculated (following Zeldis *et al.* 1997b) using this grid.

The pattern of the centroids showed that egg movement was always westward but the rate of advection, and its north-south component, varied from snapshot to snapshot (Figure 11). A pronounced northward movement in snapshot 1 declined in snapshot 2, and became slightly southward in snapshot 3. The speed of movement appeared to decline slightly between snapshots 2 and 3, and fell sharply in snapshot 4.

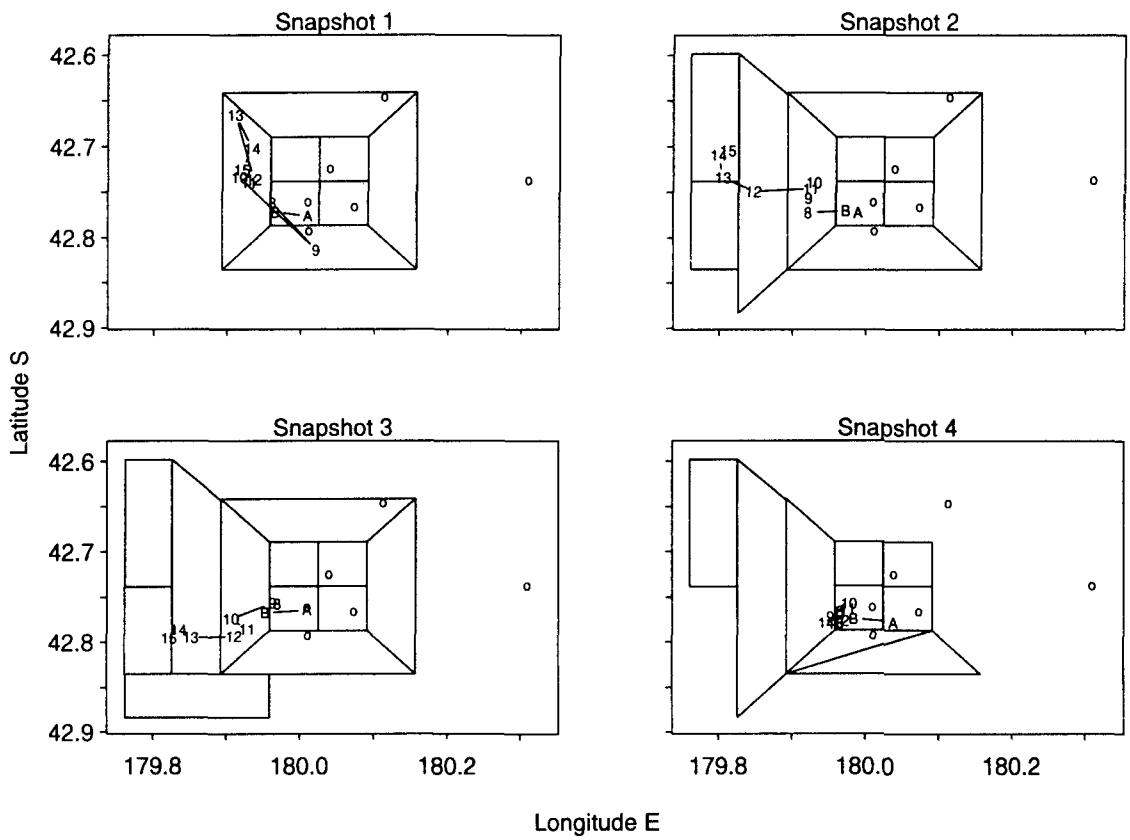

Figure 11: Positions of centroids of egg distribution by egg stage (A, B, 8, 9, ... 15) and snapshot. Stratum boundaries and hill positions (o), as in Figure 7, are also shown.

These inferences are confirmed by an examination of trends in egg density by longitude and latitude with increasing egg stage (Figure 12). The trends are least clear in snapshot 1, presumably because of the low number of stations. Ignoring the anomalous stage 9 (strongly influenced by a single catch in stratum 7), the first stage where the peak density lies at the boundary of the survey area is stage 10. This is most abundant in longitude strip 5, on the western boundary of stratum 8. Thus, this and later stages could be expected to be under-represented in this snapshot.

Much stronger trends are apparent in Figure 12 for snapshots 2 and 3. The strong western movement is readily apparent for both snapshots and there is a clear contrast between the slight northward and southward trends in snapshot 2 and 3, respectively. In both cases advection out of the survey area occurs first on the western boundary. This did not appear to be significant for eggs younger than stage 13 in snapshot 2 and stage 16 in snapshot 3.

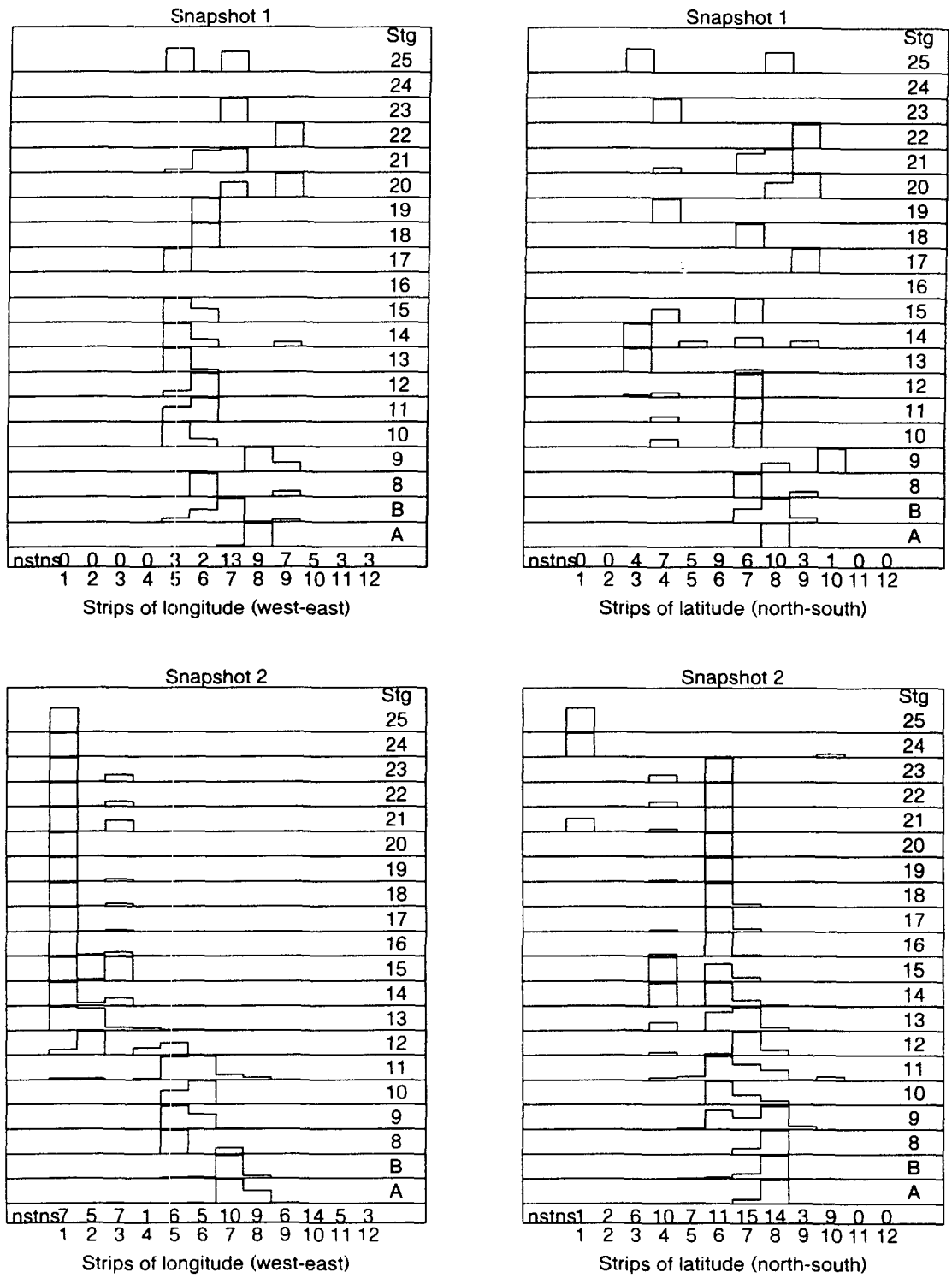

Figure 12A: Histograms of egg density (by egg stage and snapshot) across longitudinal strips. (The location of the strips is shown in the lower left panel of Figure 7).

For snapshot 4 the flow to the west is much slower and the peak abundance of all egg stages is away from the western boundary. Similarly, the slight southward movement seemed insufficient to bring any egg stages to the southern boundary.

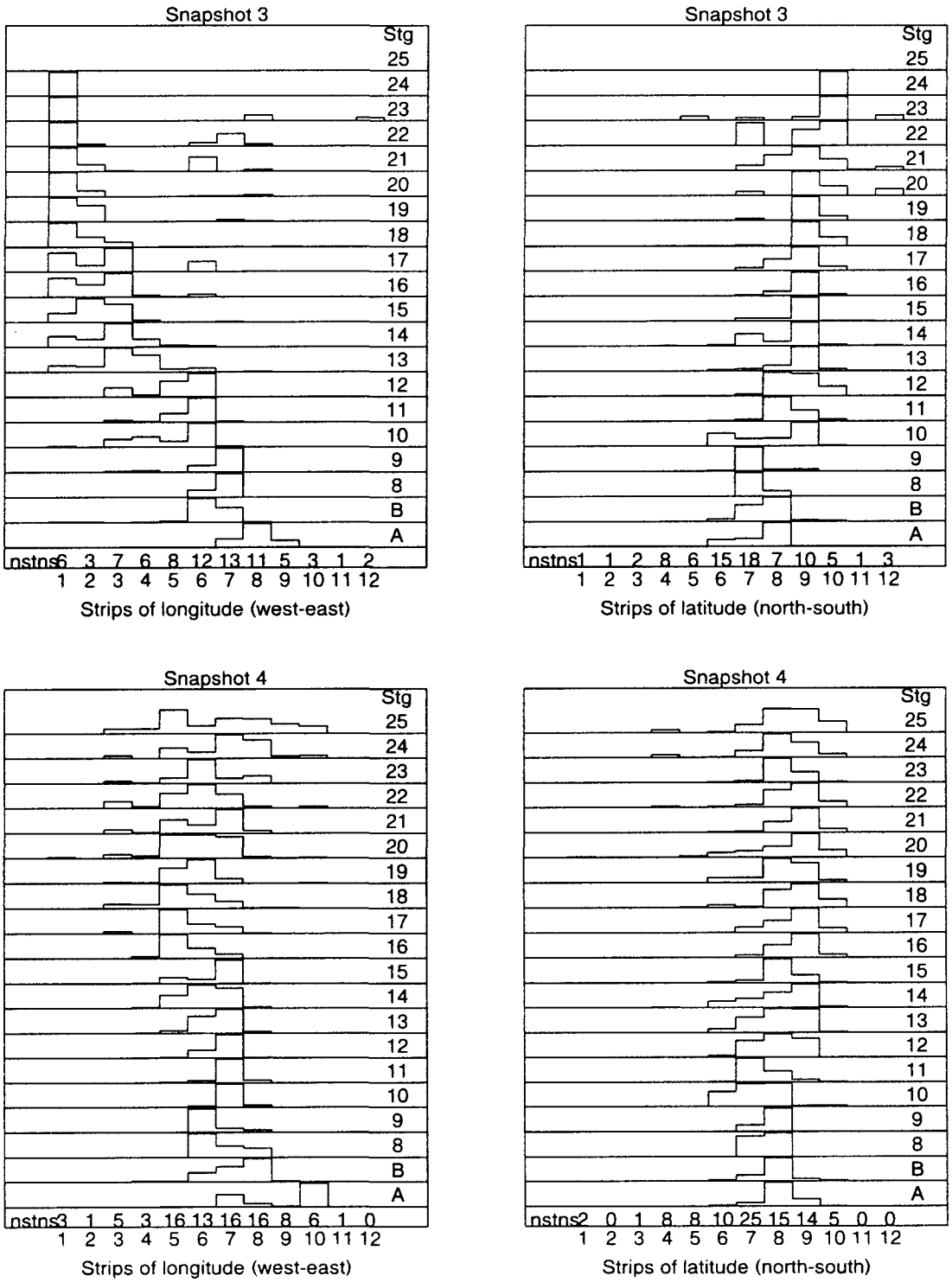

Figure 12B: Histograms of egg density (by egg stage and snapshot) across latitudinal strips. (The location of the strips is shown in the lower left panel of Figure 7).

There appeared to be very little spawning activity on Dead Ringer, in stratum 13. Egg densities were very low in this stratum (*see* Figure 10). Only one of six stations caught stage A eggs and no eggs of stage 8 or higher were caught. Note also that any significant spawning activity on Dead Ringer could be expected to result in the appearance of eggs of stages 10 and later in strata 2, 3, and 6, since these strata are about the same distance west of Dead Ringer as strata 9–11 are from Graveyard. Virtually no eggs of these stages were caught in the former strata (*see* Figure 10).

To summarise, as a result of advection only the following egg stages were included in further analyses:

Snapshot 1: A–9
Snapshot 2: A–12
Snapshot 3: A–15
Snapshot 4: A–25

Also, stratum 13 in snapshot 4 is ignored in further analyses.

5.6 Calculation of Egg Production

The maximum likelihood method of Zeldis *et al.* (1997a) was used to estimate daily egg production, N_0, and instantaneous egg mortality, Z, for each snapshot, and for all snapshots combined (Table 6, Figure 13). Z was forced to be greater than or equal to zero (necessary only for snapshot 2).

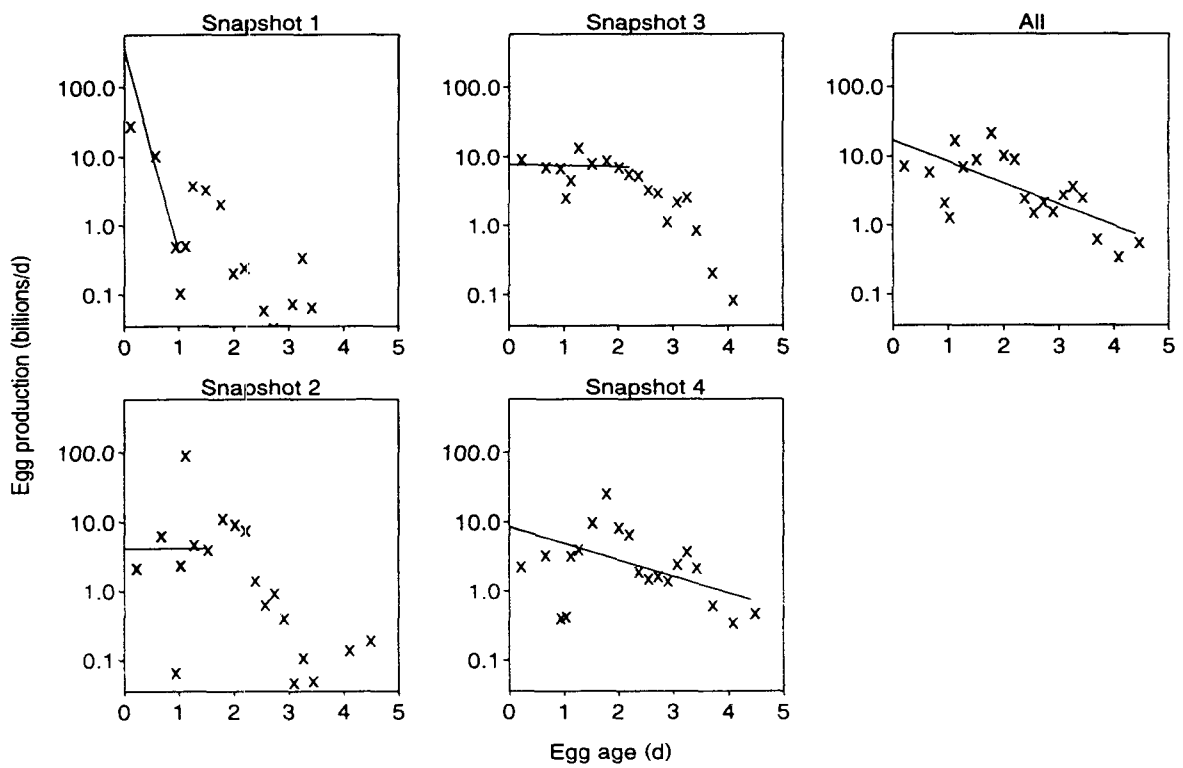

Figure 13: Plots (by snapshot, and with all snapshots combined) of egg production vs egg age, illustrating the estimation of N_0, the daily egg production and Z, egg mortality. N_0 is the y-intercept and Z is the slope of the plotted lines. Points are shown for all egg stages but the lines are fitted only to those stages which were well covered in the respective snapshot (*see* Section 5.5).

When all snapshots were combined, stations were reallocated to the strata in snapshot 3 except that stratum 7 was divided into strata 7A and 7B, as in snapshot 4. Also, for each station, only those egg stages unaffected by advection out of the survey area (see previous section) were included.

Table 6: Maximum-likelihood estimates of daily egg production, N_0, and instantaneous egg mortality, Z, from each of 4 snapshots, and for all snapshots combined. *Z forced to be ≥ 0

Snapshot	N_0 (billions of eggs day^{-1})	Z (day^{-1})
1	360	6.8
2	4.2*	0*
3	7.9	0.038
4	8.4	0.55
All	17.1	0.71

It seems likely that either daily egg production or mortality were not constant during the snapshots. This is shown in the very wide range of estimates of Z and the obvious autocorrelation in the residuals for snapshot 4 (and also for all data combined) (Figure 13). Because this violates a major assumption of the maximum-likelihood model, the bootstrap method of Zeldis *et al.* (1997a) could not be used to estimate *c.v.*s for individual estimates of N_0.

The estimate of N_0 using all the data was taken as the best estimate.

6 Estimation of Biomass

Application of the daily fecundity reduction method formula (*see* Section 2) resulted in estimates of 21 000 t for spawning females and 49 000 t for recruited fish (Table 7).

Table 7: Summary of parameter and *c.v.* estimates for the daily fecundity reduction method for the northwest Chatham Rise. '–', not estimated

Parameter	Estimate	*c.v.* (%)
S	2.29 (no units)	10
D	799 eggs kg^{-1} day^{-1}	12
N_0	17 billion eggs day^{-1}	–
B_{spf}	21 000 t	–
B_{rec}	49 000 t	–

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