

**Spawning biomass of sardine, *Sardinops sagax*,  
in waters off South Australia  
in February-March 2007**



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## **PREFACE**

The daily egg production method (DEPM) has been used to assess the status of sardine, *Sardinops sagax*, in South Australian waters since 1995 (Ward *et al.* 1998, in prep.). The estimate of spawning biomass provided in these reports is the key biological performance indicator for the South Australian Sardine Fishery. This report uses the DEPM to provide an estimate of the spawning biomass of sardine in waters off South Australia in February-March 2007.

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## **QUALITY ASSURANCE**

Egg identifications and identification of post-ovulatory follicles on histological slides were confirmed by Alex Ivey and Lachlan McLeay. Estimates of each DEPM parameter and spawning biomass were calculated independently by Alex Ivey and Lachlan McLeay and checked by Dr Tim Ward. Spreadsheet workings were then checked by Dr Jonathan Staunton-Smith (Queensland Department of Primary Industries). The publication review process was administered by Ms Suzanne Bennett (SARDI Aquatic Sciences). The report was reviewed Dr Mike Steer, Dr David Currie, Paul Rogers (SARDI Aquatic Sciences) and Dr Jonathan Staunton-Smith. The report approved for release by Dr Qifeng Ye (SARDI Aquatic Sciences).

**EXECUTIVE SUMMARY**

1. This report provides an estimate of the spawning biomass of sardine, *Sardinops sagax* in South Australian waters in 2007.
2. Data were obtained from research surveys from the RV *Ngerin* in shelf and gulf waters during February and March 2007. The total survey area was 114,490 km<sup>2</sup>.
3. Sea surface temperatures (SSTs) during the surveys ranged from 17 to 23°C and were lowest inshore off western Eyre Peninsula and west of Kangaroo Island.
4. A total of 3909 *S. sagax* eggs was collected from 151 of 341 stations. High densities of eggs were recorded in southern Spencer Gulf, Investigator Strait, south of Kangaroo Island and west of Anxious Bay. Few eggs were found in shelf waters between Cape Catastrophe and Venus Bay.
5. A total of 1226 *S. sagax* yolk-sac larvae were collected. Abundances per m<sup>2</sup> were highest west of Venus Bay, in Spencer Gulf, Investigator Strait and south of Kangaroo Island. The spatial distribution pattern was similar to the eggs.
6. A total of 20 samples comprising 2244 mature fish were collected at sampling locations in Investigator Strait, southern Spencer Gulf and the eastern Great Australian Bight.
7. Estimates of mean adult reproductive parameters were: female weight,  $W = 71.0$  g (95% CI = 64.9 - 76.4); sex ratio,  $R = 0.52$  (95% CI = 0.41 - 0.65); spawning fraction,  $S = 13.01\%$  (95% CI = 9.2 - 16.7) and batch fecundity,  $F = 20581$  (95% CI = 17788 - 23351) hydrated oocytes.
8. The total spawning area,  $A$  was 43,946 km<sup>2</sup>.
9. Mean daily egg production,  $P_0$  calculated using the log-linear version of the egg mortality model, was 116.6 eggs.day<sup>-1</sup>.m<sup>-2</sup> (95% CI = 74.2 - 182.4).
10. The estimate of spawning biomass for 2007 was 263,747 t (95% CI = 147,947 - 489,520), which lies within the upper third of the target range of spawning biomasses (150,000 - 300,000 t). The baseline TACC of 30,000 t is approximately 11.3% of the 2007 spawning biomass.

## 1. INTRODUCTION

### 1.1 Background and management

The South Australian Sardine Fishery (SASF) is managed by the South Australian Government, as custodian of the sardine resource on behalf of the broader community, in accordance with the *Fisheries (Scheme of Management - Marine Scalefish Fisheries) Regulations 2006* and *Fisheries (General) Regulations 2000*, and under the administration of the *Fisheries Act 1982* (to be replaced by the *Fisheries Management Act 2007* from 1 December 2007).

Since 1997, the annual/biannual estimate of spawning biomass obtained using the Daily Egg Production Method (DEPM) has been the key performance indicator for the fishery. The application of the DEPM has facilitated the rapid and sustainable development of the SASF, despite the effects of two mass mortality events (see Ward *et al.*, in prep). The primary limitation of the DEPM is the relatively low precision of individual estimates of spawning biomass. Recently, the main effect of this problem on the SASF, i.e. inter-annual variations in catches resulting from fluctuations in estimates of spawning biomass has been mitigated by developing a harvest strategy with performance indicators and reference points that were specifically designed to achieve a key management objective, i.e. to maximise stability in catches (Ward *et al.*, in prep).

During the first ten years that estimates of spawning biomass were used to inform management of the SASF, i.e. from 1997 to 2006, the Total Allowable Commercial Catch (TACC) for the following calendar year was set as a proportion of the spawning biomass (i.e. 10.0% to 17.5%, depending on the size of the spawning biomass). More recently, the baseline TACC was set at 30,000 t and this will be maintained as the effective TACC while the latest annual/biannual estimate of spawning biomass remains between 150,000 and 300,000 t, which correspond to exploitation rates of 20% and 10%, respectively.

The best estimate of spawning biomass of sardine in South Australian waters in 1995 was 165,000 t, but this fell by over 70% to 37,000 t in 1996, following an unprecedented mass mortality event (Ward *et al.* 2001a). Estimates of spawning biomass increased to reach 146,000 in 1998, but fell by over 70% to be approximately 36,000 t in early 1999, following a second mass mortality event. Spawning biomass increased steadily from 2000 onwards to reach ~201,000 t in 2004. Difficulties associated with the estimation of egg mortality and egg production introduced additional uncertainty into the assessment for 2005, and estimated range of spawning biomasses was approximately 130,000 to 175,000 t. The spawning biomass estimate for 2006 was approximately 226,000 t (Ward *et al.* in prep.).

The annual catch of the SASF increased from approximately 3,200 t in 1994 to over 42,000 t in 2005. The TACC was set at 32,000 t in 2007, which is approximately 14% of the estimate of spawning biomass for 2006. From 2008 onwards, the baseline TACC will be 30,000 t and this will be established as the effective TACC whilst the latest annual/biannual estimate of spawning biomass is between 150,000 and 300,000 t.

## 1.2 Daily Egg Production Method

The DEPM was first developed to estimate the spawning biomass of northern anchovy (*Engraulis mordax*) and can be applied to small pelagic fish species that produce batches of pelagic eggs during an extended spawning season (Parker 1980, 1985). This stock assessment method has been applied to the sardine stock off the west coast of North and Central America for several years (e.g. Lo *et al.* 2005). The application of the DEPM relies on the premise that spawning biomass can be calculated from the abundance of pelagic eggs produced per day in the spawning area (daily egg production) and the number of eggs produced per unit mass of population (daily fecundity). Spawning biomass ( $B$ ) is calculated according to the equation:

$$B = \frac{P_0 \cdot A \cdot W}{R \cdot F \cdot S} \quad \dots \text{Equation 1}$$

where  $P_0$  is mean daily egg production per unit area,  $A$  is the spawning area,  $W$  is the mean weight of mature females,  $R$  is the sex ratio (proportion of females by weight),  $F$  is the mean batch fecundity (number of oocytes in a batch) and  $S$  is the mean spawning fraction (proportion of mature females that spawn each night) (Lasker 1985; Parker 1985; Alheit 1993).

## 1.3 Aim and Objectives

This report provides an estimate of the spawning biomass of sardine in gulf and shelf waters of South Australia in February-March 2007. The objectives of the report are:

To describe the patterns of distribution and abundance of *S. sagax* eggs in South Australian waters in 2007 in relation to environmental parameters (sea surface temperature, depth, chlorophyll-*a*, zooplankton, etc);

1. To estimate spawning area ( $A$ ) and mean daily egg production ( $P_0$ );
2. To estimate the adult reproductive parameters, ( $W$ ,  $R$ ,  $F$ ,  $S$ );
3. To use the DEPM to estimate the spawning biomass in 2007.

## 2. METHODS

### 2.1 Study Area and Environmental Variables

#### 2.1.1 Study area

Two surveys were conducted aboard the *RV Ngerin* in shelf and gulf waters of South Australia between February and March 2007. Plankton samples were collected at 341 stations on 34 transects between Victor Harbor and Head of Bight (Fig. 1).

#### 2.1.2 Water temperature and primary production

At each station (Fig. 1), a *Sea-Bird* Conductivity-Temperature-Depth (CTD) recorder was lowered to a depth of 70 metres, or to 10 metres from the bottom in waters less than 80 m deep. Estimates of water temperature and salinity at a depth of 3 m were extracted from each profile.

Samples of surface water (<3 m) were collected at each station and filtered using a Millipore filtration system. Filters and residue were dissolved in methanol and placed in the dark for 24 hours.

Fluorescence was then measured using a Sequoia-Turner fluorometer (Model 450) with wavelengths of 665 and 750 nm. Fluorescence is an indicator of primary productivity. The concentration of chlorophyll-*a* in each sample was calculated according to the method of Parsons *et al.* (1984). Spatial plots of SST, fluorescence and extracted chlorophyll-*a* were prepared using minimum curvature algorithms in Surfer™ Version 8.

#### 2.1.3 Secondary production – zooplankton abundance

An index of zooplankton abundance at each station was estimated by dividing the volume of zooplankton (ml) collected during plankton tows by the total volume of water filtered (m<sup>3</sup>). The large fraction (>1 mm) was mostly gelatinous taxa (salps, scyphozoans) and krill *Nyctiphanes australis*. The small fraction (<1 mm) was mostly copepods and cladocerans. Spatial plots were prepared using minimum curvature algorithms in Surfer™ Version 8.

### 2.2 Daily Egg Production and Spawning Area

#### 2.2.1 Plankton sampling

Plankton samples were collected at each station using Californian Vertical Egg Tow (CalVET) plankton nets. The CalVET nets had an internal diameter of 0.3 m, 330 µm mesh and plastic cod-ends. During each tow the CalVET net was deployed to within 10 m of the seabed at depths <80 m or to a depth of 70 m at depths >80 m. The net was retrieved vertically at a speed of ~ 1 m.s<sup>-1</sup>. General Oceanics™ 2030 flow-meters and factory calibration coefficients were used to estimate the distance travelled by the net during each tow. Upon retrieval of the net following each tow, the samples from

each of the two cod-ends were washed into two sample containers. Plankton samples were fixed using 5% buffered formaldehyde and seawater.

2.2.2 Laboratory analysis

*S. sagax* eggs and larvae were identified in each sample using published descriptions (White and Fletcher 1996; Neira *et al.* 1998). Eggs in each sample were counted, staged and assigned approximate ages based on descriptions and temperature-development keys in White and Fletcher (1996). Yolk-sac larvae ( $\leq 5$  mm, body length, BL) were classified as those that had a visible yolk-sac or that showed evidence of having a yolk-sac prior to the net wash-down procedure.

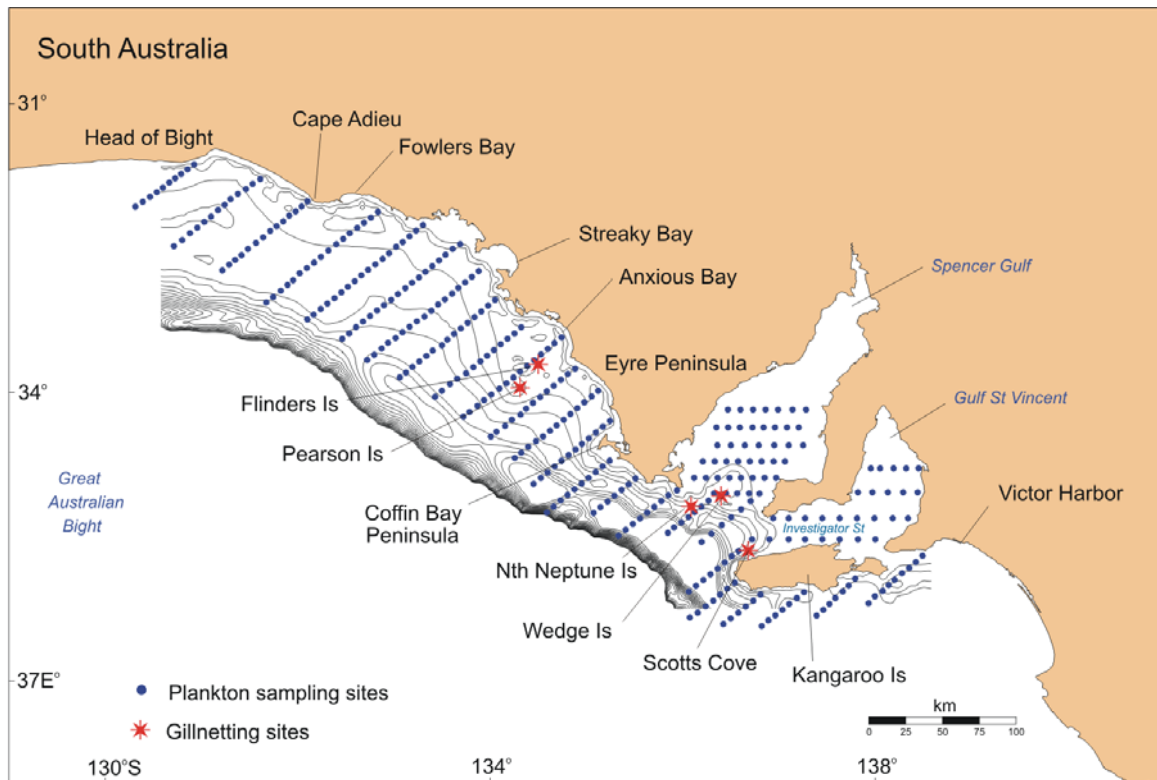


Figure 1. Map of South Australia showing stations where plankton and adult samples were collected during the 2007 DEPM surveys.

2.2.3 Egg density

The number of eggs of each stage under one square metre of water ( $P_t$ ) was estimated at each site according to equation 2:

$$P_t = \frac{C.D}{V} \quad \dots \text{Equation. 2}$$

where  $C$  is the number of eggs of each age in each sample,  $V$  is the volume filtered ( $m^3$ ), and  $D$  is the depth (m) to which the net was deployed (Smith and Richardson 1977). Plots of egg distribution and abundance were prepared using MapInfo Professional Version 8.

#### 2.2.4 Spawning time and density weightings

A previous study showed the peak spawning time of *S. sagax* in South Australia was ~0200 hours (e.g. Ward *et al.* 2001b). Ages were assigned to day-1 eggs (i.e. stages 0 – 24 hours old) by subtracting the estimated spawning time from the sampling time. Ages of day-2 eggs were assigned similarly, but an additional 24 hours were added to their ages. Densities of day-1 and day-2 eggs were weighted according to the relative size of the area from which they were taken.

#### 2.2.5 Spawning area

After the surveys were completed, the survey area was divided into a series of contiguous grids approximately centred on each station (Fig. 2). The area represented by each station ( $km^2$ ) was calculated using MAPINFO® software. The spawning area ( $A$ ) was defined as the total area of grids where live, Stage 1 – 8 (0 – 24 hour old) *S. sagax* eggs were found.

#### 2.2.6 Daily egg production and egg mortality

Biased mean daily egg production ( $P_b$ ) was calculated by fitting the linear version of the exponential egg mortality model to estimates of egg age and density at each station (Picquelle and Stauffer 1985). The linear version of the exponential egg mortality model is:

$$\ln P_b = \ln(P_i) - Zt \quad \dots \text{Equation 4}$$

where  $P_i$  is the density of eggs of age  $t$  at site  $i$  and  $Z$  is the instantaneous rate of egg mortality.

Estimates of mean egg production ( $P_b$ ) obtained using the linear version of the exponential mortality model have a strong negative bias, therefore a bias correction factor was applied following the equation of Picquelle and Stauffer (1985):

$$P = e^{(\ln P_b + \sigma^2 / 2)} \quad \dots \text{Equation 5}$$

where  $\sigma^2$  is the variance of the estimate of biased mean daily egg production ( $P_b$ ).

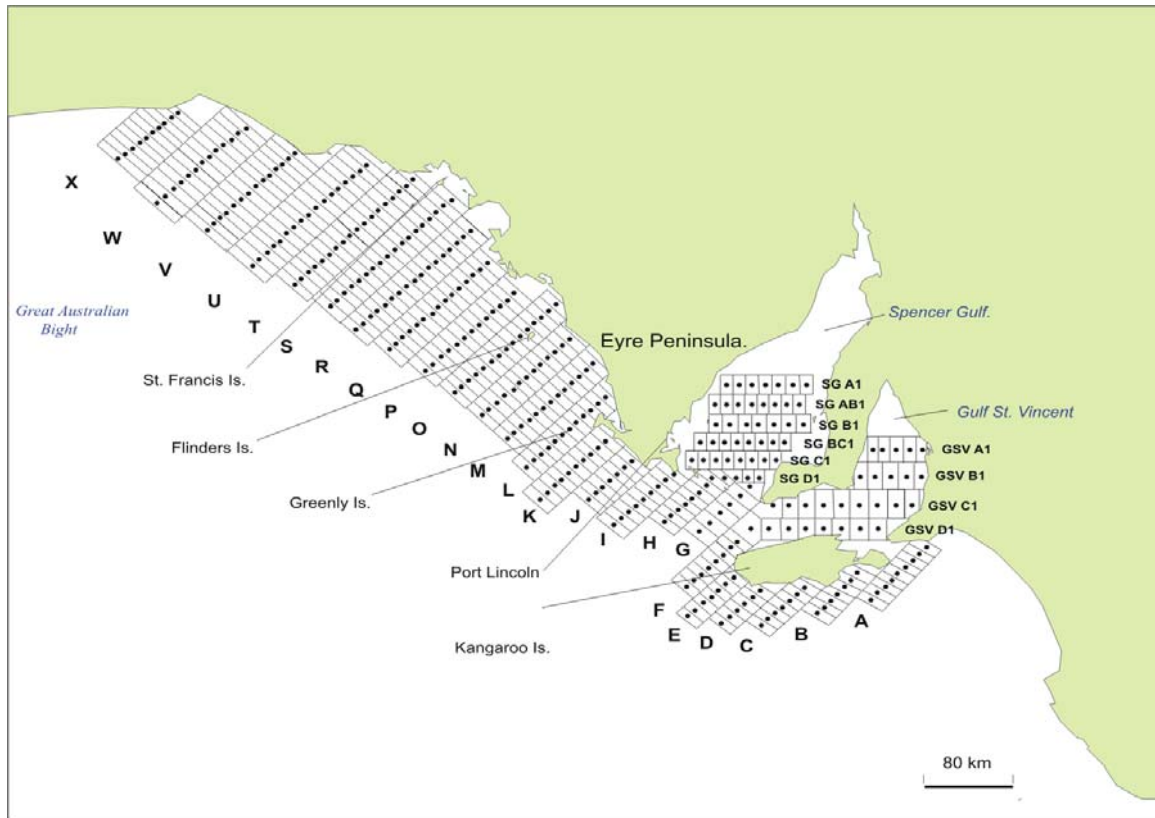


Figure 2. Location of plankton stations and the areas surrounding each station used to estimate the total spawning area in 2007.

## 2.3 Adult Reproductive Parameters

### 2.3.1 Sampling methods

Each afternoon, areas where *S. sagax* schools were known to aggregate were searched using a dual frequency echo sounder (*Furuno* - 60 and 180 KHz). The *RV Ngerin* was then anchored where several schools were observed. Samples of adults were collected using a gillnet comprising three panels, each with a different multi-filament nylon mesh size (*double diamond*: 210/4 ply meshes – 25, 28 and 32 mm). Surface and sub-surface lights (500 W) were illuminated near the net after it was set. Net soak times varied from 15 minutes to 3 hours depending on the number of fish caught. After the net was retrieved, fish were removed and dissected immediately. Mature and immature males and females were counted. Mature females were fixed in 5% buffered formaldehyde solution. Immature females and males were frozen. Calculations of female weight, sex ratio, batch fecundity and spawning fraction

were based on samples collected from Scotts Cove in Investigator Strait, Wedge and North Neptune Island in southern Spencer Gulf and Flinders and Pearson Island in the eastern GAB.

### 2.3.2 Female weight

Mature females from each sample were removed from formalin and weighed ( $\pm 0.01$  g). Fixation in formalin has a negligible effect on fish weight (Lasker 1985). The mean weight of mature females in the population was calculated from the average of sample means weighted by proportional sample size:

$$W = \left[ \overline{W}_i * \frac{n_i}{N} \right]$$

.... Equation 6

where  $\overline{W}_i$  is the mean female weight of each sample  $i$ ;  $n$  is the number of fish in each sample and  $N$  is the total number of fish collected in all samples.

### 2.3.3 Male weight

Mature males in each sample were thawed and weighed ( $\pm 0.01$  g).

### 2.3.4 Sex ratio

The mean sex ratio of mature individuals in the population was calculated from the average of sample means weighted by proportional sample size:

$$R = \left[ \overline{R}_i * \frac{n_i}{N} \right]$$

.... Equation 7

where  $n$  is the number of fish in each sample,  $N$  is the total number of fish collected in all samples and  $\overline{R}_i$  is the mean sex ratio of each sample calculated from the equation:

$$\overline{R}_i = \frac{F}{(F + M)}$$

.... Equation 8

where  $F$  and  $M$  are the respective total weights of mature females and males in each sample  $i$ .

### 2.3.5 Batch fecundity

Batch fecundity was estimated from ovaries containing hydrated oocytes using the methods of Hunter *et al.* (1985). Both ovaries were weighed and the number of hydrated oocytes in three ovarian sub-sections taken from the anterior, middle and posterior sections of each ovary were counted and weighed. The total batch fecundity for each female was calculated by multiplying the mean number of oocytes per gram of ovary segment by the total weight of the ovaries. The relationship between female weight (ovaries removed) and batch fecundity was determined by linear regression analysis and was used to estimate the batch fecundities of mature females in all samples.

### 2.3.6 Spawning fraction

Ovaries of mature females were sectioned and stained with haematoxylin and eosin. A section from each ovary was examined to determine the presence/absence of post-ovulatory follicles (POFs). POFs were aged according to the criteria developed by Hunter and Goldberg (1980) and Hunter and Macewicz (1985). The spawning fraction of each sample was estimated as the mean proportion of females with hydrated oocytes plus day-0 POFs ( $d0$ ) (assumed to be 0-23 hrs old), day-1 POFs ( $d1$ ) (assumed to be 24-48 hrs old) and day-2 POFs ( $d2$ ) (assumed to be 48+ hrs old). The mean spawning fraction of the population was then calculated from the average of sample means weighted by proportional sample size.

$$S = \left[ \overline{S}_i * \frac{n_i}{N} \right] \quad \dots \text{Equation 9}$$

where  $n$  is the number of fish in each sample,  $N$  is the total number of fish collected in all samples and  $\overline{S}_i$  is the mean spawning fraction of each sample calculated from the equation:

$$\overline{S}_i = \frac{[(d0 + d1 + d2POFs) / 3]}{n_i} \quad \dots \text{Equation 10}$$

where  $d0$ ,  $d1$  and  $d2$  POFs are the number of mature females with POFs in each sample and  $n_i$  is the total number of females within a sample.

## 2.4 Bootstrapping procedures

The 95% confidence intervals for the mean estimates of each parameter were calculated using bootstrap procedures with replacement and the percentile method. Bootstraps routines were run using Visual Basic in Excel. Each parameter was estimated 10,000 times by randomly reselecting individuals

from randomly selected samples. A balanced bootstrap design was employed (i.e. the number of samples and sample sizes reselected were the same as in the original datasets).

## **2.5 Spawning Biomass**

Spawning biomass was calculated using the estimates of each parameter (Eq. 1). The 95% confidence intervals of spawning biomass were estimated by calculating the spawning biomass 10,000 times using the 10,000 bootstrapped estimates of each parameter and using the percentile method.

### 3. RESULTS

#### 3.1. Environmental Variables

##### 3.1.1 Sea surface temperature

Sea surface temperatures (SSTs) ranged from 17.2 to 23.0°C (Fig. 3). Low SSTs (<18°C) were recorded inshore along the western coast of Eyre Peninsula and around the western tip of Kangaroo Island. High SSTs (>19°C) were recorded in central Spencer Gulf, Gulf St Vincent and across the mid-outer shelf waters of the eastern and central GAB.

##### 3.1.2 Extracted chlorophyll-*a*

Chlorophyll-*a* at each station ranged between 0 and 1.7 µg.L<sup>-1</sup> (Fig. 4). The highest values were recorded in Avoid Bay off Coffin Bay Peninsula, near Cape Adieu, south west of Kangaroo Island and in the mouth of Spencer Gulf. The remainder of coastal and shelf waters mostly had chlorophyll-*a* concentrations ranging between 0.1 and 1 µg.L<sup>-1</sup>.

##### 3.1.3 Zooplankton abundance

Total zooplankton densities for each station sampled ranged from 0.14 to 145.3 ml.m<sup>-3</sup>. Total small fraction densities ranged between 0.08 and 14.72 ml.m<sup>-3</sup> (Fig. 5). Large fraction densities ranged between 0 and 145.7 ml.m<sup>-3</sup> (Fig. 6). The patch of large zooplankton taxa observed in the eastern GAB between Streaky Bay and Coffin Bay Peninsula was comprised mostly of salps. The highest densities of small zooplankton taxa were found in Spencer Gulf, Investigator Strait, south of Kangaroo Island and the Head of the GAB.

#### 3.2 Distribution and Abundance of Eggs and Yolk-sac Larvae

##### 3.2.1 Distribution and abundance of eggs

A total of 3,909 *S. sagax* eggs were collected from 151 of 341 (41.3%) stations on 34 transects between the Head of Bight and Victor Harbor (Fig. 7). Densities ranged between 5.39 and 2,744 eggs.m<sup>-2</sup>. The stations with the highest egg densities were located in southern Spencer Gulf, Investigator Strait and on the mid-shelf west of Anxious Bay.

##### 3.2.2 Distribution and abundance of yolk-sac larvae

A total of 1,226 *S. sagax* yolk-sac larvae were collected at 42% of stations between the Head of Bight and Victor Harbor (Fig. 8). Densities were highest west of Venus Bay, in Spencer Gulf, Investigator Strait and south of Kangaroo Island and ranged between 3.26 and 1,422.8 larvae.m<sup>-2</sup>. The spatial distribution of yolk-sac larvae was similar to eggs.

### 3.3 Spawning Area

The estimated spawning area was 43,946 km<sup>2</sup>, comprising 38.4% of the 114,490 km<sup>2</sup> sampled during the survey (Table 1).

### 3.4 Daily Egg Production ( $P_0$ )

The estimate of daily egg production,  $P_0$  obtained using the linear version of the exponential egg mortality model ( $\ln$  egg density =  $-0.211 \cdot \text{Age} + 3.68$ ,  $r^2 = 0.006$ , Fig. 9) was 116.6 eggs.day<sup>-1</sup>.m<sup>-2</sup> (95% CI = 74.17 - 182.42, Table 1, Fig. 10). The estimate of egg mortality,  $Z$  was 0.211 day<sup>-1</sup> (Fig. 9).

### 3.5 Adult Reproductive Parameters

A total of 20 samples comprising 2,244 mature *S. sagax* were collected at Scotts Cove and Wedge, North Neptune, Pearson and Flinders Islands during the 2007 survey (Table 2). Estimates of adult reproductive parameters used to estimate spawning biomass were calculated from these samples (Table 2 and 3). Bootstrapped parameter estimates that provided 95% confidence intervals are shown in Fig. 10.

#### 3.5.1 Mean female weight

The mean weight of mature females in samples ranged from 36.6 to 90.9 g (Table 2). The weighted mean weight of mature females was 71.0 g (95% CI = 64.9 – 76.4).

#### 3.5.2 Sex ratio

The sex ratio of samples ranged from 0.24 to 0.95 (Table 2). The weighted mean sex ratio was 0.52 (95% CI = 0.41 – 0.65).

#### 3.5.3 Batch fecundity

Mean batch fecundities of samples ranged from 8,978 to 27,302 hydrated oocytes per batch and the weighted mean was 20,581 hydrated oocytes per batch (95% CI = 17,788 – 23,351) (Table 3, Fig. 10).

#### 3.5.4 Spawning fraction

Of the 1084 ovaries examined, 149 had hydrated oocytes and/or day-0 POFs, 239 had day-1 POFs and 35 had day-2 POFs (Table 3). The percentage of females in samples with hydrated oocytes and/or day-0 POFs ranged from 0 to 97.7%. The weighted mean spawning fraction was 0.13 (95% CI = 0.092 – 0.167).

### **3.6 Bootstrapping Procedures**

The distributions for each variable calculated using 'bootstrap replacement' procedures and the percentile method are shown in Fig. 10.

### **3.7 Spawning Biomass**

The estimate of spawning biomass calculated using the log-linear version of the exponential egg mortality models was 263,747 t (95% CI = 147,947 – 489,520).

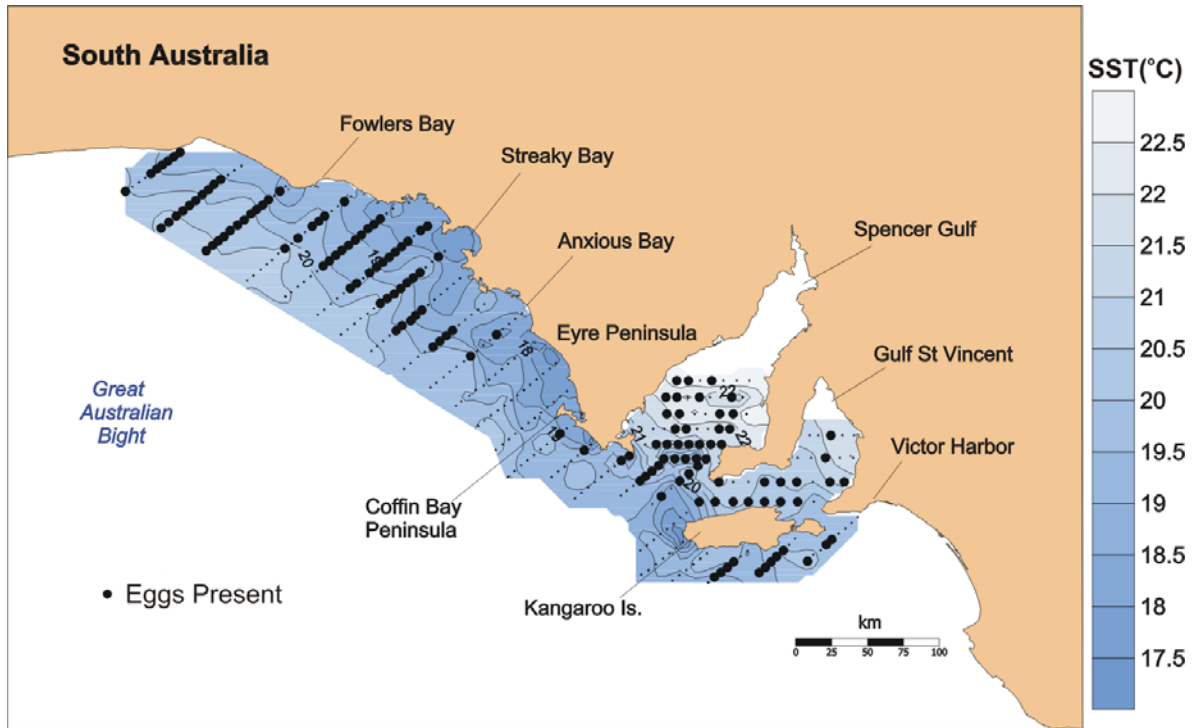


Figure 3. Relationship between sea-surface temperature and presence/absence of eggs in 2007.

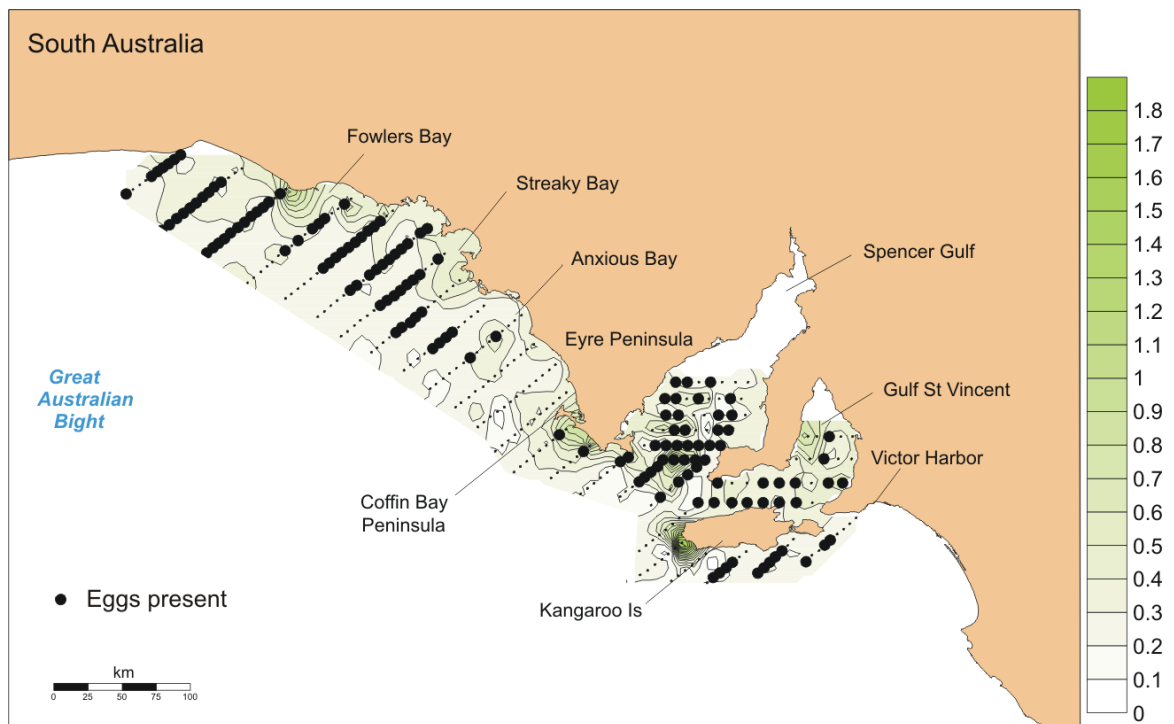


Figure 4. Concentration of chlorophyll-*a* ( $\mu\text{g}\cdot\text{L}^{-1}$ ) and presence/absence of eggs in 2007.

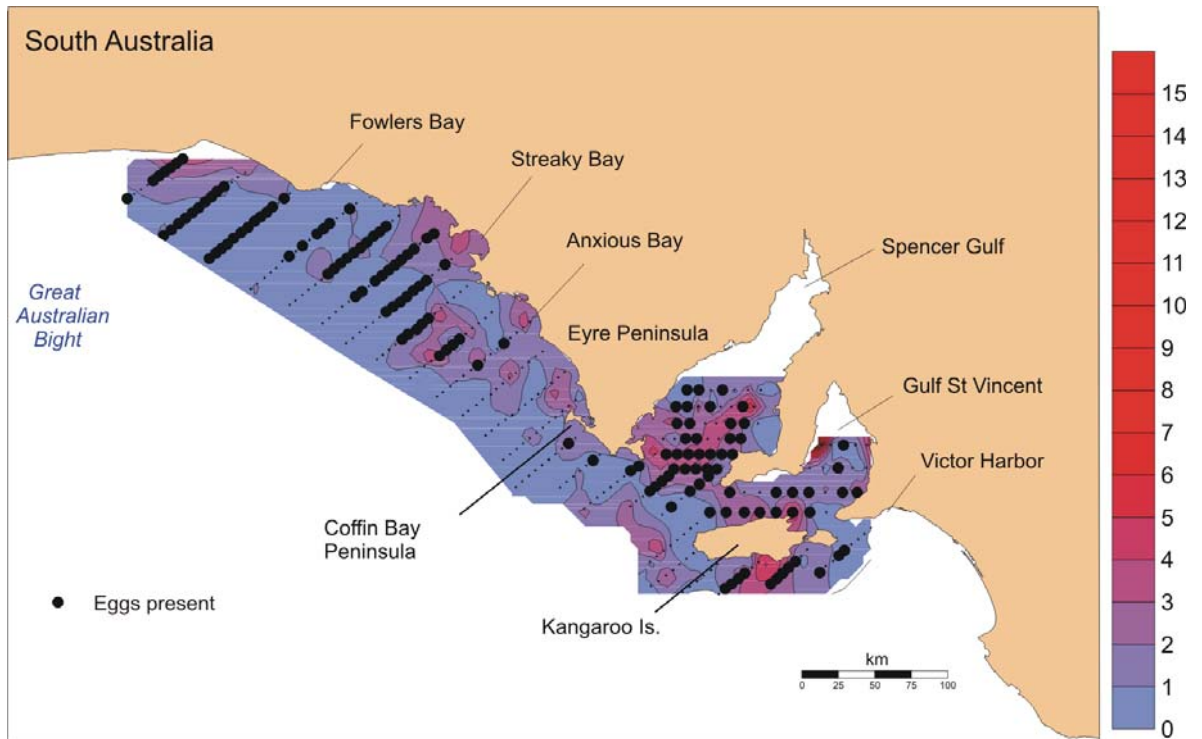


Figure 5. Abundance ( $\text{ml.m}^{-3}$ ) of zooplankton (small fraction) and presence/absence of eggs in 2007.

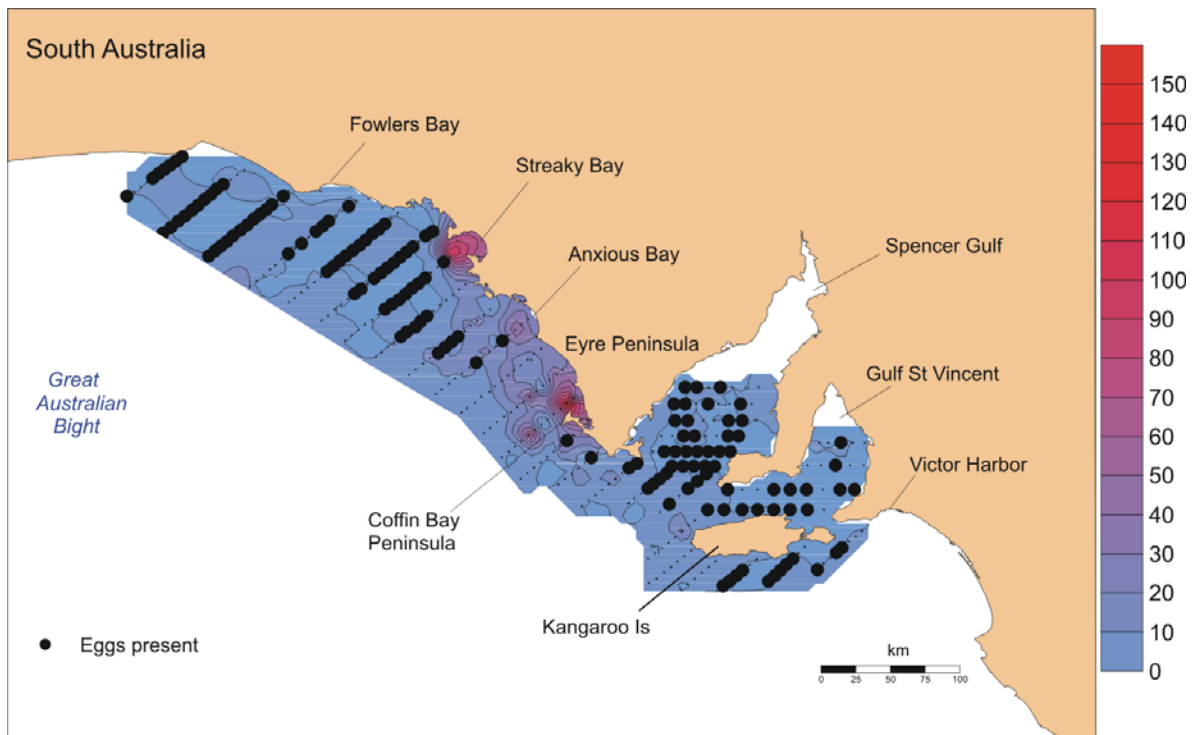


Figure 6. Distribution and abundance ( $\text{ml.m}^{-3}$ ) of zooplankton (large fraction) and presence/absence of eggs in 2007.

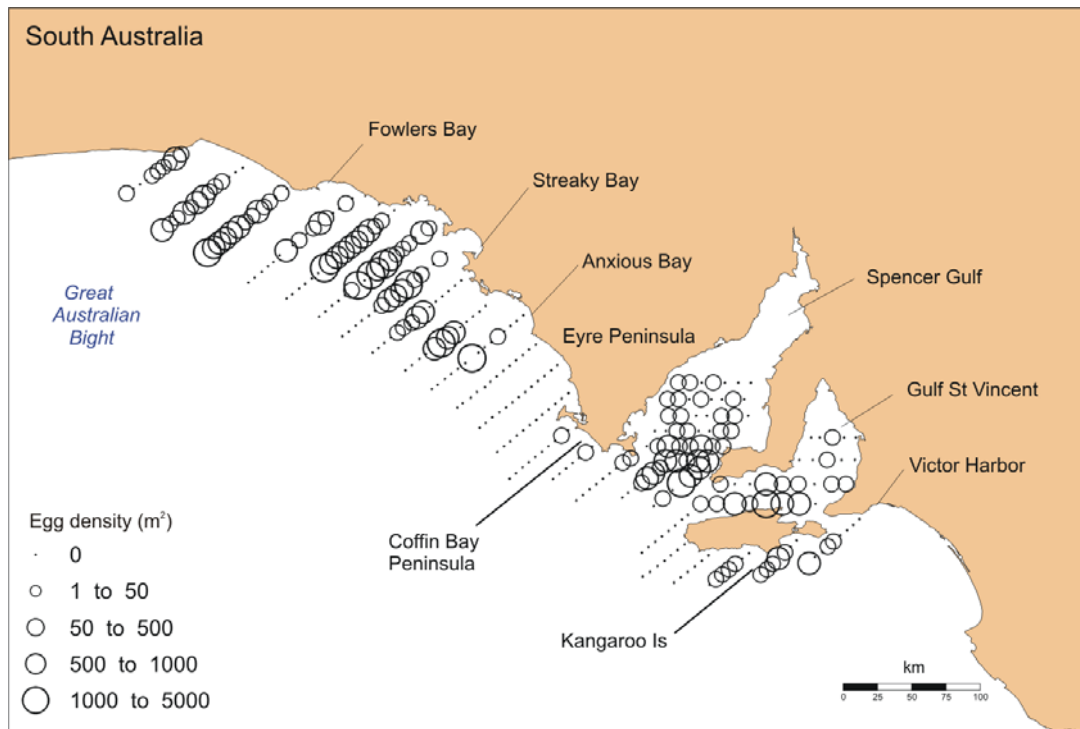


Figure 7. Spatial patterns of distribution and abundance of eggs in 2007.

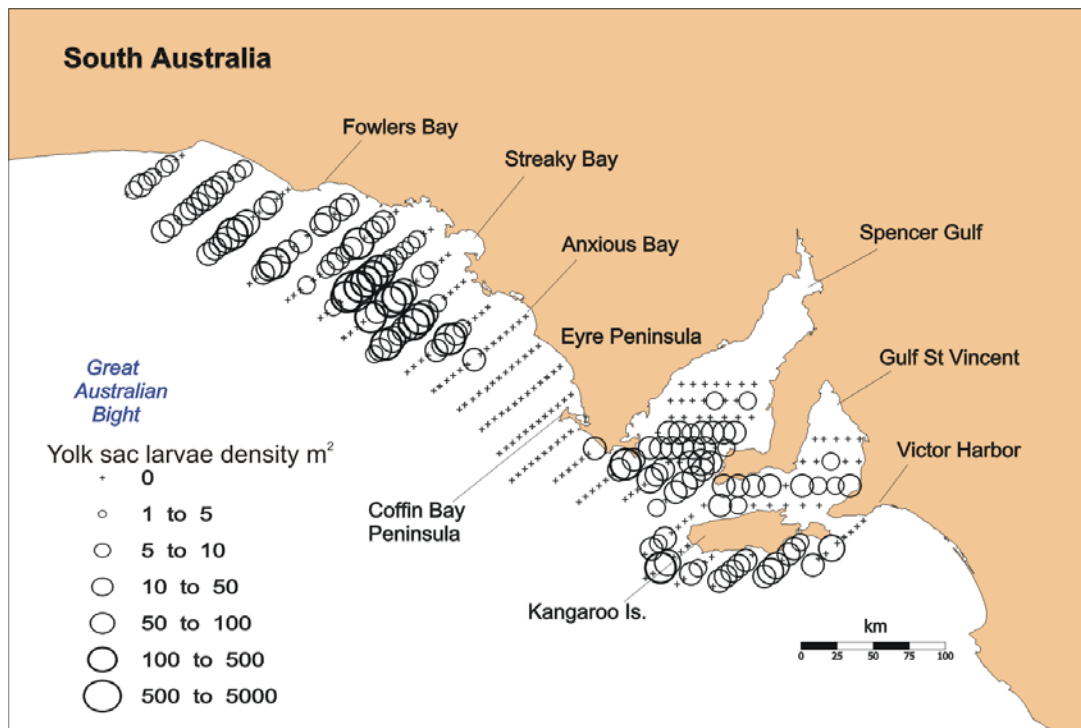


Figure 8. Spatial patterns of distribution and abundance yolk-sac larvae in 2007

**Table 1.** Area sampled, spawning area,  $A$ , daily egg production,  $P_0$ , and spawning biomass for 2007.

	Area sampled	$A$ (km <sup>2</sup> )	$A$ / Area sampled	$\sigma^2 P_b$	$P_0$ (eggs.d <sup>-1</sup> .m <sup>-2</sup> )	Spawning biomass (t)
Total survey	114,490	43,946	0.384	2.16	116.6	263,747

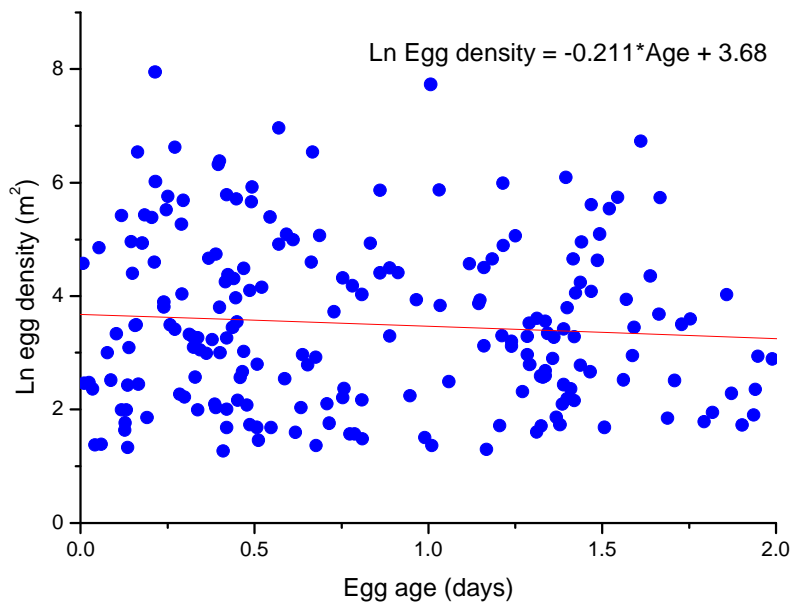


Figure 9. Linear regressions between ln-transformed egg density (m<sup>2</sup>) and age (days) in 2007.

**Table 2.** Number of individual in samples and estimates of female weight,  $W$  and sex ratio,  $R$  (proportion of females by weight) for samples collected in 2007. Values in bottom row are sums (\*) and weighted means (#).

Sample	Date	Location	$n$ fish	$n$ ♂	$n$ ♀	R	♂ wt (g)	♀ wt (g)	♀ wt	♀ wt (g)	♂ wt (g)	♀ wt (g)	R	R
						weighting	( $\bar{x}$ )	( $\bar{x}$ )	weighting	weighted	( $\Sigma$ )	( $\Sigma$ )		weighted
1	11/02/2007	Scotts Cove	101	49	52	0.90	56.3	67.4	0.96	64.6	2761	3502	0.56	0.50
2	11/02/2007	Scotts Cove	80	37	43	0.71	55.7	64.8	0.79	51.4	2060	2721	0.57	0.41
3	11/02/2007	Scotts Cove	82	41	41	0.73	57.1	64.1	0.76	48.5	2342	2627	0.53	0.39
4	12/02/2007	Scotts Cove	235	126	109	2.09	56.3	64.8	2.01	130.4	7094	7066	0.50	1.05
5	14/02/2007	Wedge Is.	81	37	44	0.72	44.4	50.4	0.81	40.9	1643	2216	0.57	0.41
6	16/02/2007	N. Neptune Is.	64	35	29	0.57	68.4	72.6	0.54	38.9	2393	2107	0.47	0.27
7	16/02/2007	N. Neptune Is.	95	46	49	0.85	62.0	68.5	0.90	61.9	2852	3354	0.54	0.46
8	16/02/2007	N. Neptune Is.	86	34	52	0.77	60.5	69.6	0.96	66.8	2058	3619	0.64	0.49
9	17/02/2007	N. Neptune Is.	131	66	65	1.17	59.1	71.7	1.20	85.9	3903	4658	0.54	0.64
10	19/02/2007	Pearson Is.	79	28	51	0.70	64.8	76.9	0.94	72.3	1813	3921	0.68	0.48
11	20/02/2007	Pearson Is.	95	14	81	0.85	62.9	83.2	1.49	124.4	881	6740	0.88	0.75
12	20/02/2007	Pearson Is.	81	5	76	0.72	74.7	84.9	1.40	119.1	374	6453	0.95	0.68
13	20/02/2007	Flinders Is.	26	9	17	0.23	66.2	82.7	0.31	26.0	596	1407	0.70	0.16
14	20/02/2007	Flinders Is.	28	16	12	0.25	70.6	81.8	0.22	18.1	1130	982	0.46	0.12
15	14/03/2007	Wedge Is.	41	16	25	0.37	32.0	40.6	0.46	18.7	513	1014	0.66	0.24
16	15/03/2007	Wedge Is.	100	65	35	0.89	30.6	36.6	0.65	23.7	1992	1282	0.39	0.35
17	22/03/2007	Pearson Is.	55	16	39	0.49	81.1	90.9	0.72	65.4	1297	3544	0.73	0.36
18	23/03/2007	Pearson Is.	171	47	124	1.52	72.2	85.2	2.29	194.9	3395	10562	0.76	1.15
19	23/03/2007	N. Neptune Is.	207	163	44	1.84	56.7	65.9	0.81	53.5	9246	2899	0.24	0.44
20	23/03/2007	N. Neptune Is.	406	310	96	3.62	55.5	64.8	1.77	114.8	17198	6220	0.27	0.96
			2244*	1160*	1084*					71.0#	65539*	76895*	0.58	0.52#

**Table 3.** Number of females in samples and estimates of spawning fraction,  $S$  and batch fecundity,  $F$  for samples collected in 2007. Values in bottom row are sums\* and weighted means#.

Sample	Location	Date	n	Weighting	Day 0	Day1	Day2	S	S	♀ wt (g)	♀ wt (g) Ovary	F	F
					#(%)	#(%)	#(%)	(%)	Weighted (%)	Ovary removed	removed weighted	(n oocytes)	weighted
1	Scotts Cove	11/02/2007	52	0.96	1(1.9)	5(9.6)	5(9.6)	7.05	6.77	64.18	61.57	19346.7	18561.5
2	Scotts Cove	11/02/2007	43	0.79	2(4.7)	10(23.3)	0(0.0)	9.30	7.38	62.11	49.27	18603.1	14759.0
3	Scotts Cove	11/02/2007	41	0.76	2(4.9)	6(14.6)	1(2.4)	7.32	5.54	61.55	46.56	18401.2	13919.7
4	Scotts Cove	12/02/2007	109	2.01	6(5.5)	16(14.7)	2(1.8)	7.34	14.76	61.95	124.59	18547.0	37299.3
5	Wedge Is.	14/02/2007	44	0.81	43(97.7)	0(0.0)	0(0.0)	32.58	26.45	47.62	38.66	13399.8	10878.1
6	N. Neptune Is.	16/02/2007	29	0.54	5(17.2)	1(3.5)	1(3.5)	8.05	4.31	68.16	36.47	20776.2	11116.4
7	N. Neptune Is.	16/02/2007	49	0.90	10(20.4)	7(14.3)	2(4.1)	12.93	11.69	64.84	58.62	19585.8	17706.7
8	N. Neptune Is.	16/02/2007	52	0.96	10(19.2)	11(21.2)	4(7.7)	16.03	15.38	66.11	63.43	20039.6	19226.2
9	N. Neptune Is.	17/02/2007	65	1.20	7(10.8)	12(18.5)	1(1.5)	10.26	12.30	68.54	82.20	20914.3	25081.8
10	Pearson Is.	19/02/2007	51	0.94	14(27.5)	7(13.7)	3(5.9)	15.69	14.76	72.43	68.15	22308.4	20991.3
11	Pearson Is.	20/02/2007	81	1.49	9(11.1)	20(24.7)	3(3.7)	13.17	19.68	79.33	118.55	24786.6	37042.7
12	Pearson Is.	20/02/2007	76	1.40	0(0.0)	27(35.5)	2(2.6)	12.72	17.84	81.03	113.62	25397.4	35612.6
13	Flinders Is.	20/02/2007	17	0.31	0(0.0)	1(5.9)	0(0.0)	1.96	0.62	77.32	24.25	24066.1	7548.4
14	Flinders Is.	20/02/2007	12	0.22	0(0.0)	1(8.3)	1(8.3)	5.56	1.23	76.87	17.02	23903.7	5292.3
15	Wedge Is.	14/03/2007	25	0.46	0(0.0)	1(4.0)	0(0.0)	1.33	0.62	39.37	18.16	10435.8	4813.6
16	Wedge Is.	15/03/2007	35	0.65	0(0.0)	0(0.0)	0(0.0)	0.00	0.00	35.31	22.80	8978.1	5797.7
17	Pearson Is.	22/03/2007	39	0.72	1(2.6)	13(33.3)	1(2.6)	12.82	9.23	86.33	62.12	27302.0	19645.3
18	Pearson Is.	22/03/2007	124	2.29	8(6.5)	21(16.9)	5(4.0)	9.14	20.91	80.61	184.42	25247.2	57761.1
19	N. Neptune Is.	23/03/2007	44	0.81	9(20.5)	28(63.6)	1(2.3)	28.79	23.37	62.84	51.02	18867.1	15316.5
20	N. Neptune Is.	23/03/2007	96	1.77	22(22.9)	52(54.2)	3(3.1)	26.74	47.36	62.58	110.84	18771.7	33248.4
			1084*		149*	239*	35*	11.94	13.01#	65.85	67.62#	19983.9	20580.9#

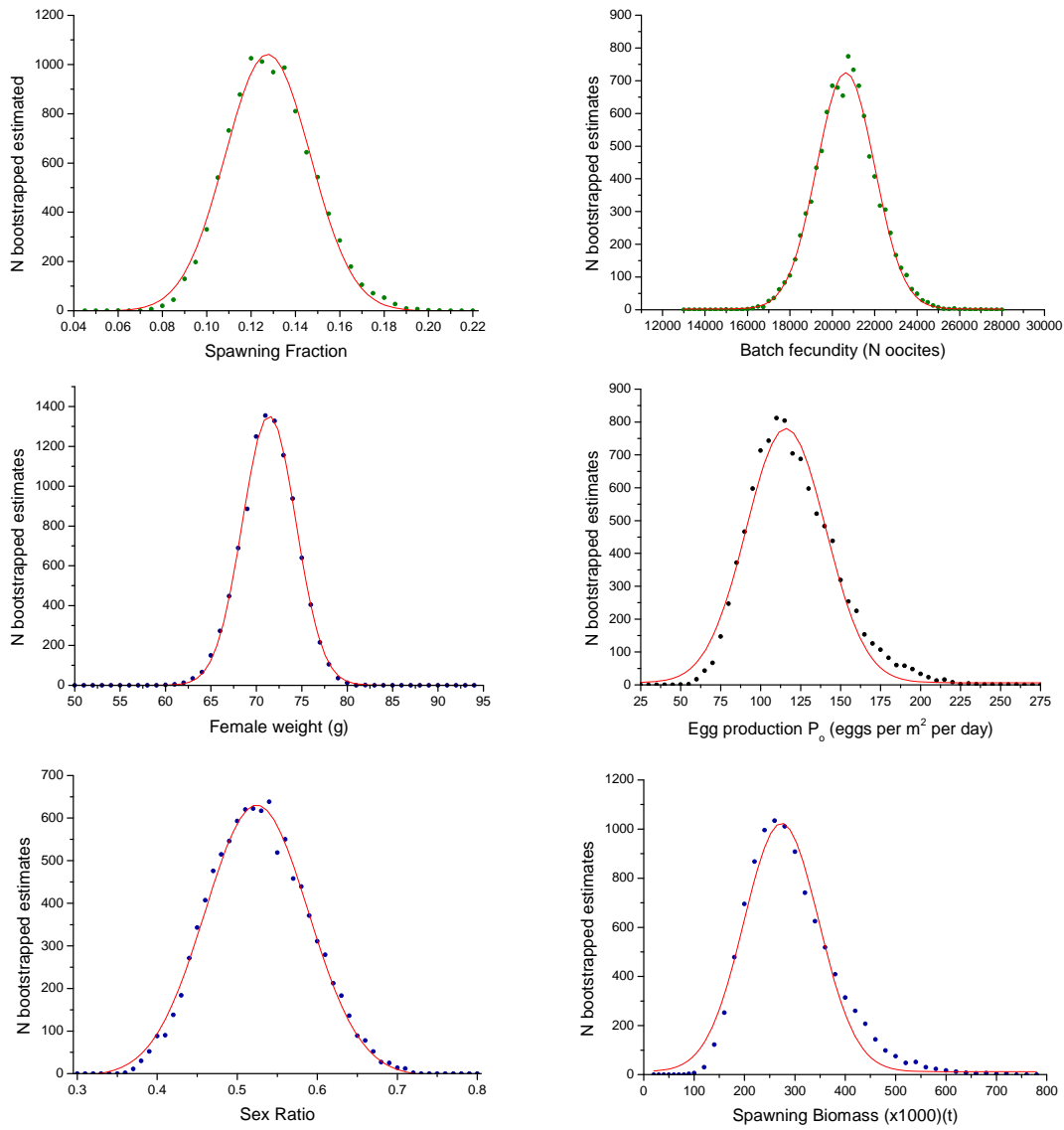


Figure 10. Distributions of bootstrapped parameter estimates ( $P$ ,  $W$ ,  $R$ ,  $S$ ,  $F$ ) and spawning biomass estimates (95% CIs).

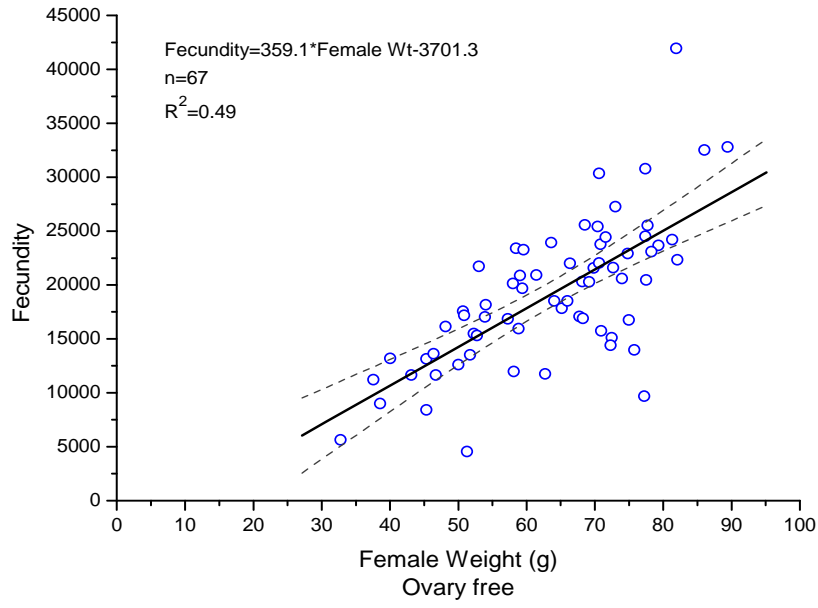


Figure 11. Relationship between gonad-free weight and batch fecundity in 2007 (dotted line = 95% CI).

## 4. DISCUSSION

### 4.1 Egg abundance and distribution

More eggs and larvae were collected in 2007 than during any other annual sardine surveys conducted in South Australian waters since 1995 (Table 5). This finding may partially reflect the rearrangement of survey sites that occurred in 2006, when sites that had not yielded any eggs over the previous decade were not sampled so that additional sites in Spencer Gulf could be sampled. However, even when the additional sites were excluded from the analysis the abundance of eggs and larvae collected from waters off South Australia during the surveys in February-March 2007 was high. This finding is clearly a positive indicator for the status of the sardine stock in 2007. It is notable that the number and percentages of eggs collected from Spencer Gulf in 2007 was also the highest since 2004. This finding suggests that the recent quota reductions have alleviated the concerns regarding localised depletion of sardines in Spencer Gulf that have been raised in previous reports (e.g. Rogers and Ward 2006; Ward *et al.* 2006).

**Table 4.** Numbers of *S. sagax* eggs collected throughout the survey area and in Spencer Gulf during the DEPM surveys between 2000 and 2007. \* denotes inclusion of data from new stations established in 2006.

Year	n eggs (Live and dead all regions)	n eggs (Live all regions)	n eggs (Live and dead) SG	n eggs (Live) SG	% total eggs (Live) SG	n SG stations sampled	n SG stations with eggs	% SG stations with eggs
2000	1,362	992	711	545	54.9	56	25	44.6
2001	1,449	1,122	508	349	31.1	52	16	30.8
2002	1,475	1,117	236	204	18.3	53	11	20.8
2003	1,718	1,260	223	185	14.7	53	17	32.1
2004	3,186	2,576	906	735	28.5	53	18	34.0
2005	1,808	1,303	86	68	5.2	54	9	16.7
2006	3,083	2,866	369(508*)	347(472*)	12.1(16.5*)	45(65*)	18(28*)	40(43.1*)
2007	3,909	3,450	739(826*)	690(781*)	19.2(22.6*)	45(65*)	27(37*)	55.5(56.9*)

As has been the case in most previous years, in 2007 the lowest SSTs (<18.0°C) and highest levels of chlorophyll a (0.5-1.8 µg.L<sup>-1</sup>) recorded during the survey were at sites located in coastal waters of the southern Eyre Peninsula and off the western tip of Kangaroo Island. However, SSTs were not as low and concentrations of chlorophyll-*a* were not as high as those recorded during 2006 (i.e. 14 – 15°C; up

to 3.3  $\mu\text{g}\cdot\text{L}^{-1}$ ). This finding suggests that upwelling was not as strong during the 2007 surveys as it was during 2006. However, as was the case in 2006, few eggs or yolk-sac larvae were present in the cool waters between Cape Carnot and Cape Finniss and there were two distinct spawning areas, one in the southern gulfs and Investigator Strait, and the other in shelf waters of the west coast. This finding provides further evidence of the need to investigate the rates of movement of adult sardines between the west coast and southern Spencer Gulf.

#### **4.2 Spawning area**

The estimate of spawning area for 2007 (43,946 km<sup>2</sup>) is slightly lower than the estimate of spawning area recorded in 2006 (44,891 km<sup>2</sup>). This is a strong positive indicator for the current status of the stock because spawning area is the DEPM parameter that is most strongly correlated with spawning biomass (Gaughan *et al.* 2004). The importance of spawning area in determining spawning biomass is the reason that SARDI recently purchased a Continuous Underway Fish Egg Sampler to estimate this parameter in future surveys to support the South Australian Sardine Fishery.

#### **4.3 Egg production and egg mortality**

The estimate of mean daily egg production obtained using the linear version of the exponential mortality model and the internationally accepted bias correction factor (Picquelle and Stauffer 1985) was 116.6 eggs.day<sup>-1</sup>.m<sup>-2</sup> (95% CI = 74.17-182.42), which is slightly higher than the estimate obtained in 2006 of 104.70 eggs.day<sup>-1</sup>.m<sup>-2</sup> (95% CI = 67.95-158.44). However, the uncertainty surrounding estimates of egg production are typically high and contribute significantly to the uncertainty in estimates of spawning biomass (Ward *et al.*, in prep). A research proposal to investigate alternative methods for estimating egg production is currently being developed for submission to the Fisheries Research and Development Corporation (FRDC) in 2007. This proposal includes consideration of the potential for including data from yolk-sac larvae to calculate egg production.

#### **4.4 Adult sampling**

During the 2007 survey, 20 samples of adult *S. sagax* containing 1084 females were collected from throughout South Australian waters, at locations including: Scotts Cove in Investigator Strait; Wedge Island and North Neptune Island in southern Spencer Gulf; and Pearson and Flinders Islands in the eastern Great Australian Bight. Although no samples were collected from the Head of the Bight, due to the lack of suitable sampling sites in the region, there is no evidence to suggest that the samples collected during this study do not provide robust estimates of the adult reproductive parameters of sardine off South Australia during 2007. However, the potential for using industry vessels to collect samples for estimating adult reproductive parameters will be investigated during 2008.

#### 4.5 Spawning biomass estimates

The estimate of spawning biomass for 2007 was 263,747 t (95% CI = 147,947 – 489,520), which is higher than the estimate of 225,389 t (95% CI = 136,060 – 417,612) obtained in 2006, and higher than any other spawning biomass estimate for sardine in South Australian waters (see Ward *et al.* in prep). The estimate of spawning biomass for 2007 also lies within the upper third of the target range of spawning biomass that has been established for the South Australian Sardine Fishery, i.e. 150,000 to 300,000 t. The baseline TACC for the SASF of 30,000 t is approximately 11.4% of the estimate of spawning biomass for 2007.

#### 4.6 Future research directions

The priority for improving estimates of spawning biomass obtained using the DEPM is to refine methods for estimating spawning area and egg production. In 2008, several approaches for collecting and using data from a Continuous Underway Fish Egg Sampler (CUFES) to estimate spawning area will be evaluated, with the aim of utilizing a CUFES in the assessment undertaken in 2009. An FRDC proposal to investigate alternative methods for estimating egg production and spawning area is also being developed. Similarly, the potential for obtaining FRDC funding to support a Ph.D. project on the stock structure and movement patterns of sardine in southern Australia is currently being investigated.

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**APPENDIX 1. RESIDUALS FOR LINEAR FIT OF EGG DENSITY AND AGE (2007).**

