Research to support the development of a Tasmanian Sardine Fishery

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Foreword

This study documents the first comprehensive evaluation of the spawning biomass of the South Eastern Stock of Australian Sardine (*Sardinops sagax,* called Sardine in this report). This stock occupies continental shelf waters from the Victorian-South Australian border, east through Bass Strait and along the north-western and north-eastern coasts of Tasmania and north to around Jervis Bay off southern New South Wales. The study applied the Daily Egg Production Method (DEPM, see Parker 1980) using the modified approach established for the adjacent Southern Sardine Stock by Ward et al. (2021).

This study combined i) information from a targeted ichthyoplankton survey of the western component of this stock undertaken in December 2023 as part of FRDC Project 2023-005 with ii) data obtained opportunistically from the eastern component of the stock from a Jack Mackerel (*Trachurus declivis*) survey conducted in January 2024 and funded by the Australian Fisheries Management Authority (AFMA).

The combined survey covered a total area of almost 150,000 km^2. More than 8,500 live Sardine eggs were collected. Sardine eggs were widespread and abundant in Bass Strait and off the coast of western Victoria. The total spawning area was almost 90,000 km^2. Adult parameters used to calculate spawning biomass were obtained from the adjacent Southern Sardine Stock. This approach is robust because these parameters are consistent for *Sardinops sagax* and other species and genera of sardine worldwide.

The spawning biomass of the South Eastern Sardine Stock was estimated to be more than 200,000 tonnes. This study demonstrates that this stock has the potential to support a large fishery. We provide recommendations to inform the development of an ecologically sustainable Tasmanian Sardine Fishery.

Information on the distribution and abundance of Jack Mackerel eggs and the likely spawning biomass of this species in the western part of the survey area will be documented in a report produced for AFMA by the Institute for Marine and Antarctic Studies.

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Acknowledgments

We gratefully acknowledge the owners, master and crew of the FV Dell Richey II, including Mr Stuart Richey (AM), Mrs Gail Richey, Mr John Richey (skipper), Mr Salvatore Cutrale (Sparrow), Mr Jayden Kelly, Mr Jesse Brooke and Ms Janine Geraghty, for their professional and cheerful assistance before, during and after the survey. We thank the Australian Fisheries Management Authority (AFMA) and operators in the Commonwealth Small Pelagic Fishery (SPF), especially Mr Tony Muollo, for allowing us to use sardine data obtained opportunistically from an AFMA-funded Jack Mackerel DEPM survey (Project Number 2022/0805). Mr Alex Ivey from the South Australian Research and Development Institute provided valuable advice about how to differentiate between Sardine eggs that were alive or dead at the time of capture. The Tasmanian Government is recognised for providing co-funding to this project through the Department of Natural Resources and Environment Tasmania (NRE Tas). We thank NRE Tas staff, especially Dr Wetjens Dimmlich, Mr Andy Warmbrunn, Ms Rosie Katunar and Mr Nick Blay for their enthusiastic support and encouragement. The Institute for Marine and Antarctic Studies at the University of Tasmania is gratefully acknowledged for providing a significant in-kind contribution to this project.

Abbreviations

Research institutions, government agencies and fisheries

AFMA	Australian Fisheries Management Authority
FRDC	Fisheries Research and Development Corporation
IMAS	Institute for Marine and Antarctic Studies
NRE Tas	Department of Natural Resources and Environment Tasmania
SARDI	South Australian Research and Development Institute
SASF	South Australian Sardine Fishery
SPF	Commonwealth Small Pelagic Fishery
UTAS	University of Tasmania

Scientific terms

DEPM	Daily Egg Production Method
P_0	Mean daily egg production
z	Instantaneous rate of egg mortality
A	Spawning area
R	Sex ratio by weight
S	Spawning fraction
F'	Relative fecundity
POFs	Post-ovulatory follicles
CV	Coefficient of Variation
95% CI	95% Confidence Interval

Executive Summary

Overview and background

This study conducted the first comprehensive evaluation of the spawning biomass of the South Eastern Stock of Australian Sardine (*Sardinops sagax*). It was initiated in response to growing evidence that a large, under-utilised Sardine resource occurs in Bass Strait and surrounding waters. The study was led by scientists from the Institute of Marine and Antarctic Studies (IMAS) and involved collaborators from the South Australian Research and Development Institute (SARDI) and Deakin University. The study was jointly funded by FRDC and the Department of Natural Resources & Environment Tasmania (NRE Tas), with in-kind contributions from the Australian Fisheries Management Authority (AFMA) and IMAS. In this study, we combined data collected in a targeted ichthyoplankton survey for Sardine (FRDC Project 2023-005) with data obtained opportunistically from a Jack Mackerel survey funded by AFMA (Project Number 2022/0805). The study was undertaken to inform the development of an ecologically, economically and socially sustainable Tasmanian Sardine Fishery.

Objectives

The project had two objectives:

1) To investigate the size, distribution and potential productivity of the South Eastern stock of Australian Sardine
2) To provide advice to Department of Natural Resources and Environment Tasmania (NRE Tas) to inform the establishment of management arrangements for the new Tasmanian Sardine Fishery.

Methodology

The spawning biomass of the South Eastern Stock of Australian Sardine was estimated using the Daily Egg Production Method (DEPM). The concept underpinning the DEPM is that the spawning biomass of fish that spawn pelagic eggs can estimated by dividing the mean number of eggs produced per day throughout the spawning area by the mean number of eggs produced per unit weight of adult fish. The five parameters used in the application of the DEPM are: mean daily egg production (P_0), spawning area (A), sex ratio by weight (R), spawning fraction (S) and relative fecundity (F').

The combined ichthyoplankton survey documented in this report covered the entire South Eastern Sardine Stock. It was conducted during December 2023 and January 2024. Plankton samples were collected at 491 sites located on 49 transects. Mean daily egg production (P_0) and spawning area (A) were estimated from samples collected during the survey. Published estimates of sex ratio (R), spawning fraction (S) and relative fecundity(F') obtained from the adjacent Southern Sardine Stock over two decades (1998-2018) were used to estimate spawning biomass. Using estimates of adult parameters obtained from an adjacent stock in the application of the DEPM is justified because these parameters, especially S which is the most influential adult parameter, are consistent for *S. sagax* and other species of sardine in multiple ecosystems throughout the world.

Results and discussion

The ichthyoplankton survey covered an area of approximately 149,837 km^2. A total of 8,512 live Sardine eggs were collected from 284 (57.8%) of the 491 sites sampled. The highest densities of Sardine eggs occurred in Bass Strait and off the coast of western Victoria. Egg densities off the east coasts of New South Wales, Victoria and Tasmania were relatively low. Mean daily egg production (P_0) was 43.2 (95% CI = 35.0-53.4) eggs.day^{-1}.m^{-2}. The spawning area (*A*) was 89,158 km^2, which was 59.5% of the area surveyed. Estimates of adult parameters obtained over two decades from the adjacent Southern Stock were: sex ratio (*R*) 0.55 (95% CI = 0.52–0.58); spawning fraction (*S*) 0.11 (95% CI = 0.10–0.12); relative fecundity (*F'*) 305 eggs.g^{-1} (95% CI: 304–306 eggs.g^{-1}). The spawning biomass was estimated to be 208,732 tonnes (95% CI = 157,791-259,673 tonnes). This estimate of spawning biomass is considered to be robust because it is based on reliable estimates of all five DEPM parameters.

Conclusions, implications and recommendations

This study provides results that the authors consider to be suitable for informing future management of the South Eastern Australian Sardine Stock. The study demonstrates that the spawning biomass of this stock is sufficiently large to support a substantial commercial fishery. It also indicates that a significant portion of this stock occurs in waters under the jurisdiction of the Tasmanian Government. Therefore, this study demonstrates the potential to establish a large Tasmanian Sardine Fishery. Because this resource has only been discovered recently, and patterns of inter-annual variability in stock abundance and recruitment are not well understood, we recommend that a precautionary approach is taken to developing this resource.

Australia's two major fisheries for small and medium sized pelagic fishes, i.e. the South Australian Sardine Fishery (SASF) and Commonwealth Small Pelagic Fishery (SPF), both set Total Allowable Catches (TACs) for Sardine using harvest strategies that apply agreed exploitation rates (also called harvest fractions) to estimates of spawning biomass obtained using the DEPM. Both fisheries initially applied and continue to apply exploitation rates that are more conservative than the level identified as being ecologically sustainable for Sardine in Australia (i.e., 33%). The current exploitation rate in the SASF is 25% with DEPM surveys conducted annually. In the SPF, the exploitation rate is 20% and DEPM surveys are conducted every five years. Initial exploitation rates applied in both fisheries were lower (e.g. 10% in the SASF). Given the current of lack of knowledge about the temporal stability of the South Eastern Sarine Stock, we recommend that an even more conservative exploitation rate (e.g., ≤15%), which is less than half the level recommended for Australian sardine, is used to set initial TACs in the Tasmanian Sardine Fishery.

Both the SASF and SPF have established spatial management arrangements to control the distribution of fishing effort. Spatial management arrangements can be used to mitigate both interactions with other stakeholders, including recreational fishers, and reduce levels of fishing effort in areas used by central place foragers, especially seabirds. Information on the distribution of adult Sardines provided in this report, combined with existing knowledge about the location of recreational fishing grounds and seabird foraging areas, could be used to determine where fishing zones and spatial closures may be established.

Future research and monitoring

If a large Tasmanian Sardine Fishery is established, a research program will be needed to monitor the status of the South Eastern Sardine Stock and inform management of the new fishery. This program should include:

1. A comprehensive DEPM survey that is conducted every five years (or more frequently) to assess the status of the resource and set TACs.
2. An Annual Fishery Assessment Report to monitor stock status between DEPM surveys and evaluate whether exploitation rates should be reduced between DEPM surveys.

It will also be necessary to establish protocols to ensure that interactions with dolphins in the new fishery are minimised and reported accurately. An ongoing monitoring program that involves both electronic monitoring and independent observers should be established from the start of the fishery. The primary objective of the electronic monitoring program should be to evaluate whether protocols established for minimising interactions with dolphins (i.e. dolphin avoidance and release procedures) are implemented in the absence of independent (human) observers. A targeted research project will be needed to establish the operational protocols (e.g., camera positioning, video analysis systems) that will be required to ensure that the electronic monitoring program achieves its primary objective.

Keywords

Daily Egg Production Method, Australian Sardine, *Sardinops sagax*, Bass Strait, Tasmania

Introduction

Two recent studies have suggested that the spawning biomass of the South Eastern Stock of Australian Sardine (Izzo et al. 2017, see Figure 1) may be large enough (e.g., 200,000 to 400,000 tonnes) to support a significant commercial fishery (Ward et al. 2022, 2023). However, both studies were based on surveys that did not cover the entire stock (see Grammer et al. 2023, Australian Sardine 2020) and emphasised the critical importance of conducting a comprehensive survey to validate their findings and inform future management of the resource.

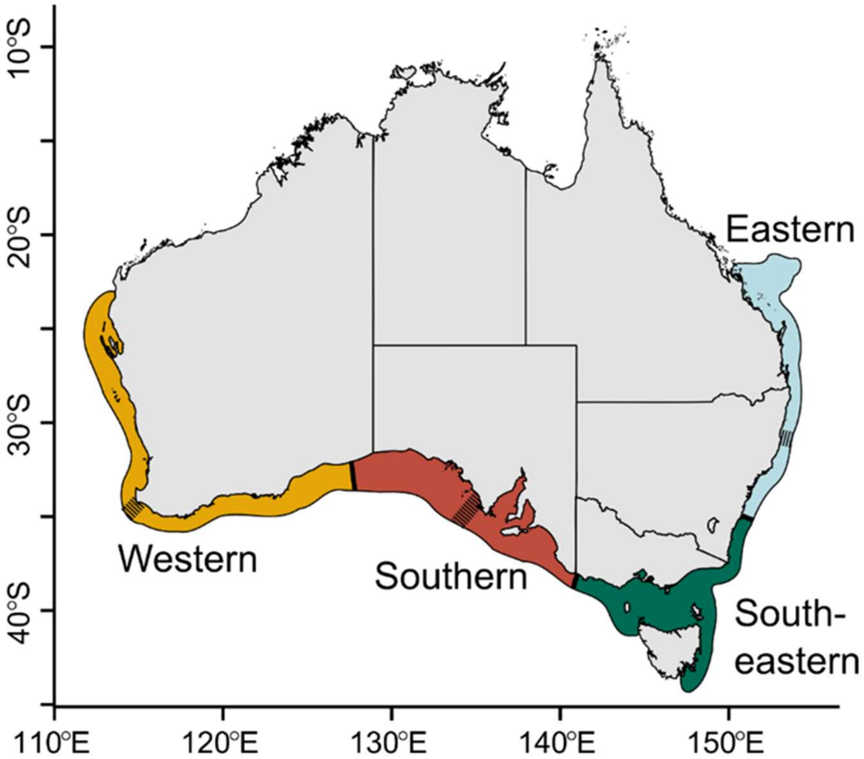

Figure 1. Map showing the four stocks of Australian Sardine (*Sardinops sagax*). Modified from Ward et al. (2023a) using information from Izzo et al. (2017), Sexton et al. (2019) and Grammer et al. (2023).

A large proportion of the South Eastern Sardine Stock occurs in waters under the jurisdiction of the Tasmanian Government under the Offshore Constitutional Settlement with the Commonwealth of Australia (1996) (Figure 2). The current study was undertaken to inform the development of a Tasmanian Sardine Fishery (Ward and Gardener 2022). The importance of this project to the Tasmanian Government is evidenced by the significant financial contribution from the Department of Natural Resources and Environment Tasmania (NRE Tas).

This project was conducted to ensure that the development of the new Tasmanian Sardine Fishery is based on robust scientific information (Ward and Gardener 2022). The approach taken in the project draws heavily on research that has been undertaken to support the development of the South Australian Sardine Fishery (SASF) and Commonwealth Small Pelagic Fishery (SPF). Both fisheries have been developed and are managed using estimates of spawning biomass obtained using the Daily Egg Production Method (DEPM, Grammer et al. 2021, Grammer and Ivey 2022; Ward et al. 1998, 2001, 2011, 2021).

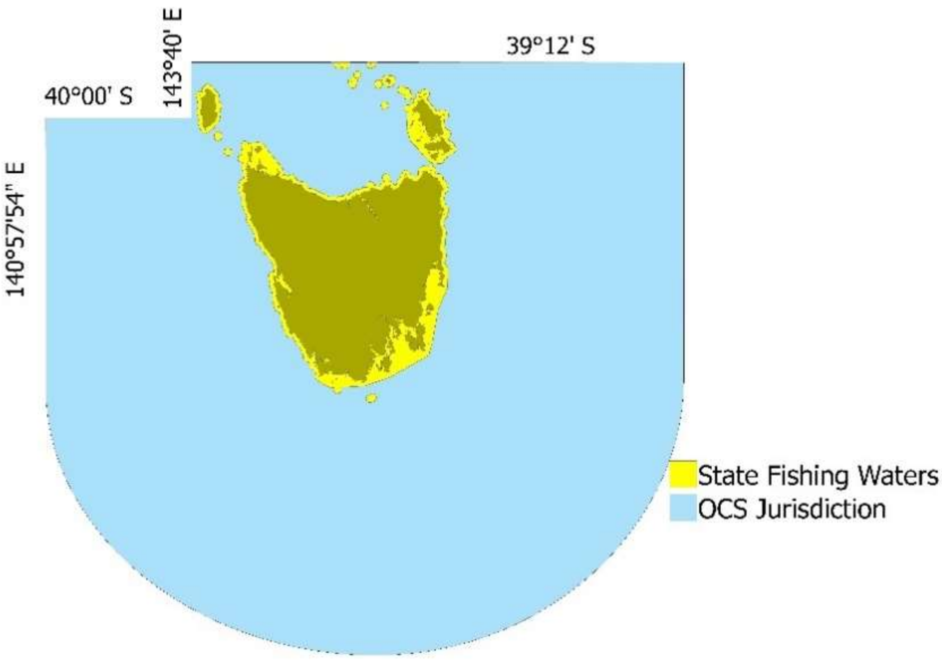

Figure 2. Map showing Tasmanian State waters and the area under Tasmanian jurisdiction for finfish under the Offshore Constitutional Settlement with the Commonwealth of Australia (1996).

Objectives

This project has two objectives:

1) To investigate the size, distribution and potential productivity of the South Eastern stock of Australian Sardine.
2) To provide advice to the Department of Natural Resources and Environment Tasmania (NRE Tas) to inform the establishment of management arrangements for the new Tasmanian Sardine Fishery.

Data on the distribution and abundance of Jack Mackerel eggs collected from the ichthyoplankton survey conducted in the western part the study area (i.e. FRDC Project 2023-005) will be documented in a separate report published by IMAS and provided to AFMA to inform the management of the SPF.

Methods

Overview

This project combines i) data from a targeted ichthyoplankton survey for Sardine (FRDC Project 2023-005) with ii) data obtained opportunistically from a Jack Mackerel survey funded by AFMA (Project Number 2022/0805) (Figure 3). The combined ichthyoplankton surveys (i.e. 'the survey') covered the entire South Eastern Sardine Stock (Figure 1, 3). The spawning biomass of this stock was estimated by applying the DEPM (Parker 1980) using the approach developed for Sardine in Australia by Ward et al. (2021, 2022, 2023a). Information obtained in the study will help to inform NRE Tas about the potential size of initial Total Allowable Catches (TACs) for the Tasmanian Sardine Fishery and evaluate other management options, including spatial management (e.g., zones, spatial closures).

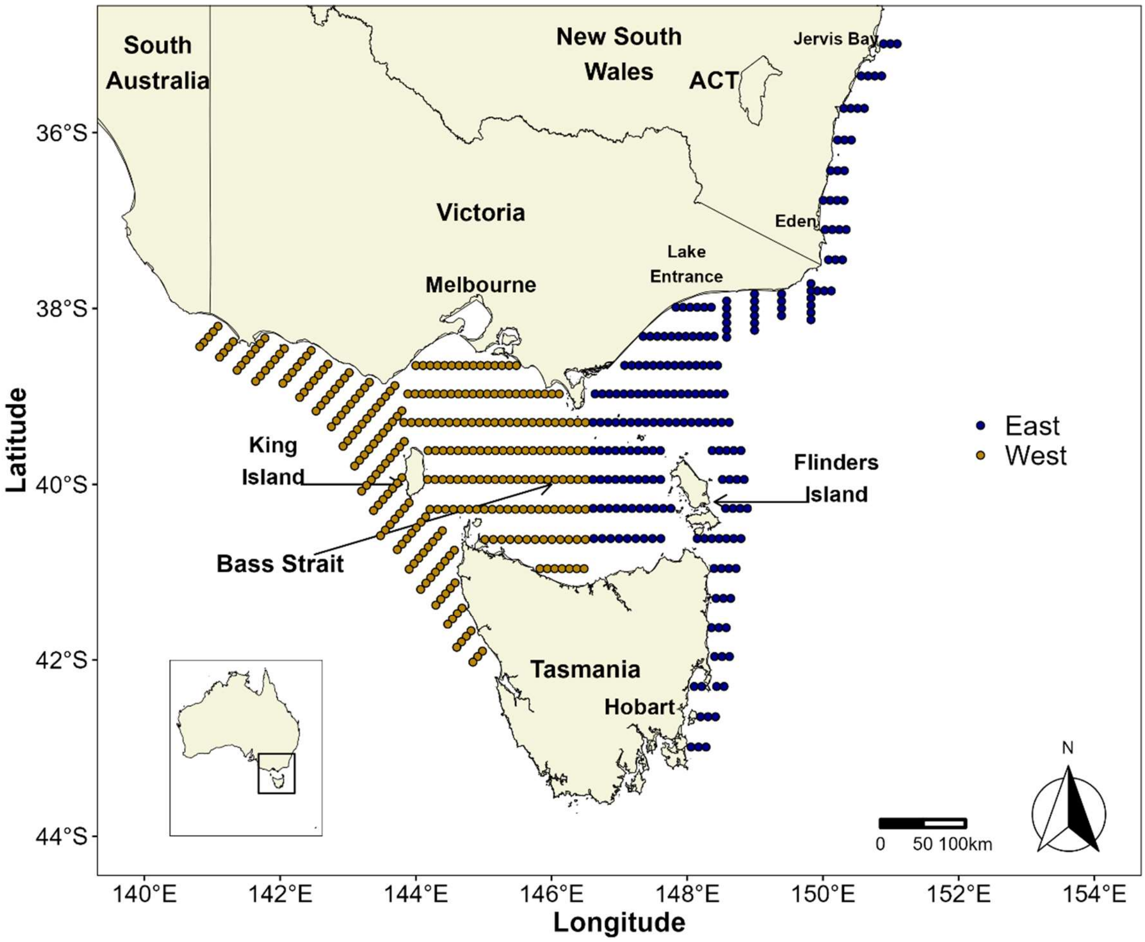

Figure 3. Map showing the location of sites at which plankton samples were collected from the FV Dell Richey II during 1-20 December 2023 as part of FRDC Project 2023-005 (orange circles) and 6-22 January 2024 as part of AFMA Project 2022/0805 (blue circles).

The concept underpinning the DEPM (Table 1, Equation 1) is that the spawning biomass of fish that spawn pelagic eggs can be estimated by dividing the mean number of eggs produced per day throughout the spawning area (i.e., total daily egg production) by the mean number of eggs produced per unit mass of adult fish (i.e., mean daily fecundity; Parker, 1980; Ward et al. 2021). Total daily egg production is calculated from estimates of mean daily egg production (P_0) and spawning area (A) obtained from ichthyoplankton surveys (Table 1). Mean daily fecundity is estimated from three adult reproductive parameters: sex ratio by weight (R), spawning fraction (S) and relative fecundity (F', Table 1). A detailed description of how the DEPM is currently applied to Sardine in Australia is provided by Ward et al. (2021). The methods section in this report provides a simple description of how the DEPM was applied in the current study. It was designed to be easily understood by non-technical stakeholders. The key equations that underpin the DEPM that are listed in Table 1. The first time that each DEPM parameter is mentioned in a paragraph we repeat the parameter name and the abbreviation because we think that this approach makes it easier for readers to recall what each abbreviation means and relate the text to the equations in Table 1.

Total daily egg production

Ichthyoplankton survey

The ichthyoplankton survey that underpinned this study was conducted from the FV Dell Richey II during 1-20 December 2023 and 6-22 January 2024. It was the first comprehensive survey of the South Eastern Sardine Stock (Figure 1) and consisted of 491 sites located on 49 transects (Figure 3).

Each plankton sample was collected using a paired bongo net made by *Aquatic Research Instruments*. Each net in the pair was made from 500 µm nylon mesh and had internal diameter of 60 cm. Each was comprised of an initial 100 cm cylindrical section followed by a 200 cm conical section. Detachable plastic cod ends attached to each net each had an internal diameter of 11 cm and 10 lateral apertures covered by 500 µm mesh. The bongo net was deployed within a purpose-built stainless-steel frame that also held a *Sea-Bird*™ 19+ V2 Conductivity-Temperature-Depth (CTD) profiler and a *Moana* sensor that had been provided to the Dell Richey II as part of FRDC Project Number 2022-007 (Figure 4).

The sampling device was deployed to 10 m above the sea floor or to a maximum depth of 200 m and retrieved vertically at ~1 $m.s^{-1}$. *General Oceanics*™ 2030 flow meters with factory calibration coefficients were used to estimate the distance travelled and calculate the volume of water filtered by each net. If there was >5% difference between the two flow meter readings, the relationship between wire length released and flow-meter units was used to determine which meter was more accurate, and that value was used for both nets. If neither flow meter was considered reliable, the relationship between wire length and flow-meter units was used to calculate the volume of water filtered.

Table 1. Equations used in the application of the Daily Egg Production Method to estimate the spawning biomass of Australia Sardine in this study. Adapted from Ward et al. (2021). Reproduced with permission of Oxford University Press.

Calculation	**Equation**	**Equation Number**	**Parameters**	Reference
Spawning Biomass	$SB = \frac{P_0\ A}{R\ S\ F'}$	1	*SB*: Spawning Biomass P_0: mean daily egg production *A*: total spawning area *R*: mean sex ratio *F'*: mean relative fecundity *S*: mean spawning fraction	Parker (1980) Ward et al. (2021)
Egg Density (sample)	$P_s = \frac{C\ D}{V}$	2	P_s: density of eggs in a sample *C*: number of eggs of each age in each sample *V*: volume of water filtered (m^3) *D*: depth (m) of net cast	Smith and Richardson (1977)
Exponential egg mortality model (P_0)	$P_t = P_0 e^{-z\,t}$	3	P_t: egg density at age *t* *z:* the instantaneous rate of daily egg mortality	Lasker (1985)
Generalised Linear Mixed Model with error structure of negative binomial	$E[P_0] = g^{-1}(-zt + \varepsilon)$	4	E[P_0]: expected value of P_0 g^{-1}: inverse-link function *zt*: the instantaneous rate of daily egg mortality at age *t* *ε*: error term	Ward et al. (2021)
Sex Ratio: sample ($\overline{R_i}$)	$\overline{R_i} = \frac{F_i}{F_i + M_i}$	5	F_i: total weight of mature females in each sample *i* M_i: total weight of mature males in each sample *i*	Lasker (1985)
Sex Ratio: population (R)	$R = \overline{\left[\frac{\overline{R_i}\, n_i}{N}\right]}$	6	$\overline{R_i}$: mean sex ratio of each sample *i* *n*: number of fish in each sample n_i *N*: total number of fish collected in all samples and	Lasker (1985)

Spawning Fraction: sample ($\overline{S_i}$)	$$\overline{S_i} = \frac{d0 + d1 + d2}{3\ n_i}$$	7	*d*0, *d*1 and *d*2: the number of mature females with post-ovulatory follicles (POFs) aged day 0, 1 or 2 in each sample *i* n_i: is the total number of females within a sample.	Lasker (1985)
Spawning Fraction: population (S)	$$S = \overline{\left[\frac{\overline{S_i}\ n_i}{N}\right]}$$	8	$\overline{S}_i$: mean spawning fraction of each sample *i* *n*: number of fish in each sample *i* *N*: total number of fish collected in all samples	Lasker (1985)
Relative Fecundity (F')	$$F' = \bar{F}/\bar{W}$$	9	*F'*: Relative Fecundity $\bar{F}$: Mean Fecundity $\bar{W}$: Mean Weight	Parker (1980)
Ratio estimator (e.g. *F'*)	$$Var(F') = \frac{1}{n_{fis}} \cdot \frac{1}{\overline{W}^2} \cdot \{(F')^2 \cdot \sigma_W^2 + \sigma_F^2 - 2 \cdot F' \cdot cov(F,W)\}$$	10	*F'*: Relative Fecundity $\bar{F}$: Mean Fecundity $\bar{W}$: Mean Weight σ_F^2 and σ_W^2: variances of $\bar{F}$ and $\bar{W}$ $cov(F,W)$: covariance of *F* and *W*	Rice (1995)

Figure 4. Photograph of the sampling device with paired bongo net and CTD deployed during the survey.

At each site, plankton collected in the two net cod-ends were combined into a single one litre container and fixed in a 5% buffered formalin and seawater solution. Location (latitude, longitude), date, time, depth, wire length, and water temperature profiles were recorded at each site.

Laboratory processing

After the survey was completed, plankton samples were sorted in the IMAS laboratories at Taroona, Hobart, Tasmania. Sardine eggs in each sample were identified and staged using the descriptions of White and Fletcher (1998). For each sample, the total number of live eggs in each of the 12 stages was counted. Eggs that were considered to have died prior to capture (due to an opaque perivitelline space and deterioration of the yolk and embryo) were assigned to a separate category (i.e. dead eggs).

Statistical analysis

Mean daily egg production (P_0)

The statistical procedures used to estimate mean daily egg production (P_0) follow the methods described by Ward et al. (2021). Samples with no live eggs were excluded from the estimation of P_0. Eggs classified as dead and those assigned to Stages 1 and 12 were also excluded from the estimation of P_0. Each sample was assigned to one of three temperature bins (i.e. 14–18°C, 18–22°C, and 22–26°C). The age of each stage in each sample was estimated using the temperature egg developmental rates determined for Sardine by Le Clus and Malan (1995).

Eggs in each sample were aggregated into daily cohorts (i.e. day-0, day-1 and day-2). The weighted mean age of each daily cohort was calculated by weighting estimates of the age of each stage by the number of the eggs in each stage. Zero counts were allocated to samples where a cohort was expected to occur in a sample (based on the water temperature, spawning time and sampling time), but was not found in that sample. The density of eggs of each daily cohort (i.e. eggs m^{-3}) in each sample was calculated by dividing the number of eggs collected by the volume of water filtered (Table 1, Equation 2). The number of eggs under one square metre of water (eggs.m^{-2}) was calculated by multiplying egg density (i.e. eggs m^{-3}) at each site by the depth (m) to which the net was deployed (Table 1, Equation 2).

The model underpinning estimation of mean daily egg production (P_0) and the instantaneous rate of egg mortality (z) is the exponential egg mortality model (Table 1, Equation 3). In this study, P_0 and z (and associated measures of precision, e.g. 95% CIs) were estimated by fitting a generalised linear model (GLM) with a negative binomial error structure to estimates of egg abundance (egg.m^{-2}) and egg age (days) of each daily cohort at each site (Table 1, Equation 4). The GLM used a log-link function with variance increasing linearly with the mean. The GLM was fitted using the glmmTMB “R” package (Brooks et al. 2017). Mean daily egg production (P_0) was also estimated by applying assumed estimates of z to the estimate of mean egg density using the method of McGarvey and Kinloch (2001).

Spawning area

The survey area was divided into continuous polygons centred on each site using the deldir package in the statistical program R (Turner 2015). Spawning area (A) was calculated by summing the area of polygons (Figure 4) located around sites where at least one live Sardine egg was collected.

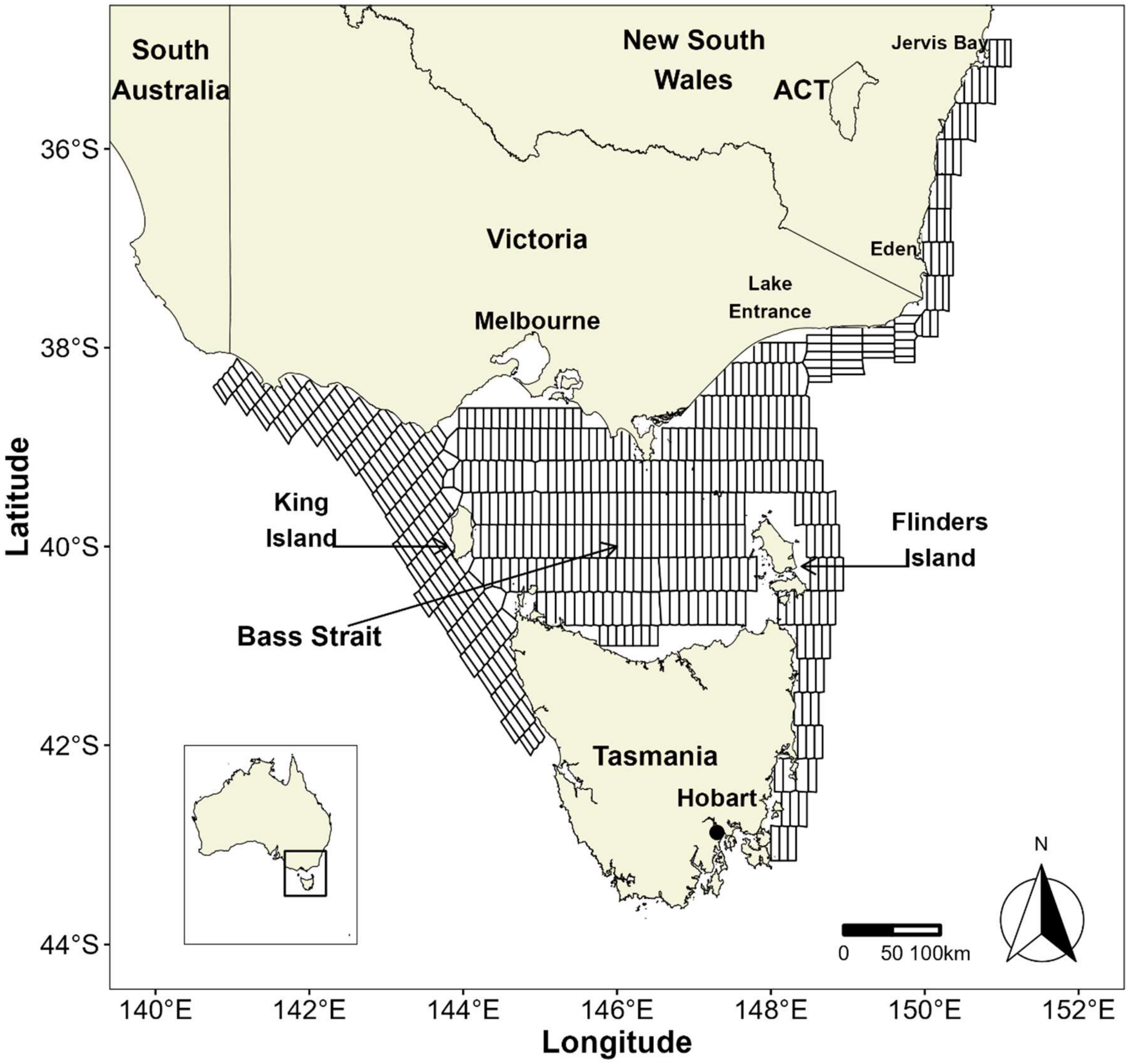

Figure 4. Polygons generated using Voronoi Natural Neighbour method to estimate spawning area (*A*).

Mean daily fecundity

Overview and justification

Adult parameters used to estimate spawning biomass, i.e. sex ratio (*R*), spawning fraction (*S*) and relative fecundity (*F'*), were obtained from published data for Sardine off South Australia collected over two decades, i.e., from 1998 to 2018 (Ward et al. 2021). Using data from the adjacent Southern Sardine Stock (Figure 1) in this study is justified because these key adult parameters are consistent for *S. sagax* worldwide and for other species and genera of sardines in multiple ecosystems (Ganias 2014; Somarakis et al. 2019). For example, the mean spawning fraction (*S*) for *Sardinops sagax* off South Australia of 0.11 (Ward et al. 2021) is similar to the global mean of 0.12 reported for this species (Ganias *et al.* 2014) and to values reported for other species and genera of sardines in other ecosystems (Somarakis *et al.*, 2019). Importantly, Ward et al. (2021) showed that estimates of these three adult parameters obtained from a single year of sampling are usually imprecise and often biased. For example, annual estimates of mean sex ratio (*R*) reported by Ward et al. (2021) ranged from 0.36 to 0.70 (mean = 0.55) and annual estimates of mean spawning fraction (*S*) ranged from 0.04 to 0.18 (mean = 0.11). Therefore, when this project was being designed it was decided that the limited resources available should be used to undertake a comprehensive ichthyoplankton survey rather than attempting to estimate adult parameters directly.

Field sampling and laboratory procedures

Adult samples used in this study were collected by Ward et al. (2021) using a relatively unusual fishery-independent sampling method that involved multi-panel gillnets and surface and sub-surface lights. In contrast, the laboratory methods used to obtain data from these samples largely followed the more traditional protocols established by Lasker et al. (1981). Detailed descriptions of the field and laboratory methods used to estimate adult parameters used in the present study are provided in Ward et al. (2021).

Statistical analysis

The statistical methods used to estimate adult parameters are also described in Ward et al. (2021). The mean sex ratio (*R*) of mature individuals (by weight) in each sample and the population were calculated using Equations 5 and 6 (Table 1), respectively. Spawning fraction (*S*), i.e. the mean proportion of females that spawn each night during the spawning season, was calculated for each sample and population using Equations 7 and 8, respectively (Table 1). Batch fecundity (*F*) was estimated from females containing hydrated oocytes using the gravimetric method described by Hunter *et al.* (1985). Batch fecundity (*F*) for females without hydrated oocytes was estimated from the relationship between *F* and gonad-free female weight derived from females with hydrated oocytes (details outlined in Ward et al. 2021). Relative fecundity, (F'), i.e. the number of eggs produced per gram of total female weight (*W*), was calculated for each female by dividing *F* by total female weight (*W*, Table 1, Equation 9). The coefficients of variation (CVs) for *S*, *R*, and *F'* were calculated using a ratio estimator (Rice 1995, Table 1, Equation 10 uses *F'* as an example).

Spawning biomass

Spawning biomass was calculated using Equation 1 (Table 1). Estimates of mean daily egg production (P_0) and spawning area (*A*) were calculated using samples collected during the survey shown in Figure 3. Estimates of sex ratio (*R*), spawning fraction (*S*) and relative fecundity (*F'*) were obtained from Ward et al. (2021). The variance around the estimate of spawning biomass was calculated by summing the squared Coefficients of Variation (CVs) for each parameter and multiplying by the square of the estimate of spawning biomass (Parker 1985). All analyses were done in the R programming environment (R Core Team, 2019).

Sensitivity analysis

Sensitivity analyses were conducted to assess the effects of potential variations in mean daily egg production (P_0), sex ratio (R), spawning fraction (S) and relative fecundity (F') on the estimate of spawning biomass. Sensitivity analyses were not conducted for spawning area (A) because there is a strong linear relationship between spawning area and spawning biomass for Sardine and this parameter largely drives interannual variations in spawning biomass (Ward et al. 2021).

Results

Egg densities and sea surface temperature

A total of 8,512 live Sardine eggs were collected from 284 (57.8%) of the 491 sites sampled during the survey conducted in December 2023 and January 2024 (Table 2). A total of 1,391 dead eggs were also collected, including 17 eggs at 15 sites where no live eggs were present. The highest densities of live Sardine eggs were recorded off the west coast of Victoria and in western and central Bass Strait (Figure 5). Densities of live eggs were relatively low off the east coasts of New South Wales, Victoria and Tasmania. Sea surface temperatures (SSTs) at individual sites ranged from 12.9°C to 23.6°C (mean = 17.4°C). Low SSTs (<15°C) were recorded off the west coast of Victoria and Tasmania and in south-western Bass Strait. High SSTs (>21°C) were recorded off southern New South Wales. Live Sardine eggs were collected at sites with SSTs ranging from 13.7°C to 22.5°C (mean = 17.1°C).

Table 2. Total number of sites sampled, number of sites with live eggs present, total number of live Australian Sardine eggs collected, total area surveyed, total spawning area and percentage spawning area.

No. of sites sampled	No. of sites with live eggs	Percentage of sites with live eggs	Total number of live eggs	Survey area (km^2)	Spawning area (km^2)	Percentage spawning area
491	284	57.8%	8,512	149,837	89,158	59.5%

Mean daily egg production

Mean daily egg production (P_0) estimated using the GLM (Figure 6) was 43.2 (95% CI = 35.0-53.4) eggs.day^{-1}.m^{-2} and the instantaneous rate of daily egg mortality (z) was 0.43 (95% CI = 0.28-0.59). Mean egg density was 67.2. eggs.day^{-1}.m^{-2}. The estimates of P_0 obtained by applying assumed estimates of z of 0.2 to 0.5 to mean egg density (67.2 eggs.day^{-1}.m^{-2}) using the method of McGarvey and Kinloch (2001) were similar to the value obtained from the GLM, ranging from 37.5 to 50.1 eggs.day^{-1}.m^{-2} (Figure 7, Table 3).

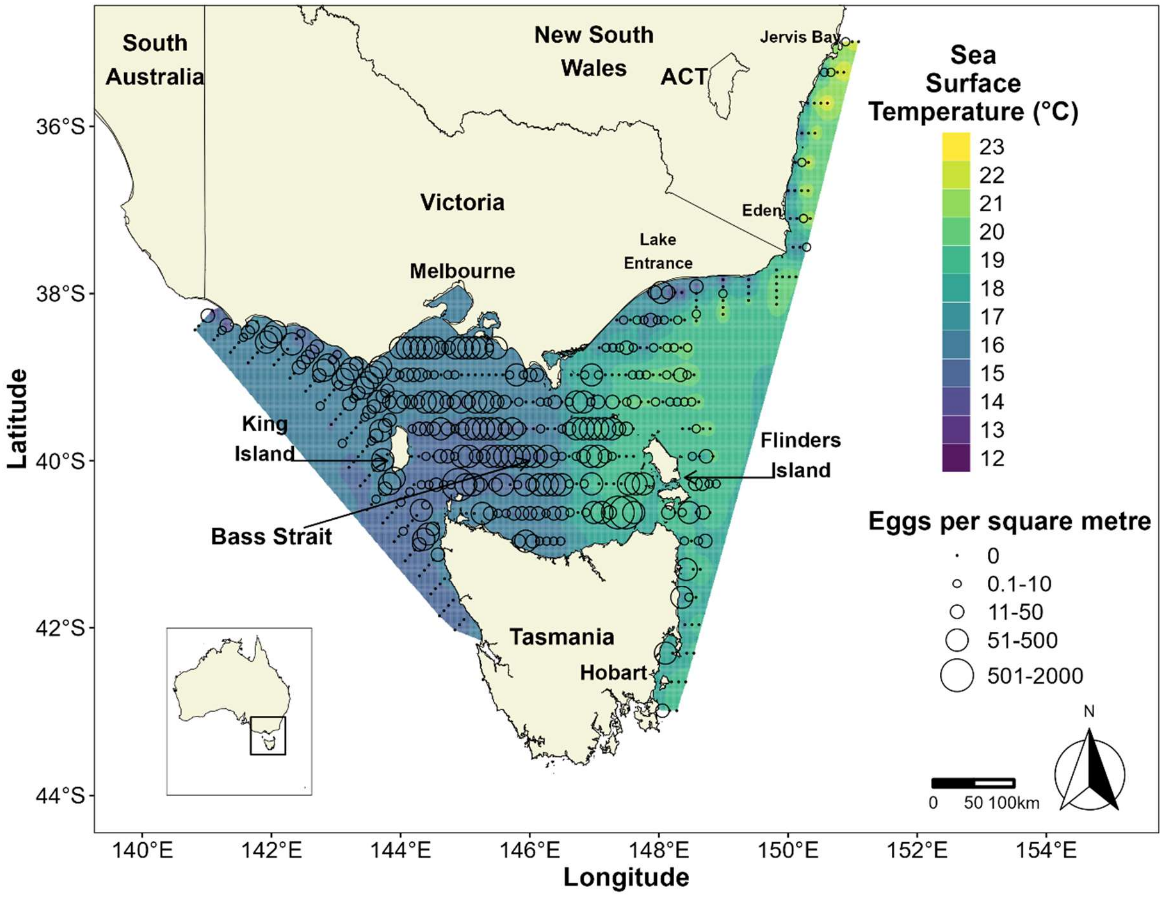

Figure 5. Map showing the distribution and densities of live Australian Sardine eggs and *in situ* measurements of sea surface temperature at sites sampled during December 2023 and January 2024.

Table 3. Estimates of mean daily egg production (P_0) and the instantaneous of daily egg mortality (z) of Australian Sardine eggs with 95% Confidence Intervals (95% CI) and Coefficients of Variation (CVs) for each parameter.

P_0	P_0 95% CI	P_0 CV	z	z 95% CI	z CV	P_0, z= 0.2	P_0, z= 0.3	P_0, z= 0.4	P_0, z= 0.5
43.2	35.0-53.4	0.1	0.43	0.28-0.59	4.4	37.5	41.4	45.7	50.1

Spawning area

The survey covered a total area of 149,837 km^2. The spawning area was 89,158 km^2 which comprised 59.5% of the survey area (Table 2, Figure 8).

Sex ratio

Annual estimates of sex ratio ranged from 0.36 to 0.70 (Table 4). The overall mean sex ratio was 0.55 (95% CI = 0.52–0.58).

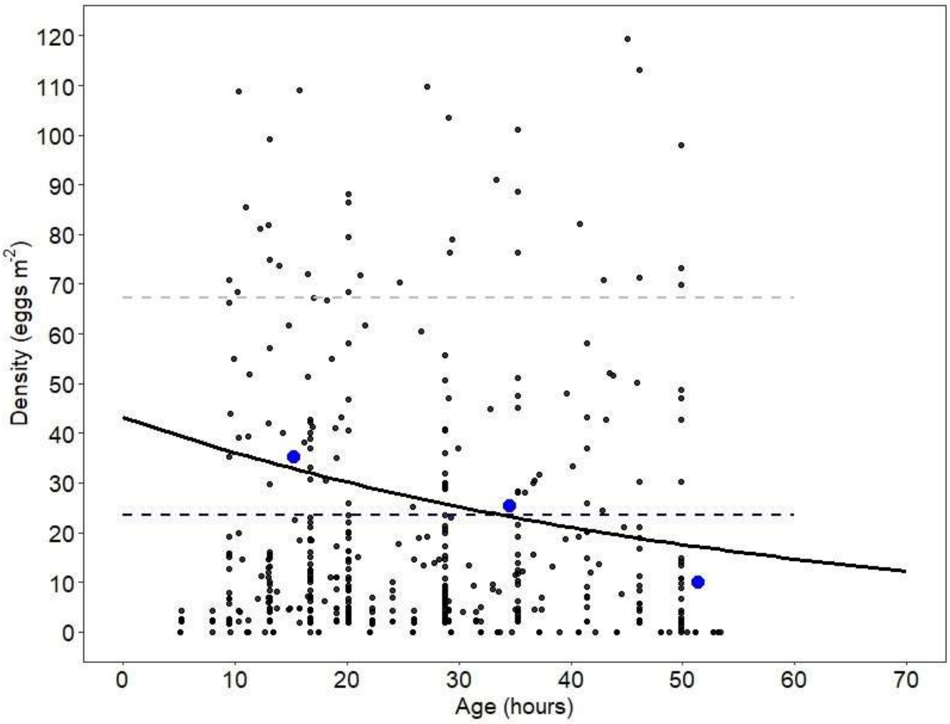

Figure 6. Generalised linear model fitted to egg densities (eggs.m^{-2}) and egg age (hours) of Australian Sardine egg cohorts collected during the survey. Grey dotted line is mean egg density. Black dotted line is mean daily egg density. Blue dots are mean density and age of each daily cohort.

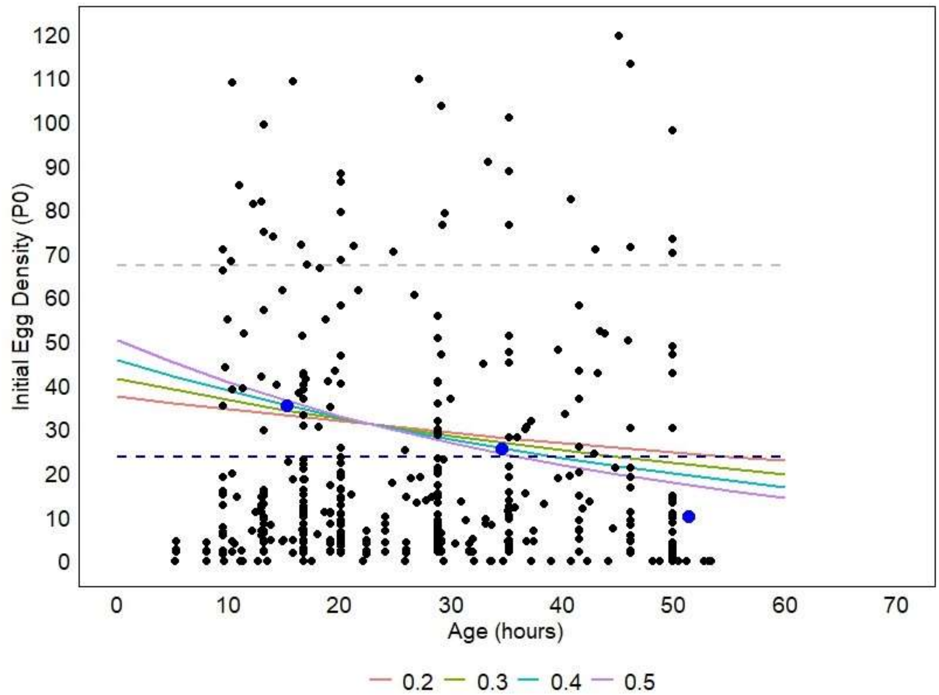

Figure 7. Curves constructed to estimate mean daily egg production (P_0) of Australian Sardine by applying assumed values of instantaneous rate of daily egg mortality (z) to the estimate of mean egg density obtained from the survey conducted in December 2023 and January 2024. Grey dotted line is mean egg density. Black dotted line is mean daily egg density. Blue dots are mean density and age of each daily cohort.

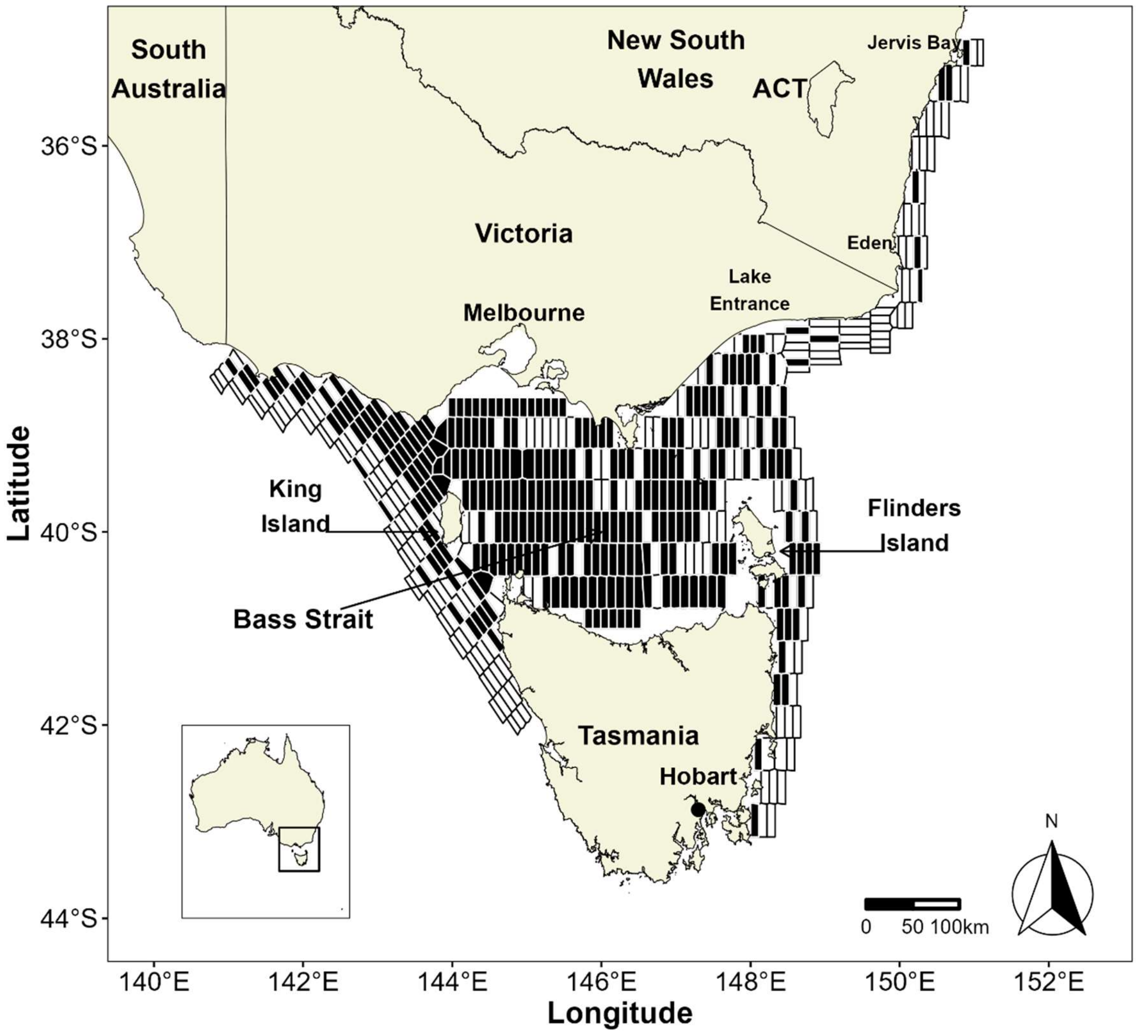

Figure 8. Map showing the Voronoi polygons at which live Australian Sardine eggs were present (black) and absent (white) during the survey conducted during the summer of 2023-24.

Table 1. Estimates of adult parameters for the Southern Stock of Australian Sardine obtained from Ward et al. (2021) that were used to calculate spawning biomass.

Parameter	Overall mean	95% Confidence Interval	Coefficient of variation	Range among years 1998-2018
Sex Ratio (*R*)	0.55	0.52–0.58	0.03	0.36–0.70
Spawning Fraction (*S*)	0.11	0.10–0.12	0.05	0.04–0.18
Relative Fecundity (*F*')	305	304–306	0.02	296–313

Spawning fraction

Annual estimates of spawning fraction ranged from 0.04 to 0.18 (Table 4). The overall mean spawning fraction was 0.11 (95% CI = 0.10–0.12).

Relative fecundity

Annual estimates of relative fecundity ranged from 296 to 313 eggs.g^{-1} (Table 4). The overall mean relative fecundity was 305 eggs.g^{-1} (95% CI: 304–306 eggs.g^{-1}).

Spawning biomass

The spawning biomass was estimated to be 208,732 tonnes (95% CI = 157,791-259,673 t).

Sensitivity analysis

The sensitivity analysis (Figure 9) shows that two of the four parameters considered, i.e. mean daily egg production (P_0) and spawning fraction (*S*), have the largest potential influence on estimates spawning biomass (*SB*). Because the 95% CI of the estimate of P_0 (i.e. 35.0-53.4 eggs.day^{-1}.m^{-2}) is narrower than the range of values examined in the sensitivity analysis (20-80 eggs.day^{-1}.m^{-2}), the uncertainty in *SB* associated with P_0 is lower than suggested by Figure 9. Because *S* is consistent for Sardine worldwide (Ward et al. 2021), the level of uncertainty of *SB* associated with variation in *S* is also likely to be lower than shown in Figure 9.

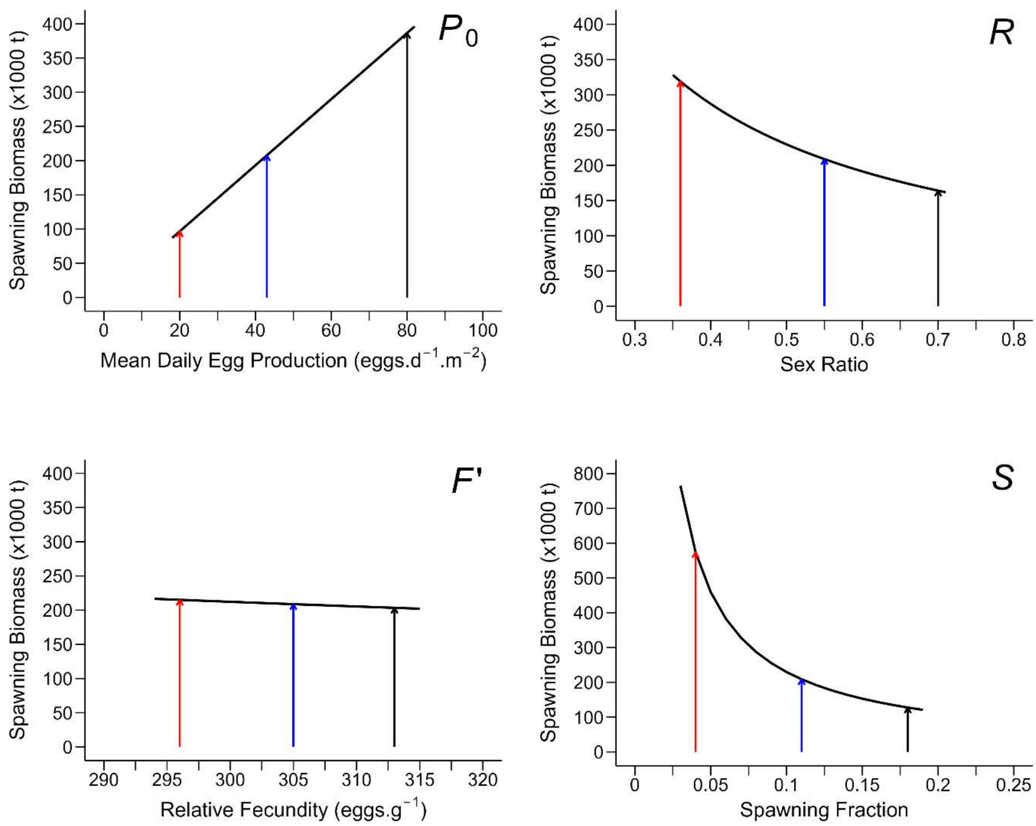

Figure 9. Sensitivity plots showing effects of variability in four DEPM parameters on estimates of spawning biomass for Australian Sardine. Blue arrow indicates values used to estimate spawning biomass in this study. Upper and lower values for P_0 are the approximate upper and lower values obtained in previous studies of this stock (e.g. Ward et al. 2023a). Upper and lower values for adult parameters are the range of values for years 1998 to 2018 shown in Table 4.

Discussion

This study confirms the findings of two previous studies (Ward et al 2021, 2023a) that suggested that a large under-exploited stock of Sardine occurs off south-eastern Australia. The estimate of spawning biomass of 208,732 t (95% CI = 157,791-259,673 t) presented in this study considered to be robust because it is based on reliable estimates of all five DEPM parameters. Perhaps most importantly, the estimate of spawning area (*A*) of 89,158 km^2 is reliable because it was estimated from an ichthyoplankton survey that covered the entire area occupied by the stock. The estimate of *A* is also considered reliable because it was defined by the presence/absence of live Sardine eggs which have distinctive morphological characteristics (White and Fletcher 1998) that make them easy to distinguish from other fish eggs. The estimate of mean daily egg production (P_0) of 43.2 (95% CI = 35.0-53.4) eggs.day^{-1}.m^{-2} is also considered to be reliable because it was estimated by fitting a statistical model (i.e., a GLM with a negative binomial error structure with variance increasing linearly with the mean) that has been demonstrated to be suitable for Australian Sardine (Ward et al. 2021). The model was also fitted to a large of number of samples (284) that contained live eggs. Importantly, the associated estimate of the instantaneous rate of daily egg mortality (*z*) of 0.43 (95% CI = 0.28-0.59) is statistically similar to the value of 0.35 (95% CI = 0.29-41) obtained for the adjacent Southern Sardine stock by fitting the same model (GLM) to data collected over 25 years (Grammer and Ivey 2023). Furthermore, the range of estimates of P_0 (i.e. 37.5 to 50.1 eggs.day^{-1}.m^{-2}) obtained by applying plausible assumed values of *z* (i.e., 0.2 to 0.5) to the estimate of mean egg density (i.e., 67.2 eggs.day^{-1}.m^{-2}) using the method of McGarvey and Kinloch (2001) is similar to the value obtained using the GLM that estimated both P_0 and *z* as free parameters. The estimate of P_0 obtained in this study is also within the range of values (i.e., approximately 20-80 eggs.day^{-1}.m^{-2}) that have been previously estimated for this stock (Ward et al. 2022, 2023). The lower value of P_0 obtained in the present study of 43.2 eggs.day^{-1}.m^{-2} compared to the estimate of 99.3 eggs.day^{-1}.m^{-2} obtained for the Southern Sardine stock by Grammer and Ivey (2023) may reflect, at least in part, differences in the volume of water filtered by the different sampling equipment used in the two studies (i.e. a bongo net in this study versus a CalVET net in South Australia). Because bongo nets filter approximately four times as much water as CalVET nets (e.g. Ward et al. 2019) and can therefore detect lower densities of eggs, bongo nets may provide lower estimates of P_0 and higher estimates of *A* than the smaller CalVET nets.

The estimates of the three adult parameters, i.e. sex ratio (*R*), spawning fraction (*S*) and relative fecundity (*F'*) that were used to estimate spawning biomass in this study are also considered to be reliable even though they were not obtained from South Eastern Sardine Stock while the ichthyoplankton survey was being conducted (see Stratoudakis et al. 2006). The authors consider that using adult parameters estimated from Sardine samples collected off South Australia over two decades (Ward et al. 2021) is more appropriate than using data collected from a single year of adult sampling from the South Eastern Stock. We hold this view because Ward et al. (2021) showed that estimates adult parameters obtained from a single year of sampling are usually imprecise and often biased. For example, annual estimates of *R* and *S* reported by Ward et al.

(2021) ranged from 0.36 to 0.70 and 0.04 to 0.18, respectively. Importantly, the overall mean values of *S* (0.11) and *R* (0.55) were more precise than estimates for individual years, which suggests that these parameters were not statistically different among years. Furthermore, in many individual years Ward et al. (2021) did not collect enough females with hydrated oocytes to estimate *F'* reliably, so there was no alternative but to use the estimate of *F'* obtained over multiple years to estimate spawning biomass. The other reason that it is appropriate to use estimates of adult parameters obtained from the Southern Sardine Stock to estimate spawning biomass is that these parameters are consistent for *S. sagax* worldwide and for other genera of sardines in multiple ecosystems (Ganias 2014; Somarakis et al. 2019). For example, the mean spawning fraction (*S*) for *Sardinops sagax* off South Australia of 0.11 (Ward et al. 2021) is similar to the global mean of 0.12 reported for this species by Ganias *et al.* (2014). Furthermore, the values of *S* reported for other species and genera of sardines in other ecosystems by both Ganias *et al.* (2014) and Somarakis *et al.* (2019) are similar to the values reported by Ward et al. (2021). For the reasons outlined above, the authors contend that using estimates of adult parameters obtained from samples collected off South Australia over two decades in this study is more appropriate than using data collected during a single year of adult sampling from the South Eastern Stock. However, if a large Tasmanian Sardine Fishery is established, consideration should be given to establishing a fishery-independent adult sampling program to estimate these parameters for the South Eastern Sardine Stock.

Conclusions, implications and recommendations

Results provided in this study are suitable for informing future management of the South Eastern Australian Sardine Stock. The study demonstrates that the spawning biomass of this stock is large enough to support a substantial commercial fishery. It also indicates that a significant portion of this stock occurs in waters under the jurisdiction of the Tasmanian Government. Therefore, this study demonstrates the potential to establish a large Tasmanian Sardine Fishery. Because this resource has only been discovered recently and patterns of inter-annual variability in stock abundance and recruitment are not well understood, a precautionary approach should be taken to developing this resource. The new fishery should also adopt many of the key features of the management systems that have been established in the SASF and SPF.

The development of the management systems for the SASF and SPF have been underpinned by extensive ecological research programs (e.g., Bulman et al. 2011; Goldsworthy et al. 2013; Smith et al. 2011, 2015). Dietary analyses and ecological modelling have shown that, unlike many other marine ecosystems worldwide (e.g. Curry et al. 2011; Pikitch et al. 2012, 2015), predatory species in the marine ecosystems off southern and south-eastern Australia are not highly dependent on one or more species of small and medium sized pelagic (forage) fishes. Harvesting these species, including sardine, both singly and in combination, has only minor impacts on other parts of the ecosystem (Smith et al. 2011, 2015). In contrast, >50% of other marine ecosystems studied by Pikitch et al. (2012) had one or more species of predator (often seabirds) that was highly or extremely dependent on forage fish. Depleting the dominant forage fish species in these ecosystems has major negative impacts on the population status of dependent predators (e.g., Curry et al. 2011; Pikitch et al. 2012, 2015). For these reasons, extremely conservative management approaches, such as maintaining one third of the stock biomass for birds (Curry et al. 2011) and maintain stock biomass at double conventional levels (Pikitch et al. 2012), have been recommended for forage fish in these ecosystems. Because Australian ecosystems function differently to those studied by Curry et al. (2011) and Pikitch et al. (2012, 2015), the extremely conservative fisheries management arrangements that have been recommended in these ecosystems are not appropriate for Australia's small pelagic fisheries (Smith et al. 2011, 2015).

Although predators in Australia's marine ecosystems are not highly dependent on Sardines or other species of small and medium sized pelagic fishes, the harvest strategies that have been established in the SASF and SPF have adopted explicitly precautionary approaches to preventing potential ecosystem impacts (PIRSA 2023; AFMA 2008 last revised 2024). In both the SASF and SPF, this precautionary approach has involved establishing exploitation rates (i.e. harvest fractions) that are lower than those that have been identified as being ecologically sustainable for Sardine in Australia's marine ecosystems (i.e. 33%, Smith et al. 2015). In both fisheries, these exploitation rates are applied to estimates of spawning biomass obtained using the DEPM. The harvest strategy that is established for the Tasmanian Sardine Fishery should adopt a similar approach to the SASF and SPF and establish exploitation rates that are more conservative than those that have been shown to be ecologically sustainable for Sardine in Australian ecosystems (i.e. 33%).

The current exploitation rate in the SASF is 25% and DEPM surveys are conducted annually (PIRSA 2023). In the SPF, the exploitation rate is 20% and DEPM surveys are conducted every five years (AFMA 2008, last revised in 2024). Initial exploitation rates applied in both fisheries were lower (e.g., 10% in the SASF). Given the current lack of knowledge about the temporal stability of the South Eastern Sardine Stock, it would be prudent to use a conservative exploitation rate (e.g., ≤15%) to set initial TACs in the Tasmanian Sardine Fishery (i.e. less than half the level recommended for Sardine in Australia of 33%). This conservative exploitation rate would likely remain in place until the next comprehensive DEPM survey is conducted. If the next survey is timed to coincide with the next AFMA-funded DEPM survey of Jack Mackerel East, it would occur in the summer of 2028-29 (i.e. five years after the current study). If the results of the next DEPM survey are positive (e.g., similar to those presented here), there may be potential to increase the exploitation rate to a level similar to that which is currently in place for Sardine in the SPF (i.e., ~20%), where DEPM surveys are also conducted every five years. More frequent DEPM surveys (e.g., at least every 2-3 years) would likely be required before consideration could be given to establishing exploitation rates above 20%.

Both the SASF and SPF have established spatial management arrangements to control the distribution of fishing effort (AFMA 2009; PIRSA 2023). Spatial management arrangements can be used to mitigate both interactions with other stakeholders, including recreational fishers, and reduce levels of fishing effort in areas used by central place foragers, especially seabirds. Consideration should be given to establishing spatial management arrangements (i.e., fishing zones and spatial closures) at the inception of the Tasmanian Sardine Fishery. Information on the distribution of adult Sardines provided in this report, combined with existing knowledge about the location of recreational fishing grounds and seabird foraging areas, could be used to determine where fishing zones and spatial closures may be established.

The other key issue that must be considered when the Tasmanian Sardine Fishery is being established is dolphin interactions. Although rare, dolphin interactions, have been one of the most significant challenges to the development of both the SASF and SPF (Ward et al. 2023b). It is critically important that protocols to ensure dolphin interactions are minimised and reported accurately are established at the inception of the fishery. Key elements of the Wildlife Interactions Code of Practice for the SASF (https://sasardines.com.au/), which outlines current best practice operational procedures for minimising interactions with dolphins in a purse-seine fishery, could be adopted from the outset. Consideration could be given to mandating adherence to these protocols, noting that they are likely to be refined over time. Experience in the SASF and SPF has shown that both electronic monitoring and independent observer programs will be required, at least initially, to evaluate how effectively interactions with dolphins are minimised and reported. The primary objective of the electronic monitoring program should be to evaluate how well dolphin avoidance and release procedures are implemented in the absence of independent (human) observers. This objective is different to many electronic monitoring programs where the primarily aim is to quantify catch composition and bycatch. Therefore, a dedicated research program will be needed to establish the operational protocols (e.g., camera positioning, video analysis systems) that will be required to ensure that this primary objective is achieved.

Future research and monitoring

If a large Tasmanian Sardine Fishery is established, an ongoing research program will be needed to monitor the status of the South Eastern Sardine Stock and inform the ongoing management of the new fishery. Six key elements that could comprise the program are listed below in the order of their importance.

1. Comprehensive DEPM survey every five years

For Sardine stocks that support significant fisheries, DEPM surveys designed to monitor the stock status and set TACs should be conducted at least every five years (Smith et al. 2015) and cover the entire spawning area (e.g., Stratoudakis et al. 2006). If a large Tasmanian Sardine Fishery is established, it is essential that a comprehensive DEPM survey similar to the present study is repeated at least every five years. In the foreseeable future (i.e., assuming catches in the SPF remain high), it seems likely that AFMA will continue to fund a DEPM survey of Jack Mackerel in the eastern sub-area of the SPF every five years (as it did in the summers of 2013-14, 2018-19 and 2023-24). If that situation continues, NRE Tas will need to ensure that a survey of the western component of the stock (i.e. west of 146°30'E) is undertaken to coincide with the next AFMA-funded Jack Mackerel survey (i.e., most likely 2028-29). If an AFMA-funded DEPM survey for Jack Mackerel is not conducted in 2028-29, a more targeted survey that focuses on key sardine spawning areas (e.g. Bass Strait) and excludes areas of limited relevance to the Tasmanian Sardine Fishery (e.g. east coast of Victoria and southern New South Wales) could be conducted instead of simply repeating the broader survey documented in this report. More frequent DEPM surveys would be required before consideration could be given to establishing higher exploitation rates in the Tasmanian Sardine Fishery.

2. Annual Fishery Assessment Report

If the main mechanism for monitoring the status of the South Eastern Sardine Stock and the Tasmanian Sardine Fishery is a DEPM survey every five years, then it is essential that a Fishery Assessment Report is produced annually to provide information about stock status between surveys. This approach is consistent with the approach outlined in the SPF Harvest Strategy. In the SPF, the Annual Fishery Assessment Report provides a detailed analysis of the data obtained from the fishery during the previous fishing season and evaluates stock status between applications of the DEPM. The report is used to evaluate if there are reasons to recommend exploitation rates lower than the maximum rates identified in the Harvest Strategy. The Annual Fishery Assessment Report for the SPF must include:

- historical catch, effort and CPUE data,
- detailed analyses of catch, effort and CPUE data from the previous fishing season,
- length–frequency and age structure information from catches,
- analysis of spatial and temporal patterns of effort and catch, and

- evidence suitable for detecting stock depletion, localised depletion or changes in the size and age structure of the catch that cannot be adequately explained by reasons other than a decline in abundance.

3. Electronic monitoring and independent observer program

Interactions with dolphins, although rare, have been one of the most significant challenges to the development of both the SASF and SPF (e.g., Ward et al. 2023b). It is essential that protocols are established for the Tasmanian Sardine Fishery that will ensure that interactions with dolphins are both minimised and reported accurately. The program that is established should involve both electronic monitoring and independent observers. The primary objective of the electronic monitoring program should be to evaluate whether protocols established for minimising interactions with dolphins are implemented in the absence of independent (human) observers. The use of a camera-based electronic monitoring program for this purpose is different from way that this technology is typically used in trawl, longline and gill-net fisheries, where the main objective is usually to identify and quantify target and/or by-catch species. Therefore, a targeted research project will be needed to establish the operational protocols (e.g., camera positioning, video analysis systems) that will be required to evaluate whether mandatory protocols for minimising interactions with dolphins are implemented when an independent observer is not present on the vessel.

4. Fishery-independent adult sampling program

If a DEPM survey is conducted every five years, then it would be beneficial if a fishery-independent adult sampling program is established to estimate adult reproductive parameters for the South Eastern Sardine Stock. In the short-term, this sampling program would ideally be conducted during each of the spawning seasons leading up to (and including) the next ichthyoplankton survey to ensure that estimates of adult parameters are robust. Sampling should be undertaken over multiple years because experience in the SASF has shown estimates of adult parameters obtained in individual years are usually imprecise and often biased. Experience in the SASF has also shown that the most effective method for fishery-independent sampling of Sardine in Australian waters involves the use of a multi-panel gill-net and surface and sub-surface lights.

5. Management strategy evaluation

The management strategy evaluation that was used to underpin the development of the harvest strategy for the SPF (Smith et al. 2015) is based on biological data for Sardine that is now ten years old. It would be beneficial if the management strategy evaluation was rerun using updated data from the South Eastern Stock when the harvest strategy for the Tasmanian Sardine Fishery is being developed.

6. Ecosystem assessments

It would be beneficial to undertake ecological studies comparable to those done in the SASF. Some of the initial studies could be done as student projects. The program could also include regular ecosystem assessments using ecological models similar to those currently undertaken in the SASF every four years.

Extension and Adoption

The Department of Natural Resources and Environment Tasmania requested IMAS to write the proposal that led to this study and provided a significant cash contribution to the project. The project was also endorsed by SPF RAG and leveraged significant investment from AFMA by utilising samples collected during the ichthyoplankton survey of the eastern stock of Jack Mackerel in the application of the DEPM to Sardine. The Principal Investigator provided updates to both NRE Tas and SPF RAG throughout the course of the project. For NRE Tas, extension included regular (often fortnightly) meetings with staff tasked with establishing the Tasmanian Sardine Fishery. Presentations included both progress reports on the current project and broader advice about how fisheries for small pelagic fishes are managed in Australia and worldwide. These broader presentations included detailed descriptions of the management systems, especially the harvest strategies, that have been established in the SASF and SPF. The presentations also described how ecosystem-based fisheries management has been implemented in these two Australian fisheries and other comparable fisheries throughout the world. NRE Tas has also been advised that interactions with dolphins, although rare, have been one of the most significant challenges to the development of the SASF and SPF, and that it is important that both appropriate operational protocols and a suitable monitoring program are established at the inception of the Tasmanian Sardine Fishery. It has also been emphasised that the monitoring program that is established should include both electronic monitoring and an independent observer program. Extension to stakeholders (e.g., commercial and recreational fishers, conservation groups and the aquaculture sector) will conducted in conjunction with NRE Tas after the current report has been finalised.

For AFMA, extension has included progress reports to the Small Pelagic Fishery Resource Assessment Group at each meeting that has been held since the project was first proposed. After this report is completed, IMAS will also provide AFMA with a report that documents the distribution and abundance of Jack Mackerel eggs and the likely spawning biomass of this species in the western part of the area surveyed in the present study.

Appendices

List of researchers and project staff

Project staff

- Dr Tim Ward (IMAS)
- Dr Katerina Charitonidou (IMAS)
- Mr Tom Alderson (IMAS)
- Mr Alex Shute (Deakin University)
- Dr Gretchen Grammer (SARDI)
- Mr Gary Carlos

Crew of Dell Richey II,

- Mr John Richey (Master)
- Mr Salvatore Cutrale (Sparrow)
- Mr Jayden Kelly,
- Mr Jesse Brooke
- Ms Janine Geraghty

Intellectual Property

Nil

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