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Characterising the spawning patterns of Jack Mackerel (*Trachurus declivis*) off eastern Australia to optimise future survey design

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ABSTRACT

Estimates of spawning biomass obtained using the daily egg production method (DEPM) are used to establish catch limits for Jack Mackerel (*Trachurus declivis*) off eastern Australia. Information from concurrent ichthyoplankton and adult surveys conducted between Port Stephens, New South Wales and South East Cape, Tasmania during January 2014 was used to assess the environmental factors that determine the spawning patterns of Jack Mackerel. Adults were collected using a modified demersal trawl net deployed during daylight hours. Samples were unbiased with respect to sex, spawning activity and size. Large fish were collected from both the inner shelf and shelf break; spawning fractions and egg densities were high inshore and low offshore. These findings suggest complex spatio-temporal patterns of spawning, different to previous studies suggesting that most spawning occurred at the shelf break (~200 m). Eggs were most abundant in sea surface temperatures (SSTs) of 15–20 °C and at depths of <130 m. Future ichthyoplankton surveys should target waters with SSTs of 14–23 °C and depths of 30–250 m. Future adult surveys should sample the same range of depths and latitudes as the ichthyoplankton surveys and be structured as systematically as permitted by the availability of habitats suitable for demersal trawling. The DEPM does not provide information about the abundance of non-spawning adults outside the main spawning area. Extending future adult surveys beyond the spawning area would address this limitation by providing estimates of the distribution and relative abundance of adults across the entire range of the population. Findings of this study will help to improve the design of future DEPM surveys.

1. Introduction

Small pelagic fishes support regionally and globally important commercial fisheries (Tacon and Metian, 2009; Smith et al., 2011). Most species are planktivorous and important sources of prey for predatory fishes, seabirds, and marine mammals, making the group a critical component of marine food webs (Last et al., 2011). For economic, social and ecological reasons, it is important that fisheries for small pelagic species are managed sustainably (Pikitch et al., 2012). Achieving this goal can be challenging as their schooling behaviours make them vulnerable to overfishing (Pikitch et al., 2012) and their abundance, distribution, and phenology are sensitive to environmental change (Checkley et al., 2009).

The Australian Commonwealth Small Pelagic Fishery (SPF) was established in 1992 (Moore and Skirtun, 2012) and is conducted in Commonwealth waters (3–200 nm from the coastline) between southern Queensland and southern Western Australia, including waters around Tasmania (Moore and Skirtun, 2012). Jack Mackerel (*Trachurus declivis*) is a target species for this fishery. Off eastern Australia, Jack Mackerel is distributed from northern NSW to southern Tasmania (Gomon et al., 1994). It is a serial spawner with a protracted spawning season (Marshall et al., 1993) and is believed to spawn progressively southward, starting in northern NSW in spring and continuing down to Tasmania (Maxwell, 1979) where spawning peaks during mid to late summer (Kailola et al., 1993). Bass Strait and waters surrounding Tasmania are considered to be the main spawning area for this stock (Bulman et al., 2008).

The oceanography of temperate waters off eastern Australia is dominated by the East Australian Current (EAC; Ridgeway and Hill, 2009), which carries warm tropical water southwards along the coast from the Coral Sea before deflecting eastward into the Tasman Sea (Last et al., 2011). Fluctuations in marine conditions in this region are driven by seasonal variations in the southern extension of the EAC (Suthers et al., 2011). A progressively southward shift of the EAC extension of ~40 km year^{-1} (Ridgeway and Hill, 2009) is occurring due to a strengthening of the current in its northern origin (Ridgway, 2007). This phenomenon has been attributed to climate

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change (Frusher et al., 2013), and due to the rapid rate of progression, has led to this region being identified as a marine climate change 'hotspot' (Last et al., 2011).

The influence of these oceanographic variations on the spawning patterns of Jack Mackerel is poorly understood. For example, in a longitudinal study punctuated by a La Niña event, Jordan et al. (1995) suggested that oceanographic variability may not influence the selection of spawning habitat by Jack Mackerel off eastern Tasmania due to the thermal stability of waters of ∼200 m depth where Jack Mackerel was observed to spawn (Jordan et al., 1995). In contrast, Neira (2011) suggested that sea surface temperature (SST) significantly influenced spawning habitat selection, concluding that Jack Mackerel spawns in waters with SSTs between 17.2 and 20.1 °C.

Large-scale purse-seining for Jack Mackerel in Australian waters began off Tasmania in the 1980s (Kailola et al., 1993). The catch peaked at ∼37,000 t in 1986/87. The catch declined to 7500 t in 1988/89 before increasing to over 15,000 t in 1990/91. Mid-water trawling replaced purse seining after 2002 (Ward et al., 2013). Catches of Jack Mackerel using this method peaked at 3000 t in 2003/04. Recruitment variability, population responses to fishing pressure, changes in oceanographic conditions and alterations in the distribution and behaviour of fish schools have been identified as potential drivers of the large inter-annual variations in catches of Jack Mackerel observed off eastern Australia over the last three decades (Williams and Pullen, 1993; Young et al., 1993).

These large fluctuations in catches of Jack Mackerel have generated significant public concern about the status of SPF stocks, especially among conservation and recreational fishing groups (Moore and Skirtun, 2012). These concerns increased in 2012 when there was an unsuccessful attempt to introduce a 140 m factory trawler, the *FV Abel Tasman*, into the SPF (Haward et al., 2013; Tracey et al., 2013). The reliability and age of estimates of the spawning biomass of key species, especially Jack Mackerel, were identified as issues of particular importance that needed to be addressed (Tracey et al., 2013).

Estimates of spawning biomass obtained using the Daily Egg Production Method (DEPM) are used in the SPF to set Total Allowable Catches (TACs) for target species (AFMA, 2009; Ward et al., 2013, Moore and Skirtun, 2012). This method is widely used to estimate the spawning biomass of batch spawning fishes (Stratoudakis et al., 2006; Bernal et al., 2012). The central tenet of the DEPM is that spawning biomass can be estimated by dividing total daily egg production (number of eggs spawned per day over a spawning area) by mean daily fecundity (the number of eggs produced per unit weight of adult fish; Lasker, 1985; Bernal et al., 2012). DEPM surveys involve ichthyoplankton sampling over the spawning area and spatiotemporally concurrent adult sampling (Ward et al., 2009). Knowledge of the life history and distribution of a species are required to optimise the timing and location of ichthyoplankton and adult surveys (Stratoudakis et al., 2006).

Many authors have highlighted the difficulties associated with estimating adult reproductive parameters for application of the DEPM, particularly spawning fraction (i.e. the proportion of females that spawn each day), and the importance of optimising the design of adult surveys (Hunter and Lo, 1993; Ganias, 2012). Difficulties estimating spawning fraction arise because some techniques, including purse-seining and mid-water trawling at night, do not sample adults representatively (Ganias et al., 2003; Slotte et al., 2007). Samples collected at night can be unrepresentative of the adult population because actively spawning and resting females aggregate in separate schools during the diel peak in spawning activity (Alheit, 1993). For example, in several species, cohorts of recently spawned females (i.e. those with Day 0 Post Ovulatory Follicles: POFs) are over-represented in samples collected from mid-water trawls conducted at night (Ganias et al., 2003). These biases have important implications because estimates of spawning biomass obtained using the DEPM are sensitive to variability in estimates of spawning fraction (Ganias et al., 2003; Ward et al., 2009). Neira (2011) published a preliminary assessment of the east coast Jack Mackerel population using information obtained from DEPM surveys that targeted other species and data from other *Trachurus* species. The estimate of spawning biomass provided by Neira (2011) was described as preliminary due to the limitations in the design of the plankton surveys and lack of samples to estimate adult reproductive parameters. A dedicated application of the DEPM to Jack Mackerel off eastern Australian was undertaken in January 2014 (Ward et al., 2016).

In this study, we use data obtained from that January 2014 DEPM survey to assess the environmental factors that determine the spawning patterns of Jack Mackerel. Findings are used to provide recommendations to optimise the design of future DEPM surveys. Sampling methods developed in this study may be applicable to other populations of *Trachurus* species. Knowledge of the relationship between reproductive patterns of Jack Mackerel and environmental conditions will also enhance our understanding of the potential responses of this species to climate change in eastern Australia, and may be relevant to trachurid stocks in other regions regarded as climate change hotspots (e.g. Horse Mackerel, *Trachurus trachurus* in the North Sea).

2. Materials and methods

2.1. Adult data collection

Adult samples were collected from a dedicated survey using a modified demersal trawl deployed during daylight hours that was specifically designed to provide high lift. The headline length was 36 m and the ground rope length was 35 m. The ground line weight was 250 kg and the boards were 100 m apart. Floats were used to lift the headline ∼4 m above the seafloor. The net was deployed at 20 stations in shelf and slope waters between St Helens (Tasmania) and Eden (NSW) during 12–18 January, 2014 (Fig. 1). A random subsample of adult Jack Mackerel was separated from each shot. Adults were processed until a subsample of approximately 100 individual females (and a corresponding number of males) was obtained. Due to occasional small catches and/or differences in the sex ratio among samples, some subsamples contained less or more than 100 males and females. Gonads of female Jack Mackerel were removed, labelled and fixed in a 5% buffered formaldehyde and seawater solution aboard the vessel. Mature females and males were labelled and frozen. Depth and location (latitude, longitude) were recorded at each station.

Adult fork length (FL) was measured from the tip of the snout to the end of the middle caudal fin rays to the nearest millimetre for all adult specimens. Spawning fraction was estimated for each shot following the post-ovulatory follicle (POF) method (Ganias, 2012). Ovaries of mature females were sectioned and stained with eosin and haemotoxylin. Three sections from each ovary were examined to detect the presence or absence of POFs. POFs were assigned to stages according to criteria developed by Macewicz and Hunter (1993) for horse mackerel *Trachurus symmetricus*. Spawning fraction *S* was calculated for each shot, following Ward et al. (2009):

$$S = ((P_0 + P_1 + P_2)/3)/\mathrm{N}$$

where P_0 = the number of females with hydrated ovaries + females that spawned the previous night, P_1 = number of females with POFs 24–48 h old, and P_2 = number of females with POFs > 48 h old.