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Shelf spawning habitat of *Emmelichthys nitidus* in south-eastern Australia – Implications and suitability for egg-based biomass estimation

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ABSTRACT

The spawning habitat of *Emmelichthys nitidus* (Emmelichthyidae) in south-eastern Australia is described from vertical ichthyoplankton samples collected along the shelf region off eastern through to south-western Tasmania during peak spawning in October 2005–06. Surveys covered eastern waters in 2005 (38.8–43.5°S), and both eastern and southern waters in 2006 (40.5°S around to 43.5°S off the south-west). Eggs ($n = 10,393$) and larvae ($n = 378$) occurred along eastern Tasmania in both years but were rare along southern waters south and westwards of 43.5°S in 2006. Peak egg abundances (1950–2640 per m^{-2}) were obtained off north-eastern Tasmania (40.5–41.5°S) between the shelf break and 2.5 nm inshore from the break. Eggs were up to 5-days old, while nearly 95% of larvae were at the early preflexion stage, i.e. close to newly emerged. Average abundances of aged eggs pooled across each survey declined steadily from day-1 to day-5 eggs both in 2005 (97-18) and 2006 (175-34). Moreover, day-1 egg abundances were significantly greater 2.5 nm at either side of the break, including at the break, than in waters ≥5 nm both inshore and offshore from the break. These results, complemented with egg and larval data obtained in shelf waters off New South Wales (NSW; 35.0–37.7°S) in October 2002–03, indicate that the main spawning area of *E. nitidus* in south-eastern Australia lies between 35.5°S off southern NSW and 43.5°S off south-eastern Tasmania, and that spawning activity declines abruptly south and westwards of 43.5°S around to the south-west coast. In addition, quotient analyses of day-1 egg abundances point to a preferred spawning habitat contained predominantly within a 5 nm corridor along the shelf break, where waters are 125–325 m deep and median temperatures 13.5–14.0 °C. Spawning off eastern Tasmania is timed with the productivity outburst typical of the region during the austral spring, and the temperature increase from the mixing between the southwards advancing, warm East Australian Current and cooler subantarctic water over the shelf. Overall, ichthyoplankton data, coupled with reproductive information from adults trawled off Tasmania, indicate that *E. nitidus* constitutes a suitable species for the application of the daily egg production method (DEPM) to estimate spawning biomass. This finding, together with evidence in support of a discrete eastern spawning stock extending from southern NSW to southern Tasmania, strengthens the need for DEPM-based biomass estimates of *E. nitidus* prior to further fishery expansion.

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1. Introduction

Most of the 15 known species currently placed in the family Emmelichthyidae support limited commercial fisheries through their geographical range, with catches used predominantly for human consumption, bait and/or fish meal. They are taken by bottom, demersal and mid-water trawling in Europe (Russia, Georgia and Ukraine), South Africa, Australia and New Zealand, either as primary target or by-catch of other offshore trawl fisheries (Heemstra and Randall, 1977; Paul, 1997; Anon, 2001; Heemstra, 2002). Of the two emmelichthyids found in temperate Australia, *Emmelichthys nitidus* have been trawled off eastern and south-western Tasmania since 2002, where captures of around 4000–8000 tonnes p.a. are processed mainly to feed farmed tuna (McLaughlin, 2006; Larcombe and Begg, 2008). This small (to 36 cm TL) mid-water schooling species occurs in shelf waters of temperate Australia ≥30°S, where it is locally known as redbait. It also occurs in New Zealand, South Africa and Chile, including oceanic islands along the same latitudes (Heemstra and Randall, 1977; Last et al., 1983; Gomon et al., 1994; Hoese et al., 2007).

Increasing commercial captures of *Emmelichthys nitidus* off Tasmania led to the implementation of a biological study ultimately

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aimed at evaluating the spawning biomass of this species via the daily egg production method (DEPM). The method combines adult reproductive data with daily egg abundances within a defined spawning area to compute mean spawning biomass within such area. As a well-known fishery-independent technique to estimate stock levels of pelagic fishes such as clupeoids and scombrids (Lasker, 1985; Priede and Watson, 1993; Lo et al., 1996), the DEPM was deemed suitable for *E. nitidus* since several attributes of its reproductive biology, including the release of pelagic eggs in batches (J.M. Lyle, unpublished data), fall within those typically exhibited by DEPM-assessed small pelagic species (Stratoudakis et al., 2006). Before such method could be applied, however, it is critical to define the spawning habitat of the target species as well as having sound information of timing and geographical extent of spawning. In the case of small pelagic fishes, the spatio-temporal characterisation of spawning habitats through the use of hydrography and shelf bathymetry is becoming increasingly important to fishery science, particularly in the context of biomass assessment and subsequent predictions of recruitment success and stock health (e.g. Checkley et al., 1999; van der Lingen et al., 2001, 2005; Castro et al., 2005; Ibaibarriaga et al., 2007; Neira and Keane, 2008).

In this paper we describe the spawning habitat characteristics of *Emmelichthys nitidus* based on eggs and larvae caught primarily during ichthyoplankton surveys carried out along shelf waters of eastern to south-western Tasmania in October 2005 and 2006. Input data for this paper follow from concurrent identification and aging protocols developed for eggs of this species by Neira et al. (2008). Supplementary ichthyoplankton data from southern New South Wales (NSW) in October 2002 and 2003 are employed to examine aspects of the geographical extent of the redbait spawning stock in south-eastern Australia. Cross- and along-shelf egg and larval distributions off Tasmania are examined in terms of environmental conditions, and results discussed in relation to linkages with regional oceanography. Overall results are discussed in terms of the suitability of the DEPM to estimate biomass of this species.

2. Materials and methods

2.1. Study area and surveys

Ichthyoplankton surveys were carried out during October 2005 and 2006, coinciding with the peak spring spawning season of *Emmelichthys nitidus* off eastern Tasmania (J.M. Lyle, unpublished data). Sampling was conducted over the continental shelf region between 38.8°S in eastern Bass Strait (north east of Flinders Is.) and 43.5°S (south of the Tasman Peninsula) in 2005, and from 40.5°S (Cape Barren Is.) around to 43.5°S off the south-west coast (Port Davey) in 2006 (Fig. 1). The continental shelf along this region is relatively narrow, decreasing in width from around 33 nautical miles (nm) at 39.7°S (off the north tip of Flinders Is.) to 7 nm at 43.2°S (off the Tasman Peninsula), before widening to 32 nm at 147°E off southern Tasmania. Two major southward-flowing oceanic currents operate seasonally off Tasmania, namely the western boundary East Australian Current (EAC) and the Zeehan Current (ZC). The EAC forms in the Coral Sea and reaches south-eastern Tasmania during the austral summer when at its maximum intensity, whereas the ZC flows along the west coast and extends eastwards into the south-east during its peak flow in winter. Oceanographic conditions along eastern Tasmanian in October reflect a mixture of warm, saline water to the north derived from the onset of EAC incursion, and cooler subantarctic water to the south following the northward retreat of the warm ZC (Ridgway, 2007a,b).

Sampling in 2005 (12–17 October) comprised 29 transects (T) perpendicular to the coastline and 10 nm apart (Table 1; Fig. 1). Up to four stations were located along each transect, and positioned each at the shelf break (200 m contour) and then every 5 nm to the shoreline except along T3, T5, T7 and T9, where stations were also positioned 5 nm offshore from the break. Sampling in 2006 was carried out in two legs, the first covering 12 transects along eastern Tasmania (T1–T12; 10–14 October), and the second covering the remaining 10 transects from the lower south-east to the lower south-west of Tasmania (T13–T22; 30–31 October); transects were also perpendicular to the coastline but 15 nm apart, each containing 4–5 stations (Fig. 1). Sampling effort was concentrated mostly along a 15-nm stretch that followed the shelf break, with stations located 7.5 and 2.5 nm inshore from the break, over the break, and 2.5 and 7.5 nm offshore from the break. The rationale for extending the sampling coverage in 2006 to include southern Tasmania was to sample as much of the southern extent of the spawning area of *E. nitidus* as feasible, based on the presence of spawning females off the south-west region (J.M. Lyle, unpublished data). In all, 201 plankton samples were collected from 198 stations across the two surveys (Table 1).

2.2. Field and laboratory procedures

Plankton samples were taken continuously day and night. Eggs and larvae in 2005 were caught using a bongo sampler consisting of 3 m long, 0.6 m diameter plankton nets of 300 and 500 μm mesh, encased within a custom-built, weighted stainless steel frame to facilitate vertical drops. Samples in 2006 were taken with a modified PAIROVET sampler (bongo version of CalVET sampler; Smith et al., 1985) consisting of 1.5 m long, 0.25 m diameter plankton nets of 300 μm mesh, placed inside a similar but smaller weighted frame.

At each station the sampler was lowered vertically to within ~5 m of the seabed or to a maximum depth of 190 m and immediately brought back on board. Sampling depth was determined using the onboard echosounder, and volume of water filtered (m^{-3}) estimated from counts provided by General Oceanic flowmeters fitted at the mouth of each net. Nets were thoroughly washed immediately after the sampler was on deck, and samples from the codends combined and fixed either in 98% ethanol (2005) or 10% formaldehyde-seawater (2006); redbait eggs fixed in ethanol were subjected to mtDNA analyses to confirm species identifications (refer to Neira et al., 2008 for details).

Vertical data on conductivity, temperature and depth were obtained simultaneously with each plankton sample using a Conductivity–Temperature–Depth (CTD) profiler fitted to the sampler's frame. Temperature data were plotted by depth for the inshore- and offshore-most stations of transects regarded as representative of the areas surveyed in October 2005 (T1, T11, T29) and October 2006 (T1, T13, T22) to determine presence and depth of thermal stratification. Temperatures and salinities at the surface (average of first 10 m) and mid-water (median to 100 m or to maximum depth if <100 m) were calculated for each station; conductivity data from all stations in 2006 were omitted as some values recorded by the profiler were deemed as erroneous. Composite, high resolution sea-surface temperature (SST) images of eastern Tasmania (NOAA AVHRR satellite) were obtained for the survey periods in 2005 and 2006 corresponding to 5-day averages centered on the sampling days (CSIRO Marine & Atmospheric Research, Hobart). Altimetric sealevel and velocity images (not shown) of 15 October 2005 and 2006 were examined to obtain data on prevailing surface currents during the sampling periods (http://www.marine.csiro.au/remotesensing/oceancurrents).

Terminology pertaining to eggs and larvae follows Neira et al. (1998, 2008). All eggs and larvae were removed from samples under a dissecting stereomicroscope, and stored in 70–98% ethanol for analyses. Redbait eggs were identified and sorted by developmental stage (I–VII; Neira et al., 2008), while larvae were separated

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