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DEPM-based spawning biomass of *Emmelichthys nitidus* (Emmelichthyidae) to underpin a developing mid-water trawl fishery in south-eastern Australia

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ABSTRACT

Spawning biomass of redbait, *Emmelichthys nitidus* (Emmelichthtyidae), was estimated using the daily egg production method (DEPM) based on egg and adult surveys conducted simultaneously off eastern Tasmania during October 2005 and 2006. Concurrent studies had confirmed that this mid-water, schooling species met all necessary requirements for DEPM-based biomass estimation, including (a) asynchronous oocyte development with release of pelagic eggs in batches; (b) spawned eggs could be assigned ages using a temperature-dependent incubation model; and (c) egg abundances follow the typical exponential decay model. Main spawning areas were identified between north-eastern Bass Strait (38.8°S) and south of the Tasman Peninsula (43.5°S) in 2005 (13220 km^2), and between Cape Barren Is. (40.5°S) and the same southern boundary in 2006 (8695 km^2). Daily egg production (P_0) was estimated by applying two statistical estimation methods to the egg abundance-at-age data, namely the traditional least squares non-linear regression (NLS) and a generalized linear model (GLM). Results indicated that the latter technique provided a better fit, resulting in improved CVs and AIC statistics over the NLS. The GLM-derived average P_0 was estimated at 4.04 eggs/0.05 m^2/day both in 2005 and 2006. Spawning biomass (CV) was ~87000 t (0.37) in 2005 and ~50800 t (0.21) in 2006, with the lower 2006 biomass largely due to a smaller spawning area and higher sex ratio. Estimates are likely to be negatively biased since spawning of *E. nitidus* probably extends as far north as southern New South Wales (35.0°S). In the absence of comparable studies on other emmelichthyids, P_0 and instantaneous egg mortality estimates are compared to those of clupeoid species previously subjected to DEPM, and the method discussed in terms of its suitability to this species in support of a developing mid-water trawl fishery in south-eastern Australia.

1. Introduction

The daily egg production method (DEPM) has become a robust fishery-independent technique to estimate stock biomass of pelagic, batch-spawning fishes such as clupeids, engraulids and scombrids. Such spawning biomass estimates result from computing total daily egg production at spawning time in the survey area over the daily specific fecundity, i.e. number of eggs per population weight per day. The denominator comprises four adult parameters, namely sex ratio, spawning fraction, batch fecundity and female weight. Both total daily egg production at spawning time and spawning area derive from egg surveys over the presumed region where spawning takes place, while daily specific fecundity is estimated from reproductively active fishes taken concurrently within the same area surveyed for eggs (Lasker, 1985; Alheit, 1993; Priede and Watson, 1993; Lo et al., 1996; Watanabe et al., 1999; Stratoudakis et al., 2006; Cubillos et al., 2007; Bernal et al., 2011).

The DEPM has not previously been used to estimate spawning biomass of a representative of the Emmelichthyidae, a small family containing 15 marine species distributed in tropical to temperate regions of the Indo-Pacific, southern Pacific, eastern Atlantic and Caribbean Sea (Nelson, 2006; Stratoudakis et al., 2006). Of the two species recorded for Australia, *Emmelichthys nitidus*, or "redbait" as it is locally known, constitutes a small (to 36 cm) mid-water schooling species confined to shelf waters ≥30°S (Hoese et al., 2007; Gomon et al., 2008). A mid-water trawl fishery targeting this species along with *Trachurus declivis* developed rapidly off Tasmania in the early 2000s with catches reaching ~8000 t by 2004/05, most destined to feed farmed southern bluefin tuna (Wilson et al., 2010). The rapid expansion of the fishery in south-eastern Australia, coupled with the pressing need to develop a scientifically defensible harvest strategy, led to the development of an integrated study to evaluate the DEPM as a technique to estimate spawning biomass of *E. nitidus*. The study found this species to be a batch spawner with asynchronous oocyte development, with females releasing batches of pelagic eggs (1.00–1.05 mm) approximately once every three days during a brief period between late September and early November, i.e. the austral spring (Ewing and Lyle, 2009; Neira

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et al., 2009). The study also found that eggs could be assigned ages using a temperature-dependent incubation model based on seven distinct developmental stages (Neira et al., 2008). Combining all results, it was concluded that *E. nitidus* fitted the criteria required for the application of the DEPM, and that spawning biomass could therefore be estimated in the same manner to that obtained for pelagic clupeoids (e.g. Somarakis et al.,2002, 2004; Stratoudakis et al., 2006; Cubillos et al., 2007) and non-pelagic teleosts such as *Pagrus auratus* (e.g. Zeldis and Francis, 1998; Jackson et al., 2011).

In this paper we report the first DEPM-based spawning biomass estimates of *E. nitidus* off eastern Tasmania in south-eastern Australia, based on egg and adult parameters derived from mid-water trawls conducted during the peak spawning period of this species in 2005 and 2006. Daily egg abundance-at-age data were employed to compute daily egg production by fitting the traditional least squares non-linear regression model (Lo et al., 1996) and a generalized linear model (Cubillos et al., 2007). Spawning area was calculated from positive stations for each egg survey (Neira et al., 2009) while the four adult parameters derive from reproductive data based on adult redbait collections (Ewing and Lyle, 2009). Average daily egg production and derived biomass estimates are compared for the two models and overall results discussed in relation to the suitability of this egg-based approach to estimate spawning biomass for this species.

2. Materials and methods

2.1. Study area

The study area comprised the continental shelf region from 38.8°S in eastern Bass Strait (north east of Flinders Is.) around southern Tasmania to 43.5°S off the south-west coast (Port Davey) (Fig. 1). The shelf along this region is somewhat narrow, decreasing in width from about 33 nautical miles (nm) at 39.7°S off northern Flinders Is. to 7 nm at 43.2°S off the Tasman Peninsula, before widening to 32 nm at 147°E off southern Tasmania. Oceanographic conditions over the eastern Tasmanian shelf are driven by the southward-flowing East Australian Current (EAC), a major western boundary oceanic feature which forms in the Coral Sea and reaches the south-eastern coast when at its peak intensity during the austral summer. Conditions during October 2005 and 2006 reflected a mixture of three water masses, i.e. warm, saline water to the north derived from the onset of EAC incursion, Tasman Sea water along the inner shelf and cooler subantarctic water to the south (Ridgway, 2007a,b; Neira et al., 2009). Composite sea surface temperature images from the time of the egg and adult surveys showed Tasman Sea water along the inner shelf (12–14 °C) and EAC-derived warmer water along the outer shelf (15–16 °C), with a longitudinal front between these two masses clearly defined along the shelf break both in 2005 and 2006 (see Fig. 2 in Neira et al., 2009). Field-derived average water temperatures off eastern Tasmania (average of medians to 100 m or to maximum depth if <100 m) ranged between 12.2 and 13.6 °C in both 2005 and 2006. In contrast, average temperatures off southern Tasmania in 2006 were lower than those along the eastern shelf, i.e. 11.7–11.9 °C (Neira et al., 2009).

2.2. Adult data

Adult *E. nitidus* were sampled from commercial mid-water trawl catches taken during the 2005 and 2006 spawning seasons (September to October) at depths of 100–140 m along the shelf break off eastern Tasmania (Fig. 1). Catches were obtained mainly at night when the species formed large aggregations, as opposed to daytime when fish tended to be dispersed and difficult to catch. Random samples of 100–200 individuals from selected trawl shots were frozen immediately after capture and thawed in the laboratory. Each of these was weighted (total weight ±1 g) and sex, gonad weight and maturity stage recorded, and the data employed to estimate average mature female weight (*W*) and sex ratio (*R*) by weight. Females deemed as mature comprised those with developing (stage III), hydrated (IV) or running ripe (V) ovaries, based on the macroscopic six-stage criteria of Mendonca et al. (2006) and adapted to *E. nitidus* by Ewing and Lyle (2009).

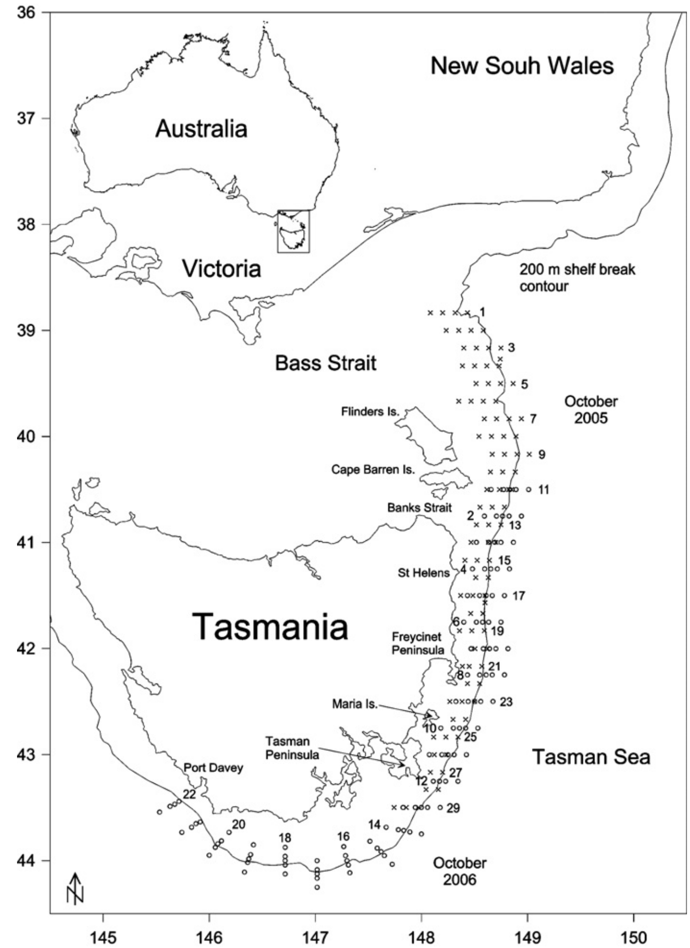

Fig. 1. Map of south-eastern Australia showing stations sampled during egg surveys off north-eastern to south-western Tasmania in October 2005 (crosses) and October 2006 (open circles). For clarity, transects have been numbered on a southerly direction using odd (2005) and even (2006) numbers, respectively.

In addition randomly selected females from most of the sampled trawl shots were dissected immediately after capture and at least 30 mature females either measured and weighted fresh (±1 g) and their ovaries removed and preserved in FAACC (10% formalin, 5% glacial acetic acid and 1.3% calcium chloride) (2005), or preserved whole (2006) (Ewing and Lyle, 2009). Preserved ovaries were processed to compute spawning fraction (*S*) and to determine batch fecundity (*F*). These samples also contributed to the estimation of average female weight (*W*) but were excluded from sex ratio estimation. Population adult parameters and sample variances were determined using the ratio estimator of Picquelle and Stauffer (1985).

The average mature female weight by year was estimated for each trawl sample and the population average weight of mature females (*W*) was calculated from the sample means weighted by sample size (Ewing and Lyle, 2009). Population sex ratio (*R*), i.e. proportion of females in the population by weight, was estimated for each year by employing the whole weights of mature females divided by the total weight of mature males and females in each