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Spawning and nursery habitat partitioning and movement patterns of *Pagrus auratus* (Sparidae) on the lower west coast of Australia

Corey B. Wakefield[a,b,*], David V. Fairclough[a], Rod C.J. Lenanton[a], Ian C. Potter[b]

[a] *Western Australian Fisheries and Marine Research Laboratories, Department of Fisheries, Government of Western Australia,*
P.O. Box 20, North Beach, Western Australia 6920, Australia
[b] *Centre for Fish and Fisheries Research, School of Biological Sciences and Biotechnology, Murdoch University, South Street, Perth, Western Australia 6150, Australia*

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ABSTRACT

The ages and lengths of *Pagrus auratus* caught by line fishing in three marine embayments (Owen Anchorage, Cockburn Sound and Warnrbo Sound) and inshore (<80 m depth) and offshore waters (>80 m depth) on the lower west coast of Australia (31°45′–32°45′ S) were used to infer the movement patterns and habitats occupied by this species at different stages in its life cycle on this coast. These data were supplemented by results obtained by tagging individuals in spawning aggregations in the embayments. 0+ *P. auratus* <200 mm FL were caught exclusively in the three adjacent embayments. The ages and lengths of immature *P. auratus*, ranging from 1+ (ca. 200 mm FL) to 5+ years (ca. 400 mm FL), increased progressively with distance from these embayments. During the spawning period (from September to January), the relative abundances of *P. auratus* with either developing, developed or recently spent gonads were far greater in the three embayments (91%) than in either inshore (12%) or offshore waters (30%). Some tagged *P. auratus* were recaptured among spawning aggregations in the same embayment during subsequent spawning seasons, while others were recaptured in these embayments outside the spawning period. However, some other tagged individuals were recaptured up to 92 km north, 33 km west and 134 km south outside the spawning period and up to five years after tagging. The results of this study emphasise that the above three adjacent marine embayments constitute important spawning and nursery areas for *P. auratus* and are thus potentially critical for sustaining the stocks of this recreationally and commercially important species on the lower west coast of Australia.

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1. Introduction

The development of sound management policies for sustaining heavily fished stocks of a species requires reliable data on various aspects of the life cycle of that species, including their habitats. It is important to determine, however, not only the habitats occupied by such species at different stages in their life cycles, but also the ages, lengths and life cycle stages and times of the year at which any movements occur between habitats. Thus, for example, if the stock of a species is shown to congregate predictably in restricted locations at a certain time of the year, it will be identified as potentially prone to particularly heavy exploitation by fishers at that time. A thorough knowledge of habitat use and migrations of the individuals of a heavily fished stock is thus required to identify which life cycle stages of that stock and their habitats may require special protection. Finally, information on habitat use and movements is important for developing an ecosystem-based approach to fisheries management and thereby to ensure that ecosystem function in the different habitats is maintained.

Habitat partitioning between life stages, e.g., juveniles and adults, has been reported for many sparids (e.g., Bennett, 1993; Gillanders, 2002; Hesp et al., 2004a). Evidence for connectivity between juvenile and adult habitats is most commonly obtained from differences in the abundance of size and/or age classes in these habitats (Gillanders et al., 2003). The movement patterns of juveniles (0+ and 1+) inferred from this approach would otherwise be difficult to obtain from direct methods, due, for example, to the high levels of mortality and low recapture rates that are associated with traditional dart and anchor tagging of small fish. Mature individuals of many fish species also undergo seasonal movements each year to and from specific locations at the commencement and completion of the spawning period, respectively (e.g., Colin, 2010; Domeier and Colin, 1997; Heyman and Kjerfve, 2008). Seasonal accumulations of mature conspecific fish at specific locations and in significantly higher densities than are found

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* Corresponding author at: Western Australian Fisheries and Marine Research Laboratories, Department of Fisheries, Government of Western Australia, P.O. Box 20, North Beach, Western Australia 6920, Australia. Tel.: +61 08 9203 0111; fax: +61 08 9203 0199.
E-mail address: corey.wakefield@fish.wa.gov.au (C.B. Wakefield).

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outside the spawning period have been termed spawning aggregations (Domeier and Colin, 1997). The locations where spawning aggregations occur may also act as important nursery areas (Fowler et al., 2005; Hamer et al., 2005).

Pagrus auratus (Forster, 1801) is distributed throughout the temperate Indo–Pacific coastal waters of Australia and New Zealand between 18° and 38° S (Paulin, 1990). Throughout its distribution, this species forms a few spawning aggregations (as defined by Domeier and Colin, 1997; Society for the Conservation of Reef Fish Aggregations, www.scrfa.org) in sheltered marine embayments (Coutin et al., 2003; Crossland, 1977; Jackson and Cheng, 2001; McGlennon, 2004; Scott et al., 1993). In Western Australia, these spawning aggregations are typically found in embayments where the geomorphology, hydrology and habitat characteristics facilitate the retention of eggs, larvae and, to a certain extent, juveniles (Doak, pers.commn.; Lenanton, 1974; Nahas et al., 2003; Wakefield, 2006). The areas where spawning aggregations of *P. auratus* form in South Australia and Victoria also constitute important nursery areas (Fowler et al., 2005; Hamer et al., 2005). For example, Fowler et al. (2005) showed that, in South Australia, the progenies of the spawning aggregations of *P. auratus* in the northern areas of Gulf St Vincent and Spencer Gulf in 1991 remained in those areas for up to the first three years, before dispersing along more than 2000 km of the South Australian coast (Fowler et al., 2005). The fact that, all snapper from the 1991 year class that were sampled from this large stretch of the South Australian coast were found to originate from the northern waters of the two gulfs, clearly demonstrated the importance of such discrete spawning/nursery areas for recruitment and sustainability of broader adult stocks.

Tagging studies have shown that the extent to which *P. auratus* move varies among populations. For example, individuals of this species can move up to 1650 km in a northerly direction along the lower east coast of Australia (Sanders, 1974), whereas, those of the three stocks of *P. auratus* in the inner gulfs of Shark Bay in Western Australia (ca. 26° S) remain in the same area, with the majority moving <20 km from their location of release (Moran et al., 2003). The extent of the movements undertaken by the individuals of a given population of *P. auratus* thus presumably represents the degree to which the various life cycle stages are adapted to a given environment (Moran et al., 2003).

P. auratus forms spawning aggregations during the austral spring/summer in three adjacent marine embayments on the lower west of Australia, i.e., Owen Anchorage, Cockburn Sound and Warnbro Sound (Fig. 1), but do not apparently spawn in the waters immediately to the west (Wakefield, 2010). The geomorphology of Cockburn and Warnbro Sounds and the prevailing south-westerly winds during spring/summer result in a counter-clockwise gyre, which coincides with the spawning period of *P. auratus* and facilitates the retention of eggs and larvae in these embayments during this period (Wakefield, 2010). This suggests that these relatively small, discrete embayments are potentially an important source of recruitment for nearby adult stocks along the lower west coast of Australia.

This study compares the length and age compositions of *P. auratus* in the three marine embayments (and particularly Cockburn and Warnbro Sounds, in which the spawning aggregations are by far the largest) with those in the nearshore shallow (<80 m depth) and offshore deeper (>80 m) areas. These comparisons were used to determine whether habitat partitioning by *P. auratus* occurs in this region during the year and at different stages of their life cycle. Particular attention was paid to ascertaining the relative abundance of juvenile and mature *P. auratus* in all areas to gain an understanding of the importance of the three embayments as spawning and nursery areas for *P. auratus*. Finally, a mark-recapture tagging program was undertaken at known spawning aggregation locations (Cockburn and Warnbro Sounds) during the spawning period, in an attempt to determine the directions and distances that adult *P. auratus* might move from such locations.

2. Methods

2.1. Sample collection and measurements

Samples of *P. auratus* were collected from 2002 to 2006 from three areas between ca. 31°45′ and 32°45′ S on the lower west coast of Western Australia (Fig. 1). The offshore and inshore areas were located at depths greater and lesser than 80 m, respectively, and were situated immediately west of the marine embayments area which comprised Owen Anchorage, Cockburn Sound and Warnbro Sound (Fig. 1). These marine embayments have been identified previously as locations where spawning aggregations of *P. auratus* (Wakefield, 2006) and assemblages of 0+ juveniles (Lenanton, 1974) occur each year.

P. auratus was caught by line fishing from either research vessels or recreational charter vessels with research staff onboard who were permitted to keep fish less than the minimum legal length (410 mm total length at that time). This sampling, which was undertaken at least monthly from April 2003 to March 2005, was not accompanied by the tagging of fish (described later). Although fishing effort was not quantified, the sample sizes of *P. auratus* were sufficient to determine the proportions of the different life history stages in each area in all months. The same range of hook sizes and variety of rig types, which were known collectively to catch a large size range of *P. auratus* (Otway and Craig, 1993), were used on each sampling occasion. *P. auratus* caught from research vessels were later processed in the laboratory, while those caught from recreational charter vessels were processed onboard during each trip. The fork length (FL) of each *P. auratus* was measured to the nearest 1 mm. The two sagittal otoliths were removed from each fish, cleaned and stored in paper envelopes, and the macroscopic appearance of the gonads were used to sex each fish and to determine its stage of development (Table 1).

2.2. Treatment of otoliths

The right otolith of each fish was embedded in epoxy resin and, using a slow speed saw (Buehler Ltd.) with a diamond tipped saw blade, sectioned transversely through its primordium, perpendicular to the sulcus acusticus. The sections were mounted on a glass microscope slide with a cover slip using casting resin.

The opaque zones in each otolith section were counted under reflected light at 20–40 times magnification, without any knowledge of the length of the fish or its date of capture. The first opaque zone was easily distinguished, as its formation resulted in the development of an inflection point in the Subcupular Meshwork Fibre zone (Francis et al., 1992).

A single opaque zone has previously been shown to form annually in the otoliths of *P. auratus* from the lower west coast of Australia (Wakefield, 2006). Thus, the age of each *P. auratus* on its date of capture was estimated using a combination of an average birth date and the number of opaque zones in its otolith. An average birth date of 1 November was chosen because it represented the approximate peak time of spawning derived previously from the trends exhibited throughout the year by mean monthly values for gonadosomatic indices and the proportions of mature fish in samples collected from the lower west coast of Australia (Wakefield, 2006). These trends in gonadal variables demonstrated that *P. auratus* spawn from spring to mid-summer, i.e., from September to January each year (Wakefield, 2006).

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