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Presettlement schooling behaviour of a priacanthid, the Purplespotted Bigeye *Priacanthus tayenus* (Priacanthidae: Teleostei)

Julia Santana-Garcon · Jeffrey M. Leis · Stephen J. Newman · Euan S. Harvey

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Abstract We report *in situ* behavioural observations of presettlement schooling in *Priacanthus tayenus* off Coral Bay, Western Australia collected using pelagic Baited Remote Underwater stereo-Video systems. Two groups of fish (8 and 9 individuals) were observed that aggregated into a single school. Mean total length was 24.1 mm (12.5–30.2 mm). The fish swam at a mean speed of 8.5 cm s^{-1} in a group spacing themselves more or less evenly at a distance of around one body length from the nearest neighbour within the school. *P. tayenus* appeared to be sometimes associated with juveniles of other species. The results presented here add to the limited, but growing body of literature on the schooling behaviour of the early pelagic stages of demersal fishes.

Keywords Pelagic juvenile reef fish · Mid-water baited remote underwater stereo-video · Demersal fish · Ningaloo Reef · Western Australia

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J. Santana-Garcon (✉) · E. S. Harvey
The School of Plant Biology and UWA Oceans Institute (M470), Faculty of Natural and Agricultural Sciences, The University of Western Australia, Crawley 6009 Western Australia, Australia
e-mail: j.santanagarcon@grs.uwa.edu.au

J. M. Leis
Department of Ichthyology, Australian Museum, 6 College St, Sydney, NSW 2010, Australia

J. M. Leis
Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania 7001, Australia

S. J. Newman
Western Australian Fisheries and Marine Research Laboratories, Department of Fisheries, Government of Western Australia, P.O. Box 20, North Beach, WA 6920, Australia

Introduction

Most marine teleost fish species have a pelagic larval phase during their early life-history. The processes that occur during that period determine their dispersal and recruitment, and may influence the distribution of adult populations (Mora and Sale 2002). Extensive research has focused on the biology of the pelagic phase of demersal fishes, but direct observations and quantitative data on their behaviour in the pelagic environment is limited and only available for a small number of species (Leis and Carson-Ewart 1998; Leis 2010; Masuda et al. 2003; Masuda 2009). Leis (2010) reviewed the limited information available on the ontogeny of schooling in the pelagic larvae of marine demersal fishes. Schooling may provide protection from predators, accelerate learning and enhance swimming and orientation abilities (Masuda 2009; Shaw 1978).

Presettlement schooling has been described in a few reef fish families including Gobiidae (Breitburg 1991),

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Mugilidae (Kingsford and Tricklebank 1991), Mullidae (Leis and Carson-Ewart 1998; McCormick and Milicich 1993), Lutjanidae, Microdesmidae and Pomacentridae (Leis and Carson-Ewart 1998). However, the difficulties associated with studying these small and inconspicuous fish in situ has resulted in most behavioural studies relying on estimates from fish collected in plankton nets, purse seines or light traps (McCormick and Milicich 1993; Ohman et al. 1998) and on observations of reared larvae or laboratory experiments (Leis et al. 1996; Leis and Carson-Ewart 1998; Masuda 2009).

We report in situ observations of presettlement schooling behaviour in priacanthids off Coral Bay, Western Australia. The behaviour of juvenile *Priacanthus tayenus* (Richardson, 1846) was recorded using pelagic Baited Remote Underwater stereo-Video systems (stereo-BRUVs). This technique was being trialled to investigate the distribution of pelagic fish assemblages as it potentially provides a standardised, non-destructive and fishery independent approach to estimate abundance, diversity and length of fish in the pelagic environment (Harvey et al. 2004; Heagney et al. 2007). Presettlement reef fishes were observed in all 48 video deployments; these observations present a unique opportunity to describe their behaviour in situ. Presettlement priacanthids were observed in five of the 48 videos, and schools of two or more fish were recorded on three of those five deployments. This observation provides the first quantitative data on their presettlement schooling behaviour.

Priacanthids, commonly called bigeyes, comprise a small circum-tropical family of marine fishes that are characterised generally by extremely large and bright eyes, a deep body, rough scales and red coloration (Starnes 1988). Some species are commercially valuable in South East Asian trawl fisheries and in reef-based fisheries throughout the tropics (Senta 1978; Lester and Watson 1985; Seah et al. 2011). The Purplespotted Bigeye, *Priacanthus tayenus*, is a small species (maximum total length 29 cm) characterised by deep purple to inky black spots in the pelvic fins (Starnes 1999). Adults are epibenthic, can occur in large schools and inhabit rocky reefs and open bottom areas at depths between 20 and 200 m. Larvae and the early juvenile stages are pelagic (Starnes 1988).

Most aspects of the biology of the early life-history stages of priacanthids are largely unknown, in particular, behaviour during the pelagic dispersal phase. Schooling behaviour has not been reported for juvenile priacanthids; nonetheless, large aggregations have been reported around surface lights at night in the West Indies (Caldwell and Bullis 1971), the western North Atlantic (Caldwell 1962) and from trawl net catches in the Philippines (Senta 1978).

This study aims to contribute to the knowledge of presettlement schooling behaviour in the early stages of *Priacanthus tayenus*. Accurate length measurements, swimming speed and schooling parameters are described. Stereo-video techniques offer unique abilities to study the ontogeny of fish behaviour, and this study presents the first in situ quantitative data on schooling behaviour of the pelagic early-life history stage of a demersal fish species.

Materials and methods

The data presented here are based on observations of *Priacanthus tayenus* in March 2012 at Coral Bay (23° 1′ S; 113° 44′ E), Ningaloo Marine Park. Ningaloo Reef is a fringing coral reef which stretches for approximately 270 km adjacent to the semi-arid north-west cape of Western Australia. The pelagic stereo-BRUVs consisted of two SONY HDR CX12 video cameras mounted 0.7 m apart on a base bar inwardly converged at 8° to gain an optimised field of view of 7 m (Harvey and Shortis 1995). The cameras recorded video imagery at 25 frames per second in MPEG Transport Stream format (MTS) which was converted to high-definition MPEG format (Harvey et al. 2010). The system was deployed offshore of the reef slope in a depth of 35 m, and left moored for 3 h in mid-water, 15 m above the bottom (Fig. 1). The bait consisted of ~800 g of pilchards (*Sardinops sagax*) in a wire mesh basket suspended 1.2 m in front of the two cameras. The video images were analysed using the software 'EventMeasure (Stereo)' (SeaGIS Pty Ltd, see http://www.seagis.com.au/event.html). EventMeasure Stereo is a purpose built event logger which an operator can use to manually record the identification and number of fish and their behaviour at a particularly time on a video sequence. By using a mouse, an operator can determine the location of a point in three-dimensional space (x, y and z) relative to the centre of the two cameras. As the time sequence is recorded it is possible to calculate the swimming speeds of a fish. It is also possible to measure the distance to a fish (Harvey and Shortis 1995; Harvey et al. 2004) and make accurate and precise measurements of fish length (Harvey et al. 2001a,

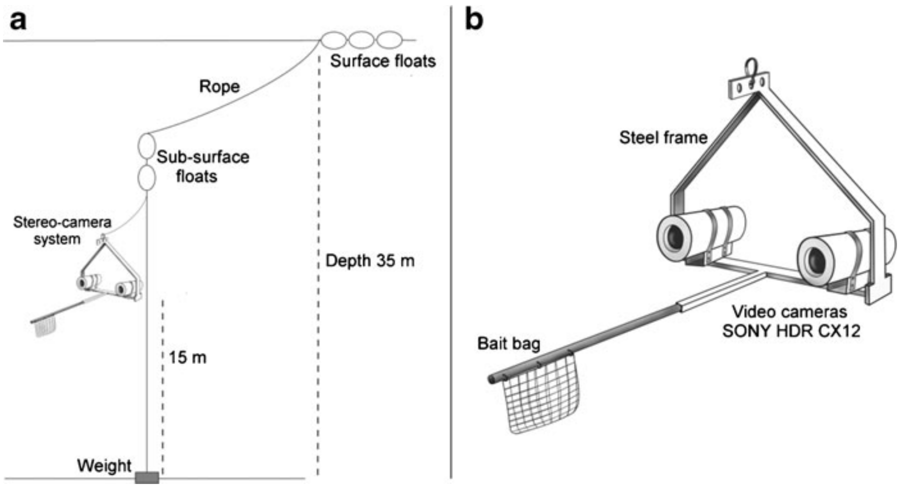

Fig. 1 Deployment method (**a**) and details (**b**) of the pelagic stereo Baited Remote Underwater Video system (stereo-BRUVs)

b, 2002). Species identification was confirmed by Wayne Starnes (pers. comm.) from still images and video clips (Fig. 2).

In order to obtain quantitative measurements of fish using stereo-video, individuals must be observed simultaneously in the field of view of the two stereo cameras. Furthermore, to ensure precision and accuracy of measurements, fish must be within a predefined distance and orientation to the camera system (Harvey et al. 2010). Given the small size of the fish targeted in the present study, individuals were only measured within 2 m of the cameras and, whenever possible, when the head and tail of the fish aligned at more than 50° perpendicular to the stereo-video system. Only individuals from three of the five videos that recorded priacanthids met the above criteria. Consequently, the quantitative data presented is from one video that recorded presettlement schooling behaviour and two videos that showed solitary fish.

From the image analysis, the behaviour of presettlement priacanthids was described and their total length (TL) measured from the stereo-video imagery. Total length for each individual was determined as the average of the measurements at five different frames and the mean TL for each group was calculated from the replicate measurements of all the individuals in the school. The present study defines schooling to be fish of the same species swimming in the same direction and in close proximity, approximately one to two body lengths apart (Shaw 1978). The term ‘group’ is used here to facilitate the description of schools that enter the field of view at different times. Two groups of presettlement

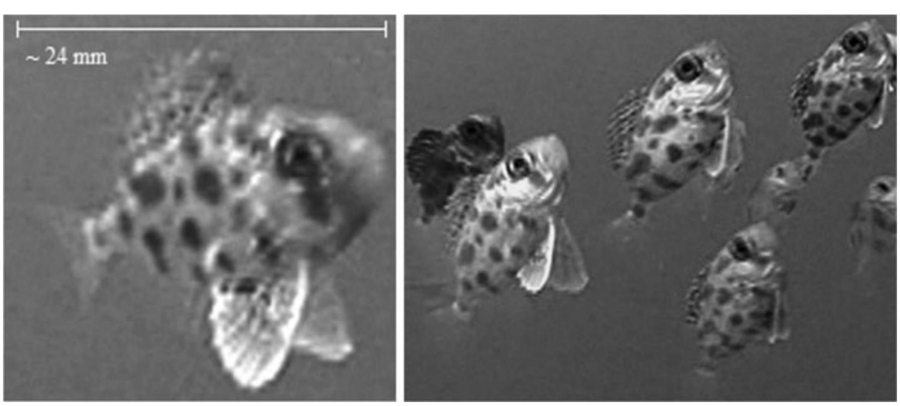

Fig. 2 Still photos of presettlement *Priacanthus tayenus* (mean total length 24.1 mm) captured from video recorded in Coral Bay, Western Australia

fish (A and B) aggregated into a single school, group (AB). Nearest Neighbour Distance (NND), a quantitative measurement of schooling behaviour, is the average distance between each fish in the group and its nearest neighbour (Masuda et al. 2003; Masuda 2009). From the stereo-video imagery, NND was sampled from ten different frames for group A and B and from five different frames for group AB. The difference in replicates is due to the short time that group AB was visible from both cameras. Replicate measurements were at least 25 frames apart (1 s). The mean NND was divided by the average TL of fish in the group (NND/TL) to facilitate comparison among aggregations of individuals of different sizes.

Swimming speed was estimated by measuring the distance travelled by an individual over 25 video frames (equivalent to 1 s) averaged across three consecutive seconds. Mean swimming speed of presettlement schooling priacanthids was obtained from the speed estimated for ten individuals at various times of the video. The swimming speed of solitary fish could only be measured for a single individual in one video; therefore it was discarded from the analysis.

Results

In the deployment that recorded schooling, the first priacanthid individuals were observed after 40.5 min. At that time, a school of four *P. tayenus* entered the field of view for only 1 s, and no measurements were made because the group was only visible from one of the cameras of the stereo system. Presettlement priacanthids entered the field of view a second time at 60.8 min for a period of 2 min and the school at that time had eight individuals (group A). The mean total length of the priacanthids in this group was 24.4± 0.3 mm (± standard error) and the individuals ranged from 23.0±0.9 to 27.0±0.4 mm. The NND of group A was 40.0±3.6 mm and the NND/TL averaged 1.6.

A second school of nine *P. tayenus*, group B, entered the field of view nearly 2 min after the first group (at 62 min) and was visible for 30 s until both schools merged into a single group (AB). Individuals in group B were estimated to average a total length of 23.9± 2.2 mm (mean ± S.E.) and ranged from 12.5±0.6 to 30.2±0.4 mm. The mean NND for group B was 22.3± 2.4 mm and the NND/TL was 0.9.

The combined group AB consisted of 17 *P. tayenus* and was visible for only 18 s. The mean TL of individuals in the school was 24.1±0.5 mm and the NND was 32.3±1.8 mm. The NND/TL was 1.3. There was no clear relationship between the size of the groups and their NND. Figure 3 provides a summary of the quantitative measurements estimated for the three groups of presettlement *P. tayenus*.

Further observations included a school of seven priacanthids recorded 20 min later (at 81 min), but no measurements were possible because the group was visible from only one of the cameras of the stereo video system. Later in the video (110.2 min) a school of 25 fish was recorded. One juvenile carangid, four nomeids and 20 presettlement priacanthids could be distinguished in that school. However, the small size of the individuals and their distance from the camera prevented identification of all individuals, estimation of their TL or confirmation of that group as AB.

Mean swimming speed of the observed presettlement *P. tayenus* was 8.5±1.5 cm s^{-1} and the measurements for ten individuals ranged between 4.8 and 18.2 cm s^{-1}. These estimates are equivalent to a mean swimming speed of 3.6±0.7 TL s^{-1} and ranged between 2.0 and 7.5 TL s^{-1}.

In the two videos analysed with solitary presettlement priacanthids, TL of the individual was also determined as the average of the measurements in five different frames. One solitary individual was 17.3±0.2 mm and the other was 24±0.8 mm. Priacanthids and monacanthids were the only identifiable demersal fishes in their pelagic stage observed during this study. Monacanthid fishes, observed in most video deployments, were very structure-orientated, attracted to the structure of the camera system, and did not join the schools of priacanthids.

Discussion

These results provide the first observations and quantitative data on the presettlement schooling behaviour of any priacanthid during its pelagic phase. The presettlement *P. tayenus* observed schooling were on average 24.1 mm TL (12.5–30.2 mm), and swam in a group spacing themselves more or less evenly at around one body length from the nearest neighbour within the school (Fig. 3). *P. tayenus* appeared to be sometimes associated with juvenile carangids or nomeids. The individuals observed alone were within the same size range as those observed schooling. Due to the small sample size, the results presented here

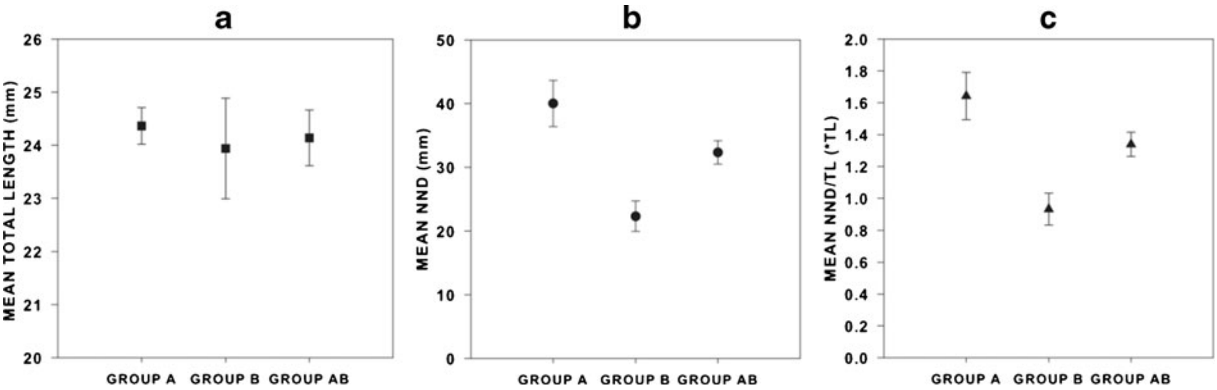

Fig. 3 Quantitative parameters for three groups of presettlement *Priacanthus tayenus* recorded using pelagic stereo cameras in Coral Bay, Western Australia (group A, 8 individuals; group B, 9 individuals and group AB, 17 individuals). **a** Mean Total Length (TL; mm); **b** mean Nearest Neighbour Distance (NND; mm) and (**c**) mean NND divided by the average TL. *Error bars* represent standard error

may not reflect all the natural behaviours of this species. However, this study provides the first look at in situ presettlement behaviour using a video technique and may stimulate further work in this field.

Many fish species school during their pelagic phase regardless of their behaviour after settlement or as adults (Shaw 1978). NND is the parameter most commonly used in studies of fish schooling behaviour and NND/TL can be used to compare schooling across different size classes and species (Masuda et al. 2003; Soria et al. 2007; Masuda 2009; Torisawa et al. 2011). The values of NND calculated for the observed presettlement *P. tayenus* (0.9–1.6 NND/TL) are comparable to the estimates for other species. Schools of the carangid *Pseudocaranx dentex* at 25 mm TL have a NND/TL of 0.5 to 1.2 (Masuda 2009) and the scombrid *Scomberomorus niphonius*, which is considered to form loose schools in comparison to most pelagic fishes, has a NND/TL of 1.2 to 1.5 at a standard length of 19 to 23 mm (Masuda et al. 2003). However, these studies on the ontogeny of schooling behaviour focus on pelagic fish species and are limited to laboratory based experiments using hatchery reared larvae.

Generally, marine fish in their pelagic phase swim at speeds between 3 and 15 body lengths per second (Leis 2010). The in situ swimming speed estimated for the observed priacanthids, on average 3.6 TL s^{-1} (8.5 cm s^{-1}), fits in the slower end of this general estimate. An average swimming speed greater than 3 cm s^{-1}, is considered to be influential for the dispersal of marine fishes (Leis 2006, 2010). However, the measurements of swimming speed presented here should be treated with caution as speeds are expected to vary and estimates may be influenced by physical processes such as current and surge.

The limited information available on the behaviour of priacanthids at early stages makes difficult the comparison and interpretation of the data presented here. Senta (1978) noted that maturing juveniles of *P. tayenus* are recruited into schools at about 90–100 mm standard length (SL) and reach 200 mm SL one year after recruiting. It is not known if the individuals observed in this study, 12.5–30.2 mm, were near settlement. However, *Pristigenys alta*, another priacanthid species that has similar maximum size to *P. tayenus*, is reported to transform from pelagic to demersal phase at 35 to 55 mm SL (Caldwell 1962; Starnes 1988).

Pelagic stereo-video systems may have the potential to overcome some of the difficulties associated with studying the behaviour of juvenile fish in the pelagic environment. Juveniles of various pelagic and demersal species were attracted to these mid-water structures. Video techniques could be used for in situ behavioural research at depths beyond the limits of diver-based studies and also for night observation using a range of light wavelengths or image intensification technology (Harvey et al. 2012), and thus could contribute to overcoming a major gap in knowledge about diel effects on the behaviour of fish larvae (Leis 2010). Despite the difficulties of identifying juvenile fish to the species level from video alone, this technique could be used in combination with other methods, such as purse seine or light traps, to facilitate identification and allow for further morphological and genetic studies. Further work is needed to understand the strengths and limitations of pelagic stereo video techniques for studying juvenile fish in their pelagic phase.

In conclusion, the observations on priacanthids presented here add to the limited, but growing body of literature on the schooling behaviour of larval and juvenile demersal fishes. *P. tayenus* swam in small groups and merged with other presettlement conspecific schools to form larger groups. Sometimes these presettlement schools swam in association with other species. Presettlement schooling behaviour has also been observed in at least six other families of demersal fish and seems to represent an important behaviour in the early life stages of many demersal fish species (Leis and Carson-Ewart 1998).

The observations and measurements of the behaviour of presettlement fishes presented demonstrate the potential of non destructive stereo-video techniques for collecting additional information which is complementary to the existing techniques. Rather than using bait, artificial or natural materials could be placed in front of the camera system to form a fish aggregation device for juvenile fishes.

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