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Where are the little ones: distribution and abundance of the threatened serranid *Epinephelus daemelii* (Günther, 1876) in intertidal habitats in New South Wales, Australia

By D. Harasti[1], C. Gallen[1], H. Malcolm[2], P. Tegart[3] and B. Hughes[4]

[1]*NSW Department of Primary Industries, Fisheries Research, Marine Ecosystems, Nelson Bay, NSW, Australia;* [2]*NSW Department of Primary Industries, Fisheries Research, Marine Ecosystems, Coffs Harbour, NSW, Australia;* [3]*Fish Ecology Laboratory, School of the Environment, University of Technology, Sydney, NSW, Australia;* [4]*Hunter-Central Rivers Catchment Management Authority, Taree, NSW, Australia*

Summary

A survey of intertidal habitats, including coastal rock pools, was undertaken across New South Wales (NSW), Australia, February to May 2012, to test the hypothesis that the distribution and abundance of threatened juvenile black cod *Epinephelus daemelii* (Günther, 1876) does not differ across marine bioregions. An assessment was also provided on their habitat use and site fidelity. Various methods were trialled to determine the best method for detecting juvenile *E. daemelii,* with the most suitable method being the deployment of small baited underwater high definition video cameras for a period of 30 min. Using these baited video cameras, sampling occurred across four bioregions in NSW, covering approximately 800 km of coastline. Within each bioregion, a minimum of nine locations was selected, and at each location a minimum of six intertidal habitats was surveyed for the presence of *E. daemelii*. Of 412 sites surveyed, a total of 20 juveniles (mean size = 16.7 cm ± 1.1 cm SE) were found in intertidal habitats along approx. 420 km of coastline. The smallest juvenile was L_T 3 cm and the largest fish was stereo measured at L_T 26.5 cm. *E. daemelii* were found to tolerate a large range of water quality parameters, particularly temperature (mean 21.7°C ± 0.7 SE, min = 16.8°C and max = 31.2°C) and dissolved oxygen (mean 11.2 mg L^{-1} ± 1.3 SE, min = 5.7 mg L^{-1} and max = 19.2 mg L^{-1}). *E. daemelii* were found in habitats dominated by boulders and overhangs, indicating a preference for structural features that provide solid cover. No *E. daemelii* were recorded at sites that had algae as the dominant habitat type. Juvenile *E. daemelii* were found to display site fidelity to rock pool habitats, with two individuals recorded as remaining at their same sites for a period of 471 days, even though the rock pools were open to the ocean at high tides. This study indicates that the abundance of juvenile *E. daemelii* is low, especially north of Port Stephens where adults are most abundant. Use of the small baited video cameras proved to be a successful sampling method to confirm that juvenile *E. daemelii* utilise rock pool and shallow reef intertidal habitats in the early stages of their life cycle.

Introduction

Worldwide, fishes in the *Epinephelus* genus are considered to be important fishery species; however, several species are considered as being under threat from overfishing, a result of their life history characteristics (Coleman et al., 1999; Sadovy de Mitcheson et al., 2012). The characteristics that make *Epinephelus* sp. vulnerable to overfishing include slow growth, long life, late sexual maturity, site fidelity and aggregation spawning (Sadovy, 1997; Sadovy and Eklund, 1999; Pears et al., 2007). One species that displays these life history characteristics and is considered threatened in parts of its range is *Epinephelus daemelii* (Günther, 1876), a subtropical fish species from the Serranidae family that occurs in the south-west Pacific Ocean in Australia, New Zealand and the nearby islands of the Kermadec, Lord Howe and Norfolk (Francis, 2012). New South Wales (NSW) is considered to be the western extent of its range in the south-western Pacific Ocean, and was previously considered to be widespread along the NSW coast (Roughly, 1916). However, it declined in abundance as a result of line and spearfishing, with extensive targeting from the 1950s to 1970s (Andrewartha and Kemp, 1968). As a result of overfishing, the species was protected in NSW in 1983, and is now legislated in NSW and nationally as a vulnerable species and classified as 'Near Threatened' under the IUCN Red List (IUCN, 2013). *Epinephelus daemelii* is a large reef-dwelling grouper/cod species and in Australia, it is also known under several common names such as black rockcod and saddled rock cod; in New Zealand it is generally referred to as spotted black grouper (Francis, 2012). The colour pattern of *E. daemelii* is highly variable, and can change quickly from a uniform dark grey-black to a blotched or distinctively banded dark and light pattern (Harasti and Malcolm, 2013). In Australia, large adults are known to attain at least 1.5 m total length and weights of up to 81 kg (Hutchins and Swainston, 1986). They have been recorded as large as 1.8 m in New Zealand, but more usually seen there at lengths of between 40 and 80 cm (Paulin and Roberts, 1992). The species is a protogynous hermaphrodite and changes from female to male at 100–110 cm (Francis and Lyon, 2012), however it is unknown at what size they change sex in Australia as this has not been investigated, nor at what size they initially mature as females.

From 2009 to 2011, *E. daemelii* surveys were undertaken in northern NSW using roving diver counts that found *E. daemelii* to be smaller in the southern localities (Port Stephens), and significantly smaller on inshore than offshore reefs (Harasti and Malcolm, 2013). No post-larvae or juvenile *E. daemelii* smaller than 26 cm were recorded in these surveys and most fish were larger than 50 cm. Harasti and Malcolm (2013) speculated that either recruitment of *E. daemelii* in NSW was very low or that the juvenile-associated habitats were entirely different from those used by sub-adult and adult fish. Juveniles are believed to be associated with near-shore reefs, estuaries and rock pools (Paulin and Roberts, 1992). In NSW, juvenile *E. daemelii* are anecdotally known to inhabit rock pools and shallow rocky reefs around headlands on the NSW central-south coast, but little is known about their abundance, distribution and microhabitat use in these habitats. The only known published record of *E. daemelii* under 10 cm is by Griffiths (2003a,b), who found a small number in intertidal rock pools in several locations on the NSW south coast and indicated that they may provide a valuable nursery habitat for this species.

The NSW recovery plan for the species (DPI, 2011) recommends scientific assessment of *E. daemelii* distribution, abundance and collection of life history data as a high priority. Specifically, the recovery plan actions state: (i) Conduct and/or facilitate targeted surveys to determine the current distribution and abundance of *E. daemelii* in NSW waters; and (ii) Initiate projects to investigate the biology and ecology of *E. daemelii* (e.g. life history, habitat requirements, fecundity, reproductive biology, movements, response to climate change and water pollution, etc.). Given the lack of detailed information on many aspects of distribution and life-history of the species, this project aims to test the hypotheses that: (i) distribution and abundance of juvenile *E. daemelii* in intertidal habitats does not differ across marine bio-regions in NSW; and, (ii) occurrence of juvenile *E. damelii* in intertidal habitats is not affected by the micro-habitat (boulders, macro-algae, overhangs). Water quality characteristics at sites where *E. daemelii* were detected and the fidelity of juveniles to intertidal sites are also assessed. Additionally, to assist in testing these hypotheses, various field methods will be trialled and compared to determine the most suitable method for detecting juvenile *E. daemelii* within intertidal habitats.

Materials and methods

Sites

Sampling locations along the NSW coast were randomly selected through visual identification of rock platforms using online mapping tools and aerial photographs. Selected was a minimum of nine locations in four bioregions in NSW, plus three locations sampled at Lord Howe Island (see Table 1 for details). The bioregions used in this study are those defined by IMCRA (1998). The most northern sampling location was at Sandon (29°40′27.42″S; 153°19′58.79″E) and the most southern was Bermagui (36°25′44.85″S; 150°5′4.54″E) (Fig. 1). Selected locations required the presence of a rock platform that contained rock pool habitats and shallow intertidal reef habitat accessible for sampling. Within each location, six replicate sites minimum were sampled to ensure that each location was representatively sampled; however, some sites had more than six replicates when there were more suitable rock pools/shallow reef habitats available for sampling (Table 1); 412 sites total were sampled across all locations. While depth varied from site to site (30–300 cm), average depth was 66.4 cm ± 3.7 SE.

Table 1
Sampling locations, number of sampling sites and location of *E. daemelii* observations

Marine bioregion	Location	Number of sites (replicates)	Number of juvenile *E. daemelii*
Tweed	Sandon	9	
	Minnie Water	12	
	Diggers Camp	12	
	North-west Island	10	
	Arrawarra	11	
	Woolgoolga	12	
	Flat top Rock	12	
	Sawtell	8	
	Nambucca	7	
Manning	Diamond Head	8	1
	Crowdy Head	8	
	Red Head	9	
	Black Head	10	
	Fingal Head	8	4
	Big Rocky	8	2
	Middle Rocky	8	
	Little Rocky	8	
	Boat Harbour (east)	8	
	Boat Harbour (west)	8	2
Hawkesbury	Catherine Hill Bay	11	
	Norah Head North	9	
	Norah Head South	10	1
	Kilcare	10	
	Terrigal	9	
	Dee Why	8	3
	Freshwater	8	1
	Maroubra	8	
	Bondi	8	
	Coalcliff	8	
	Austinmer Point	8	
	Bellambi Point	8	
Batemans	Kiama	8	
	Shellharbour	8	
	Bass Point	9	
	Gerringong	8	2
	Currarong	8	1
	Murray Beach	8	
	Stoney Creek	8	2
	Bendalong	8	1
	Kioloa	8	
	Malua Bay	8	
	Wimbie Beach	6	
	Narooma	8	
	Merimbula	7	
	Bermagui	6	
Lord Howe Island	Mermaid Pools	7	
	Middle Beach	9	
	Signal Point	7	

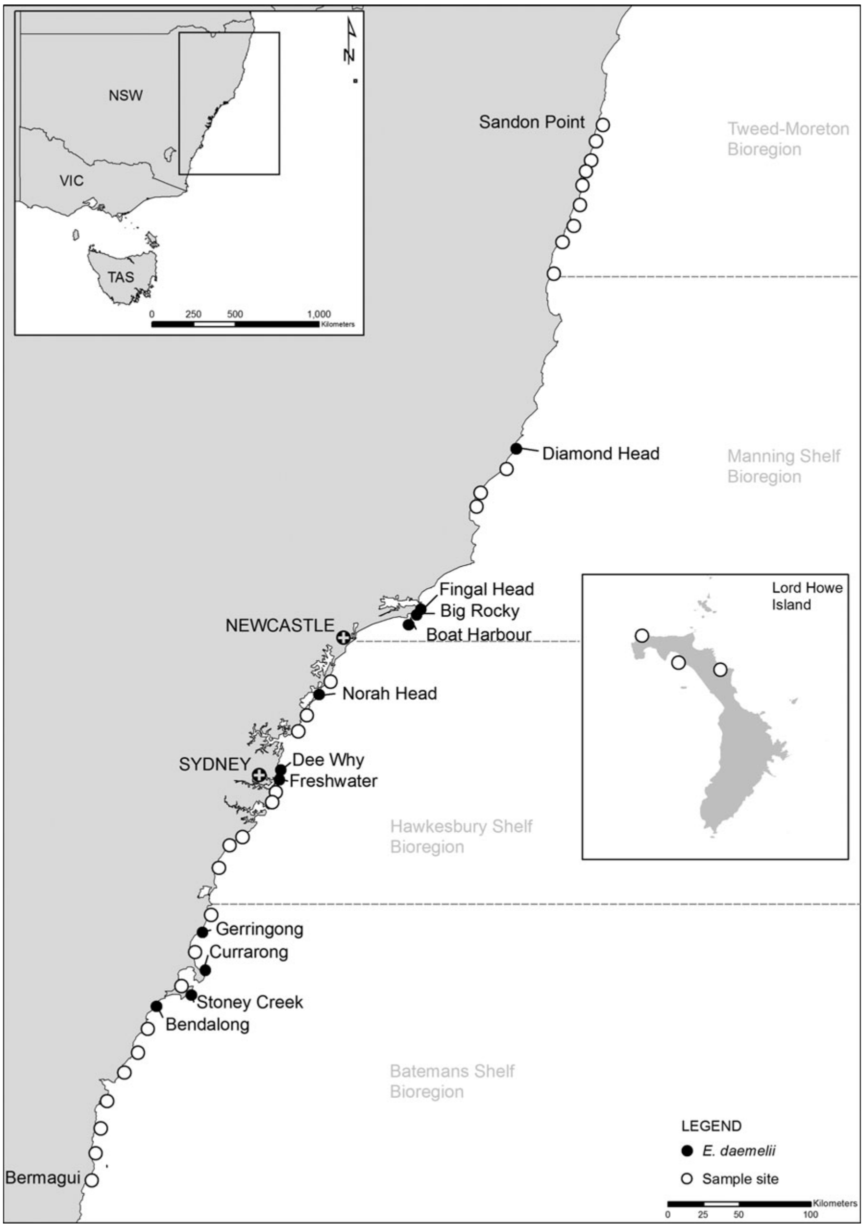

Fig. 1. Survey site locations and sites where juvenile *Epinephelus daemelii* occurred in New South Wales

Baited video cameras

A mini Baited Remote Underwater Video (BRUV) (hereafter referred to as a 'mini-BRUV') system was used to survey for the presence/abundance of *E. daemelii* within intertidal habitats as well as for the presence of other fish species within the site. The use of BRUV is an established method for studying fish assemblages (Malcolm et al., 2007; Ebner and Morgan, 2013); however, the generally large size of the standard BRUV is impractical for use in intertidal habitats. Utilising small high definition GoPro HERO2 underwater video cameras (www.gopro.com), a compact mini-BRUV system was developed that incorporated a 30 cm bait arm with 2×2 kg weights to weight the system along with a small mesh bait bag (Fig. 2). Bait consisted of three pilchards, *Sardinops neopilchardus,* that were crushed inside the bait bag. Each camera was in a underwater housing, with the field of view set to 1700 wide with a resolution of 1920×1080. Cameras were randomly placed into the rock pool/reef habitat; however, an attempt was made to have the camera pointing towards any overhangs or small holes where *E. daemelii* were more likely to occur. Wherever possible, the cameras were positioned with the sun behind them as this made video analyses clearer on the computer. All sampling was conducted between 08.00 and 15.00 hours, within 2 h either side of low tide, when sea conditions on the intertidal zone were calmest and deployment and retrieval safest, and thus minimising the effects of wave action on the video.

Trial of survey methods

Duration of set. To determine the optimum set time for the mini-BRUVs in the intertidal habitat, a trial was conducted

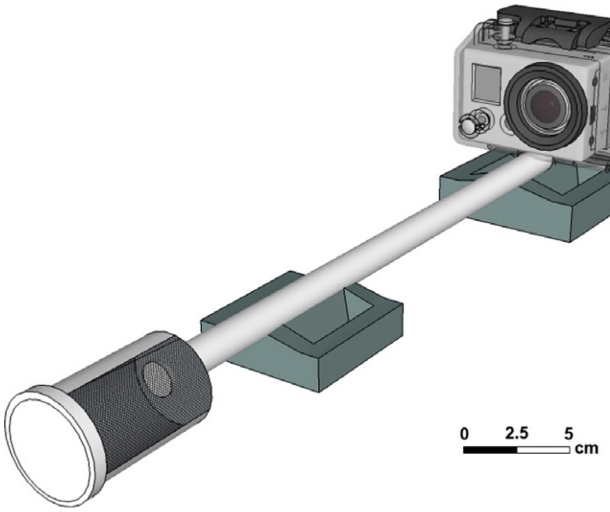

Fig. 2. Design of mini-BRUV system with weights and bait arm

in February 2012 at two locations (Fingal Head and Boat Harbour) where the camera was set for both 30 and 60 min in six different sites at each location. Cameras were randomly set first for either 30 or 60 min, removed from the water, and then reset after a small break (approximately 15–30 min) before being placed in the same location for the other time duration. This ensured that each habitat was sampled consistently for *E. daemelii* and for overall fish species richness; it was important to have both samples taken within a small time frame because all species could enter/exit the habitat on an incoming high tide.

Visual survey vs mini-BRUVs. A comparison between visual survey and mini-BRUV methods was undertaken to determine the effectiveness of both methods in detecting *E. daemelii*. Similar to the set time experiment, six sites were selected at two locations (Fingal Head and Boat Harbour). The visual survey involved watching the rock pool/intertidal habitat from above for a period of 10–30 min (time varied depending on size of rock pool) and recording all fish species present. When the rock pool was large and deep enough (>5 m width, >3 m length and >1 m depth), a diver would snorkel in the water and record all species encountered. Following the visual observation, approx. 15 min later a mini-BRUV was placed into the site and all species were recorded for a period of 30 min.

Baited vs un-baited. To determine the effects of bait attraction for *E. daemelii*, a comparison was undertaken where the mini-BRUV was set unbaited for 30 min, removed from the water for approx. 30 min and then reset in the water with three pilchards used as bait. This experiment was conducted at six sites at Fingal Head and Boat Harbour, where *E. daemelii* were known to occur, to determine if the use of bait was beneficial in attracting *E. daemelii* to the camera.

Baited traps (L40 cm, H20 cm, W20 cm) were also trialled as a method to detect juvenile *E. damelii* at sites where they were known to occur; however, no results are reported as no fish were captured.

Video analysis

Video analysis for each site was undertaken using SeaGIS EVENTMEASURE 3.31 software (www.seagis.com.au) where each species present in the 30 and 60 min videos was identified and recorded. Other parameters recorded in the video analysis included time of first *E. daemelii* appearance and time to first feeding as well as *E. daemelii* colouration.

Measurements

Size estimates for each individual *E. daemelii* were estimated wherever possible by comparing their size in reference to the known size of the bait bag. To improve size estimates, a small mini-stereo camera system was developed by SeaGIS that utilised two small HERO2 video cameras in separate custom-made underwater housing on a precision engineered base bar that overlapped the video taken by each camera (both cameras were angled in towards each other at a precise angle). The methods for stereo calibration and measuring fish are similar to those reported by Harvey and Shortis (1998); to ensure that the stereo camera remained in calibration, it was tested with a calibration scale bar with three known lengths prior to use each day. Video files from each camera were converted to high definition AVI files using the Wondershare video converter (www.wondershare.com) to allow for analysis in EVENTMEASURE. Measurements of juvenile *E. daemelii* were undertaken from the frame where the fish was in the best position relative to the camera and where the fish could be completely seen, fully extended with no body curvature. All length measurements are for total length (L_T).

Site fidelity

Sites at two locations (Boat Harbour and Fingal Head) where juvenile *E. daemelii* were detected were monitored from January 2012 to June 2013, to determine their fidelity to each site. Presence or absence was determined through redeployment of the baited mini-BRUVs, with maximum intervals of 3 months between surveys, to determine if *E. daemelii* were still present at the site.

Habitat and water quality data. At each site a variety of biophysical habitat data was collected including size of habitat, depth of site, species of algae present and dominant available habitat type. Intertidal sites were classified as 'shallow reef' (site open to constant ocean water flow at low tide) or 'rock pools' (sites not exposed to the open ocean at low tide). An assessment of the dominant habitat features available for juvenile *E. daemelii* to use were recorded for each site using three habitat category classes (boulders, overhang, algal); an estimate of the most dominant boulder size was undertaken and separated into three classes: small= <30 cm, medium= 30–70 cm, and large= >70 cm). Additionally, for each site the most dominant algae was recorded and the total percentage of algal cover was estimated.

For each location, water quality parameters were recorded using an HORIBA water checker U-10 (www.horiba.com) and the parameters of pH, temperature, conductivity, dissolved oxygen and salinity were recorded to provide an

Table 2
Details for *Epinephelus daemelii* observed on mini-BRUVs from all locations with associated mean water quality parameters

Site	Location	Water Temp (°C)	Salinity (ppm)	pH	Conductivity (ms cm^{-1})	DO (mg L^{-1})	Intertidal habitat	L_T (cm)
DH02	Diamond Head	20.8	3.4	8.2	52.1	6.3	Rockpool	3
BH01	Boat Harbour	16.8	3.3	8.4	50.8	11.6	Rockpool	10
BH02	Boat Harbour	31.2	3.2	9	48.1	5.7	Rockpool	14.2
FH01	Fingal Head	20.1	3.2	8.1	49.6	9.7	Rockpool	14
FH02	Fingal Head	19.2	3.2	8.6	50.4	10.1	Rockpool	20
FH05	Fingal Head	20.3	3.2	8.9	50.8	19.3	Rockpool	18
FH07	Fingal Head	19.2	3.2	8.6	50.4	10.1	Rockpool	26.5
BR05	Big Rocky	21.4	3.3	8.3	50.4	11.6	Shallow reef	20
BR08	Big Rocky	21.4	3.3	8.3	50.4	11.6	Shallow reef	20
NHS08	Norah Head South	21	3.2	8.3	52.1	12	Shallow reef	10
DEE06	Dee Why	23.5	3.2	8.9	53.6	8.4	Shallow reef	20
DEE06	Dee Why	23.5	3.2	8.9	53.6	8.4	Shallow reef	25
DEE08	Dee Why	21.9	3.3	8.7	53.4	8.7	Rockpool	10
FRE08	Freshwater	21	3.3	8.6	53.7	8.8	Shallow reef	10
BEN03	Bendalong	26.6	3.4	9.1	53.5	7.9	Rockpool	15
SC02	Stoney Creek	19	3.2	8.3	49.6	8.1	Shallow reef	14
SC07	Stoney Creek	19	3.2	8.3	49.6	8.1	Rockpool	20
CU01	Currarong	22	3.3	8.3	50.4	8.9	Shallow reef	12
GG05	Gerringong	28.8	3.2	8.3	49.1	5.9	Rockpool	20
GG07a	Gerringong	27.5	3.1	8.7	48.2	12	Rockpool	20

understanding of the physical water column characteristics of the juvenile *E. daemelii* intertidal habitats. All water quality measurements were taken on low tide and water quality data was collected three times for each site on the day of sampling with means presented (Table 2).

Statistical analysis

To determine if species richness differed between the 30 and 60 min set times, a single factor analysis of variance (ANOVA) (Krebs, 1999) was undertaken with the set time treated as a fixed factor (with six replicates for each set time). To compare if species richness differed between survey methods (visual vs mini-BRUV), a single factor ANOVA was undertaken with the survey method treated as a fixed factor (six replicates for each survey method). Data analysis was undertaken using SPSS 20 (Pallant, 2010) (www.ibm.com/spss).

Results

Trial of survey methods

Duration of set. There was no significant difference in recorded species richness of fishes in the rock pools between 30 min and 60 min set times (single factor ANOVA: $F_{1,46} = 0.104$, $P > 0.75$; Fig. 3). Additionally, four *E. daemelii* were observed in the 30 min sets whilst only three *E. daemelii* were observed in the 60 min sets. The only site where *E. daemelii* was not seen on concurrent sets was at a site at Fingal Head, where it was first observed on the 30 min set but not subsequently seen on the 60 min set.

Visual survey vs mini-BRUVs. During the comparison trial, a total of five juvenile *E. daemelii* were encountered with the mini-BRUVS whilst only one *E. daemelii* was observed using the visual survey method. Species richness surveyed with the mini-BRUVS was also significantly higher than in the visual surveys (single factor ANOVA: $F_{1,22} = 44.89$, $P < 0.005$; Fig. 4). This included a similar-looking serranid species, the eastern wirrah *Acanthistius ocellatus* (Günther, 1859), which was not recorded on any of the visual surveys.

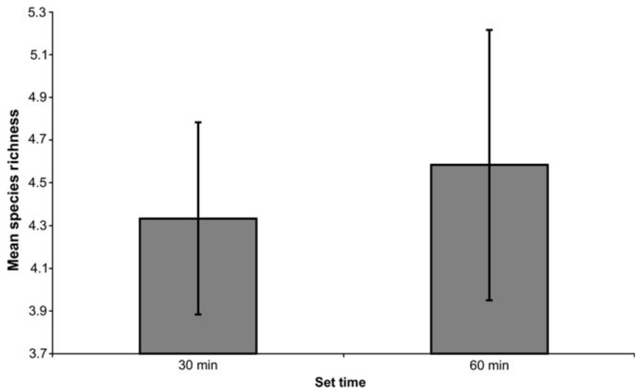

Fig. 3. Comparison of mean species richness (with SE) on mini-BRUVS for 30 min and 60 min set times

Baited vs non-baited video. For the baited mini-BRUV sets, *E. daemelii* were recorded on video at all six sampled sites. Only one *E. daemelii* was recorded on a non-baited mini-BRUV at the Fingal Head site.

As a result of the survey methods trials, all relative abundance and distribution surveys for juvenile *E. daemelii* were undertaken using baited mini-BRUVS set for a period of 30 min.

Relative abundance and distribution

Twenty juvenile *E. daemelii* were recorded in the intertidal habitats surveyed using mini-BRUVs; as the observed

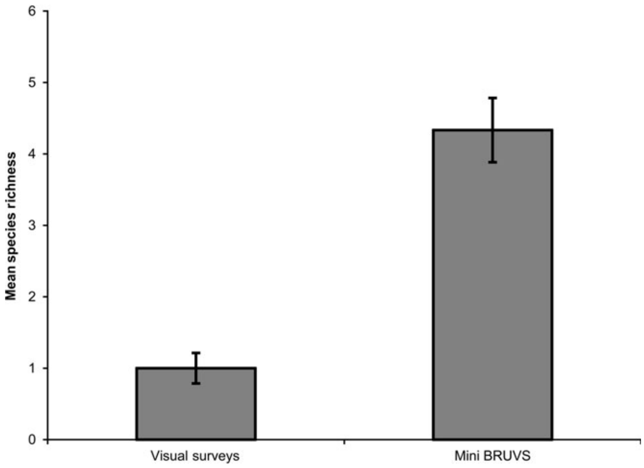

Fig. 4. Comparison of mean species richness (with SE) between visual surveys and mini-BRUVs

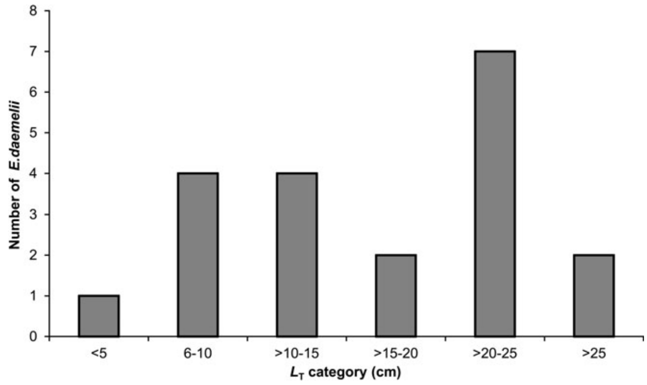

Fig. 5. Total length (L_T) of *Epinephelus daemelii* recorded on mini-BRUVs in New South Wales. Combined measurements from a stereo camera, and size estimates from video analyses

numbers were low, statistical analysis comparing abundance between bioregions, locations and habitats was not feasible. *Epinephelus daemelii* only occurred at 4.6% of sites surveyed along approx. 800 km of coast. A single individual was recorded at a shallow reef site at Lord Howe Island, however, it was not considered to be a juvenile as it was over 30 cm in length (approx. 45 cm), although it is important to note that given the lack of size at maturity data, this is an arbitrary cut-off measurement in the absence of biological information. There was also a small recruit, measuring approx. 3 cm, visually observed at Terrigal (33°26′47.53″S; 151°27′1.00″E) during the survey period. However, this fish was not detected by the mini-BRUV when the same rock pool was surveyed a week later and was not included in the 20 observed juveniles.

No *E. daemelii* were detected at sites north of Diamond Head on the NSW mid-north coast whilst the furthest south recorded was Bendalong in the Batemans bioregion. Nine *E. daemelii* were recorded in the Manning bioregion, six in Batemans and five in the Hawkesbury bioregion. Whilst no *E. daemelii* were recorded in the Tweed bioregion, there were several juvenile (<15 cm) estuary cod *E. coioides* (Hamilton, 1822) detected in the rock pool habitats. Therefore, the hypothesis that distribution and abundance of *E. daemelli* is equally distributed along the marine bioregions in NSW is rejected.

The location with the highest number of juvenile *E. daemelii* was Fingal Head in the Port Stephens-Great Lakes Marine Park, which had four juveniles inhabiting the same rock platform. There was only one location where more than one *E. daemelii* occurred within the same site, with two individuals found inhabiting the same rock pool at Dee Why Beach in Sydney.

Size and colouration

The average size for juvenile *E. daemelii*, from stereo video measurements and size estimates from video observations, was 16 cm ± 1 cm SE; highest frequency L_T class from all locations was 20–25 cm (Fig. 5). The largest juvenile was recorded at Fingal Head, accurately measured with a stereo camera at 26.5 cm, with the smallest fish estimated at 3 cm from Diamond Head. The colouration of each individual varied considerably at first sightings, although juveniles in general would start with a very dark colouration. However, mini-BRUV observations illustrated that as the juveniles came out of their hiding place into the open, their colouration would lighten within seconds.

Time to first appearance and first feeding

Time to first appearance for *E. daemelii* varied, with average time 12:18 min (±2:11 SE). Twelve of the 20 juvenile *E. daemelii* were observed feeding on the bait with an average 'time of first feeding' at 14:11 min (±1:37 SE). The earliest sighting of a juvenile was after 30 s and the latest 'time of first appearance' was 29 min.

Habitat

Epinephelus daemelii were recorded in two different micro-habitat classes (boulders and overhangs), but none was observed in habitats dominated by algae. Therefore the null hypothesis that the occurrence of juvenile *E. damelii* in intertidal habitats is not affected by habitat availability is rejected. Ten of the *E. daemelli* were observed hiding under an overhang habitat, whilst six were in a large boulder habitat, two in medium boulders, and one in a small boulder habitat. The smallest fish (3 cm) recorded was observed swimming in mid-water. Twelve of the *E. daemelii* were observed in rock pool habitats whilst the other eight were in sites classified as shallow intertidal reef.

Water quality

The average temperature for sites where *E. daemelii* were encountered was 21.7°C (±0.7 SE), with a minimum recorded at 16.8°C and a maximum of 31.2°C. Dissolved oxygen varied greatly amongst *E. daemelii* sites with the average DO = 11.2 mg L^{-1} (±1.3 SE), with a minimum of 5.7 mg L^{-1} and a maximum of 19.2 mg L^{-1}. Salinity, pH and conductivity varied little across all sites where *E. daemelii* occurred (Table 2).

Site fidelity

At two locations (Boat Harbour and Fingal Head), six *E. daemelii* were regularly monitored; the number of days they remained at each site varied. Two individuals were found to reside in their original sites at Fingal Head for a period of 471 days with another individual recorded at the location for 176 days; all of these sites were open to the sea on high tide. One of the individuals monitored at Boat Harbour was in a rock pool elevated ~2 m above sea level and considered to be in a closed system, as the water could not exit on a high tide. This had the highest recorded water temperature and lowest recorded dissolved oxygen. Three individuals on the Fingal Head platform were all found to have disappeared in June 2012 after periods of 113, 113 and 101 days of site fidelity; this disappearance is most likely attributable to the extremely large swell event (8 m+ swell) recorded off the Port Stephens coast on 07 June 2012. This demonstrates that juvenile *E. daemelii* can show strong site fidelity to their intertidal habitats.

Discussion

Juvenile *Epinephelus daemelii* occur in intertidal shallow reefs and rock pools in NSW, particularly as small recruits. This demonstrates an ontogenetic change in habitat use, as adults were not recorded in this study but found predominantly on offshore rocky reefs and islands (Harasti and Malcolm, 2013). Other studies on rock pool fishes in NSW recorded only a small number of *E. daemelii* (Griffiths, 2003a,b; Griffiths et al., 2006) or none at all (Silberschneider and Booth, 2001), although their survey methods differed from those used in the present study.

The low relative abundance of juvenile *E. daemelii* recorded in this study corresponds with an existing perception of low abundance of adult *E. daemelii* in NSW (Harasti and Malcolm, 2013). This perception is based on comparisons of historical anecdotal fishing and diving reports with recent relative abundance estimates. Although protected since 1983, an apparent slow recovery of *E. daemelii* may be a result of combined life history traits of slow growth, late maturity and longevity (Francis and Lyon, 2012), as well as low recruitment levels. This is consistent with many other studies on related *Epinephelus* sp. that indicate a host of life history traits for Epinephelids that make them more vulnerable to overfishing and population decline (Coleman et al., 1999; Sadovy and Eklund, 1999; Sadovy de Mitcheson et al., 2012). The current low relative abundance of adult *E. daemelii* may be contributing to low levels of recruitment into intertidal habitats along the NSW coast and vice versa in relation to population recovery.

This study found that juvenile *E. daemelii* were primarily found to occur from Port Stephens to Bendalong, with only one individual (3 cm recruit) observed north of Port Stephens. This indicates that the central to south coast of NSW is an important area for their recruitment into intertidal habitats and may relate to the transport influence of the East Australian Current (EAC). Northern NSW is the most important region for adult *E. daemelii* in Australia (Harasti and Malcolm, 2013), but no juveniles were recorded in the intertidal habitats in the northern region, although a few have been recorded in estuarine rocky reef habitats near Coffs Harbour and Brooms Head (H. Malcolm, unpubl. data and H. Folpp, pers. comm.). We hypothesise that adult *E. daemelii* spawn in the northern waters of NSW, where adult numbers are highest (Harasti and Malcolm, 2013). Larvae are then most-likely advected southwards in the EAC. The EAC can transport larvae into the waters of central to southern NSW as described by Roughan et al. (2011), and similar to that shown to occur for tropical species (Booth et al., 2007; Feary et al., 2013). Once *E. daemelii* larvae approach the coast they may swim on their own accord and/or be driven by swell, wind and current into intertidal habitats (Leis et al., 2011).

This study found several juvenile *E. daemelii* displaying strong site fidelity, with two fish found in their original sites 471 days after their initial detection. Both of these fish were found utilising the same sort of habitat, as they were each living under a singular large boulder in each rock pool. Both of these fish had the opportunity to leave their individual rock pools and boulders during this study, as the pools were open to the sea on a high tide, however, they remained. In a study on site fidelity of rock pool fishes, White and Brown (2013) found that rock pool fishes display long-term site fidelity to individual rock pools, especially those species considered to be resident rock pool species such as *Bathygobius cocosensis* and *Enneapterygius atrogulare*. *Epinephelus daemelii* is not considered to be a resident rock pool species, as sub-adult and adult fish are found inhabiting coastal rock reefs and offshore islands (Harasti and Malcolm, 2013). However, this study indicates that in their early life stage they may spend up to 2 years, and potentially longer in the intertidal habitat, but appear to leave before reaching ~30 cm. Fish >30 cm were not observed in rock pools whilst fish of 30–50 cm in size have been observed on inshore subtidal rocky reefs (Harasti and Malcolm, 2013). Ontogenetic variation in habitat use has been recorded in various fish species (Light and Jones, 1997; Boaden and Kingsford, 2013), including a few *Epinephelus* sp. (Dahlgren and Eggleston, 2001; La Mesa et al., 2002; Machado et al., 2003).

There were differences in the micro-habitat utilised by *E. daemelii* within these shallow protected rock pools and intertidal habitats. All individuals were detected in boulder and overhang habitats and none amongst algal-dominated habitats. Juvenile *E. daemelii* are thought to occur exclusively in rocky habitats. Although seagrasses have been found to be an important habitat for other juvenile fish species in NSW (Middleton et al., 1984), extensive seine netting surveys (by NSW DPI) of seagrass, algal and sand-flat habitats in estuaries throughout NSW have not detected *E. daemelii* (DPI, unpubl. data). While an algal habitat can provide cover and protection from bird predation and may reduce fish predation, the physical protection provided by structurally complex rock habitat may further minimise the risk of predation from larger fishes and physical injury from wave action (Beukers and Jones, 1998; Fulton and Bellwood, 2004).

The rock platforms and associated rock pool habitats where *E. daemelii* were detected are susceptible to extreme daily fluctuations in environmental conditions (i.e. water temperature and dissolved oxygen) due to influences of weather such as prolonged exposure to the sun, high-energy wave action or freshwater run-off. Although juvenile *E. daemelii* are temporary residents in rock pools, this study found that they show eurythermic tendencies (tolerance to a range of salinities) and adaption to survive in oxygen-poor water in their early life history, similar to that found for other species in rock pools (Rummer et al., 2009).

The mini-BRUVs were a successful sampling method to assess the occurrence of juvenile *E. daemelii*, and were more effective than visual surveys or trap capture. These systems are small and lightweight, making them easy for transport to survey sites, especially to locations that are remote and/or difficult to access. The time to the first appearance of *E. daemelii* averaged 12 min, therefore deployment of baited cameras for 30 min is sufficient to detect their presence/absence. However, implementation of a tagging study on juvenile *E. daemelii*, combined with repeat sampling using mini-BRUVs, would allow a greater understanding of their site fidelity and growth.

This study has confirmed that intertidal habitats are settled by juvenile *E. daemelii* and demonstrated a strong latitudinal gradient in their occurrence. Overall, their numbers were very low. Further work is required on adjacent sub-tidal habitats, including estuarine rocky reefs, using these methods.

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Author's address: David Harasti, NSW Department of Primary Industries, Fisheries Research, Marine Ecosystems, Locked Bag 800, Nelson Bay, NSW 2315, Australia.
E-mail: david.harasti@dpi.nsw.gov.au