A SURVEY OF THE WESTERN BLUE GROPER IN WESTERN SOUTH AUSTRALIA

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Adult male and female blue groper Photo: Thierry Laperousaz

Juvenile blue groper Photo: David Muirhead

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SUMMARY
The abundance of western blue groper (WBG), *Achoerodus gouldii*, was examined on near-shore rocky coasts of western Eyre Peninsula. Densities of juveniles (< 20 cm), sub-adults (20-60 cm) and adults (>60 cm) were obtained at nine sites in different conditions of depth, exposure to swell, and rocky bottom relief. In all 928 WBG were seen on 137 transects each of 500 m^2. Sub-adult densities were in the range 2-9 per 500 m^2, about twice the densities of those on southern Yorke Peninsula. Juveniles were largely restricted to shallow, sheltered waters to depths of about 1 m adjacent to exposed coasts, sub-adults were common in adjacent waters to greater depths, and adults only on exposed coasts where depths exceeded about 10 m. Overlap occurred between juvenile and sub-adult habitat, and sub-adult and adult habitat. Habitat correlates of juvenile abundance included depth, rocky bottom relief and exposure to swell. We inferred from size-frequency data that in general juveniles moved into deeper water with increasing size, while sub-adults ranged extensively from juvenile to adult habitat.

INTRODUCTION
This is the third in a series of reports on the distribution and abundance of the western blue groper (WBG), *Achoerodus gouldii*, on the coasts of South Australia. Earlier reports (Shepherd *et al.* 2002, Shepherd & Brook 2003a) described the biology and ecology of the species, and gave abundance data for Kangaroo I. and southern Yorke Peninsula. The second report (Shepherd & Brook 2003a) suggested that WBG recruited into shallow water adjacent to more exposed, deeper habitat. This study set out to examine that hypothesis in western South Australia by obtaining abundance data from sheltered to exposed habitats along depth gradients at nine sites. We plan to extend the study to southern Eyre Peninsula. Ancillary data collected on the abundance of other reef fishes will be presented elsewhere.

METHODS
After initial surveys were carried out by one of us (SAS) on 28-30 January 2003 from Pt Sinclair to Waterloo Bay, the authors, with a team of Reef Watch divers, surveyed the region in greater detail on 1-6 December 2003 at the sites shown in Fig. 1. The visual census technique along strip transects was used to estimate the relative abundance and size of fishes seen.
At each site the area to be surveyed was apportioned beforehand among divers to achieve maximum coverage, the number of replicate transects per site depending on the number of divers available. All divers were experienced in recognition of fish species, and most in estimating length. Those inexperienced in the latter received

training on the first day, and their data used when we were satisfied as to their accuracy.
Divers swam along 100 m transects at a constant depth recording the species of fish and the length of every individual seen within a swathe 5 m wide. The data were recorded on waterproof data sheets fixed to underwater slates (see earlier reports for greater details of method). Characteristics of the substratum were noted in terms of composition, relief, and dominant canopy algal species. As in the previous studies, the dominant algae were used in a subjective assessment of the exposure index (EI), which ranged from 0 (extreme shelter) to 4 (fully exposed to swell) (see Table 1). Dominant species used in this EI assessment (after Shepherd & Womersley 1981) were: *Acrocarpia, Scytothalia* (EI=4); *Cystophora moniliformis, C. siliquosa, Ecklonia, C. racemosa* (EI=3); *C. siliquosa, C. brownii* (EI=2); *C. subfarcinata, C. monilifera* (EI=1); *Scaberia, Sargassum* spp. (EI=0). In Waterloo Bay earlier studies (Shepherd & Womersley 1981) had mapped EI values around the Bay, and these data were used to estimate an EI value for each transect.
Density data for WBG are presented in three length classes: juveniles <20 cm, sub-adults 20-60 cm, and adults >60 cm (after Gillanders 1997). In all, nine sites were examined, cumulatively covering a range of habitats from sheltered to exposed, from low (<0.5 m) to high (>2 m) relief.

RESULTS

Site descriptions

The west coast of South Australia is exposed to strong SW swell, but the indented coast, barrier reefs and embayments provide shores with a range of exposures from severe to sheltered. Two exposed sites (Sites 3,4) had a Precambrian crystalline bedrock (here termed granite), and the remaining sites a calcarenite mantle, compressed and eroded to form a friable, coarsely grained rock (Edyvane 1999). The calcarenite extended from the intertidal into the subtidal with low to high relief. The following sites were examined.
(**Site 1**) At Point Sinclair transects ran over calcarenite reef from a sheltered point inside the bay (depth 1-2 m) around the point to fully exposed conditions at 2-5 m depth.
(**Site 2**) At Cape Bauer transects were done on both sides of a small calcarenite headland on the northern, more sheltered side of the Cape.
(**Site 3a,b**) The Granites lagoon (3a) is a 350 m section of coast NE of Granite Rock, protected from swell by a low barrier granitic reef some 20-40 m offshore, partly enclosing a lagoon 1-3 m deep, with several small openings to the open sea throughout its length as well as at the eastern end. The substratum is smooth granite blocks and boulders, with rocky/sandy bottom to 3 m deep. Site 3b was outside the lagoon in more exposed conditions
(**Site 4**) Smoothpool is a lagoon, completely separated from the open sea at low tide by a low (<0.5 m above low water) granitic reef some 5-10 m wide, such that at high tide the lagoon is inundated. The lagoon is about 250 m × 20-40 m, mostly 1 - 2 m deep, with granite boulders or blocks, and some patches of bare sand and seagrass (*Posidonia* spp).
(**Site 5**) On the northern shore of the Westall Peninsula the calcarenite mantle has been eroded to form broad granitic shore platforms falling away steeply to depths of 10 + m where rock meets sand. Transects were done from the extremity of Point Westall, with transects at 5, 10 and 15 m, to the sheltered eastern end of the Peninsula at a constant depth of 1-5 m. The substratum of the most easterly transect at 700 m

distance was calcarenite, while all other transects were over granitic boulders and blocks at the eastern end, grading to large blocks with increasing exposure toward the Point.

(**Site 6**) Speeds Point, and a barrier reef extending from it, projects into northern Sceale Bay, partly enclosing a small unnamed bay on its northern side, commonly known as Speeds. The substratum of Speeds is mostly calcarenite of low to high relief, with some seagrass patches. Transects were run from the barrier reef for about 400 m eastwards into the bay to cover an area of about 400 m × 200 m.

(**Site 7a,b**) South Head (7a), at the entrance to Venus Bay with calcarenite substratum was surveyed, and transects continued within the Bay along the shore from the Head toward the jetty for 400 m (7b).

(**Site 8**) The southern end of Anxious Bay has patchy calcarenite rock of low to high relief among extensive *Posidonia* and *Amphibolis* beds. Transects were run along approximate depth contours from the shallow margins of the bay to a depth of 3-5 m.

(**Site 9**) Waterloo Bay with similar substratum was surveyed around the margins from Pt Wellington on the south side to Pt Wellesley on the north side to a depth of 3-4 m, and also behind fringing reef at Salmon Point outside Pt Wellesley. The substratum was mainly of about 0.5-1 m relief, increasing to 2 m near the bar at the Bay's entrance.

The sites examined, the substratum, estimated exposure index and dominant canopy species are summarised in Table 1. Algal cover at all sites was high, usually 90-100%, except in Venus Bay (Site 7b) where it was mostly <5%.

Abundance and size of WBG

The mean densities of juveniles, sub-adults and adults at all sites are given in Table 2, with data on the number of transects per site. A length-frequency distribution (N = 928) of WBG for all sites combined is shown in Figure 2.

The highest densities were at Sites 3a, 4, and 6, all in sheltered or semi-enclosed waters adjacent to exposed coasts, with lower densities at more open sites, and zero densities in embayments without exposure to swell such as Venus Bay. At a geographic scale substratum type seemed unimportant, as high (and low) densities occurred on both calcarenite and granite.

The smallest size classes (5-10 and 10-15 cm) were recorded mainly in lagoonal situations or very shallow inshore reefs, dissected with grooves, galleries and tunnels as on calcarenite substratum or in shallow, sheltered, granitic boulder habitats. Adults were only found in habitats adjacent to deep water (> 10 m).

We examined by linear regression the relation between overall juvenile (J_d) and sub-adult (S_{ad}) densities for the nine sites and derived the equation:

$$S_{ad} = 1.89 + 1.10\, J_d \quad (R^2 = 0.73; P<0.01)$$

To determine the influence of habitat variables on juvenile and sub-adult WBG abundance, we examined the relation between depth, exposure and rocky bottom relief, and WBG density for those sites with adequate data.

At Point Sinclair (Site 1) juveniles were seen only within the bay at 1-1.5 m depth in sheltered habitats, and sub-adults only further offshore in deeper (2-5 m) and more exposed habitat (Table 2). Mean size of juveniles were 18.0 (s.e.0) cm, and of sub-adults 25.5 (s.e. 0.8) cm.

At Cape Bauer (Site 2) the same pattern was observed, and the results are summarised in Table 3. Juveniles (mean size 15.5 (s.e. 0.6) cm) were found only on the inshore

Table 1. Habitat features of survey sites on western Eyre Peninsula. Estimated range of exposure indices given is from: 4 – fully exposed to SW swell; 3 – moderately exposed to swell; 2 – moderately sheltered; 1 - very sheltered; 0 - extreme shelter. Substratum complexity (SC) is: 0 – flat rock, usually covered with sediment, holes or crevices rare; 1 - rock to 1 m relief with some crevices; 2 - reef of moderate relief (1-2 m) with numerous crevices; 3 – reef of high relief (>2m) with many crevices and caves.

Site No.	Site (Lat. Long.)	EI	Substratum	Algal dominants
1	**Point Sinclair** 32° 6′ 30″ S; 132° 59′ E.	1-4	Calcarenite. SC=1	*Scaberia, Cystophora* spp. *Ecklonia*
2	**Cape Bauer** 32° 41′ 47″ S; 134° 4′ 32″ E.	1-2	Calcarenite SC=1	*Ecklonia, Cystophora, Scaberia*
3a	**Granites lagoon** 32° 52′ 54″ S; 134° 5′ 34″ E.	1	Granitic SC=0-1	*Ecklonia, Cystophora, Scaberia*
3b	**Granites-(outside lagoon)**	2	Granitic SC=0-1	*Ecklonia, Cystophora*
4	**Smoothpool** 32° 55′ 35″ S; 134° 4′ 40″ E	1	Granitic SC=1	*Ecklonia, Cystophora monilifera, Scaberia*
5	**Point Westall** 32° 54′ 30″ S; 134° 3′ 38″ E	2-4	Granitic SC=1	*Ecklonia, Cystophora, Scytothalia*
6	**Speeds** 32° 56′ S; 134° 7′ E	1-3	Calcarenite SC=1-3	*Cystophora, Scaberia*
7a	**South Head (VB)** 33° 13′ 56″ S; 134° 39′ 24″ E	3	Calcarenite SC=1	*Ecklonia, Cystophora*
7b	**Venus Bay** 33° 13′ 58″ S; 134° 39′ 32″ E	0	Calcarenite SC=0	Gradation of *Ecklonia, Cystophora* spp. to *Scaberia*
8	**Anxious Bay** 33° 37′ 3″ S; 134° 50′ 28″ E	1-3	Calcarenite SC=1-3	*Cystophora*
9	**Waterloo Bay** 33° 39′ 22″ S; 134° 53′ 1″ E	0-3	Calcarenite SC=1-3	*Ecklonia, Cystophora, Scaberia*

transects (depth 1-1.5 m), but sub-adults were found at all depths, with no significant trend with depth. Mean size of sub-adults increased with depth, but the increase was not significant.

At The Granites both the abundance of juveniles and sub-adults declined with depth in the lagoon (Site 3a), but outside the lagoon on exposed reef (Site 3b) juveniles were absent and sub-adult abundance was very low (Table 4). The decline in abundance of juveniles, but not of sub-adults, with increasing depth in the lagoon was significant. The regression equation of juvenile density (J_d) vs depth (D) is:

$$J_d = 5.78 - 2.17D \qquad (R^2 = 0.42: P<0.01)$$

The variation in mean size of sub-adults (Table 4) was not significant.

Table 2. Density (numbers.500 m^{-2}) of juvenile (<20 cm), sub-adult (20-60 cm), and adult WBG at 9 sites on Eyre Peninsula. N = number of replicate 500 m^2 samples. Standard errors (s.e.) in brackets.

Site	N	Juveniles (s.e.)	Sub-adults (s.e.)	Adults (s.e.)	Total
1. Point Sinclair	3	1.3 (1.1)	2.7 (1.2)	0	2.7 (1.2)
2. Cape Bauer	10	1.9 (1.1)	2.5 (0.9)	0	4.4 (1.3)
3a. Granites lagoon	15	2.5 (0.7)	6.1 (1.1)	0	8.6 (1.2)
3b. Granites –outer	4	0.5 (0.3)	0.5 (0.3)	0	1.0 (0.4)
4. Smoothpool	10	5.0 (1.3)	8.2 (1.6)	0	13.2 (2.5)
5. Point Westall	18	1.3 (0.6)	4.9 (1.0)	0.4 (0.3)	6.7 (1.5)
6. Speeds	19	6.4 (0.8)	8.8 (1.7)	0.2 (0.1)	15.4 (2.1)
7a South Head (VB)	3	0.3 (0.3)	3.3 (2.7)	0	3.7 (2.6)
7b Venus Bay	9	0	0	0	0
8. Anxious Bay	16	2.1 (0.8)	3.7 (1.2)	0	5.8 (1.6)
9. Waterloo Bay	27	2.0 (0.8)	2.0 (0.5)	0	4.0 (1.0)

Table 3. Density (numbers.500 m^{-2}) of juvenile and sub-adult WBG and mean size (cm) of sub-adults at Cape Bauer.
N = number of transects. Standard errors in brackets.

Depth (m)	N	Juveniles (s.e.)	Sub-adults (s.e.)	Sub-adult size (s.e.)
1-2	3	6.3 (2.1)	3.3 (2.3)	26.0 (0.7)
2-5	7	0	2.1 (0.7)	27.9 (1.4)

Table 4. Density (numbers.500 m^{-2}) of juvenile and sub-adult WBG and sub-adult mean sizes (cm) at The Granites at different depth intervals. N = number of transects. Standard errors in brackets.

Site	Depth (m)	N	Juveniles (s.e.)	Sub-adults (s.e.)	Sub-adult size (s.e.)
Lagoon	0.5-1	5	4.6 (1.2)	8.2 (2.2)	27.0 (0.6)
Lagoon	1-2	5	2.8 (0.7)	5.8 (1.8)	26.1 (0.9)
Lagoon	2-3	5	0	4.2 (1.0)	26.8 (1.0)
Exposed reef	1-3	4	0	0.5 (0.4)	22.5 (0)

Smoothpool (Site 4) was too small and depth too variable to enable trends in abundance or size to be examined either with depth or relief. Mean length of juveniles was 16.0 (s.e. 0.3) cm and of sub-adults 24.8 (s.e. 0.6).
At Pt Westall (Site 5) a plot of linear trends in abundance alongshore from exposed to sheltered conditions (Fig. 3a) shows that juveniles were present only in the area 300-

500 m from Pt Westall, whereas sub-adult abundances peaked offshore as well as at 300-500 m from the Point. Two adults (each >1.2 m) were in deeper water offshore from Pt Westall, and other smaller ones (70-90 cm) at 400-500 m from the Point. The mean size of sub-adults also decreased with increasing distance from Pt Westall (Fig. 3b), i.e. from 35 cm at the Point to 26.2 cm at 500 m distance. The decrease was significant ($r = -0.85$; $P<0.05$). No WBG were seen at the most distant transect at 700 m distance from the Point.

At Speeds (Site 6) the abundance of juvenile WBG declined both with depth and with increasing relief, while the abundance of sub-adults increased with depth and with increasing relief (Fig.4a). The parameters depth and relief were highly correlated with each other($r=0.89$; $P<0.001$). As the correlations with depth were stronger than with relief, here we simply present curvilinear curves of best fit. The equations relating density of juveniles (J_d) and sub-adults (S_{ad}) to depth (D) are:

$$J_d = 8.54 - 0.44\,D^2 \quad (R^2 = 0.38;\ P<0.01)$$

$$S_{ad} = 8.11 + 5.01 \ln D \quad (R^2 = 0.45;\ P<0.01)$$

Mean size of juveniles and sub-adults also increased with depth (Fig. 4b). This was tested by examining the proportional frequency of size classes in three depth intervals. The increase in frequency of larger size classes with increasing depth was significant ($\chi^2 = 88.2$; $P<0.001$).

At Venus Bay (Site 7) WBG were only recorded at South Head (sub-adult mean size 30.5 (s.e. 1.4) cm), and none in transects along the southern coast from the Heads toward the jetty where the substratum was a calcarenite platform, virtually without relief. However, some sub-adults were observed swimming under the jetty.

In Anxious Bay (Site 8) abundances of juveniles and sub-adults were very variable. On some transects seagrass cover was high (30-60%) and exposed calcarenite substratum often had little or no relief and few fish were seen. Juveniles were mainly found among patches of calcarenite with some relief. Although abundances of juveniles declined with depth, and abundance of sub-adults increased with depth (Table 5), neither trend was significant. However, abundances of sub-adults (S_{ad}), but not of juveniles, increased significantly with increasing rocky bottom relief (R), and the equation best describing the curvilinear relation is:

$$S_{ad} = 6.57 + 3.85 \ln R \quad (R^2 = 0.49;\ P<0.01)$$

The mean length of juveniles and sub-adults at this site showed no significant trend with depth. Rocky bottom relief also increased with depth, and the most sub-adults were found on deeper reefs of high relief.

Table 5. Density (numbers.500 m^{-2}) and mean length (cm) of juvenile and sub-adult WBG and rocky bottom relief in Anxious Bay at three depth intervals. N = number of transects. Standard errors in brackets.

Depth (m)	Relief (m)	N	Juveniles (s.e.)	Sub-adults (s.e.)	Juv. length (s.e.)	Sub-adult length (s.e.)
0.5 - 1.5	< 0.5 (-1)	5	3.8 (1.9)	0.2 (0.2)	13.8 (0.8)	22.5 (0)
1.5 - 2.5	0 – 1	6	1.8 (1.2)	4.7 (2.5)	16.1 (0.7)	29.1 (1.1)
4 – 6	2 – 2.5	5	0.8 (0.5)	6.8 (0.8)	15.0 (1.3)	30.1 (1.1)

In Waterloo Bay (Site 9) densities of both juveniles and sub-adults declined with depth (Table 6). The decline of juvenile density (J_d) with depth (D) was significant, and a curvilinear regression was fitted to the data. The regression equation of best fit is:

$$J_d = 6.38 - 6.52 \ln D \qquad (R^2 = 0.45; P<0.001)$$

Larger size classes of juveniles and sub-adults were proportionally more abundant with increasing depth, a significant shift ($\chi^2 = 42.6$; P<0.001), as shown by the change in mean sizes with depth (Table 6). Although rocky bottom relief tended to increase with depth (Table 6) there was no correlation between juvenile or sub-adult density and relief.

Table 6. Density (numbers.500 m^{-2}) and mean size (cm) of juvenile and sub-adult WBG, and rocky bottom relief in Waterloo Bay at three depth intervals. N = number of transects. Standard errors in brackets.

Depth (m)	Relief (m)	N	Juveniles (s.e.)	Sub-adults (s.e.)	Juv. Length (s.e.)	Sub-adult length (s.e.)
0.5-1	0.5	6	7.5 (2.3)	3.0 (1.3)	14.4 (0.5)	24.2 (0.8)
1.5-2.5	0.5-1.5	12	0.67 (0.37)	1.8 (0.5)	16.4 (0.7)	26.7 (0.9)
3-4	1-2	9	0.22 (0.14)	1.7 (0.4)	15.8 (1.4)	27.8 (0.9)

DISCUSSION

Overall, the abundance of WBG was greater in this survey than in the survey of southern Yorke Peninsula (Shepherd and Brook 2003a). This was due to the greater numbers of sub-adults, but not of juveniles, whose densities were similar in both regions. Highest numbers of juveniles were recorded in lagoons or sheltered waters, and lower numbers on more open coasts. Other studies (Shepherd in prep.) show that the detectability of juveniles is very low (about 0.3 at one site, due to the fact that they retreated into shelter for 70% of the daytime). Hence, juvenile densities, recorded in broad scale surveys such as this, are unlikely to be a reliable index of recruitment due to the cryptic behaviour of small WBG. Shepherd and Brook (2003a) suggested that the significant correlation between juvenile and sub-adult densities between sites was due to gradual movement by juveniles into adjacent deeper water with increasing size. The same relationship found in this study supports that suggestion. However, in this study the slope of the regression of sub-adult vs juvenile densities (1.10) was more than twice that of the equivalent regression for southern Yorke Peninsula (0.53). This may be due to differences in survival or differences in detectability of juveniles between regions. Whatever the explanation, the abundance of sub-adult WBG may provide a better index of recruitment than abundance of juveniles. A greater abundance of WBG on western Eyre Peninsula than on Yorke Peninsula is not surprising, given that the latter region is closer to the eastern geographic limits of the species.

A consideration of the coastal topography of sites gives clues as to factors, which may influence juvenile and sub-adult abundance. Lagoons on exposed coasts or partly enclosed bays, sometimes with lagoons, such as Smoothpool, Speeds, Anxious Bay and Waterloo Bay with likely high retention of settling larvae, have relatively high juvenile abundances, whereas open sites (Pt Sinclair, Pt Westall and South Head) with little capacity to retain larvae, have much lower abundances.

The habitat correlations with juvenile or sub-adult abundance recorded in this study, i.e. depth at five sites, relief at two sites, and exposure at one site, allow us to better characterise the habitat of these smaller sizes classes of WBG. Shallow and sheltered rocky areas, especially lagoonal situations on high energy coasts seem to be consistently the most important requirement for juveniles. We exclude shallow (or any) seagrasses as juvenile WBG habitat, because they are consistently avoided.

Rocky habitat provides shelter for fishes and is obviously necessary for small WBG, but characterisation of its critical features (e.g. crevice type, size and abundance) is virtually impossible to measure satisfactorily. Relief is a simple measure that captures only one aspect of substratum complexity, but even this measure is difficult to apply because it may vary within a transect (as at Cape Bauer), or may covary with depth making its individual effect difficult to determine. Similarly exposure to swell is difficult to measure, although a gradient may be easily recognised in the field, as at Pt Sinclair and Pt Westall. Here, the longshore trends in abundance, in the absence of other major habitat differences, are best explained in terms of exposure to swell.
The trends in mean sizes of juveniles and sub-adults with depth enable us to infer their respective movement patterns. The absence of any trend in mean size between depths suggests complete mixing (e.g. Smoothpool and The Granites), whereas size changes with depth suggest habitat shifts with increasing size (e.g. Pt Sinclair, Cape Bauer, Pt Westall, Speeds, Anxious Bay and Waterloo Bay). Hence we can conclude that in general with increasing size, sub-adults move to deeper water and/or toward more exposed sites. Shepherd and Brook (2003b) recorded sub-adult WBG at all exposures around the St Francis Isles to 20 m, suggesting that our sampling in this study has only touched the shallow margin of sub-adult sub-tidal habitat.

ACKNOWLEDGEMENTS

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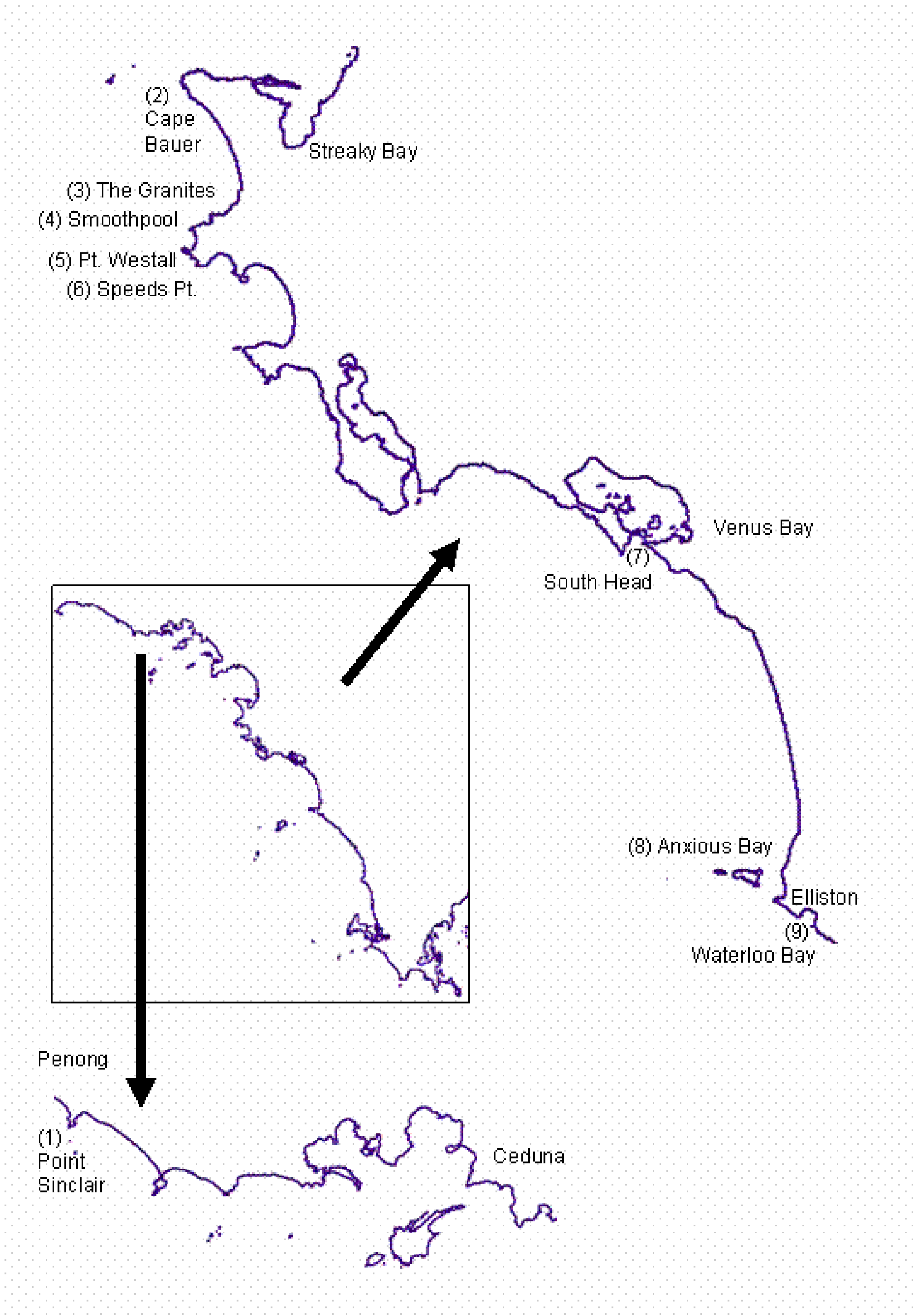

Fig. 1. Map of upper western Eyre Peninsula showing study sites.

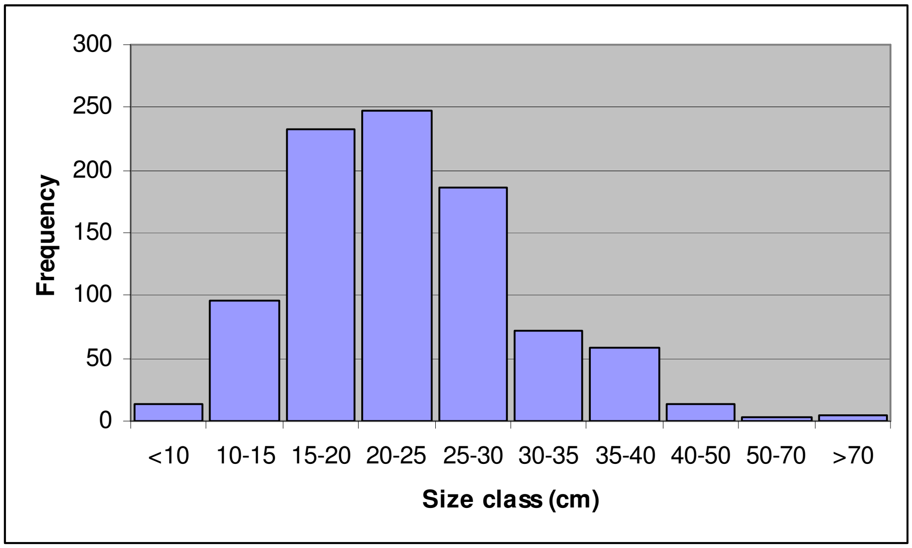

Fig. 2. Length frequency distribution (in 5 cm size groups to 40 cm then 10 cm size groups) of western blue groper for all sites combined.

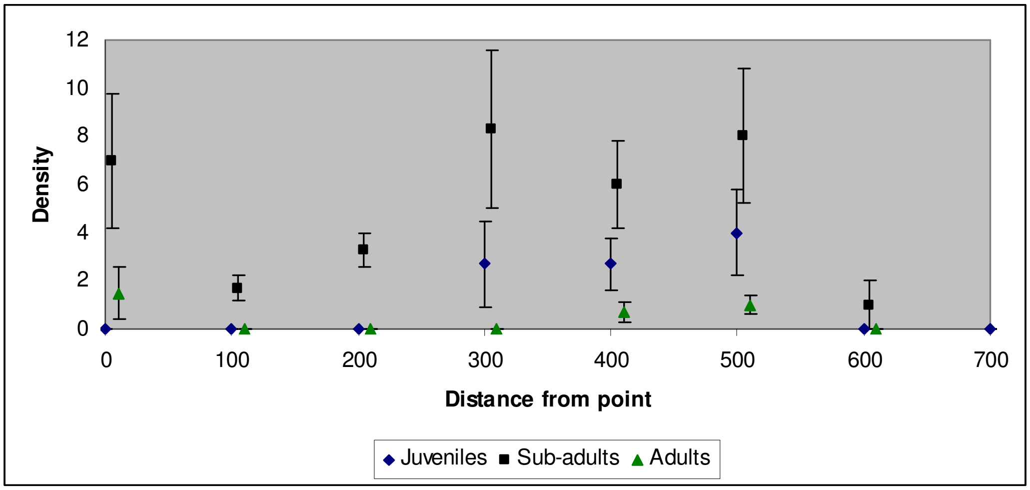

Fig. 3. (a) Scatter plot of abundance of juvenile, sub-adult and adult western blue groper (numbers.500 m^{-2}) vs distance (m) from Pt Westall along the northern shore of the Peninsula. The first data point (zero distance) was taken at 10-15 m depth, and the remaining data, grouped in 100 m intervals, at 3-5 m depth. The most distant point (700 m) was over a calcarenite substratum where no WBG were recorded.

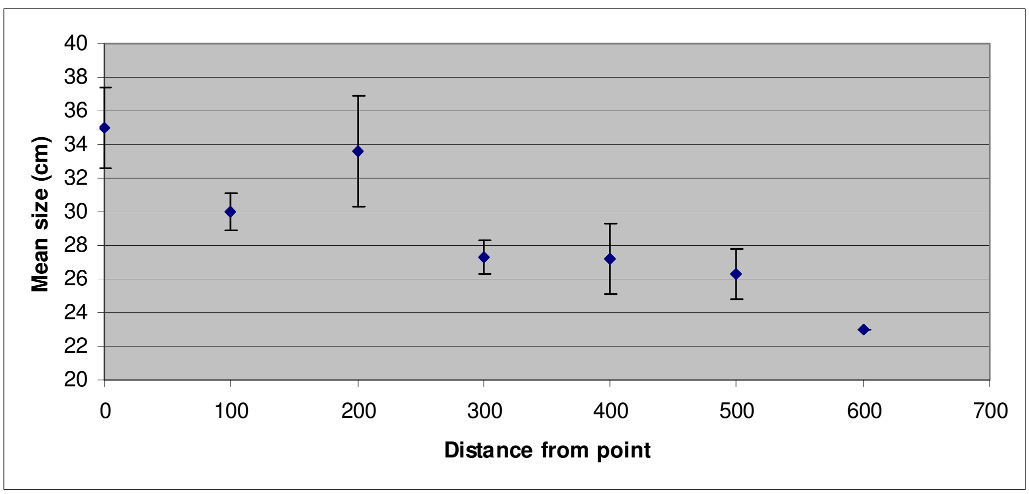

Fig. 3 (b) Plot of mean size of sub-adult WBG vs Distance from Pt Westall (m).

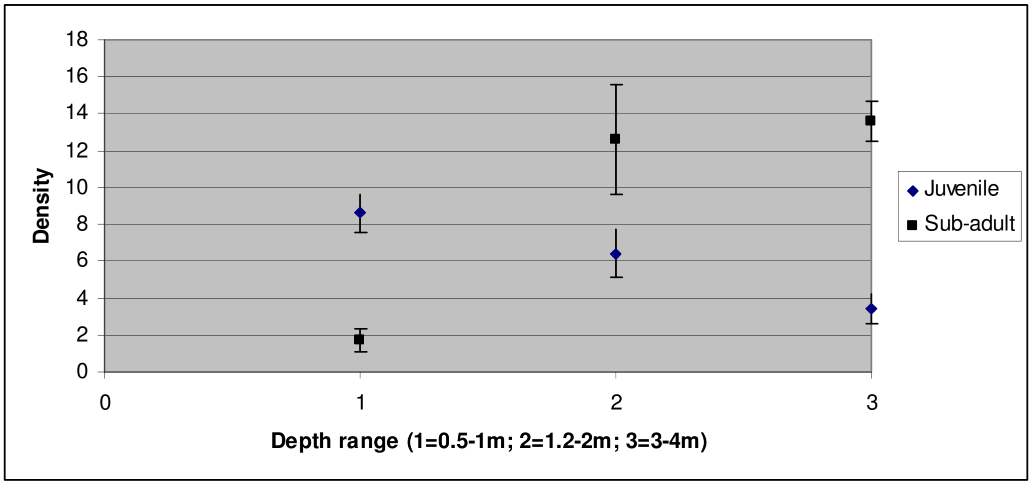

Fig. 4. (a) Density (numbers.500 m^{-2}) of juvenile and sub-adult WBG vs depth at Speeds. Bars are standard errors.

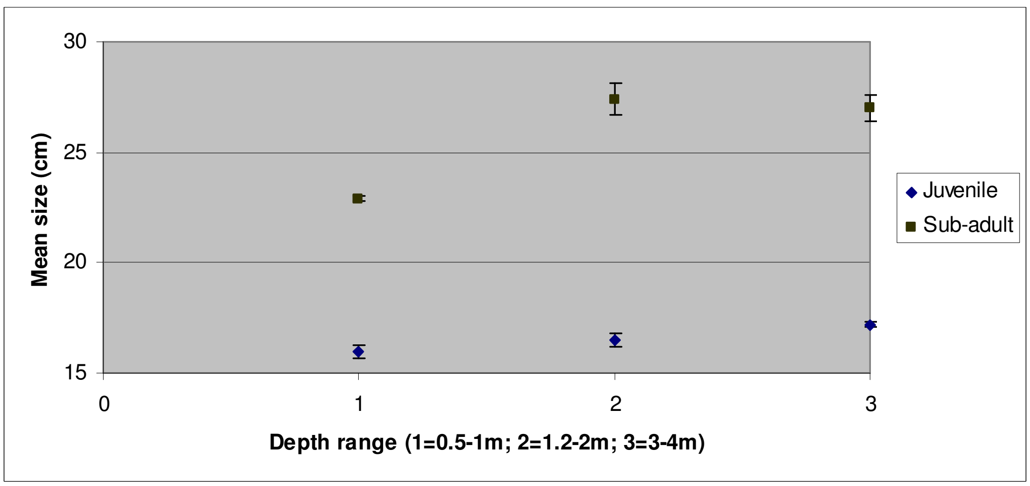

Fig. 4 (b) Plot of mean size of juvenile and sub-adult WBG vs Depth at Speeds. Bars are standard errors.