AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS

Aquatic Conserv: Mar. Freshw. Ecosyst. **25**: 174–186 (2015)

Published online 6 February 2014 in Wiley Online Library
(wileyonlinelibrary.com). DOI: 10.1002/aqc.2431

Size isn't everything: movements, home range, and habitat preferences of eastern blue gropers (Achoerodus viridis) *demonstrate the efficacy of a small marine reserve*

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ABSTRACT

1. Marine protected areas (MPAs) are important conservation tools, however, efficacy can, in part, be a function of their size in relation to the home range of the target species.

2. The eastern blue groper, *Achoerodus viridis*, is a long-lived, protogynous hermaphrodite, and an 'iconic' marine species in eastern Australia, with several MPAs having been established specifically for their protection.

3. Site fidelity, habitat use, and home range size were assessed for 29 adult eastern blue gropers monitored for up to 374 days using passive acoustic telemetry within and around a small marine reserve.

4. The fish exhibited long residency times and no movement was recorded between adjacent reefs, suggesting sand acts as a natural barrier to movement.

5. Core ranges were calculated using 50% kernel utilization distributions (KUD) and estimated between 0.005 and 0.092 km^2. Males had larger core ranges than females or fish of indeterminate sex. There was no statistical difference between the breeding/non-breeding seasons.

6. Home ranges were calculated using 95% KUD and ranged between 0.03 and 0.54 km^2. Home range size was largest for males and significantly larger for all sexes in the breeding season. Fish tagged in the 'no-take' area of the MPA had smaller home ranges than fish tagged in the area where fishing is permitted.

7. This study indicates that even relatively small MPAs can provide effective protection for adult eastern blue groper, supporting the proposition that large reef dwellers with long residency times can be used as flagship species to gain public support for the designation of MPAs.

Received 29 March 2013; Revised 15 October 2013; Accepted 17 November 2013

KEY WORDS: passive acoustic telemetry; site fidelity; kernel utilization distributions; marine reserve design; Labridae; no-take marine reserve; core range; coastal; fish; tracking

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INTRODUCTION

Although the aims and likely efficacy of marine protected areas (MPAs) are often debated (Lester *et al*., 2009; Fenberg *et al*., 2012; Kearney *et al*., 2012, 2013), MPAs are an important mechanism by which to conserve marine biodiversity and their establishment has for the most part been encouraged globally (Kelleher, 1999; Lester *et al*., 2009). With an increasing need for effective marine conservation, there is now a wealth of research focusing on the design (Botsford *et al*., 2003; Hastings and Botsford, 2003), implementation (Roberts and Hawkins, 2000; Wielgus *et al*., 2008), and efficacy of MPAs for commercially exploited and threatened species (Egli and Babcock, 2004; Edgar *et al*., 2008). Many countries around the world have been declaring representative networks of MPAs (Gladstone *et al*., 2003; Wells *et al*., 2007) to meet commitments made under the 2002 World Summit on Sustainable Development to effectively protect 20–30% of each marine habitat by 2012 (IUCN, 2003). Australia has the third largest marine jurisdiction in the world and implemented a plan for a National Representative System of MPAs (NRSMPA) in 1998 after signing up to the Convention on Biological Diversity (CBD) in 1993. Since 1998, a system of multi-scale MPAs has been established and in 2012 a further expansion of MPAs to cover a third of its marine environment was announced (Commonwealth of Australia, 2012). Many of the large MPAs were established offshore, while networks of small MPAs protect the coastal regions (Commonwealth of Australia, 2012) owing to stakeholder conflicts restricting the size of inshore reserves (Wescott, 2006; Agardy *et al*., 2011; Kearney *et al*., 2012).

Focal species, such as ‘charismatic megafauna’, have been used as flagship species to gain public support for MPAs, while ensuring the overall biodiversity objectives can still be met (Zacharias and Roff, 2001; Hooker and Gerber, 2004). If an MPA is to provide effective protection for a target species, knowledge of the species home range and movement is an essential component of effective MPA design (Kramer and Chapman, 1999; Moffitt *et al*., 2009).

Acoustic telemetry offers a simple, cost-effective way of determining the movements of multiple fish over a large temporal and/or spatial scale (Voegeli *et al*., 2001; Simpfendorfer and Heupel, 2004). Many of the studies focusing on the movement patterns of species relating to MPAs have used passive acoustic telemetry to assess home ranges and site fidelity (Afonso *et al*., 2011; Topping and Szedlmayer, 2011). Tracking data coupled with detailed habitat maps has aided in determining habitat use of specific species (Meyer and Holland, 2005; Bellquist *et al*., 2008; Mason and Lowe, 2010), which in turn aids the design of MPAs to ensure important habitats are included.

Eastern blue gropers (*Achoerodus viridis*) are found throughout south-eastern Australia, with the highest densities occurring in New South Wales (NSW; Gillanders, 1995b). They are long-lived, protogynous hermaphroditic labrids, with males living more than 35 years (Gillanders, 1995b) and growing to 1000 mm (Gillanders, 1997). They are considered an ‘iconic’ marine species, popular with divers and snorkellers, and are the state marine emblem for NSW. They are therefore ideal as a flagship species with which to gain public support for the conservation of specific areas (Zacharias and Roff, 2001). No research, however, has been done on the home ranges or site fidelity of adult eastern blue groper, nor on the efficacy of existing MPAs in protecting this particular species.

Bronte-Coogee Aquatic Reserve (BCAR) is a small MPA (0.43 km^2) in the Sydney metropolitan area. The reserve was initially implemented to provide protection for invertebrates, but community pressure resulted in part of the reserve being designated a ‘no-take’ area for the iconic eastern blue groper. It serves as an example of an MPA that was implemented with one purpose (conserve benthic diversity) and then re-designated for another purpose (protect a fish species). The current study aimed to determine site fidelity and home range of adult eastern blue groper to assess whether small MPAs such as BCAR can effectively protect this particular species. In addition, evaluations were made to determine whether there were differences in home range sizes between the sexes, breeding vs. non-breeding season, and between take and no-take areas of the reserve.

MATERIALS AND METHODS

Study site

This study was conducted in BCAR (33° 54’S, 151° 16’ E) a small MPA (0.43 km^2) with a no-take area for eastern blue gropers (area 0.16 km^2; Figure 1). It comprises areas of high and low relief rocky reef, consisting of typical habitats found along the NSW coast (e.g. urchin-grazed barrens, *Ecklonia* forest; Underwood *et al.*, 1991). These reef habitats slope onto a sandy bottom at 10–25 m depths. A habitat map of the study site and surrounding areas was produced from a multibeam swath by the Office of Environment and Heritage NSW (OEH NSW) following methods detailed in Jordan *et al.* (2010) providing the reef structure and depth contours of the whole area.

Acoustic tracking

Thirteen stationary underwater receivers (VR2W, Vemco Ltd, Nova Scotia, Canada) were placed both inside and outside the reserve (Figure 1). Range testing was conducted to determine the effective detection range of the receivers within the reserve using methods described in Heupel *et al.* (2006) and was estimated at a minimum 300 m radius in the worst oceanic conditions. The receivers outside the reserve were placed at major headlands along the coast, up to 8 km from the reserve to detect any long-range movement. In addition, the Australian Animal Tagging and Monitoring System (AATAMS, www.imos.org.au) maintains a line of 30 VR2W receivers perpendicular to the shore extending to the continental slope from Bondi, 1.8 km north of the study site (Figure 1). Receivers were deployed on bottom moorings 1.5 m above the seabed, away from any rocky outcrops that could block detections from acoustic shadowing. A sentinel tag was deployed in a stationary position within range of a single receiver (R5) to determine variation in acoustic detectability. The tag was deployed for 40 days during variable environmental conditions. Receivers were deployed

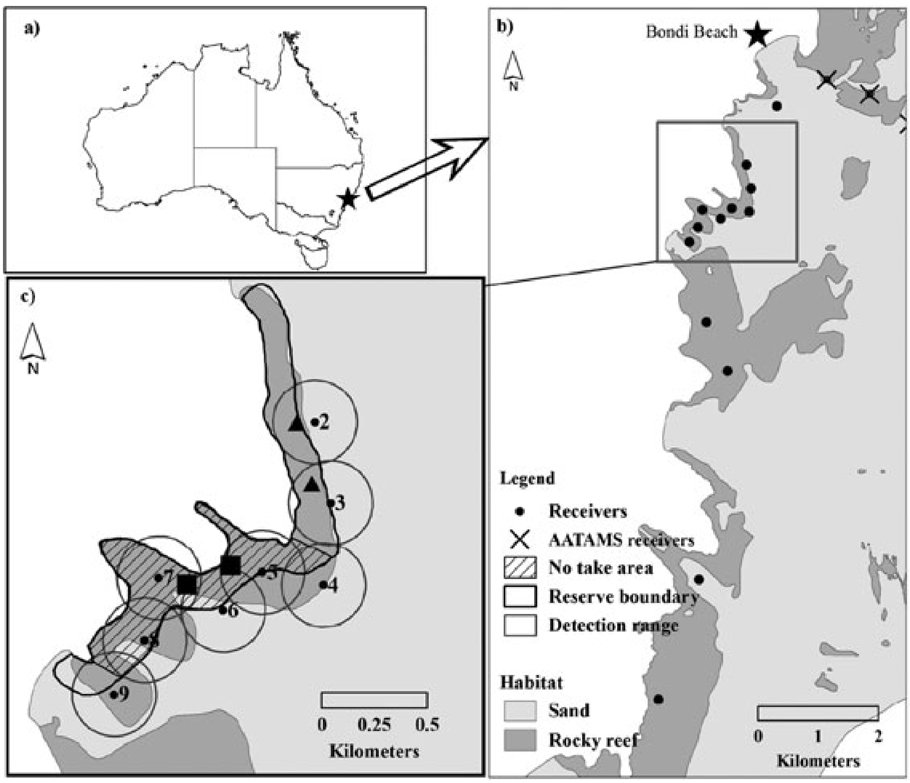

Figure 1. Habitat map of Bronte-Coogee Aquatic Reserve. (b) The whole of the array. (c) Close-up of BCAR. The thick line indicates the boundary of the reserve; the hashed area indicates the boundaries of the area prohibiting fishing for eastern blue groper; circles represent the 300 m detection range of each receiver; squares indicate tagging areas within no-fishing zone and triangles indicate tagging locations in area where fishing is permitted.

from June 2009 to December 2010. However, because of a number of faulty receivers, data analysis was restricted to between 3 July 2009 and 23 June 2010 when data from the full array were available.

Eastern blue gropers were caught using barbless baited hooks on monofilament line. Although sampling was conducted throughout the reserve, the fish tagged within the reserve (n = 22) were only caught at four locations (Figure 1); two within the 'no-take' area and two within the area of the reserve where blue groper fishing is permitted ('take' area). Fish were also caught and tagged at four locations outside the reserve (n = 7), on adjacent reefs. Once aboard the research vessel, fish were anaesthetized in a 200 L tub containing an oxygen-enriched solution of 20 ppm eugenol (AQUI-S, AQUIS-S NZ, Wellington, New Zealand). An acoustic transmitter, with a built-in pressure sensor to measure depth (accuracy ± 2.5 m when deployed at a maximum depth of 50 m; V13-1P with a pulse interval of 120–240 s), was surgically implanted into the peritoneal cavity using standard surgical techniques described in Bryars *et al.* (2012). During recovery the total length of each fish was measured to the nearest centimetre and an external dart tag fitted to allow easy identification if recaptured (Mason and Lowe, 2010). Fish were released once they were swimming in an upright position with the same tail strength as when they were first caught. The sex of the fish was designated following Gillanders (1995b), who found that all individuals smaller than 500 mm standard length were female, while all individuals larger than 580 mm standard length were male. All fish between 500 and 580 mm were classified as 'indeterminate sex'. Standard length was estimated post hoc using conversions available for the congener species, the western blue groper *Achoerodus gouldii* (Coulson *et al.*, 2009), where:

$$SL = \frac{TL}{1.19} - 7.93$$

with SL = standard length and TL = total length.

Data analysis

Site fidelity

Site fidelity within the reserve was quantified using a residency index (RI). RI was calculated by dividing the number of days a fish is detected on any of the receivers within the reserve by the duration of the study. A value of 0 indicated no residency and a value of 1 permanent residency (Bryars *et al.*, 2012; La Mesa *et al.*, 2012). An individual was considered 'present' within the array if it was detected at least twice within a 24-h period, eliminating the possibility of 'false detections' (Pincock, 2011). Data from the first 36 h post-tagging were excluded owing to potential atypical behaviours as a result of the tagging. A Spearman's rank test was used to assess association between the total length (TL) and RI.

Diel activity patterns

The diurnal behavioural pattern of each individual fish was assessed as the proportion of detections in the day (06:00 to 18:00) and night and compared using a paired Wilcoxon test. To determine diel activity patterns within the day a standardized mean detection frequency (SDF) for each hourly bin was calculated for each individual using the formula from Payne *et al.* (2010).

To determine if the diel difference in SDF was a function of increased movement by the fish (both horizontally and vertically), and therefore an increase in the number of receivers detecting the fish or a change in depth of reef utilized, the mean SDF was calculated for all the fish tagged (excluding fish #5 which most likely died, see results). Linear regression was used to determine if there was a correlation between square-root transformed SDF for all the fish, the number of receivers the fish were detected on, and mean depth difference (the mean depth for all hours for each fish was subtracted from the mean depth for each hourly bin and the mean for each hour calculated for all the fish) for each hourly bin.

Habitat use

Habitat type and depth data were combined to determine habitat use by eastern blue groper. Depth data from the fish tags were classified into three groups: reef, reef-sand, or sand depending on the depth contour data from OEH NSW.

Two log-likelihood tests (χ^2) were used to examine heterogeneity and habitat selection (Manly *et al.*, 2002; Rogers and White, 2007). A large difference between the two chi-squares is evidence that on average the fish were not using the habitats proportional to availability (Manly *et al.*, 2002). To determine which habitats were selected a habitat selection ratio and associated standard error was calculated for each sex and habitat type (Manly *et al.*, 2002). Selection for a habitat type is indicated by values greater than one and avoidance less than one.

Home range estimates

The home range of an animal is commonly estimated using kernel utilization distributions (KUD) with 50% and 95% contours representing the core and home range respectively (Parsons *et al.*, 2010; Simpfendorfer *et al.*, 2012). Core and home ranges were calculated for the breeding and non-breeding season for each fish detected in both seasons (i.e. not fish #5, #9 or #11). The breeding season has been assessed to be from mid-July to the end of October (Gillanders, 1995b), the non-breeding season was selected as January to the end of April (excluding November, December, May or June) to ensure no overlap of seasons. KUDs were calculated using the 'ks' package (Duong, 2007) in R (R Core Development Team, 2009) using the plug-in bandwidth selector, which has been shown to be the most appropriate bandwidth for home range studies (Gitzen *et al.*, 2006). The centre of activity (Simpfendorfer *et al.*, 2002) was calculated at 6-min intervals using R (script provided by Marshell *et al.*, 2011) to ensure detections were evenly spaced. To obtain the X and Y coordinates for each of the fish detections, the 300 m detection range for each receiver was overlaid with depth contours using ArcGIS 9.3 (ESRI, California). Depth contours were measured to ±2 m accuracy, so that each line was buffered with this error to produce polygons containing the area in which fish potentially may be located for each receiver/depth combination. The X and Y coordinates were then calculated by randomly selecting a point anywhere inside the respective polygon for each detection, calculating the core or home range size and running 10 000 iterations. The core and home ranges for each fish were taken as the mean of the 10 000 estimates produced for each fish.

Mixed-effects modelling was used to determine if there was a significant difference between the sexes, breeding/non-breeding season or tagging location (whether the fish was tagged in the 'no-take' or 'take' area), and using the unique fish identity code as the random effect. Data exploration was conducted following the protocol of Zuur *et al.* (2010). Two interactions were tested: between breeding/non-breeding season and sex; and between sex and tagging location. The most parsimonious model structure was found following the protocol set out in Zuur *et al.* (2009) testing generalized least squares (no random effect), linear mixed effects models using the 'nlme' package in R (Pinheiro *et al.*, 2013) and generalized additive models using the 'mgcv' package (Wood, 2006). Variance structures (Pinheiro and Bates, 2000) were used during the model selection process and their inclusion or exclusion based on both residual patterns and Akaike's Information Criterion for small sample sizes (AIC_c) values of the models. Support for each model was measured using the differences in AIC_c (ΔAIC_c) where the 'best' model ΔAIC_c equals zero and ΔAIC_c of less than two show models with substantial support (Burnham and Anderson, 2002). If ΔAIC_c showed support for more than one model, model averaging across normalized Akaike weights was conducted using the 'MuMIn' package from R (Barton, 2012). Significance of the optimal model terms was tested using analysis of deviance (Zuur *et al.*, 2009).

RESULTS

Twenty-two eastern blue gropers (420–830 mm TL) were tagged between 13 June and 27 August 2009 and passively monitored by an array of 13 receivers for 299 to 374 days (mean 345 days) recording in total 447 974 detections. There were no detections on receivers located outside the reserve from any of these individuals, nor on the AATAMS Bondi line immediately north of the reserve. Nineteen of the 22 tagged fish were detected within the reserve from the date of tagging up to the final download (Figure 2; Table 1). One fish (#5) was removed from further analysis because it was only

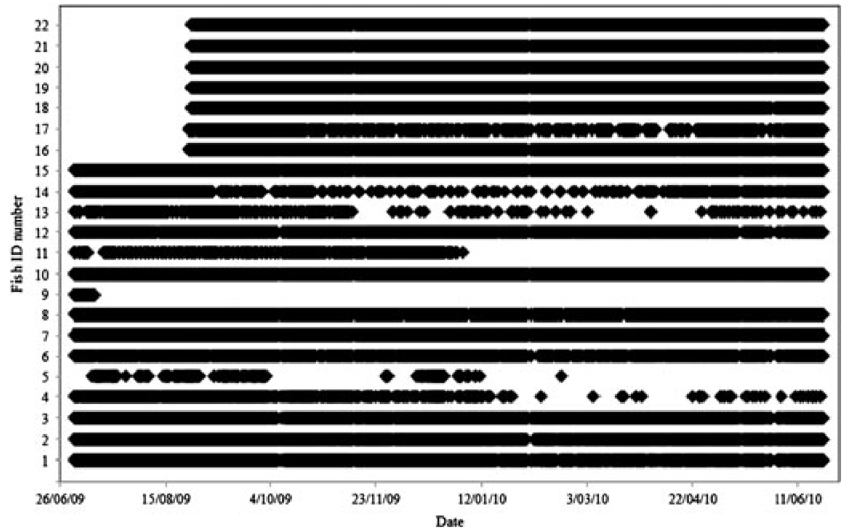

Figure 2. Time series of detections per fish tagged within Bronte-Coogee Aquatic Reserve.

ever recorded on a single receiver and the depth records oscillated with the tides suggesting that the fish died. An additional seven eastern blue gropers were tagged outside the reserve. These individuals were detected only by the receivers closest to their tagging sites outside the reserve and have been excluded from all subsequent analysis.

Site fidelity for the 21 eastern blue gropers tagged within the reserve measured using a residency index (RI) ranged from 0.05 to 1.00 (0.83 ± 0.06; mean ± SE) with 14 (67%) having RIs greater than or equal to 0.9. There was a weak association between total length (TL) and RI (Spearman's rank: $r_s = 0.27$, $P = 0.21$).

The standardized mean detection rate was higher during the day than at night for all blue groper (day: 0.96 ± 0.01; night: 0.01 ± 0.04; mean ± SE). There were significantly more detections during the day

Table 1. Summary of 22 *A. viridis* tagged within Bronte-Coogee Aquatic Reserve

Fish ID	TL (mm)	SL (mm)	Colour	Sex	Date tagged	Area tagged	First day detected	Last day detected	Residency index
1	670	555	Brown	I	13/06/09	No-take	13/06/09	23/06/10	0.87
2	700	580	Green	M	13/06/09	No-take	13/06/09	23/06/10	0.99
3	830	690	Blue	M	13/06/09	No-take	13/06/09	23/06/10	0.98
4	420	345	Brown	F	15/06/09	No-take	15/06/09	22/06/10	0.53
5	540	446	Green	F	15/06/09	No-take	11/07/09	11/01/10	0.19
6	580	479	Brown	F	15/06/09	No-take	15/06/09	23/06/10	0.94
7	650	538	Blue	I	15/06/09	No-take	15/06/09	23/06/10	1.00
8	770	639	Blue	M	15/06/09	No-take	15/06/09	23/06/10	0.98
9	520	429	Brown	F	22/06/09	No-take	22/06/09	12/07/09	0.05
10	530	437	Brown	F	22/06/09	No-take	22/06/09	23/06/10	1.00
11	600	496	Brown	F	22/06/09	No-take	22/06/09	03/01/10	0.38
12	610	505	Brown	I	22/06/09	No-take	22/06/09	23/06/10	0.97
13	620	513	Blue	I	22/06/09	No-take	27/06/09	22/06/10	0.41
14	710	589	Green	M	22/06/09	No-take	22/06/09	23/06/10	0.61
15	750	622	Blue	M	22/06/09	No-take	22/06/09	23/06/10	1.00
16	590	488	Brown	F	26/08/09	Take	26/08/09	23/06/10	1.00
17	730	606	Blue	M	26/08/09	Take	26/08/09	23/06/10	0.76
18	570	471	Brown	F	27/08/09	Take	27/08/09	23/06/10	1.00
19	580	479	Green	F	27/08/09	Take	27/08/09	23/06/10	1.00
20	660	547	Green	I	27/08/09	Take	27/08/09	23/06/10	1.00
21	730	606	Blue	M	27/08/09	Take	27/08/09	23/06/10	1.00
22	810	673	Blue	M	27/08/09	Take	27/08/09	23/06/10	1.00

TL = total length; SL = standard length; F = female; M = male; I = fish of indeterminate sex.

than at night (Wilcoxon paired test, $P < 0.05$). The magnitude of variation in the diel patterns varied between individuals. There was an overall increase in detections at dusk and dawn with a decrease during the middle of the day (Figure 3). As the SDF decreased, the mean number of receivers that the fish were detected on increased as did the mean depth difference (Figure 4; mean number of receivers, regression: $t_{df} = 5.5_{21}$; P-value < 0.001; mean depth difference, regression: $t_{df} = -2.6_{21}$; P-value $= 0.02$).

Habitat use was calculated for all the fish tagged within the reserve. The maximum log likelihood was significant for both chi-squared tests ($\chi^2_{L1} = 508.9$, df $=42$, $P < 0.001$; $\chi^2_{L2} = 1201.4$, $df^2 = 44$, $P < 0.001$) indicating that habitats were indeed selected. Average selection was not proportional to availability ($\chi^2_{L2} - \chi^2_{L1} = 692.6$, df $=2$, $P < 0.001$). Reef was preferred by all sexes (selection ratios ≥ 1.61) and sand and reef-sand boundary were avoided (all selection ratios ≤ 0.61).

Core ranges (50% KUD) varied between 7678 m^2 and 91 775 m^2 in the breeding season (35 438 ± 5544 m^2; mean ± SE) and 5370 m^2 and 60 612 m^2 in the non-breeding season (27 614 ± 3968 m^2; mean ± SE). Home ranges (95% KUD) varied between 50 008 m^2 and 543 548 m^2 in the breeding season (273 528 ± 28 017 m^2; mean ± SE), and 31 490 m^2 and 420 182 m^2 in the non-breeding season (186 492 ± 25 470 m^2; mean ± SE). There was

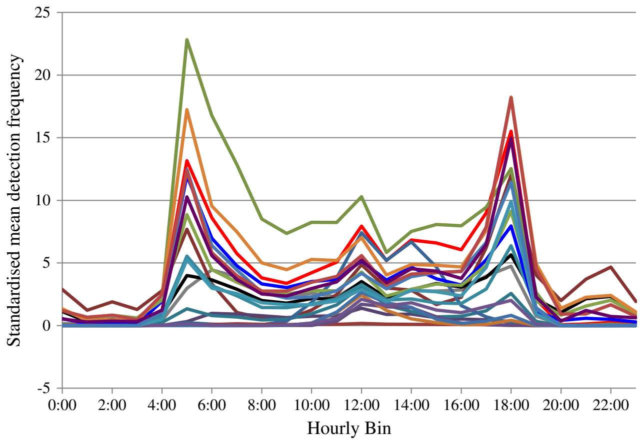

Figure 3. Mean detection frequency of each individual fish per time of day (standardized by the overall mean detection rate across all 24 hours following Payne *et al*. (2010)).

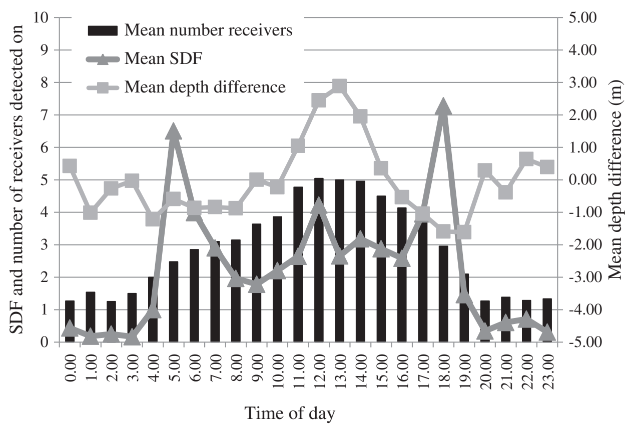

Figure 4. Standardized detection frequency (SDF), mean number of receivers detected on and the depth difference from the mean for all hourly bins for all fish.

high individual variation in the size of core and home ranges (Figure 5).

Generalized additive mixed models (GAMM) produced the lowest AICs of the model types tested for the core and home ranges. Model selection on core ranges produced two candidate models with ΔAICc <2 (Table 2) with the following fixed effects structures: sex only ($\Delta AIC_c = 0$; weight = 0.68) and sex + breeding/non-breeding season (ΔAICc = 1.55; weight = 0.32). Sex had a relative importance of 1 while breeding/non-breeding season had a relative importance of 0.32. Therefore, sex was the best predictor for core range sizes of eastern blue gropers with core ranges significantly larger in males (*P*-value = 0.009). Core range did not differ between females and those of indeterminate sex (*P*-value = 0.47), nor was there a significant difference in core range size between the breeding and non-breeding season (*P*-value = 0.23).

Model selection on home ranges produced two candidate models with $\Delta AIC_c < 2$ (Table 2), with the following fixed effects structures: breeding/non-breeding season + sex + tagging location ('take' vs 'no-take' area; $\Delta AIC_c = 0$; weight = 0.7) and breeding/non-breeding season + sex ($\Delta AIC_c = 1.74$;

Table 2. The five 'best' model candidates, based on AICc, for GAMM analyses of core and home range sizes. All models had the same random effect structure. *Season* is the breeding/non-breeding season variable; *tagging* is tagging location ('take' or 'no-take' area) and *df* is the number of parameters in the model

Model	df	AIC_c	ΔAIC_c	Model weight
Core ranges (KUD50)				
KUD50 ~ sex	6	851.95	0.00	0.68
KUD50 ~ sex + season	7	853.50	1.55	0.32
KUD50 ~ sex + tagging	7	854.63	2.68	0.00
KUD50 ~ sex + season + tagging	8	856.39	4.44	0.00
KUD50 ~ 1 [Null model]	4	859.29	7.34	0.00
Home ranges (KUD95)				
KUD95 ~ sex + season + tagging	8	982.86	0.00	0.70
KUD95 ~ sex + season	7	984.60	1.74	0.30
KUD95 ~ sex* tagging + season	10	986.56	3.70	0.00
KUD95 ~ sex*season + tagging	10	989.52	6.66	0.00
KUD95 ~ sex + tagging	7	990.43	7.57	0.00

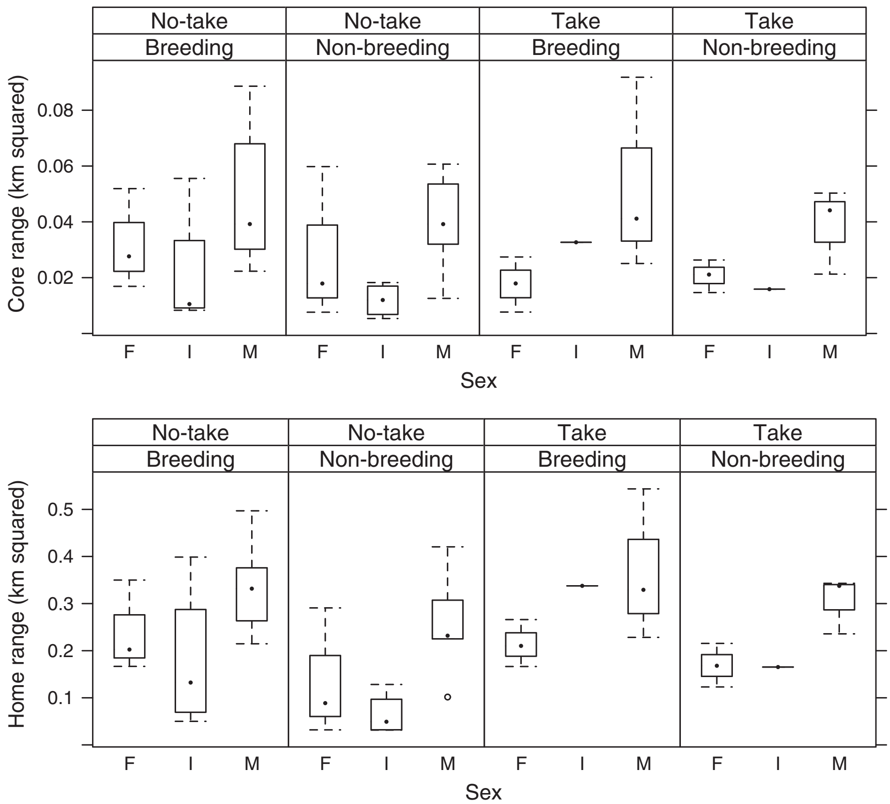

Figure 5. Core and home ranges of eastern blue groper for the breeding and the non-breeding season, grouped by whether they were tagged in the 'no-take' area or 'take' area. F = female; I = fish of indeterminate sex; M = males. The dot inside the box indicates the median; the box indicates the first and third quartile and the whiskers indicate the minimum and maximum values.

weight = 0.3). Sex and breeding/non-breeding season had relative importance of 1 while tagging location had a relative importance of 0.70. Therefore, sex and season are the best predictive factors for home range size for eastern blue gropers with home ranges significantly larger in males (*P*-value = 0.001). As with the core ranges, there was no significant difference between females and fish of indeterminate sex (*P*-value = 0.69). Home ranges were larger in the breeding season than the non-breeding season for all sexes (*P*-value < 0.001) and larger in the 'take' areas than the 'no-take' area (*P*-value = 0.04).

DISCUSSION

The design of a marine protected area (MPA) is predicated on the intended purpose of the area, and when targeting protection of specific species, must incorporate their essential requirements, in particular, critical feeding and breeding habitat. This study has shown that for an iconic reef fish, the eastern blue groper, a relatively small protected area can meet the spatial requirements of adult fish. Given that MPA designation requires significant public support, and that flagship species are often the most effective way to generate support (Zacharias and Roff, 2001), this finding has important implications for coastal MPAs. This study is the first to quantify the home ranges and movements of adult eastern blue groper. It shows that adult eastern blue groper have a high degree of site fidelity, strong diurnal activity patterns, and restricted home ranges. Fourteen of the 21 tagged fish were detected daily for 90% or more of the study period, with no movement of adult fish detected between adjacent reefs. Long residency times and high site fidelity appear common in labrids (Kingsford and Carlson, 2010; Afonso *et al.*, 2011), including the western blue groper (Bryars *et al.*, 2012).

Fish movements and activity

All the tagged fish were detected more often during the day than at night. The magnitude of detection frequencies during the day varied between individuals, with a substantial increase at sunrise and sunset and a decrease during the middle of the day. The decrease in detection rate and number of receivers that fish were detected on at night may be due to fish leaving the study area or to fish hiding in caves and crevices of the reef to rest. Considering the residency index and small home range obtained, the complexity of the study area, and anecdotal observations of eastern blue groper hiding in crevices at night (D. Coulson, pers. comm.), it is likely that the decrease in detection rate was due to fish seeking refuge in sheltered areas blocking the acoustic signal. A similar pattern was also observed in western blue groper, where night time refuging was also hypothesized to explain the strong diurnal patterns (Bryars *et al.*, 2012). However, unlike Bryars *et al.* (2012), the detection rate observed in this study had two distinct peaks at sunrise and sundown with a lower detection rate during the day. In addition, the mean number of receivers that detected the fish increased during the middle of the day at the same time that the standardized detection rate decreased. The increased number of receivers detecting fish and concomitant decrease in detection rate may be related to heightened activity and suggests foraging behaviour, most likely in complex areas of high relief as reported by Gillanders (1995a).

Home range

Home ranges of adult blue groper varied considerably among individuals and between the breeding and non-breeding season. While the social structure of eastern blue groper has not been studied, many protogynous fish species have dominance hierarchies (Pastor *et al.*, 2009; Raposeiro and Azevedo, 2009; Kline *et al.*, 2011). Typically, a social group will have a single terminal phase male, who actively defends a territory against other males and the largest females (see Kline *et al.*, 2011 and references within). In this study, males had significantly larger home ranges than females or fish of indeterminate sex, which might reflect this social structure. However, all sexes had increased home range sizes during the breeding season. While other studies have examined the intra-specific difference in home range size of other sedentary labrids (Jones, 2005; Kingsford and Carlson, 2010), few have examined the differences between breeding and non-breeding seasons. Females may increase home range during the breeding season to lay eggs in areas less vulnerable to predation as seen in New Zealand spotty (*Notolabrus celidotus*) (Jones, 1981). Alternatively, all the fish may show increased home ranges during the breeding season to have the opportunity to spawn with multiple individuals, as observed in California sheephead (*Semicossyphus pulcher*) (Adreani *et al*., 2004).

Two hypotheses can explain the smaller home range in the fish tagged in the 'no-take' area of the reserve compared with the 'take' area. The fully protected area of this reserve is a popular snorkelling and scuba-diving location where people often feed eastern blue groper (K. Lee, pers. obs.). Such feeding might have altered the behaviour of the eastern blue gropers, as shown in other species where regularly supplemental food has resulted in decreased activity spaces (Corcoran *et al*., 2013). Alternatively, the 'no-take' MPAs can also alter fish home range size with fish inside MPAs displaying different movement patterns to those in surrounding areas (Parsons *et al*., 2010) or through changes of their response to approaches by humans (Gotanda *et al*., 2009; Januchowski-Hartley *et al*., 2012). The 'take' area within BCAR, where fishing is permitted, is a popular spear and line fishing location (K. Lee, pers. obs.) and the larger home range sizes observed in fish tagged within this area could be a result of fish avoiding fishers. This type of behaviour has, however, been previously observed only in fish primarily targeted by spear fishers (Januchowski-Hartley *et al*., 2011), which is illegal for eastern blue groper in NSW. Further research is, therefore, required to identify which factor is the main driver of the difference in home range size observed in this current study.

Acoustic telemetry has become an important tool for estimating the movement parameters of aquatic species (Heupel *et al*., 2006; Cooke, 2008) and is frequently used to estimate home range sizes (Parsons *et al*., 2010; Bryars *et al*., 2012; La Mesa *et al*., 2012). This paper presents a different method of estimating the coordinates of fish detections and the subsequent home range sizes. However, this method is only possible when detailed, accurate bathymetry maps of the study site are available and the study species is benthic, and thereby restricted to the relief of the reef. For areas of low reef relief, such as a single depth contour throughout the detection range of a single receiver, this method would result in subsampling the locations within large areas and be unlikely to be more beneficial than other methods, such as the estimation of centre of activities (Simpfendorfer *et al*., 2002).

Efficacy of marine protected areas for large reef dwellers

The results of this study indicate that small marine protected areas that include rocky reef can adequately encompass the home ranges of large reef dwelling reproductively active fish, such as eastern blue groper. Large generalist feeders, such as eastern blue groper, appear highly adapted to reef habitat and abundance is not linked to specific habitat types (Gillanders and Kingsford, 1998). Thus, the specific type of rocky reef habitat (i.e. urchin-grazed barrens or *Ecklonia* forest) within potential reserves is unlikely to be an important factor in marine reserve design for large labrids. Considering the lack of movement between adjacent reefs, which were separated from the reserve by sand, and the habitat preference analysis showed avoidance of the sand and the reef–sand edge, sandy habitats may act as a natural barrier for the movement of adult eastern blue groper. This result could have been biased by the receiver array design outside the reserve. Fish moving to the adjacent reef south of the reserve may move only to the nearest reef edge and therefore would not have been within the detection range of a receiver. In addition, such dispersal cannot be distinguished from other factors, such as natural predation. However, the high level of site fidelity observed suggests that the probability of such movement would be low among the population. Previous studies have also found that sand can act as a barrier to fish movement, such as the western blue groper (*Achoerodus gouldii*; Bryars *et al*., 2012) as well as other smaller, temperate labridae species such as bluethroat wrasse

(*Notolabrus tetricus*), senator wrasse (*Pictilabrus laticlavius*) and rosy wrasse (*Pseudolabrus psittaculus*) (Barrett, 1995). To ensure the efficacy of marine reserves designed around large reef dwellers, discrete habitats need to be protected instead of dividing continuous areas of reef (Chapman and Kramer, 2000; Meyer and Holland, 2005; Marshell *et al.*, 2011).

Networks of small marine protected areas are one of the principal methods proposed to aid marine conservation (Kelleher, 1999). They are most effective when biological and ecological processes are considered, in particular connectivity (Roberts, 1997; Sala *et al.*, 2002). Larval dispersal and genetic connectivity of eastern blue groper between large spatial scales is unknown. However, since the movements of adult eastern blue groper appear limited by habitat, immigration into a small reserve such as BCAR is likely to be dominated by recruitment from estuarine habitats (Gillanders, 1997). Movements of juveniles from nursery areas may extend tens of kilometres (Gillanders and Kingsford, 1996; Gillanders *et al.*, 2003) and in western blue groper sub-adults may swim up to 60 km (Shepherd and Brook, 2007), suggesting that there could be at least localized genetic connectivity between reserves tens of kilometres apart. This suggests that networks of small MPAs could be an effective conservation strategy for large, sedentary reef fish with similar dispersal and movement patterns.

ACKNOWLEDGEMENTS

This project was funded by an Australian Government Caring for Country grant and funding from the Sydney Aquarium Conservation Fund and SeaWorld Research and Rescue Foundation. Thanks to Australian Animal Tagging and Monitoring Systems (AATAMS-IMOS) for in-kind contributions and in particular Andrew Boomer for his continuing support. KL was supported by a Macquarie University Research of Excellence Scholarship. Thanks to Paul Rogers and all the volunteers who helped on this project. Approved by Macquarie University Animal Ethics Committee ARA 2009-024.

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