Aquat. Living Resour. 22, 255–264 (2009)

DOI: 10.1051/alr/2009046
www.alr-journal.org

Aquatic Living Resources

Assessing the distribution and relative abundance of wobbegong sharks (Orectolobidae) in New South Wales, Australia, using recreational scuba-divers

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Received 1st July 2009; Accepted 15 September 2009

Abstract – Wobbegongs are benthic sharks that are commercially targeted in New South Wales (NSW), Australia. Given a dramatic reduction of more than 50% in landed catch in a decade, there is a clear need to ensure that basic ecological data such as distribution and abundance are available for management use. Opportunistic sightings of wobbegongs collected by recreational scuba-divers were used to assess the distribution and relative abundance of wobbegongs in NSW. From July 2003 until January 2005, 304 dives were undertaken by recreational divers and 454 wobbegongs were reported. Larger numbers of wobbegongs were sighted in northern compared to southern NSW. Spotted and ornate wobbegongs were sighted in similar numbers, but species composition was highly variable across locations. Only a few juvenile and newborn spotted wobbegongs were sighted, whereas small ornate wobbegongs were mostly sighted north of central NSW. The latter were possibly the third, cryptic species, the dwarf ornate wobbegong. The paucity of sightings of small wobbegongs suggests that juveniles and newborns are inconspicuous to divers or that small wobbegongs are found in areas not visited by divers. Potential species and size segregation suggest that closing areas to fishing may enable populations to sustain current levels of commercial exploitation. The cost-effectiveness of using recreational scuba-divers to opportunistically collect distribution and relative abundance data was apparent from this study. However, the lack of spatial and temporal homogeneity in diving effort suggests that future studies should consider incorporating organized surveys and a facilitator, rather than using opportunistic records of sightings.

Key words: *Orectolobus ornatus* / *Orectolobus maculatus* / *Orectolobus halei* / Survey / Tasman sea

Résumé – Les « wobbegongs » sont des requins benthiques qui sont recherchés en Nouvelles-Galles du Sud (NSW, Australie) à des fins commerciales. En regard de la réduction considérable des débarquements, plus de 50 % depuis une dizaine d'années, il est nécessaire de prendre des mesures pour que les données écologiques de base, telles que la répartition et l'abondance, soient disponibles en vue de leur gestion. Les observations occasionnelles de ces requins recueillies par des plongeurs sous-marins amateurs sont utilisées pour estimer la répartition et l'abondance relative des wobbegongs en NSW. De juillet 2003 à janvier 2005, 304 plongées ont été effectuées par des plongeurs amateurs et 454 wobbegongs ont été dénombrés. De plus grands nombres de wobbegongs ont été observés dans le nord comparé au sud de NSW. Des wobbegongs tachetés et ornés ont été vus en nombre égale mais la composition entre espèces est fortement variable entre les sites. Seuls, quelques juveniles et un nouveaux-nés de wobbegong tacheté ont été vus, tandis que de petits wobbegongs ornés ont été vus principalement au nord de NSW. Les derniers étaient probablement la troisième espèce cryptique de wobbegong orné nain. La rareté des observations de petits wobbegongs suggère que les juvéniles et nouveaux-nés sont invisibles aux plongeurs ou qu'ils sont situés dans des zones non prospectées par les plongeurs. Une ségrégation potentielle des espèces et des tailles suggère que des zones fermées à la pêche pourraient permettre aux populations de supporter les niveaux courants d'exploitation commerciale. L'intérêt du coût d'utilisation de plongeurs amateurs est évident dans cette étude pour collecter occasionnellement des données d'abondance relative et de répartition. Cependant, le manque d'homogénéité spatiale et temporelle dans l'effort de plongée suggère que les études futures devraient considérer l'incorporation de campagnes organisées plutôt que d'utiliser des enregistrements d'observations occasionnelles.

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1 Introduction

Wobbegong sharks (Orectolobidae) are benthic sharks found in temperate to tropical continental waters of the western Pacific (Compagno 2001). In Australia, wobbegongs have been commercially targeted in NSW by the Ocean Trap and Line Fishery since 1991 for sale as "boneless fillet" or "flake". Their catch has declined from about 120 tonnes in 1990/1991 to about 55 tonnes in 1999/2000, a decrease of more than 50% in a decade (Scandol et al. 2008). Although fishing effort is unknown and this reduction might be due to a decrease in fishing effort, this large decrease in total catches led to wobbegongs being listed as "vulnerable" in NSW under the World Conservation Union (IUCN) Red List assessment (Cavanagh et al. 2003). Despite their commercial importance, little is known of the current population size and distribution of wobbegongs. Given the decline in landed catch, there is a clear need to ensure that basic ecological data, such as distribution and abundance are available for commercially harvested species to enable ecologically-minded management. Amateurs and volunteers represent a large pool of potentially skilled unpaid labour, and have helped collect and gather data for scientific purposes for centuries (Mims 1999; Fore et al. 2001). The use of volunteers has rapidly increased (USEPA 1998) with volunteers used worldwide in many conservation orientated projects to conduct baseline surveys, and to monitor marine (Halusky et al. 1994; Evans et al. 2000; Barrett et al. 2002) and terrestrial organisms (Johnson 2001; Brandon et al. 2003). Recreational scuba-divers are a specialized type of volunteer that have previously been used to investigate distribution and relative abundance of marine species (e.g. Parker and Bucher 2000; Otway et al. 2003; Goffredo et al. 2005), and to assess the effects of marine protected areas (MPA) (Barrett et al. 2002).

In this study, recreational scuba-divers were asked to collect data to document the distribution and relative abundance of wobbegongs in NSW. Information on species composition and length frequency were also collected.

2 Methods

The present study was promoted to recreational scuba-divers through scuba-diving and spearfishing magazines, e-mails to dive clubs and shops, and on scuba-diving websites and forums. Any willing recreational diver was able to participate in the study. Training sessions about the project's aims and methods were provided at diving clubs and shops with the aim of training scuba-divers to identify wobbegong species found in NSW and correctly complete a sighting form printed on waterproof paper. Information requested on the sighting form included the lead diver's name and address, dive site details (site, nearest major town, date, time, and dive duration) and details on each wobbegong sighting (depth, time, species, estimated total length: 0–50 cm, 50–100 cm, 100–150 cm, 150–200 cm, and >200 cm, and habitat: rock, boulder, sand, and "other" such as corals or algae). An instruction sheet was provided with each form to ensure its correct completion and an identification key with pictures of ornate and spotted wobbegongs was provided on the back of the form to help divers distinguish between the species (using colour pattern and dermal lobe counts).

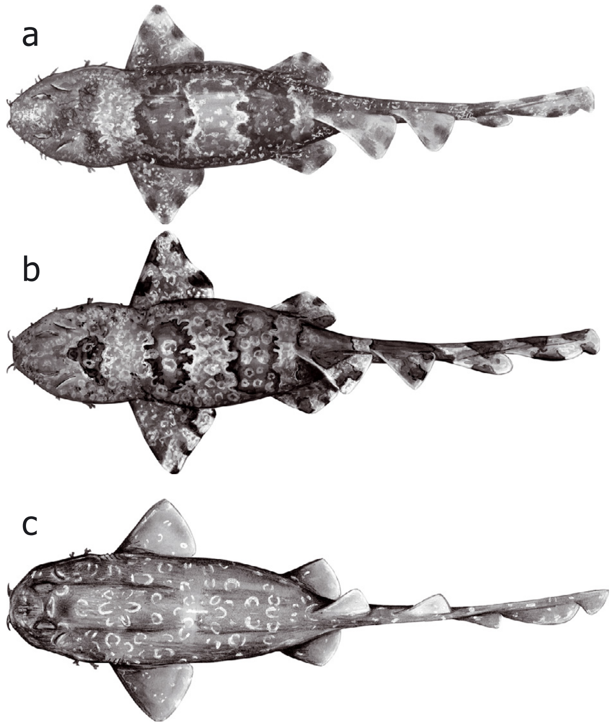

Fig. 1. Illustrations of (a) *Orectolobus ornatus*, (b) *O. halei*, and (c) *O. maculates* (not to scale).

The principal investigator dived with about 20% of the participants to ensure the efficacy of the training sessions. Furthermore, contact between the principal investigator and participating scuba-divers was made at approximately 6-week intervals. Divers were asked to record information on each wobbegong sightings by completing the form during all of their usual dives in NSW, including dives during which no wobbegongs were sighted.

At the time the study was conducted, only two species of wobbegongs were known to occur in NSW, the spotted wobbegong *Orectolobus maculatus* (Bonnaterre 1788) and the ornate wobbegong *O. ornatus* (De Vis 1883). A third species, the large ornate or gulf wobbegong *O. halei* Whitley, 1940 formerly synonymized with *O. ornatus*, has since been found to differ from *O. ornatus* (Huveneers 2006; Corrigan et al. 2008) (Fig. 1). As the differences between the two species of ornate wobbegongs were unknown at the time of the study, the distribution and relative abundances of the dwarf (*O. ornatus*) and large (*O. halei*) ornate wobbegong were combined in this study as ornate wobbegongs. Geographically proximate dive sites (within 100 km of each other) were combined to give a total of nine different sampling locations (Fig. 2). Multiple counts of the same wobbegongs were avoided by avoiding repeated sightings at any one dive site completed on the same day. When multiple counts occurred, the mean number of wobbegongs recorded was used for the analysis.

Depth and habitats occupied by the wobbegongs, together with species proportions, were simply described because small sample sizes prevented any further statistical analyses. Due to

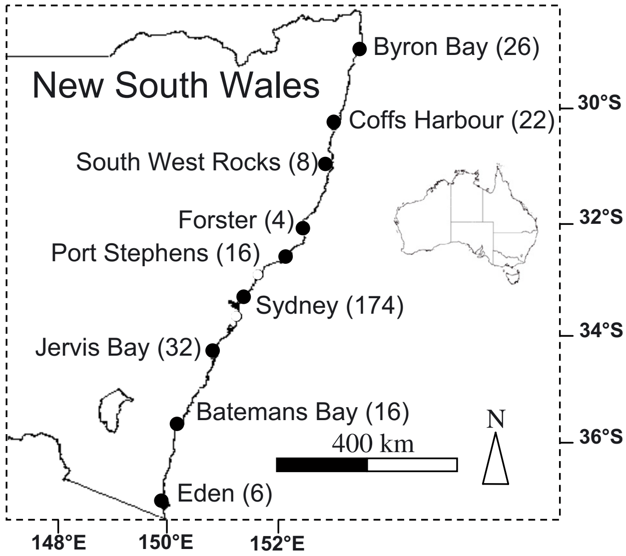

Fig. 2. Map of New South Wales coast showing "locations" where dives were undertaken. Number of dives undertaken at each location is indicated in parenthesis.

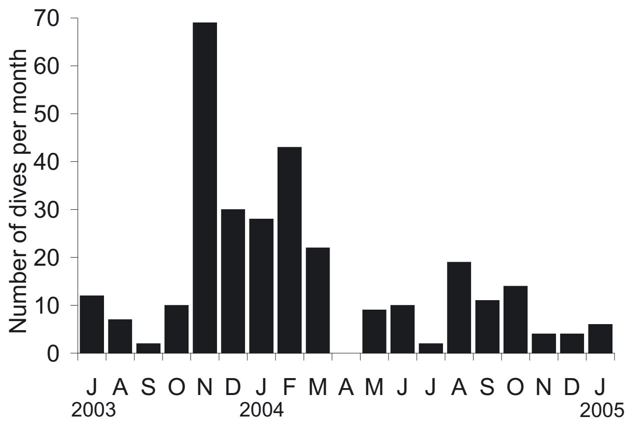

Fig. 3. Diving effort throughout NSW during the 19-month study period.

spatial and temporal heterogeneity in diving effort (Figs. 2 and 3), it was not possible to discern seasonal variations in relative abundance from differences among locations and months. Statistical analyses were, therefore, limited to locations and periods of the year sampled consistently. As a result, the number of wobbegongs sighted at each location was examined for January–February and October–November. Temporal fluctuations in the relative abundance of wobbegongs were only examined for wobbegongs sighted off Sydney with the 19-month study period pooled by month.

During data collection dwarf (*O. ornatus*) and large (*O. halei*) ornate wobbegong sightings were combined because of unresolved taxonomy. However, these two species differ in their respective maximum total length (110 cm vs. 300 cm) and distribution within NSW (from the NSW/Queensland border to Sydney vs. the whole NSW coast) (Compagno 2001; Huveneers 2006). Length frequencies were therefore divided between locations north and south of Sydney to account for the difference in distribution. Estimates of total length were not provided with sufficient regularity to permit statistical analysis.

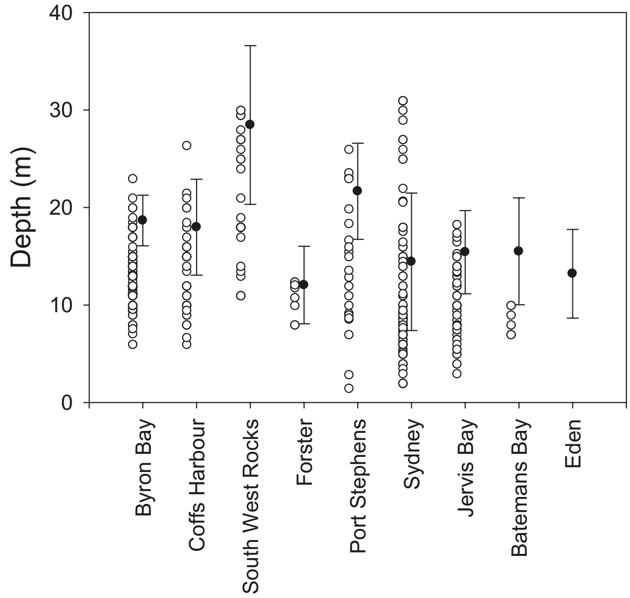

Fig. 4. Maximum diving depths and depths of wobbegong sightings against locations. Black circles are mean maximum dive depth ± standard deviation; white circles are depth at which wobbegongs were sighted at each location.

3 Results

Sixty-one recreational scuba-divers undertook 304 dives at 142 different dive sites within nine locations along the NSW coast. The locations spanned about 1280 km from Byron Bay to Eden, and the dives occurred over 19 months from July 2003 to January 2005. A total of 454 wobbegongs was recorded over the 304 dives. At least one wobbegong was seen in 140 dives with a maximum of 14 wobbegongs sighted in a single dive. The diving effort was neither homogenous spatially (Fig. 2) nor temporally (Fig. 3). There was a strong spatial bias with the largest proportion of dives (56%) undertaken off Sydney. Furthermore, a much larger proportion of dives were undertaken between late spring and early autumn with nearly 70% of the dives undertaken in the five months from November 2003 to March 2004. The number of dives per month peaked at about 70 dives in November 2003 (49 of which were off Sydney), after which it decreased to about 8 dives per month over the period of April 2004 to January 2005 (Fig. 3).

Ornate and spotted wobbegongs were found in depths ranging from 3–30 m (n = 191) and 4–31 m (n = 263), respectively. However, the depth at which wobbegongs were sighted was positively correlated with the maximum depth of the dive (Spearman's rank correlation: r_s: 0.71, $p < 0.001$) (Fig. 4). Subsequently, any observed depth preference or difference between locations might be an artefact of the maximum depth dived rather than an actual wobbegong depth preference or difference. The predominant habitat observed during

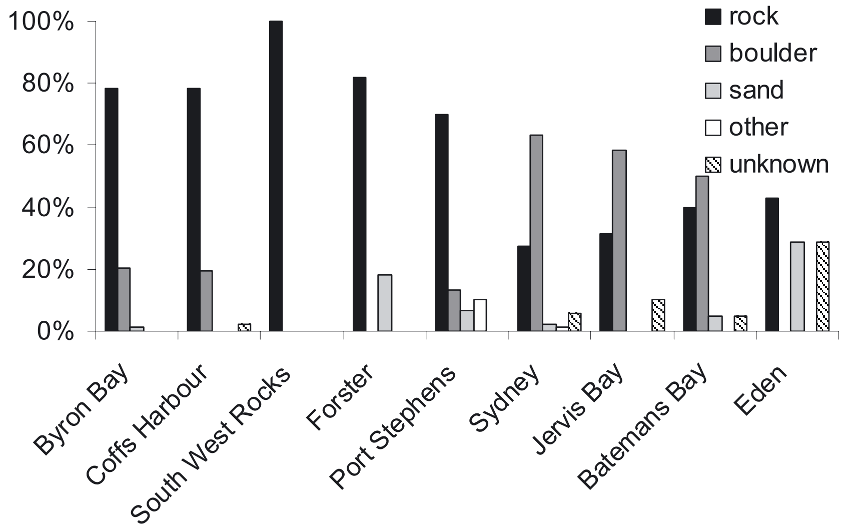

Fig. 5. Proportion of predominant observed habitat during a dive across locations.

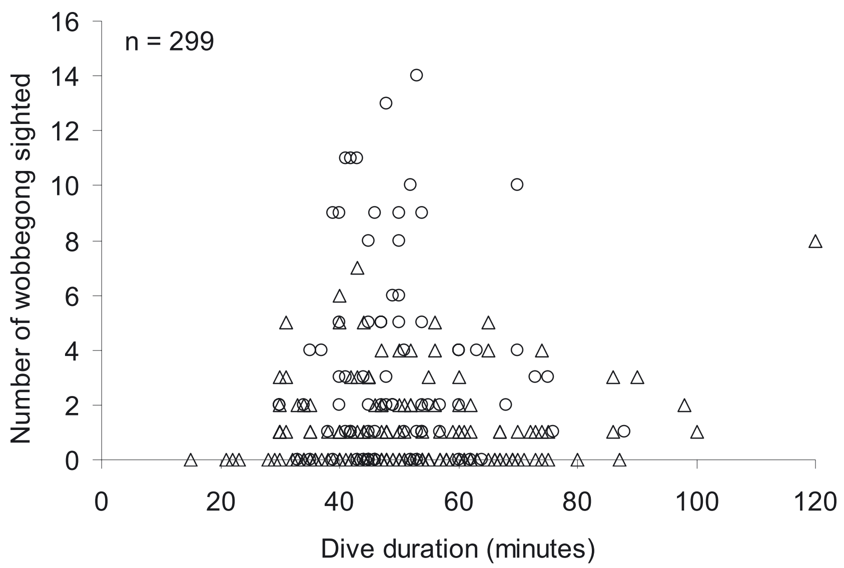

Fig. 6. Relationship between the number of wobbegongs sighted and dive duration. "*n*" indicates the number of dives with dive duration provided. The discrepancy between the total number of dives (304) and "*n*" (299) is due to five dives for which dive duration was not provided by divers. Circles indicate dives undertaken north of Sydney; triangles indicate dives undertaken in or South of Sydney.

the dive differs between the north and south regions. In northern NSW, the rocky habitat was more frequently observed than boulders (~80% vs. 20%), whereas boulders were more commonly found in the southern locations (~60% vs. 35%) (Fig. 5). Wobbegongs were most often sighted underneath rocks (about 45%) and boulders (about 25%). Spotted wobbegongs were sighted more frequently on sand patches than ornate wobbegongs (23% and 6%, respectively).

As sightings were recorded during recreational dives, dive duration was highly variable (30 to 120 min, mean 50 min; Fig. 6). Accordingly, abundance as a function of dive time might be expected to be a more accurate reflection of the relative abundance of wobbegongs. However, there was no correlation between the number of wobbegongs recorded and dive duration (Spearman's rank correlation: $r_s = 0.015$, $p > 0.05$). There were also no correlation between the number of wobbegongs recorded and dive duration in dives undertaken north of Sydney only (Spearman's rank correlation: $r_s = 0.011$, $p > 0.05$) nor in dives undertaken in or South of Sydney only (Spearman's rank correlation: $r_s = 0.007$, $p > 0.05$) (Fig. 6). Therefore, the actual numbers of wobbegong sighted were used for all analyses.

Parametric analyses such as ANOVA examining the relative abundances of wobbegong among locations in January–February and October–November were prevented because of heterogeneity of variances (Levene's test: $F_{8,71} = 18.04$, $p < 0.001$ and $F_{5,90} = 4.21$, $p < 0.01$, respectively). However, non-parametric analyses showed that the number of wobbegong sighted differed significantly among locations in January–February and again in October–November

(Kruskal-Wallis: $F_8 = 39.68$, $p < 0.001$; $F_6 = 26.79$, $p < 0.001$, respectively). During January–February, the number of wobbegong sighted per dive was significantly greater off Byron Bay (6.9 mean, 1.26 standard error, s.e.) than off Port Stephens (0.5 mean, 0.5 se), Sydney (0.6 mean, 0.17 s.e.), Batemans Bay (0.5 mean, 0.21 s.e.), and Eden (0 mean, 0 s.e.) (Dunnett test: all $p < 0.05$). The number of wobbegong sighted was also significantly higher in Coffs Harbrour (2.3 mean, 0.47 s.e.) than in Eden (0 mean, 0 s.e.) (Dunnett test: $p < 0.05$). In October–November, the number of wobbegong sighted in Byron Bay (6.8 mean, 1.4 s.e.) was significantly higher than in Sydney (1.4 mean, 0.3 s.e.) (Dunnett test: $p < 0.05$) (Fig. 7).

Temporal patterns in the relative abundance of wobbegongs off Sydney were also characterized by heterogeneous variances (Levene's test: $F_{10,163} = 11.47$, $p < 0.001$). In Sydney, there was a significant difference in the number of wobbegong sighted between months (Kruskal-Wallis: $F_{10} = 44.82$, $p < 0.001$). The number of wobbegong observed in November (1.5 mean, 0.27 s.e.) was significantly higher than in March (0.1 mean, 0.7 s.e.), May (0 mean, 0 s.e.), June (0 mean, 0 s.e.), July (0 mean, 0 s.e.), August (0.1 mean, 0.09 s.e.), October (0 mean, 0 s.e.), and December (0.2 mean, s.e.) (Dunnett test: $p < 0.001$) (Fig. 7).

A total of 428 wobbegongs was identified as ornate or spotted wobbegongs. Although the number of ornate wobbegong was similar to the number of spotted wobbegong across the whole NSW coast (199 and 229 respectively, with 26 unidentified sightings), species composition was variable among locations (Fig. 8). For example, Coffs Harbour had approximately equal frequencies of spotted and ornate wobbegongs, whereas ornate wobbegongs were more frequently sighted at South West Rocks, located only 50 km South of Coffs Harbour. Similarly, most of the sharks sighted were ornate wobbegongs in Port Stephens (200 km North of Sydney), whereas the majority of sharks sighted in Sydney were spotted wobbegongs. Species composition also varied temporally in some locations. While sightings in Jervis Bay were mostly of spotted wobbegongs throughout the study period, sightings changed from ornate wobbegongs to spotted wobbegongs in Coffs Harbour, Forster and Sydney. The differences were not tested statistically due to small sample sizes.

Estimates of total length were obtained for 405 wobbegongs. Length frequency differed between species, with large numbers of spotted wobbegongs observed having estimated total lengths of 100–150 cm and 150–200 cm (36% and 33%, respectively). In contrast, ornate wobbegongs showed a greater range in size, with similar proportions of individuals (about 25% in each size class) exhibiting estimated total lengths of 50–100 cm, 100–150 cm and 150–200 cm. Very few wobbegongs with estimated total lengths smaller than 50 cm were obsererved (3.7 and 5.5% for ornate and spotted wobbegongs, respectively). When size classes were examined between regions, the frequency of small ornate wobbegongs (<1.5 m) was much lower in the southern (17%) compared to the northern (62%) region (Fig. 9).

4 Discussion

Wobbegong sightings collected by recreational scuba-divers represent valuable information on the distribution and relative abundance of wobbegongs in NSW. The present study was only possible through the participation of a large number of scuba-divers. A total of 304 dives was undertaken over 550 days, along 1280 km of coast without incurring substantial cost thanks to the use of volunteers (Darwell and Dulvy 1996; Forster-Smith and Evans 2003).

A major limitation of this study was the lack of consistency in sampling effort across locations and months. When using a network of volunteers without organized survey events, effort is likely to be greater in some areas and at particular seasons. This was the case in our study with 56% of the dives undertaken around Sydney. This bias may be a reflection of human demography as 62% of the NSW population indicated that they lived in Sydney in the 2001 census (ABS 2001 Census). However, numerous other factors including lack of reporting from other locations may have affected the study.

Furthermore, recreational divers undertake their sport for pleasure and often choose dive sites that are more enjoyable. Therefore, many sites may not have been dived because of the absence of interesting fauna and flora, cold water, exposed conditions and/or general inaccessibility. The repetition of detailed studies at single sites has also been found to lead to a drop in the level of interest in other studies (Barrett et al. 2002), and this may have led to the temporal decrease in the number of dives and concomitant reduction in the amount of data received. Diver interest was difficult to maintain in the present study as illustrated by a decline in the number of dives after the first summer's sampling. Colder water in winter and spring further limits the ability to keep a regular program underway throughout the year as interest waned when water and air temperatures fell below comfortable levels.

Wobbegongs are cryptic sharks often occupying cracks and crevices (Carraro and Gladstone 2006) and thus, sighting rates may vary according to the proportion of divers' time actively spent searching for wobbegongs in these habitats. Although the extent to which divers actively searched for wobbegongs could not be quantified, dive duration was recorded as a measure of effort and was not related to sighting success. However, possible biases caused by the different searching skills of divers were assumed to be evenly distributed across locations, and thus, we suggest that the observed trends reflect actual variability in abundance rather than observer bias.

The higher percentage of wobbegongs found around rocks and boulders is consistent with earlier reports that wobbegongs prefer topographically complex habitats (Carraro and Gladstone 2006). We also found a larger number of wobbegong sightings in northern NSW. The larger number of wobbegong sighted in the northern locations might be related to the relatively large proportion of rocky habitat which wobbegongs seem to favour. However, the predominant habitat in southern NSW, boulders which can be similar to rocks for recreational divers, is also a type of habitat that wobbegongs seem to favour. Therefore, the difference observed might instead be due to semantics. Water temperature has also been found to influence chondrichthyan distribution directly and indirectly (Casey and Kohler 1992; Morrissey and Gruber 1993; Economakis and Lobel 1998) indicating that wobbegongs in NSW might prefer waters with warmer mean temperatures. Targeted fishing of wobbegongs might have also affected the relative

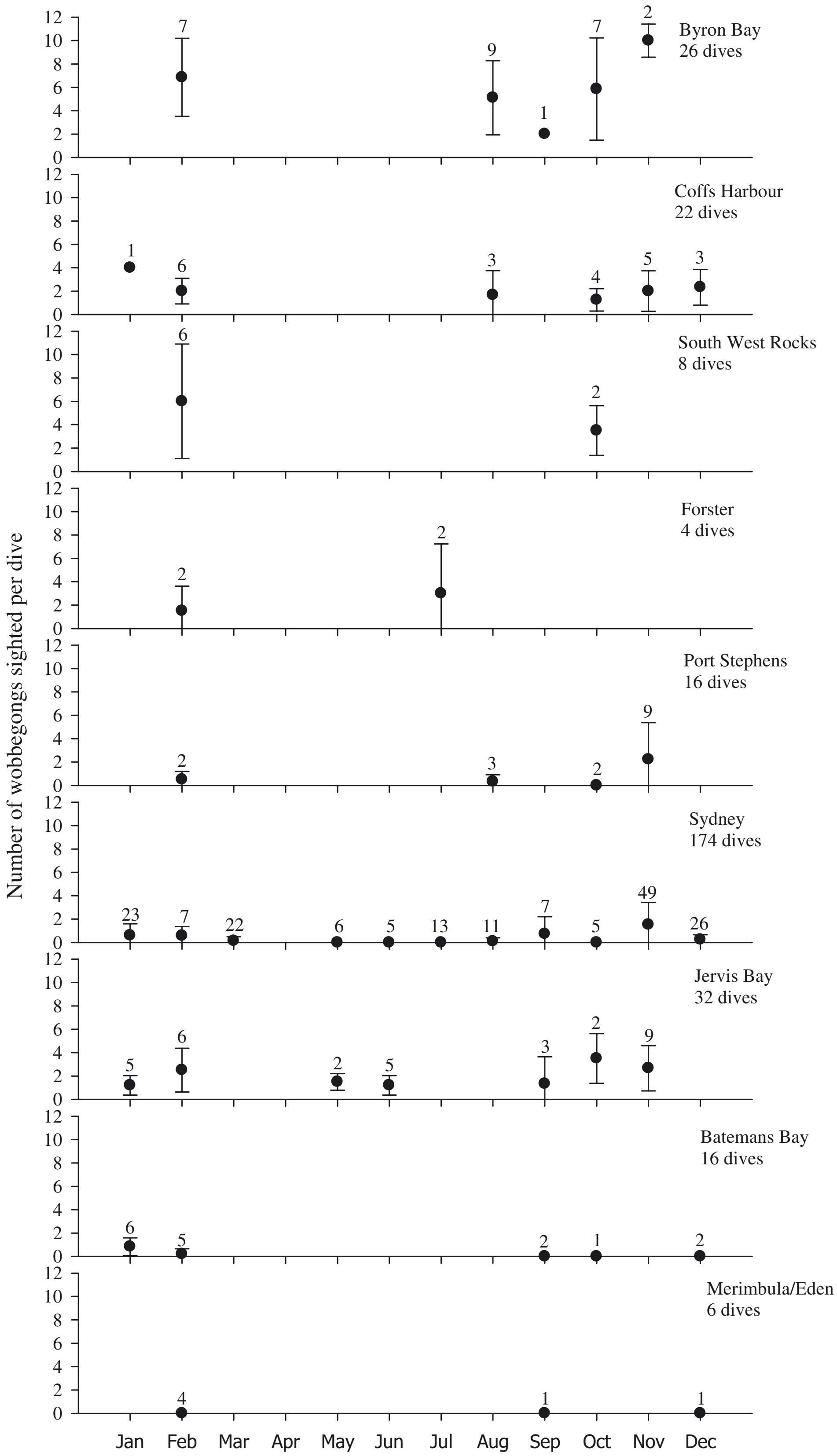

Fig. 7. Comparison of the mean number (± s.e.) of wobbegongs sighted per dive over the 19-month study period (pooled over 12 months) and among locations. Numbers above mean indicate the number of dives undertaken at each location during that month.

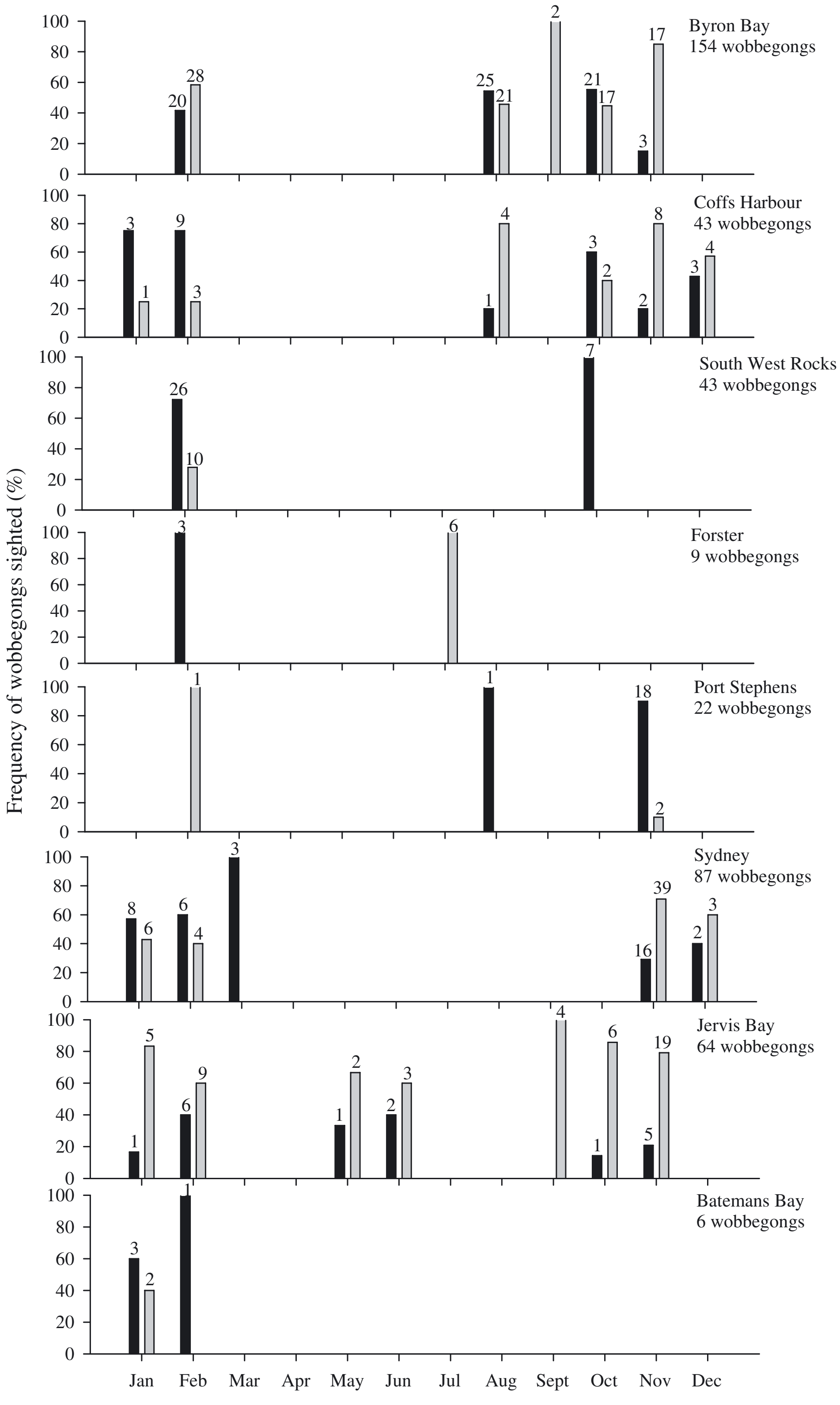

Fig. 8. Percentages of ornate (black) and spotted (grey) wobbegong species sighted at each location over the 19-month study period (pooled by month). Numbers above bar denote the number of individuals at each location in that month.

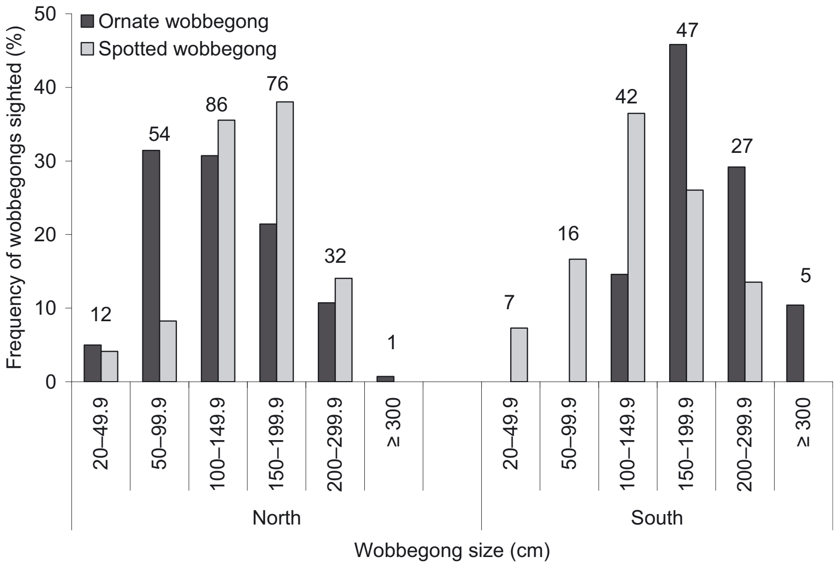

Fig. 9. Size frequency of ornate (black) and spotted (grey) wobbegongs sighted in the northern and southern regions. Numbers above bar indicate the number of wobbegongs for which length was estimated. Lenghts from 261 and 144 wobbegongs were estimated in the northern and southern region, respectively.

abundance of wobbegongs in NSW. Anecdotal information from divers has suggested that the extensive fishing effort south of Sydney might have depleted local wobbegong populations. Potential for localised depletion is further suggested by the high site fidelity observed in some *O. ornatus* and *O. halei* (mis-identified as *O. ornatus*) individuals which were recorded within the same area for up to 20 months (Carraro and Gladstone 2006; Huveneers et al. 2006). Fisheries catch reports from the targeted fishery could not be used to investigate potential relationships between wobbegong abundance and fishing pressure due to the lack of data on fishing effort.

Only a few small spotted wobbegongs were sighted by divers. Similarly, only a few small ornate wobbegongs were sighted by divers south of Sydney. Sixty-two percent of ornate wobbegongs sighted north of Sydney were smaller than 1.5 m. *Orectolobus halei* was formerly considered to be the adult specimens of *O. ornatus*, whereas what is now identified as *O. ornatus* was previously mistaken for juveniles. It is possible that many of the small ornate wobbegongs north of Sydney were actually adult *O. ornatus*. The southern limit for *O. ornatus* is Sydney (Huveneers 2006), possibly explaining the lack of small ornate wobbegongs in Southern NSW. Small *O. halei* may therefore be rare along the whole NSW coast. This is supported by data collected from commercial catches in which small juvenile and newborn wobbegongs are only sporadically caught (Huveneers et al. 2007). Wobbegongs in NSW have a size-at-maturity of 175 cm for large ornate, 135 cm for spotted wobbegong and 80 cm for dwarf ornate (Last and Stevens 2009; Compagno 2001; Huveneers et al. 2007). Therefore, most sharks sighted might have been large juveniles or mature sharks, whereas small juvenile and young of the year were only sighted in small numbers. However, the observed increase proportion of small wobbegongs in northern NSW might have also been due to an ontogenetic shift in distribution with small wobbegongs preferring the warmer water temperatures in northern NSW.

Size segregation of wobbegongs has been reported to occur around Byron Bay by Baker (1998) with populations comprising mainly juvenile ornate wobbegongs (60–100 cm total length) and adult spotted wobbegongs. The reclassification of *O. ornatus* and *O. halei* by Huveneers (2006) suggests that the proposed size segregation might be erroneous as many of the juvenile ornate wobbegongs may actually be adult *O. ornatus*. Consequently, the wobbegong population at sites around Byron Bay may simply comprise juvenile and adult dwarf ornate and adult spotted wobbegongs.

Newborn and small juvenile wobbegongs were only observed in small numbers in this study and may have been in small cracks and thus, inconspicuous to divers. Alternatively, juvenile wobbegongs may occur in areas that were not dived. These habitats might not have been explored due to their difficult access (e.g. offshore in deeper waters where it is dangerous for divers to dive or possibly within estuaries where visibility and currents are usually poor for diving) or in areas which are characterized by a lack of "interesting" things to see for divers (e.g. large tracks of seaweed). If these different habitats are important to wobbegongs to ensure that pups and juveniles grow sufficiently to reach maturity and enter the breeding population, then the identification of these areas is an important conservation priority (Heupel et al. 2007).

Species composition varied across geographically close locations. This indicates patchiness in the distribution of wobbegong species and may be explained by species-specific site preference. The establishment of suitable sized aquatic reserves or marine parks at those sites where a particular species of wobbegongs is found may help protect the species. If this is the case, studies focusing on the identification of suitable areas and sites would be required. The potential use of specific sites as marine reserves is supported by the long-term residency (i.e.

over 2 years) of individual wobbegongs at a site on the mid-north coast of NSW (Huveneers et al. 2006).

The conservation value of using recreational scuba-divers to collect data, albeit opportunistically, is apparent from this study. Although the use of organised survey events with their own limitations was avoided by using recreational dives, the need to ensure the program is executed properly and ensure data quality and homogeneity of survey effort is vital. This requires substantial organisation input at a professional level to facilitate such project. This may be accomplished by using a full-time employee or facilitator. The need for such a skilled facilitator increases the cost of running a volunteer program and highlights the decisions that need to be made by the chief investigators when deciding whether or not to use volunteers.

The data provided in the present study are analogous to a pilot study and permitted possible trends to be established at low cost. These results can now be used as a basis for designing cost-effective, randomly-stratified sampling programs involving underwater visuals censuses or other sampling techniques such as baited traps or Baited Remote Underwaer Video Systems (BRUVS) to rigorously quantify the spatial and temporal patterns of relative abundance of the three wobbegong species in NSW waters.

Acknowledgements. The authors would like to thank all divers who helped gathering information during the study and in particular S. Newson and S. Walsh who sent the most forms back and have helped with their insights on the scuba-diving community in Australia. Wobbegong illustrations were provided by S. Corrigan and drawn by L. Marshall of Stickfigurefish (www.stickfigurefish.com). S. Allen, M. Braccini, W. Robbins and P. Rogers are thanked for their constructive comments helping to greatly improve earlier versions of this manuscript. Charlie Huveneers was supported by an international Macquarie University Research Scholarship. Financial support by the Graduate School of the Environment, Department of Primary Industries (NSW) and the Australian Geographic Society was provided for sample collection. This study was undertaken under the NSW DPI permit number PO03/0057 and a Macquarie University Ethics Committee approval number 2003/011.

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