Title: Use of stereo baited remote underwater video systems (stereo-BRUVs) to estimate presence and size of white sharks *Carcharodon carcharias*

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ABSTRACT

Stereo baited remote underwater video systems (stereo-BRUVs) are commonly used to assess fish assemblages and, more recently, to record the localised abundance and size of sharks. This study investigated the occurrence and size of white sharks (*Carcharodon carcharias*) in the near-shore environment off Bennett's Beach, part of a known nursery area for the species in central New South Wales, Australia. Six stereo-BRUV units were deployed approximately fortnightly between August and December 2015 for periods of five hours in depths of 7 to 14 m. Stereo-BRUVs successfully recorded 34 separate sightings of 22 individual white sharks. The highest number of individuals detected during a single day survey was eight All *C. carcharias* observed on stereo-BRUVs were juveniles ranging in size from 1.50 m to 2.46 m total length (mean size of 1.91 m ± 0.05 S.E, *n*=22). The time to first appearance ranged from 15 to 299 mins (mean 148 mins ± 15 mins). This study demonstrates that the use of stereo-BRUVs is a viable non-destructive method to obtain estimates of size and presence of white sharks, and may be useful to estimate relative abundance in near-shore environments where they are known to frequent.

ADDITIONAL KEYWORDS: beach, elasmobranch, nursery area, Port Stephens, stereo camera

INTRODUCTION

Baited remote underwater video systems (BRUVs) are now a commonly used method for sampling fish assemblages world-wide (Mallet and Pelletier, 2014). Bait is used to attract species into the field of view of cameras so that they can be recorded, identified and counted (Cappo et al., 2004). Sampling using BRUVs is considered non-destructive, as opposed to capture-based methods, and suitable for sampling depths below the limits of standard diving surveys or in areas where the risks to divers are unacceptably high (Lindfield et al., 2014, Malcolm et al., 2007). They have been used in numerous studies assessing species within marine protected areas (Coleman et al., 2015, Cappo et al., 2003, Harasti et al., 2015) and assessing fish-habitat associations (Poulos et al., 2013, Schultz et al., 2015). The application of twin camera systems (stereo-BRUVs) allows fish lengths to be accurately estimated in a non-destructive and cost-effective manner (Langlois et al., 2010, Harvey et al., 2012b, Watson et al., 2010) and such systems have been specifically deployed to assess the relative abundance and lengths of commercially important and threatened fishes (Harasti et al., 2014, Malcolm et al., 2015).

The use of bait to attract predatory fishes has made BRUVs particularly well suited to sampling sharks. For example, reef sharks were found to increase in abundance within MPAs in Belize and Australia (Bond et al., 2012, Espinoza et al., 2014) with hard coral habitats defined as an important predictor for shark distribution on the Great Barrier Reef (Espinoza et al., 2014). Stereo-BRUVs have been successfully used to estimate lengths of various shark species, such as bronze whaler *Carcharhinus brachyurus*, dusky whaler *Carcharhinus obscurus* and tiger sharks *Galeocerdo cuvier* (Santana-Garcon et al., 2014, Santana-Garcon et al., 2014, Letessier et al., 2013), as well as being used to assess differences in shark biomass between fished and non-fished sites (Goetze and Fullwood, 2013), and to estimate shark cruising speeds (Ryan et al., 2015).

White sharks have previously been detected on BRUVs (De Vos et al., 2015, Kempster et al., 2016), and have been recorded on a few occasions in BRUVs surveys of rocky reef fish assemblage around Port Stephens, New South Wales, Australia (NSW DPI *unpublished data*). The Port Stephens region has been identified as a nursery area for the species, particularly the Bennett's Beach area located north of the Port Stephens estuary (Bruce and Bradford, 2012, Bruce et al., 2013). Juvenile white sharks are predominantly present in the area from August to December each year, where they can be found near to or within the surf zone (Bruce et al., 2013). The aim of the study was to assess the occurrence and size of white sharks through the deployment of stereo-BRUVs along Bennett's Beach. This study demonstrates that stereo-BRUVs are a suitable method for assessing the presence and length of white sharks occurring in a known nursery area in south-eastern Australia.

METHODS

Surveys using stereo-BRUVs were repeated from 19 August to 15 December 2015 along the southern section of Bennett's Beach, Hawks Nest, in the Port Stephens Great Lakes Marine Park (32°40'24.25"S 152°11'25.79"E). Surveys were conducted approximately fortnightly with a total of 22 completed. Of these, six surveys were discarded due to poor visibility caused by extensive algal blooms. For each survey, six stereo-BRUVs were deployed in a straight line, approximately 200 m apart, with the stereo-BRUVs line randomly located between 32°40'14.08"S 152°11'20.31"E and 32°41'33.60"S 152°11'59.43"E. Cameras were deployed for a set time of 5 hours, from approximately 0900 to 1400, in depths of 7 – 14 m, at a distance of 100 – 300 m from shore.

The stereo-BRUVS consisted of twin Canon HG25 video cameras with wide angle lens and long-life batteries in custom-made SeaGIS Pty Ltd. housings (http://www.seagis.com.au). Cameras were calibrated following methods detailed by

(Harvey and Shortis, 1998). Stereo-video is a proven method for accurately measuring fish lengths (Harasti and Malcolm, 2013, Harvey et al., 2012a). Camera calibrations were checked regularly with scale bars of known lengths to ensure measuring accuracy. An estimate of standard error was obtained by taking five individual measurements of a fixed length scale bar (2.31 m) at a distance of 5 m from the camera for each of the six stereo-BRUV units. The standard error for the six cameras combined was mean 0.7 cm ± 0.4 cm S.E. Approximately 1 kg of crushed pilchards (*Sardinops neopilchardus*) was mashed into a plastic mesh bait bag attached to the end of each bait-pole (~1.5 m distance from the frame) to attract sharks to the field of view. At a distance of 5 m from the camera, which was considered the maximum distance that sharks could be accurately measured based on visibility, the field of view was 6.5 m horizontal and 3.8 m vertical.

After each five-hour deployment, video cameras were retrieved and downloaded with videos converted into avi files using Wondershare Video Converter (www.wondershare.net) for analysis. Videos were analysed using SeaGIS EventMeasure software (version 3.1), with 30 hours video time recorded for each survey (6 cameras x 5 hours set time), equating to 510 hours of usable video footage. Where possible, all sharks sighted were uniquely identified using various stereo length measurements and the natural markings along the flank, caudal fins (Domeier and Nasby-Lucas, 2007, Robbins and Fox, 2013) and inside of the pectoral fins. The snout-to-first dorsal fin, dorsal fin-to-precaudal, fork (FL), precaudal (PCL) and total length (TL) were measured using SeaGIS EventMeasure. Total lengths estimates were derived from the mean of all length measurements obtained for each individual shark when the shark could be fully measured. If a total length estimate was not possible, as often the top of the caudal fin was outside the frame of the video screen, a total length was estimated using a pre-caudal length regression for juvenile white sharks of TL=1.251 PCL + 5.207 (Cliff et al., 1996).

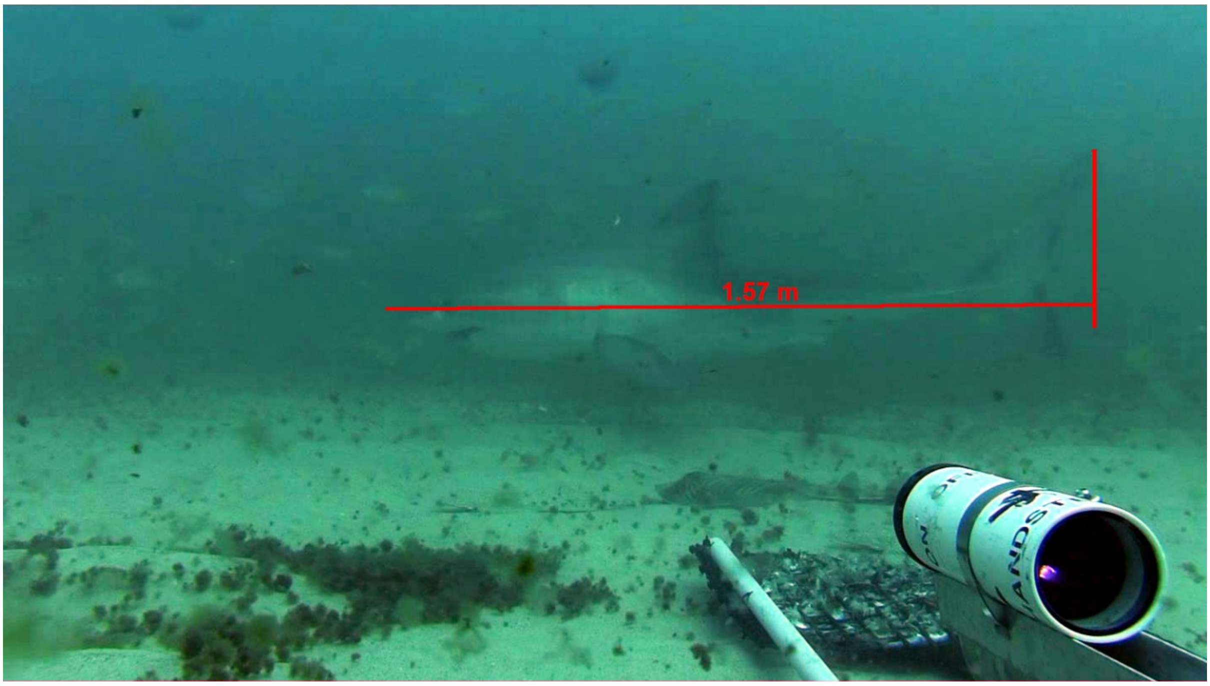
Each time a shark was sighted, the time of its first and last pass through the stereo-BRUV field of view was recorded. A 'sighting' of a shark was defined as a shark passing within the video field of view within a four minute period of a previous pass. Four minutes was determined as the sighting time as this was the minimum amount of time between two different sharks on the same stereo-BRUV. If a shark was sighted after four minutes it was recorded as a new 'sighting'. During the four minute period it was assumed to be the same shark unless obvious natural markings or size indicated otherwise. It was not feasible to determine the sex of each shark due to the restricted visibility from the algae and it was difficult to determine the presence of claspers on the juvenile sharks.

RESULTS

Thirty-four separate *C. carcharias* observations were recorded by the stereo-BRUVs (see examples: Fig. 1). Twenty-two sharks were individually identified from a combination of natural markings and size estimates. Of the individually identified sharks, none were seen on subsequent survey days and individuals were only ever recorded on the one stereo-BRUV each day (i.e. they were never detected on the other five stereo-BRUVs deployed at the same time). Additionally, no two sharks were observed during the same sighting period (within the 4 minute sighting period). The number of individually identified sharks sighted per day ranged from 1 to 8 and there were no sharks sighted on seven of the 16 survey days. The highest number of sightings occurred in October (Fig. 2), with sightings declining in November and December.

a.

b.



c.

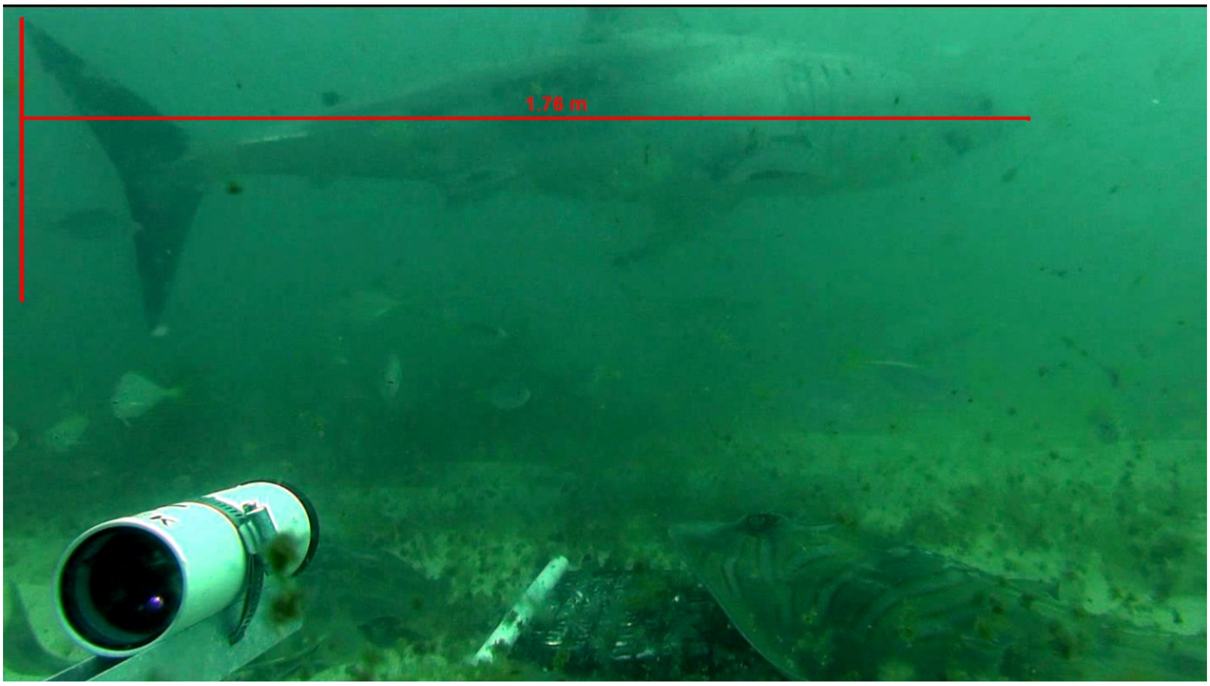


Fig. 1a-c. Examples of white sharks detected on stereo-BRUVs off Hawks Nest in NSW with associated total length (m) derived from stereo length measurements.

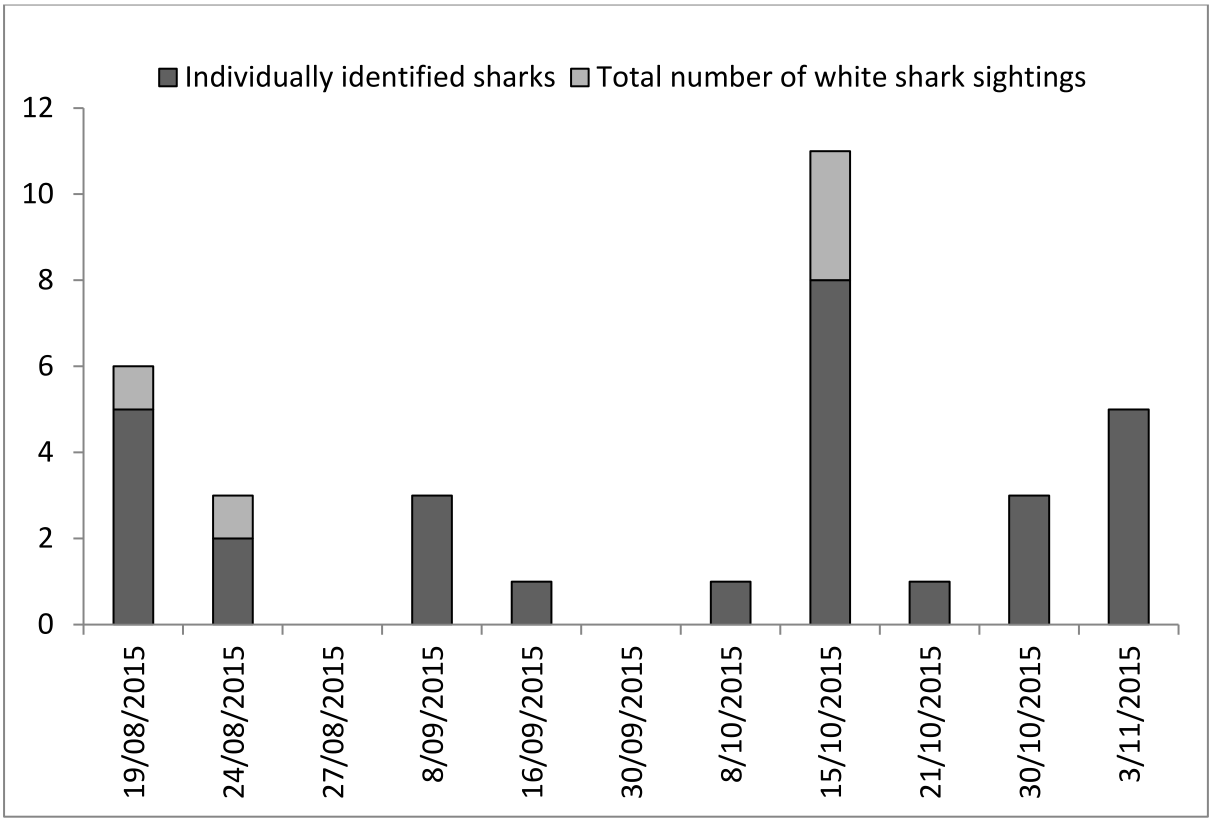


Fig. 2. The number of sharks individually identified (black bar) using natural markings / lengths and the total number of sharks sighted per day (grey bar) on

stereo-BRUV surveys. Five surveys conducted from 4/11/2015 to 15/12/2015 not shown on graph as zero sharks sighted.

At least one measurement was obtained for 31 out of the 34 sightings. No measurements were recorded for two sightings due to stereo camera malfunction and one where water visibility was too poor. Total length was estimated for 22 sharks. Estimates of length ranged from 1.50 to 2.46 m (TL; SeaGIS precision estimates – 0.37 to 1.19 cm) (Fig. 3) with a mean size of 1.91 m ± 5.2 cm. There was no significant difference in size (TL) between sharks sighted as the 'season' progressed taking comparisons between Aug-Sept and those in Oct-Nov (Single factor ANOVA: $F_{1, 20} = 0.21$; $P > 0.05$).

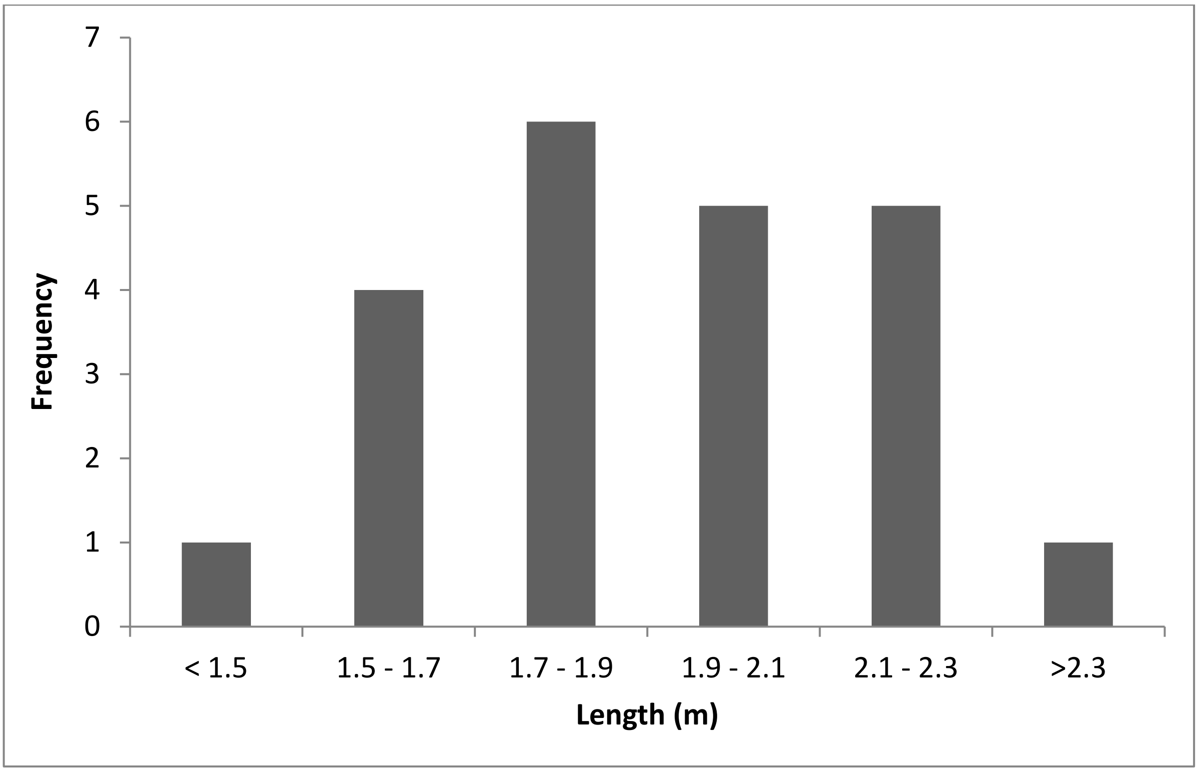


Fig. 3. Frequency of different length measurements obtained for *C. carcharias* sighted on stereo-BRUVs.

The mean time to first arrival for a shark to be sighted on the stereo-BRUVs after deployment was 148 mins ± 15 mins. However, there was considerable variability in first arrival time which ranged from 15 mins to 299 mins. The mean length of time that sharks spent at the same stereo-BRUV was 4.10 mins ± 1.2 mins with the longest time being 23 mins; this individual visited the same stereo-BRUV four times within a 118 min period of the deployment. This latter individual made 22 passes in front of the camera, whereas the mean number of passes across all sharks was 7.5 ± 1.3. Even though several sharks were found to spend considerable time around a stereo-BRUV, there were no attempts by any sharks to feed on the bait bag.

DISCUSSION

This study demonstrates that stereo-BRUVs can be an effective sampling tool for detecting juvenile white sharks in coastal environments, identifying individuals and measuring their size. This indicates that the use of stereo-BRUVs may provide a means for estimating shark abundance. A limited number of coastal nursery areas have been identified for white shark populations across their global range including California (Lowe et al., 2012, Lyons et al., 2013), Mexico (Domeier and Nasby-Lucas, 2013, Santana-Morales et al., 2012), eastern US (Casey and Pratt Jr, 1985, Curtis et al., 2014), South Africa (Dicken and Booth, 2013) and eastern Australia (Bruce and Bradford, 2012). Nursery areas may offer significant advantages for estimating trends in white shark populations over other aggregation sites, such as pinniped colonies, where site fidelity, carrying capacity and shark behaviour complicate the estimation of abundance and its interpretation for a wider population-scale analysis (Burgess et al., 2014, Chapple et al., 2011, Sosa-Nishizaki et al., 2012).

Juvenile abundance in nursery areas, including young of the year sharks, may provide an estimate of recruitment trends, as has been conducted for juvenile shortfin mako (*Isurus oxyrinchus*) and blue (*Prionace glauca*) sharks (Runcie et al., 2016), and hence a more direct estimate of adult white shark population status than monitoring older sub-adults at feeding aggregation sites. Sub-adult sharks are known to show fidelity and residency patterns to specific pinniped colonies making the assessment of population-scale abundance and trends difficult to interpret from site specific monitoring (Burgess et al., 2014, Sosa-Nishizaki et al., 2012) and estimates of survival to such stages are poor or non-existent (Kanive et al., 2015), making the inference to adult population status more difficult. The limited number of nursery areas identified across white shark populations suggests that site selectivity by sharks is less likely to complicate abundance estimates across these early life history stages provided survey methods to do so can be identified (Bruce and Bradford, 2012). Previous attempts to monitor juvenile white sharks in coastal nursey areas have come from aerial surveys. However, aerial surveys are inherently expensive, limited to certain environmental conditions, can be subject to a number of observational biases and require a variety of correction factors before data can be appropriately scaled for estimates of abundance (Bruce et al., 2013, Dicken and Booth, 2013, Robbins et al., 2014).

Stereo-BRUVs surveys may offer a more cost effective alternative to aerial surveys in white shark nursery habitats. The ability to individually recognise juveniles may offer a mark-recapture-style method of estimating abundance (Seber, 1982) provided assumptions of equal chance of sighting/resighting and regarding the veracity of photographic identification can be met, or at least the errors associated with these can be accounted for (Burgess et al., 2014, Sosa-Nishizaki et al., 2012). A further opportunity for mark-recapture estimates of juvenile abundance within such nursery areas is to combine stereo-BRUVs surveys with acoustic tagging. Sharks can be individually identified through their unique acoustic tag ID which allows identification throughout the life of the tag (~ 10 years) and their 'resighting' used in a concurrent and supplementary mark-recapture format. The Port Stephens nursery area has been the site of extensive acoustic tagging of juvenile white sharks with the annual return of individuals to the Bennett's Beach area (Bruce and Bradford, 2012). Deploying stereo-BRUVs within an acoustic receiver array may offer the ability to identify individually tagged sharks as they present in the survey zone and distinguish them from untagged animals at this and other nursery areas where tagging programs are in place.

Stereo-BRUVs also offer the opportunity to measure the length of individual white sharks in nursery areas and monitor their growth rates over time. Age and growth in white sharks is a debateable topic at present with recent estimates based on bomb radio-carbon dating suggesting much slower growth and higher longevities (Andrews and Kerr, 2015, Hamady et al., 2014, Christiansen et al., 2016, Natanson and Skomal, 2015) than more traditional, but un-validated, vertebral band-pair counts (Cailliet et al., 1985, Wintner and Cliff, 1999). The propensity for individual juvenile white sharks to revisit the Bennett's Beach area in successive years (Bruce and Bradford, 2012) offers the prospect of annual measurements of length providing information on individual growth and hence selection between such conflicting growth models. Estimates of total length for juvenile white sharks in this study suggest that stereo-BRUVs provided a high degree of precision. However, the accuracy of these measurements was difficult to assess as no tagged shark, that had been captured and measured prior to detection by a stereo-BRUV, was recorded during this trial. To improve length measurements of sharks in the future, it is recommended that the stereo-BRUVs be raised higher off the seafloor, by at least 30 cm, as this would reduce the problem where the top of the caudal fin was occasionally cut off in the top of the video frame.

It was found that time for sharks to first appear on the stereo-BRUVs varied considerably. Several studies have been conducted to determine the most appropriate set time for BRUVs (Gladstone et al., 2012, Harasti et al., 2015); however, these studies have focused on set times for fish species and no studies have assessed the most suitable set time to detect shark species. Given that the mean time of first detection was 148 mins, a camera record time of 5-6 hours should be sufficient for detecting the presence of white sharks. Additionally, given that individual sharks were only ever detected on a single stereo-BRUV, deploying the stereo-BRUVs at a distance of 200 m apart should be used as a minimum spacing between units to increase the likelihood of detecting sharks in the area of interest.

It is evident from this study that stereo-BRUVs are a useful method to detect white sharks, and that stereo-BRUVs provide a useful non-intrusive method to obtain estimates of length and assess presence of white sharks in the region. The use of stereo-BRUVs to assess changes in fish assemblages, species abundance and size over time is now a commonly accepted practise (Mallet and Pelletier, 2014). Stereo-BRUVs could be a useful tool in future studies to determine relative abundance of white sharks in a given area, allow temporal and/or spatial comparisons to be made and assess if size of white sharks are changing over time.

ACKNOWLEDGEMENTS

This project was supported with funding from the Australian Government's National Environmental Science Programme. Research was undertaken in accordance with NSW Department of Primary Industries Animal Care and Ethics Committee permit 12/07. Thanks to NSW DPI technical staff Brett Louden and Peter Gibson who assisted with deployment and retrievals of BRUVs, Dr Hamish Malcolm and two anonymous reviewers for comments on initial manuscript and to Jim Seager from SeaGIS for advice regarding stereo-BRUVs.

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