National Environmental Science Programme

Estimating growth in juvenile white sharks using stereo baited remote underwater video systems (stereo-BRUVs)

Final Report - May 2019

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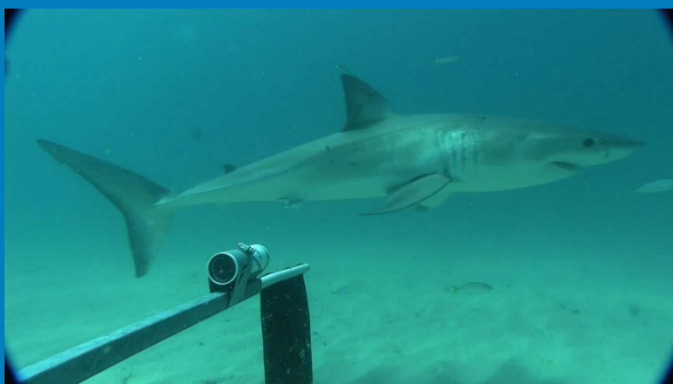
Project A3 – A national assessment on the status of white sharks

Milestones 3 and 16, Research Plan v3 (2017)



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Important Disclaimer

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EXECUTIVE SUMMARY

This report provides a summary of a two-year study using stereo baited remote underwater video stations (stereo-BRUVs) to assess the viability of using this sampling method to obtain estimates of growth in juvenile white sharks. Surveys were conducted off Bennetts Beach, Hawks Nest, on the New South Wales mid-north coast monthly from January 2017 to December 2018 with six stereo-BRUV units deployed three times each month. A total of 2,160 hours of video footage was collected and analysed for the presence of white sharks.

Over the two year period, a total of 142 white shark sightings were recorded on the stereo-BRUVs. The abundance of white sharks observed on the stereo-BRUVs was highest in November with an average of 4.3 ± 1.1 sightings per day. Overall significantly fewer sharks were sighted during autumn (March to May) than in other seasons, with no significant difference in sightings detected among the other seasons. The average size of white sharks observed on stereo-BRUVs was 191.1 cm ± 2.4 cm, with no significant difference in average size detected between seasons.

A total of seven white sharks tagged with acoustic transmitters were observed on the stereo-BRUVs. Of these, the largest observed growth in a white shark occurred for a shark first tagged in October 2015 at 198 cm (fork length) that was remeasured at 259 cm in November 2017, giving an increase in length of 61 cm over the ~700 day period between tagging and stereo-BRUV measurement. This study demonstrates that stereo-BRUVs are a useful sampling method for recording the presence of white sharks in an area, and that stereo-BRUVs provide a useful non-intrusive method to obtain estimates of shark length and growth.

1. INTRODUCTION

The efficacy of close kin mark recapture (CKMR) analyses in estimating adult population size and key parameters for modelling population trends are dependent on knowing the age of sampled animals. Obtaining and validating age-growth information normally requires lethal sampling that is unsuitable for protected species. Age and growth estimates in white sharks (*Carcharodon carcharias*) are shown to vary between studies with recent estimates based on bomb radio-carbon dating suggesting much slower growth and higher longevities (Hamady et al. 2014, Andrews and Kerr 2015, Natanson and Skomal 2015, Christiansen et al. 2016) than more traditional, but un-validated, vertebral band-pair counts (Cailliet et al. 1985, Wintner 1999). Validating and thus identifying which growth model to use represents a major impediment to CKMR analyses which currently assume (un-validated) Australian-US models of juvenile white shark growth are correct.

A recent study of the population abundance of adult white sharks along the east coast of Australia and New Zealand indicated that there were 280 – 650 adult individuals (Hillary et al. 2018). Improved data on key demographic parameters for juvenile white sharks, such as growth, would help strengthen population dynamics modelling (Hillary et al. 2018).

Obtaining estimates of growth can be difficult as it generally involves recapture of tagged animals and remeasuring. Subsequent recaptures can put stress on animals and cause harm, particularly in fishes (Kohler and Turner 2001, Pine et al. 2003). The use of stereo-camera systems in water is considered a non-harmful method for collecting growth data if the individuals can be individually identified. Stereo-camera systems have been demonstrated to be a proven method for obtaining accurate length estimates for fishes (Harvey et al. 2002, Davis et al. 2015). Stereo-BRUVs have been successfully employed to obtain length estimates for shark species (Goetze and Fullwood 2013, Santana-Garcon et al. 2014), including white sharks (Harasti et al. 2016). Estimates of total length for juvenile white sharks in the Harasti et al. (2016) study suggest that stereo-BRUVs provide a high degree of precision.

The use of stereo-BRUVs provides the opportunity to measure the length of individual white sharks in nursery areas and monitor their growth rates over time. A previous study using stereo-BRUVs indicated that it was a useful method for observing the abundance of juvenile white sharks within a known nursery area, Bennetts Beach within the Port Stephens-Great

Lakes Marine Park on the mid-north coast of New South Wales (NSW) (Harasti et al. 2016). The propensity for individual juvenile white sharks to revisit the Bennett's Beach area in successive years (Bruce and Bradford 2012, Bruce et al. 2019) offers the prospect of repeated measurements of length providing information on individual growth and hence selection between such conflicting growth models.

This study used stereo-BRUVs to test if growth increments could be reliably measured for tagged juvenile white sharks. Tagged and measured juveniles were monitored in their known nursery area of Bennetts Beach in NSW with sharks being individually identifiable via their internal acoustic tags. In addition, data were collected to assess the suitability of stereo-BRUVs data to assess the size frequency of juvenile white sharks present in the monitored area over a two year period and their local abundance to be assessed over 24 months.

2. METHODS

Surveys using stereo-BRUVs were repeated from 01 January 2017 to 31 December 2018 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, Figure 1). Surveys were conducted three times every month, with a minimum of two days between sampling periods in a month with sampling generally occurring once a week. There were a total of 72 survey days (36 each year).

For each survey, six stereo-BRUVs were deployed in a line, approximately 400 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 (Figure 1). Cameras were deployed for a set time of five hours, from approximately 0900 to 1400, in depths of 7 – 14 m, at a distance of approximately 500 m from shore.

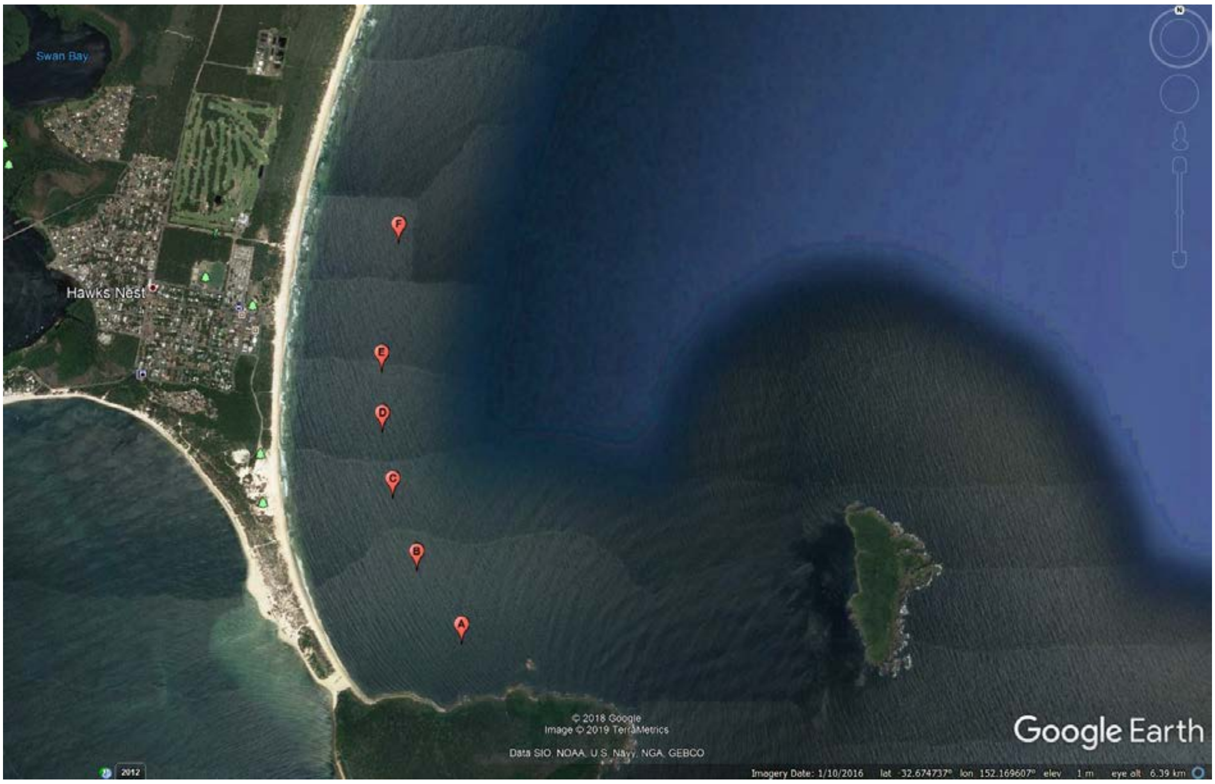

Figure 1: Map of study area with example of positioning of stereo-BRUVs off Bennetts Beach, Hawks Nest, New South Wales.

Stereo-BRUV cameras (Figure 2) consisted of 2 x Canon HG25 video cameras with wide angle lens and long-life batteries in custom-made SeaGIS Pty Ltd. housings (http://www.seagis.com.au). A plastic mesh bait bag was attached to the end of each stereo-BRUV (~1.5 m distance from the frame) and filled with ~1 kg of crushed pilchards (*Sardinops neopilchardus*).

Figure 2: Photo of stereo-BRUVs system prior to deployment.

An acoustic receiver (VR2W: www.vemoco.com) was placed on each stereo-BRUV unit to detect the acoustic signal from tagged white sharks, with the acoustic receiver being timed synchronised to the stereo-BRUV cameras. This allowed re-measurement of sharks' lengths for sharks previously measured during tagging (

Figure 3).

To ensure camera calibrations were accurate, cameras were checked regularly, using a 2.31 m scale bar. To gain an understanding of potential measurement error, five individual measurements were taken of the scale bar, at a distance of 5 m, for each of the six stereo-BRUV units. The standard error for the six cameras combined was 0.7 cm ± 0.4 cm (mean ± S.E.). At 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.

Figure 3: Juvenile white shark observed on stereo-BRUV.

Following each five-hour deployment, BRUVs were retrieved and video footage analysed by examining footage from the left video camera attached to a monitor. With 30 hours of video recorded for each survey (6 cameras x 5 hours set time), this equated to 2,160 hours (30 hours x 72 surveys) of usable video footage to review. In the review process whenever a shark was observed, videos clips for both left and right cameras (stereo video pair) were downloaded and converted to AVI format using Xilisoft Video Converter Ultimate (www.xilisoft.com).

Each stereo video pair was subsequently analysed using SeaGIS EventMeasure software (version 3.1) to determine shark fork lengths in cm (Figure 4). Fork lengths were derived from the mean of all fork length measurements obtained for each individual shark. In this study, fork lengths were used instead of total length as it was often found that the tip of the tail was cut off from the screen whereas the fork length could be estimated. Where the shark could not be fully measured in a single image, fork length estimates were obtained by summing measurements obtained from sequential images of sections of the shark body (e.g. fork length = nose–dorsal length + dorsal–fork length). Where possible, all sharks were uniquely identified using the above stereo length measurements and the natural markings along the flank, caudal fins and the inside of the pectoral fins (Domeier and Nasby-Lucas 2007, Robbins and Fox 2013, Harasti et al. 2016).

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 used as the sighting time as this was the minimum time between sightings of two different sharks on the same stereo-BRUV in previous research (Harasti et al. 2016). 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 due to difficultly determining the presence of claspers on the juvenile sharks.

Data were analysed using analysis tools from the PERMANOVA+ software package (Anderson et al. 2008, Clarke and Gorley 2015). Single-factor PERMANOVA analyses were conducted to test for significant differences among seasons using univariate data for frequency of shark sightings for each sampling day and shark fork length for each measured shark. Pairwise PERMANOVA analyses were then conducted, where significant differences were detected, to further examine significant effects among seasons.

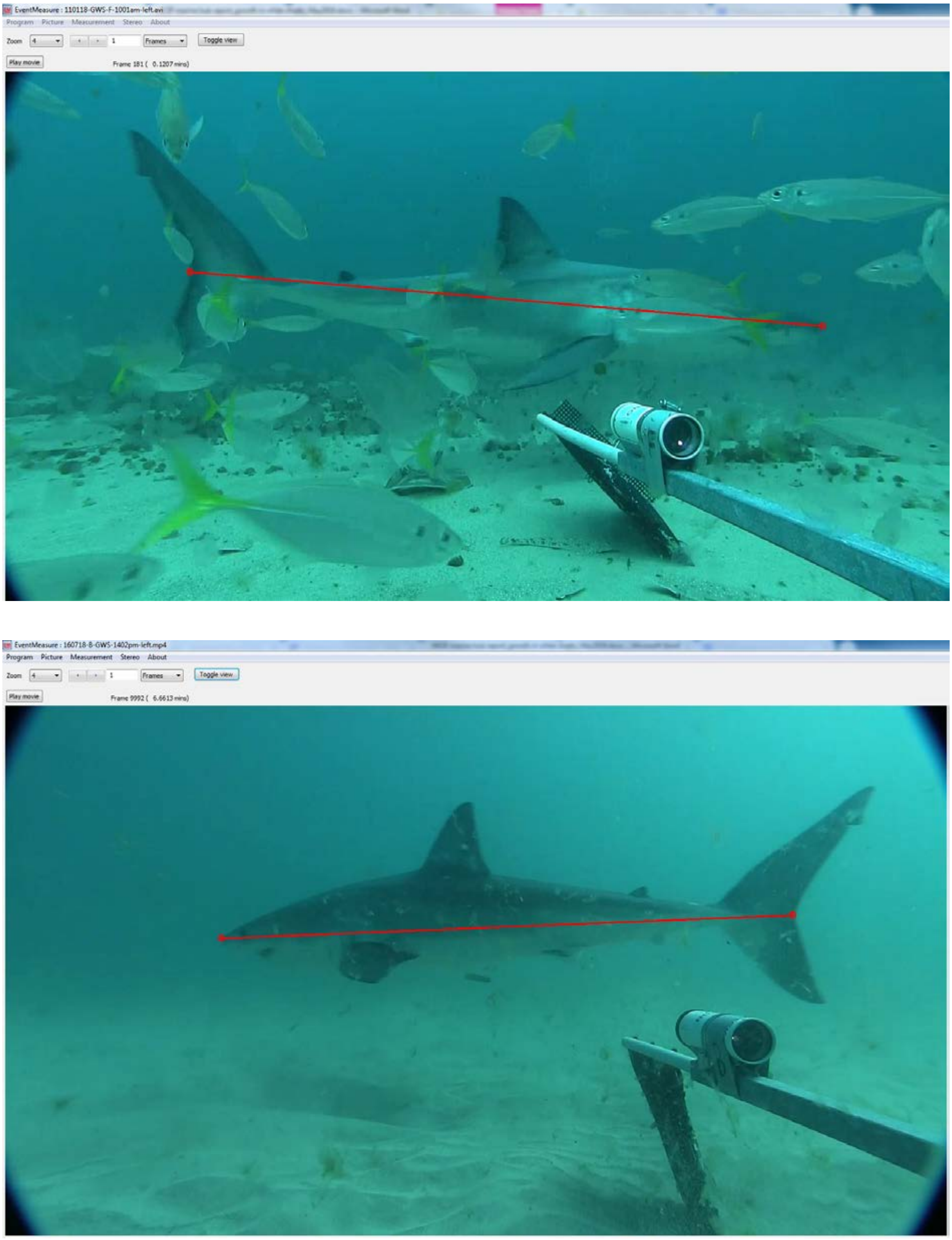

Figure 4: Two examples of white shark measurement in Event Measure. The top shark measured 1.65 m and the bottom shark measured 1.70 m (Fork Lengths).

3. RESULTS

From January – December 2017, a total of 70 white shark sightings occurred across the 36 days that stereo-BRUVs were deployed, with a further 72 sightings recorded in 2018. In 2017 the peak month for sightings was November, with an average 4.7 sightings per day (Figure 5). There was a maximum of eight sightings in a single day on 24/1/17 and 9/11/17, while no sightings were recorded from March to May 2017 inclusive (Figure 5).

In 2018, peak sightings again occurred in November (avg. 4.0, max 7 sightings, Figure 6), while 2018 also had no shark sightings in March, as per 2017. However, in 2018 there was a much lower number of sightings in January and sightings increased earlier in autumn in 2018 than in 2017 (Figure 6), indicating that sighting frequency was variable between years, potentially due to underlying differences in ecological driving forces (e.g. water temperature).

Significant seasonal variations in the abundance of white sharks were detected at Bennetts Beach (Figure 7, $P = 0.003$) with significantly lower sightings in autumn than in all other seasons ($P < 0.003$, all tests). No significant differences were detected in the frequency of sightings among the other seasons (Figure 7, $P > 0.077$, all tests).

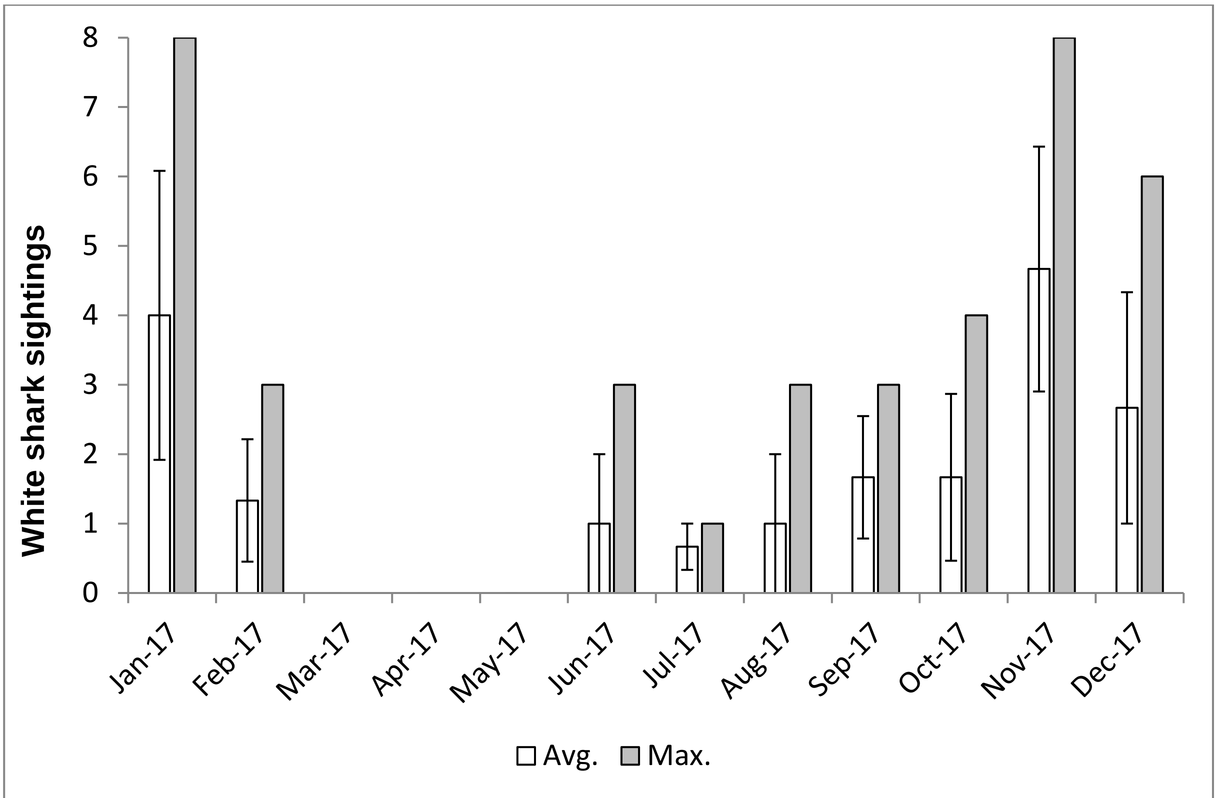

Figure 5: BRUV average sightings per day (± S.E) and maximum sightings per day for 2017

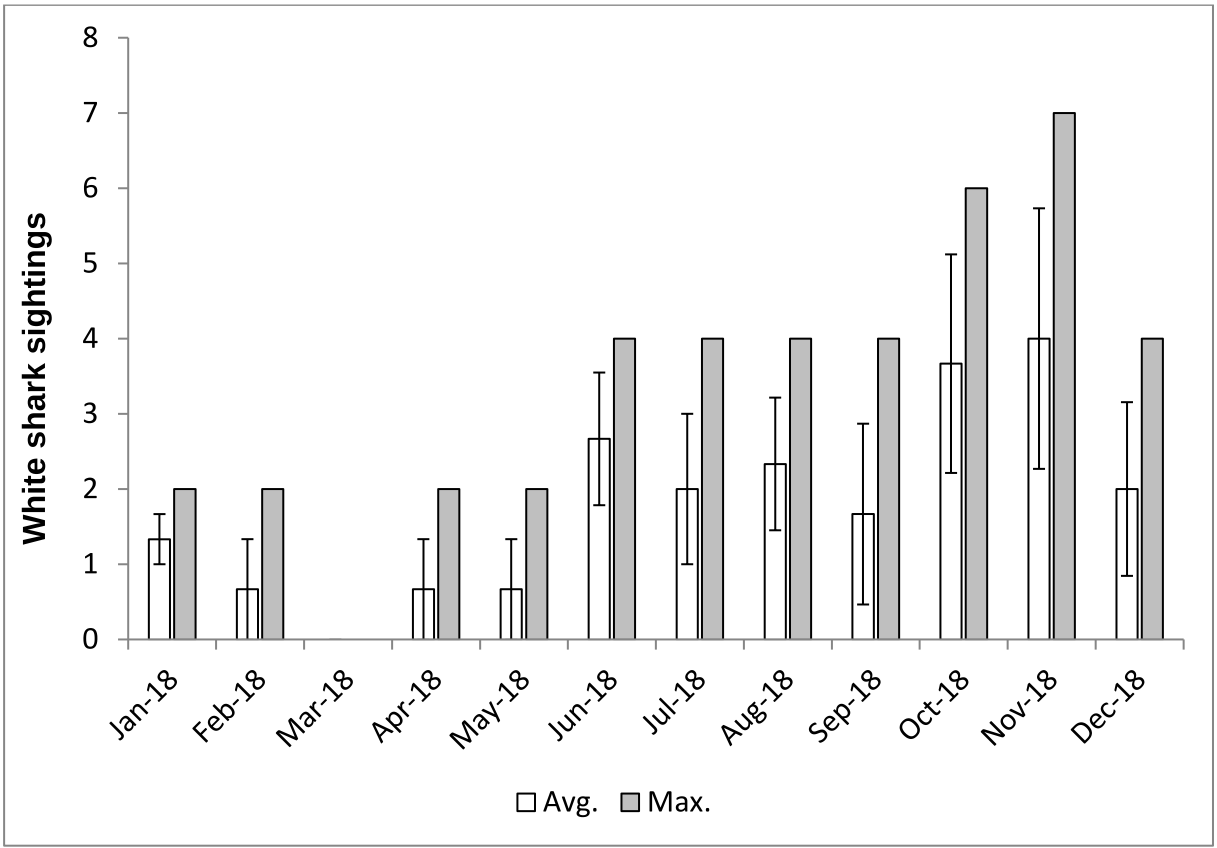

Figure 6: BRUV average sightings per day (± S.E) and maximum sightings per day for 2018

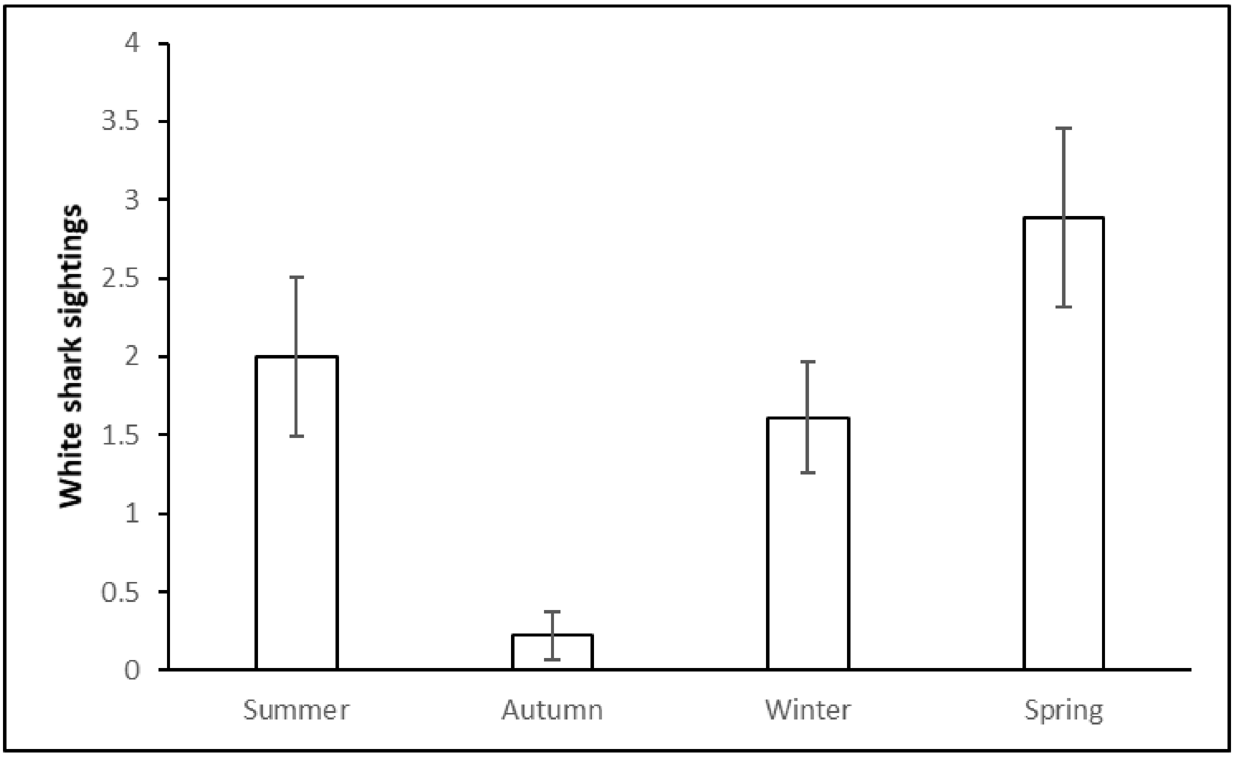

Figure 7: BRUV average sightings per day (± S.E) by season for 2017/2018

3.1 Size-Frequency

Fork lengths for white sharks measured in Eventmeasure from stereo-BRUVs in 2017/2018 ranged from 1.47 m to 2.59 m, with an average of 1.91 m ± 2.4 cm (mean ± S.E.), with the highest number of sharks (22) occurring in the 1.90–1.99 m size class (Figure 8). Overall no significant difference in average size of sharks was detected between seasons (Figure 9, P = 0.915).

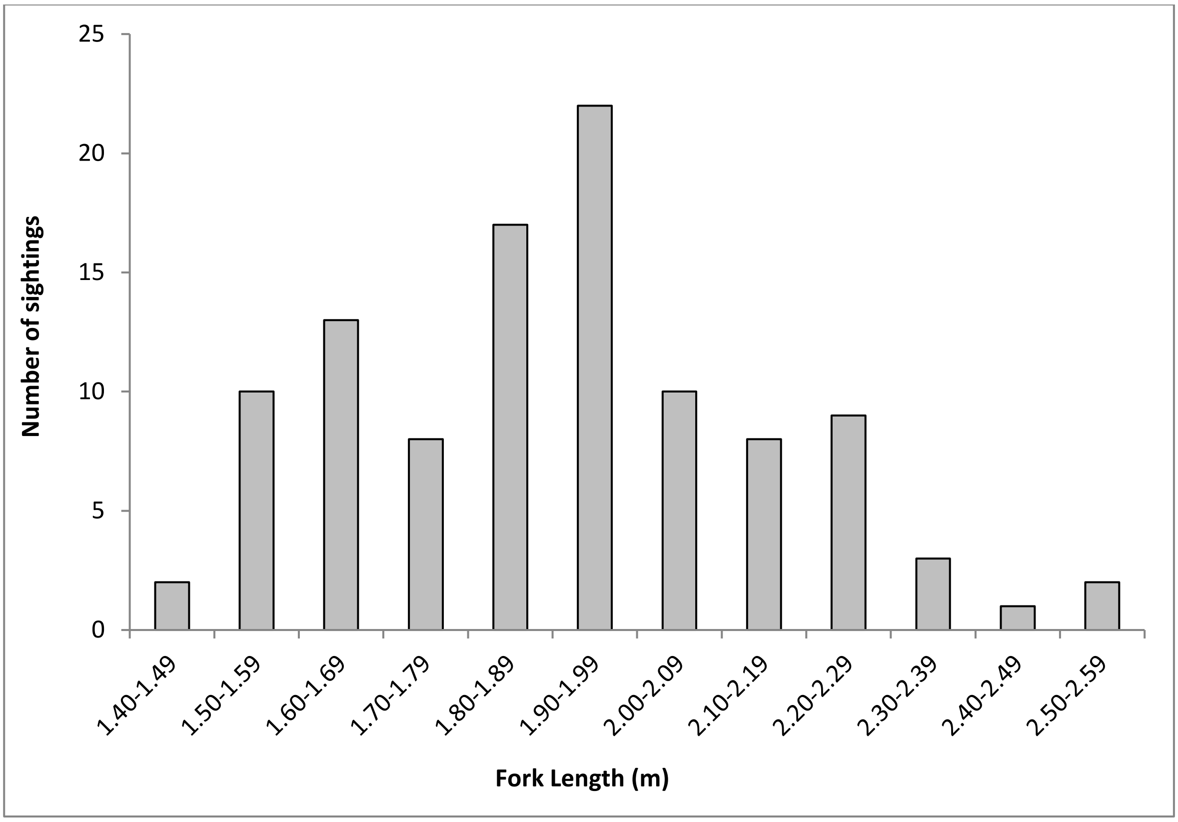

Figure 8: Size class distribution for white sharks measured by stereo-BRUVs at Bennetts Beach (2017/2018)

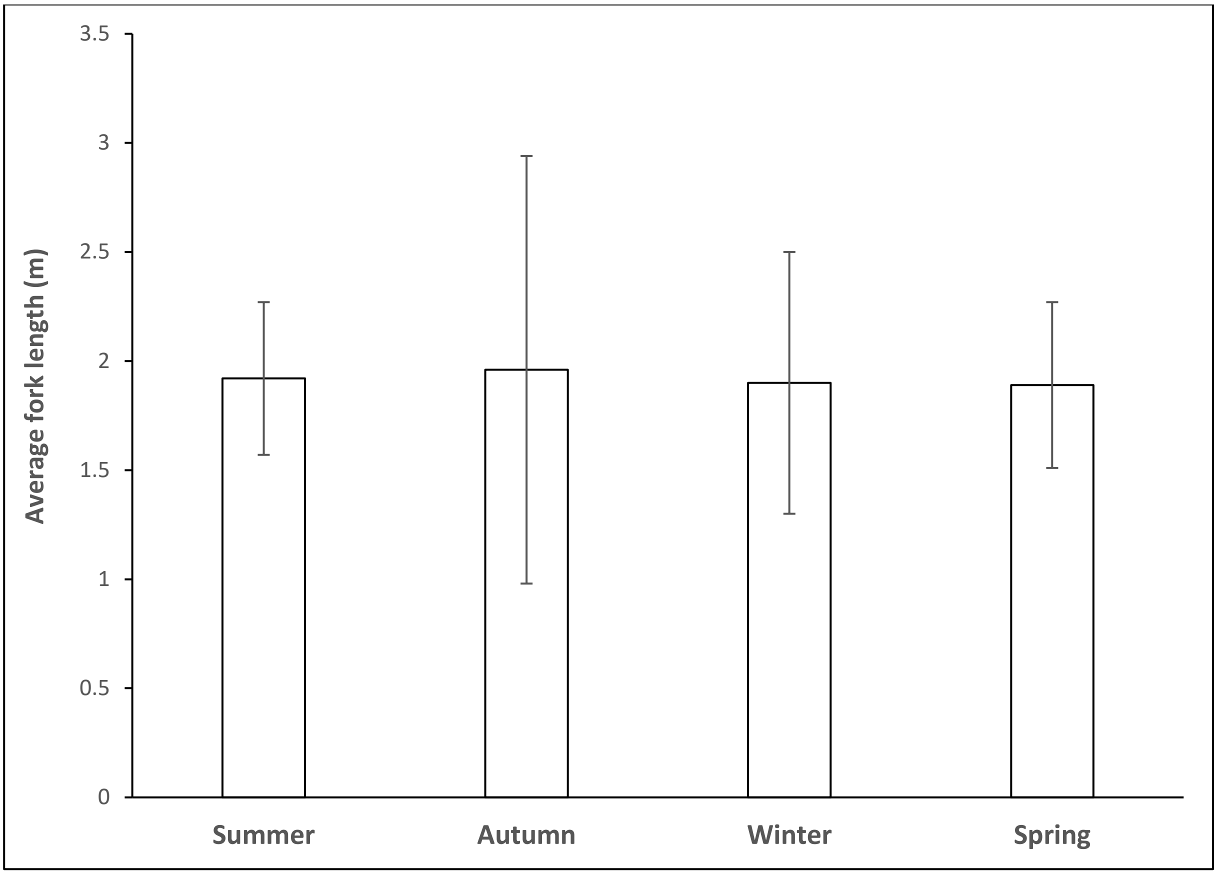

Figure 9: Variation in fork length (mean ± S.E.) for white sharks at Bennetts Beach by season

3.2 Growth

In 2017, two tagged white shark were resighted and re-measured using stereo-BRUVs (Shark Acoustic Tag IDs: 30008, 16483). Shark 30008 was tagged on 30 Oct 2015 (FL = 1.98 m) and was re-measured by a single BRUV on 12/10/17 (A = 2.59 mm) and by two stereo-BRUVs on 9/11/17 (stereo-BRUV B = 2.59 m, C = 2.54 m,
Table 1). During the 713–741 days between these measurements the fork length for this shark increased by an average 59.6 ± 1.8 cm. This contrasts with shark 16483 where the re-measured fork length decreased by 7.7 cm in the 86 days between tagging and BRUV measurement (Table 1).

In 2018, there were six tagged animals resighted on the stereo-BRUVs with useable growth measurements obtained from five animals (Table 1). There were high levels of variability in growth rates with five measurements, for sharks 12966, 13835 and 18748, indicating that shark lengths increased between tagging and BRUV measurement, while three measurements, for sharks 13861 and 16483, indicated that shark lengths decreased between tagging and BRUV measurement (Table 1, Figure 10).

Table 1: Tagged sharks resighted on stereo-BRUVs in 2017/2018. Sightings in **BOLD** indicates sharks where body length (cm) has decreased between measurements with time.

Date sighted on BRUV	Tag ID	Date tagged	Fork length when tagged	Fork length from BRUV	Growth estimate
12/10/17	30008	30/10/15	1980	2593	61.3 cm in 713 d
09/11/17	30008	30/10/15	1980	2595	61.5 cm in 741 d
09/11/17	30008	30/10/15	1980	2541	56.1 cm in 741 d
09/11/17	**16483**	**15/08/17**	**2170**	**2093**	**-7.7 cm in 86 d**
26/06/18	12966	23/11/17	2360	2380	2.0 cm in 215 d
11/07/18	13835	24/08/17	1870	2006	13.6 cm in 321 d
11/07/18	13835	24/08/17	1870	2038	16.8 cm in 321 d
09/11/18	**13861**	**07/10/17**	**2100**	**1996**	**-10.4 cm in 398 d**
04/12/18	16468	01/08/17	2220	N/A	N/A
31/10/18	**16483**	**15/08/17**	**2170**	**1960**	**-21.0 cm in 442 d**
16/11/18	**16483**	**15/08/17**	**2170**	**1951**	**-21.9 cm in 458 d**
21/06/18	18748	24/10/17	1590	1851	26.1 cm in 240 d
21/06/18	18748	24/10/17	1590	1837	24.7 cm in 240 d

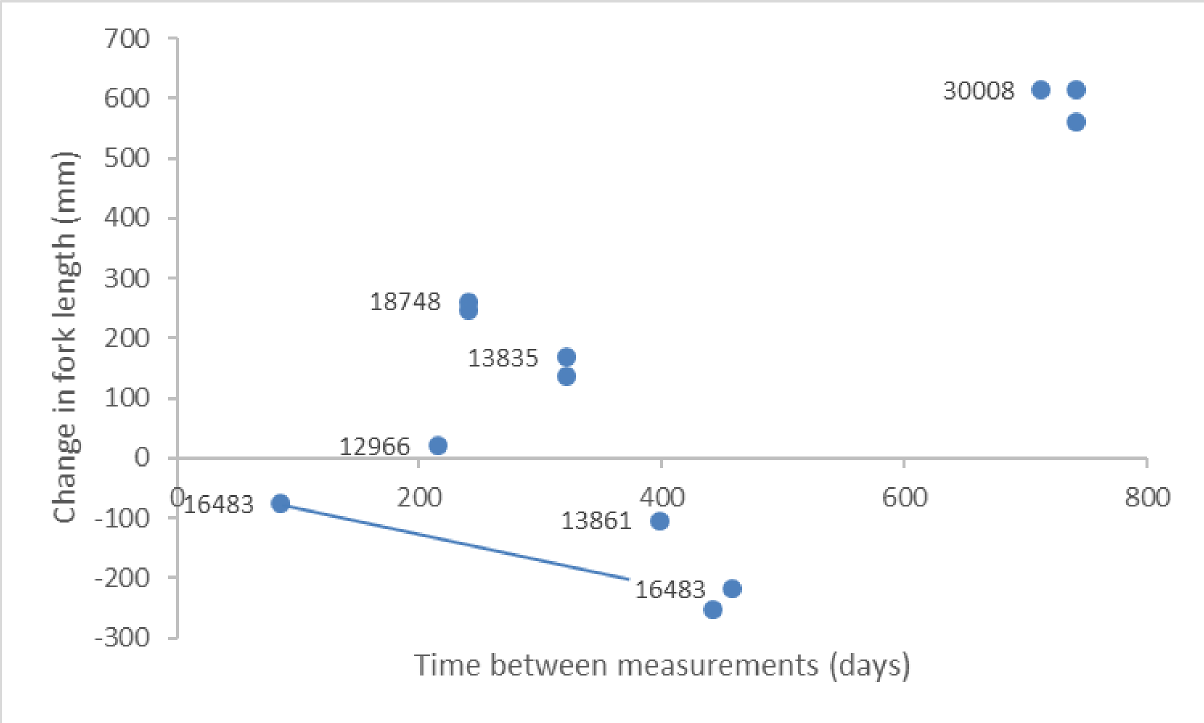

Figure 10: Change in white shark fork length between tagging and BRUV measurements. Line indicates reducing fork length of shark 16483 between BRUV measurements in 2017 and 2018.

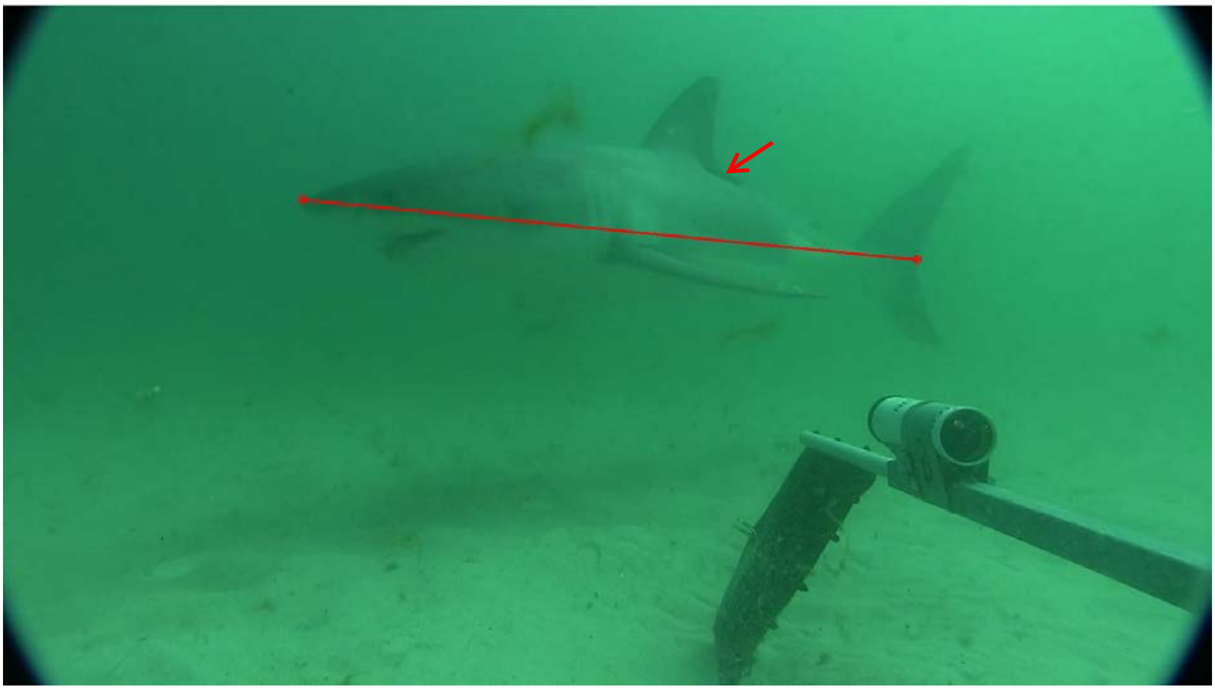

Figure 11: Measuring a tagged juvenile white shark. The external acoustic tag is indicated by the red arrow. Shark (ID: 13835) measured 2.04 m (Fork length).

3.3 Population abundance estimate

There were insufficient recaptures of tagged white sharks to allow any meaningful population abundance analysis.

4. DISCUSSION

This two year stereo-BRUVs study provides a detailed insight into the abundance and size of white sharks that occur in the known juvenile nursery area off Bennetts Beach, New South Wales, Australia. Regular sampling on a monthly basis over the two years allowed seasonal and temporal assessment to be made on when white sharks are likely to occur in the area. It was shown that the peak time for juvenile white sharks to occur along Bennetts Beach is during spring with the month of November being the peak time for abundance recorded for both 2017 and 2018. This is similar to previous findings (Harasti et al. 2017, Bruce et al. 2019) that also found that the occurrence of white sharks in the region was highest during spring. Sharks were absent during the month of March for both years and during autumn shark abundance was significantly lower when compared to other seasons, similar to the findings of (Bruce et al. 2019).

One of the aims of the study was to try to assess population size of juvenile white sharks using mark-resight of tagged animals. Unfortunately a population assessment was not possible as a result of the low resighting of tagged animals (2 in 2017 and 6 in 2018). Between 2008 and 2015, 45 juvenile white sharks had been tagged by CSIRO at either Bennetts Beach or Stockton Beach (located 10 km to the south); however, only one of these animals was detected (Shark ID: 30008) during the two year stereo-BRUVs study, the other detected tagged sharks were from NSW DPI from the associated NSW Shark Management Strategy in northern NSW. It is likely that the sharks tagged between 2008 to 2015 now infrequently visit the Bennetts Beach nursery area and travel much more broadly (Bruce et al. 2019).

Whilst the occurrence of recording tagged individuals on the stereo-BRUVs was low, those tagged animals that were detected were able to be measured when they passed in front of the stereo-BRUVs. As there has been no tagging in the Bennetts Beach region since 2015, it also reduced the likelihood of recently tagged sharks being captured by the stereo-BRUVs. To improve the success of using stereo-BRUVs to estimate growth in white sharks, they should be used in conjunction with a focused tagging program at the same time otherwise the likelihood of detecting tagged animals will be very low.

The effectiveness of using stereo-BRUVs to assess growth in white sharks is feasible; however, there are limitations that need to be recognised. Several of the sharks (n=3) were found to decline in length from the time of initial tagging to resighting on the stereo-BRUVs. This is most likely attributed to error on initial measurement during capture/tagging as it is difficult to get a precise measurement on a shark tethered to the side of the boat during tagging, especially for the larger animals over 2 m. In addition, variations between repeated BRUV length measurements on individual sharks were found to be up to 143 mm, with an average difference between length measurements of 41.6 ± 1.5 mm. This relatively high level of variation between length measurements was caused by a range of factors including; variations in shark body length from body arching during swimming, inherent limitations in BRUV measurement accuracy, and difficulties in precisely locating the nose and tail fork in images when visibility was reduced or when sharks were a substantial distance (>5 m) from the BRUV when measured.

While it would be reasonable to assume that the reported reductions in shark lengths were as a result of measurement inaccuracies, this may not be entirely the case, with several mark and recapture studies reporting negative growth in other shark species including *Carcharhinus tilstoni* and *Carcharhinus sorrah* (Davenport and Stevens 1988), *Sphyrna lewini* (Duncan and Holland 2006) and *Galleorhinus galeus* (Stevens 1990). Of particular note is the white shark in the current study with tag 16483 which was measured by stereo BRUVs on 3 separate occasions, on three different camera systems, with all measurements indicating that the shark length decreased after tagging. Furthermore, there was a substantial decrease in the stereo-BRUV measured length for shark #16483 between 2017 and 2018 (i.e. length reduced by 142–177 mm). Further investigation into negative growth in white sharks warrants further investigation.

A major hindrance to the fieldwork encountered during the study was poor visibility as a result of algal blooms. At least 13 days of sampling were discarded over the two-year study as a result of poor visibility on the cameras. On the days where visibility was considered suitable, there were still problems of measuring sharks as algae moving in front of the camera made it difficult to get point measurements accurately on the nose and tail fork of the sharks.

4.1 Conclusion

The use of stereo-BRUVs to monitor abundance and size of juvenile white sharks has proven to be successful with this study demonstrating the practicality of using stereo-BRUVs over a 24 month period to assess changes in size and abundance within a nursery area. Obtaining estimates of white shark growth was more problematic as there are errors associated with the initial measurement of the shark on capture and the subsequent positioning of the shark when recorded on the stereo-BRUVs. Even with the limitations, several sharks were shown to increase in size from initial capture to resighting on the stereo-BRUVs and with further size data collected from stereo-BRUVs, a better understanding of growth in juvenile white sharks can be made in the future.

4.2 Acknowledgements

In NSW samples were collected under NSW DPI Animal Care and Ethics Committee permit number 12/07-CSIRO and NSW DPI Scientific Collection Permit P07/0099-6.0 (and their precursors). An overarching Animal Ethics Permit was granted by the Tasmanian Department of Primary Industries, Parks, Water and Environment (AEC 22/2015-16). We are grateful to the numerous people that helped out with the research, including but not limited to: Roger Laird, Ben Kearney, Brett Louden, Peter Gibson, Gwen Cadiou, Alice Pidd and Callum Dittes.

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