Assessment of shark sighting rates by aerial beach patrols

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March 2012

Fisheries Final Report Series
No. 132
ISSN 1837-2112

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Published By: NSW Department of Primary Industries
Postal Address: Cronulla Fisheries Research Centre of Excellence, PO Box 21, Cronulla, NSW, 2230
Internet: www.dpi.nsw.gov.au

Cover photograph by W.D. Robbins

ISSN 1837-2112

Note: Previous issues of the 'Fisheries Final Report Series' (ISSN 1837-2112) have been published as follows: (i) No.'s 1 – 66: 'NSW Fisheries Final Report Series' (ISSN 1440-3544); (ii) No.'s 67 – 110: 'NSW Department of Primary Industries – Fisheries Final Report Series' (ISSN 1449-9967); (iii) No.'s 111 – 129: 'Industry & Investment NSW – Fisheries Final Report Series' (ISSN 1837-2112).

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ACKNOWLEDGEMENTS

We wish to thank both the fixed-wing and helicopter staff and crews for their generous assistance with this project. We also thank P. O'Connor and A. Genders for logistical support, D. Collins for valuable statistical advice and S. McGreal for entry of the aerial patrol data. LCDR R. J. Kyle and CPO G. Jesser of the Royal Australian Navy and M. Carr of the Jervis Bay Marine Park are thanked for their support of this project. This project was funded through NSW Department of Primary Industries Shark Meshing (Bather Protection) Program.

EXECUTIVE SUMMARY

Aerial surveys are a recognised technique to identify the presence and abundance of marine animals. However, the capability of aerial observers to reliably sight coastal sharks has not been assessed, nor have differences in sighting rates between aircraft types been examined. In this study we assessed the ability of fixed-wing and helicopter observers to sight 2.5 m artificial shark analogues constructed of marine ply. The use of artificial analogues allowed us to control the depth and spatial distribution of potential sightings while providing a realistic visual image for aircrew observers. Analogues were traced from the silhouette of a white shark, with some of the heads modified to represent tiger sharks and hammerhead sharks. The depth at which the shark analogues could be seen was very shallow, averaging only 2.5 m and 2.7 m below the water surface for fixed-wing and helicopter observers, respectively. Substratum depth and analogue head type did not affect sighting rates. A succession of shark analogues was then deployed at ~2 m depth in a 5 km grid, and their sightability to observers in both aircraft assessed through a series of transects flown up to 500 m distant. Low overall sighting rates of only 12.5% and 17.1% were recorded for fixed-wing and helicopter observers, respectively. Helicopter observers had consistently higher success rates at sighting analogues up to a distance of 250 m, however neither aircraft observers sighted more than nine percent of analogues deployed greater than 300 m from their flight paths. Environmental observations showed that the helicopter observations were more affected by air and sea conditions, while the range of water turbidities recorded during the study had no effect on sighting rates of either aircraft observers. We conclude that aerial observers have limited ability to detect the presence of submerged animals such as sharks, especially when the sharks are deeper than 2.5 m, or more than 300 m distant from the aircraft's flight path. This raises serious concerns about the utility of programs such as aerial beach patrols as a warning system for sharks. Examination of sighting records from 20 actual coastal aerial patrols confirmed this concern, with very low shark sighting rates (0.69 – 1.18 sharks 100 km^{-1}), likely underestimating the presence of many shark species known to occur in the area.

1. BACKGROUND

1.1. Aerial sightings of sharks

Aerial surveys using helicopter and fixed-wing aircraft have been used to estimate the presence and abundance of terrestrial and marine animals for many years. Terrestrial surveys have focused on large quadrupeds such as moose, oryx, elk, deer, horses and zebras (Anderson & Lindzey 1996, Freddy *et al.* 2004, Krueger *et al.* 2007, Dawson & Miller 2008, Gilbert & Moeller 2008, Parker *et al.* 2011), although abundances of kangaroos, goats, emus and smaller birds have also been assessed (Hone & Short 1988, Ayers & Anderson 1999, Cairns *et al.* 2008, Rice *et al.* 2009, Vrtiska & Powell 2011). Numerous factors affect the ability of observers to sight terrestrial species, including group size, individual activity and the frequency at which animals are obscured by vegetation (Graham & Bell 1989, Anderson & Lindzey 1996, McIntosh *et al.* 2009).

Although not affected by vegetation cover, aerial sighting rates of marine animals are influenced by environmental and biological factors. Water turbidity, wind strength and sea chop can all reduce sighting rates (Ross *et al.* 1989, Pollock *et al.* 2006), as can the size and behaviour of the animals. Marine aerial surveys have therefore focussed primarily on the abundance of air-breathing animals, such as bottlenose dolphins, right whales, sea lions, harbour seals, dugongs, turtles, sea otters and penguins (Marsh & Sinclair 1989b, Cockcroft *et al.* 1992, Bodkin & Udevitz 1999, Gales *et al.* 2004, Cardona *et al.* 2005, Lowry & Forney 2005, Southwell *et al.* 2008, Clark *et al.* 2010, Cunningham *et al.* 2010). Sightings of such air-breathing marine species are easier than for submerged species, as they are more visible on the water surface (Ross *et al.* 1989). Moreover, sighting animals as they surface to breathe removes the obscuring effects of turbidity, and creates additional sighting cues such as a high-contrast wake as individuals break the surface. This effect is enhanced when surveying species such as dolphins travelling in pods, where up to 300 individuals may be present in a single group (Ross *et al.* 1989).

Targeted aerial surveys of sharks have focused mostly on large (≥10 m) species, such as whale sharks (*Rhincodon typus*) and basking sharks (*Cetorhinus maximus*) (Wilson 2004, Burks *et al.* 2005, Cliff *et al.* 2007, Rowat *et al.* 2009). These species frequent the surface for feeding and courtship (Harvey-Clark *et al.* 1999, Motta *et al.* 2010), allowing groups of individuals to be readily detected. Smaller (<3 m) lemon sharks (*Negaprion brevirostris*) have been identified by aerial surveys, but only in shallow lagoonal waters in conjunction with other tracking methods (Gruber *et al.* 1988). Shark species such as blue sharks (*Prionace glauca*) and hammerhead sharks (*Sphyrna* spp) have also been recorded in marine mammal aerial surveys (Kenney *et al.* 1985). However shark species are generally absent or reported in low numbers in marine aerial survey records (O’Donoghue *et al.* 2010). In addition to generally not forming aggregations, most sharks are much smaller than the large shark species targeted by aerial surveys, and spend much of their time below the surface of the water (Bonfil *et al.* 2005, Chapman *et al.* 2007). This makes them a difficult target for aerial observers to detect and identify.

Systems to alert and protect beach bathers against shark attack includes the reporting of sharks by the beachgoing public, surveillance by surf lifesavers in beach towers and headlands (Parrish & Goto 1997, Kock *et al.* 2012), and aerial patrols to survey larger expanses of beach (Blackweir & Beckley 2004). In New South Wales (NSW), Australia, two operators provide privately-sponsored fixed-wing (*Australian Aerial Patrol*) and helicopter (*Surfwatch Australia*) aerial patrols of beaches surrounding the Sydney area. Each year, the operators cite large numbers of shark sightings, resulting in substantial public support for this form of perceived protection against shark attack. However, with large dangerous coastal sharks such as white sharks and tiger sharks spending much of their time close to the substratum (Holland *et al.* 1999, Bonfil *et al.* 2005), the reported sightings may represent only a small proportion of sharks present.

The NSW government withdrew its support for the use of aerial patrols as a preventative measure against shark attack in 2007 following a negative assessment of their suitability in the 2006 NSW Scientific Shark Protection Summit (Anon 2006). However, over the summers of 2009/10 and 2010/11, the government agreed to review their suitability through sponsored aerial beach patrols. Helicopter surveys were undertaken in 2009/10, but few sharks were sighted (Anon 2010b). A lack of confidence due to potential under-reporting of sharks led to a review of the data required to more accurately assess the suitability of aerial surveys to offer protection to bathers in NSW. The summer of 2010/11 therefore included further surveys, and a series of conjunctive scientific trials assessing shark sighting rates by helicopter and fixed-wing observers.

1.2. Objectives of the research

This report outlines the findings of the 2010/11 NSW aerial patrols, beginning with the structured assessment of shark sighting rates from observers in two aircraft types. As the real-time tracking of live sharks was logistically and economically impractical, we assessed aerial sighting effectiveness using life-sized shark analogues. Artificial animal analogues have been successfully used for this purpose during aerial surveys of dugong (*Dugong dugong*) in Queensland (Pollock *et al.* 2006), and allow control over deployment depth and distance from the aircraft. The depths at which large (2.5 m) plywood shark analogues were sighted by fixed-wing and helicopter observers was assessed first, and using this information, the effects of horizontal distance on sighting rates subsequently determined. These findings were then contrasted with genuine coastal aerial patrols undertaken by both aircraft.

2. METHODS

2.1. Study location

The study was conducted at the northern side of Jervis Bay, NSW (35.0167ºS, 150.7311ºE). This is a large embayment (~112 km^2) with a substratum consisting primarily of sand and seagrass, and a topography offering protection from winds and swells. The bay was located within a 30 min flight to the Albion Park airbase near Wollongong.

2.2. Equipment

Two aircraft were used in this study: A Cessna 182 fixed-wing aeroplane and a Robinson R44 Clipper II helicopter. The fixed-wing company had considerable experience with aerial shark detection, while the helicopter company had no prior experience. The aircrews of both aircraft consisted of a pilot, an observer to sight the shark analogues and a data recorder. Due to cockpit configurations, the observer looked out to the right in the fixed-wing aircraft and to the left in the helicopter.

The artificial shark analogues consisted of 2.5 m (total length) plywood cutouts, painted a similar shade of grey to that of large sharks. The analogue shape was traced from a white shark (*Carcharodon carcharias*) incidentally captured through the NSW DPI Shark Meshing (Bather Protection) Program. The head morphology was altered in a number of analogues to mimic blunt-headed tiger sharks (*Galeocerdo cuvier*) and hammerhead sharks (*Sphyrna* sp.) (Fig. 1). The hammerhead outline was traced from a stored head at the Cronulla Fisheries Research Centre of Excellence, while the tiger shark head outline was drawn from a photograph taken by the lead author. Wire cables of sufficient length to allow the analogues to sit approximately horizontal in the water were attached to each corner, terminating in a single metal ring to which an anchor rope was attached. The analogues were inherently buoyant, although a small (3 cm) grey/yellow surface float was attached via a string to aid the boat crew in relocating submerged analogues. These floats were not visible to the aircraft observers.

2.3. Depth trial

A series of stations consisting of a small galvanised pulley attached to 28 kg of coal chain as an anchor were deployed in 6 m and 12 m water depths. A 6 mm rope was threaded through the pulley, with one end attached to a shark analogue, and the other end held taut by a crewmember on a 5.7 m runabout vessel anchored ~20 m away. Each analogue was initially sunk to a depth of 5 – 6 m, whereby an aircraft would then orbit (fixed-wing) or hover (helicopter) at 500 ft (~150 m) above the position of the analogue while it was slowly raised towards the surface by the boat crew member releasing the rope. The aircrew radioed the boat once the analogue was seen, at which time the depth of the analogue below the water surface was digitally measured. The boat crew member randomly changed the speed of the surfacing analogue to prevent it becoming visible to the aircrews after a predictable period. Each analogue type (white shark, tiger shark and hammerhead shark) was tested three times in each of the two water depths for each aircraft. Water turbidity was established using a 25 cm secchi disk deployed in the shade of the boat throughout the day. Data was log(x+1) transformed to reduce variance homogeneity, and analysed using ANOVA in SPSS 17. Aircraft, depth and analogue type were treated as fixed factors, and day as a random factor.

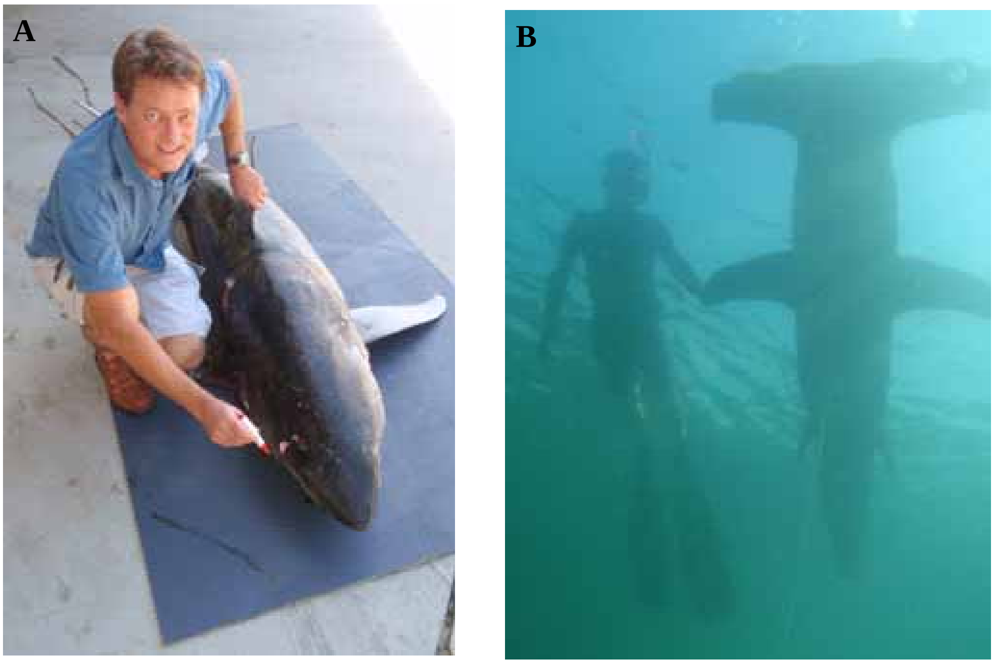

Figure 1. (A) Tracing the white shark outline for all analogues. (B) An *in-situ* hammerhead shark analogue with snorkeller alongside.

2.4. Distance trial

A 5 km x 0.25 km grid was established using a hand-held Garmin GPS (Fig. 2A). Analogues were anchored at pre-determined positions within the grid, using 14 kg of coal chain anchor attached to a 6 mm rope. Following the results of the depth trial, all analogues were deployed at 1.8 – 2.2 m below the water surface, depending on the state of the tide. This ensured that all analogues were potentially visible to aircraft observers.

Three separate trials were conducted by each aircraft each day. Each trial consisted of the aircraft flying a set of six 5 km-long transects as determined by GPS, with observers looking for the shark analogues. Between three and nine analogues were deployed for each trial, with analogues added/removed by the boat crew between trials once the aircraft left the area. Analogues were placed at least 500 m apart, giving a minimum of ~10 sec between potential sightings while flying at 100 kts. The same analogue configurations were employed for both aircraft each day, although in reverse order. This ensured direct comparison between aircraft sightings. An additional single shark analogue with a visible yellow float was deployed on the surface for 12 trials per aircraft. These surface deployments were not included in analyses, but were used to provide a consistent sighting event to calibrate observer distance estimates.

Each day, each aircraft conducted two of their trials at their cruising speed (100 kts for fixed-wing, 60 kts for helicopter), without stopping or deviating from their flightpath. The third trial allowed the fixed-wing aircrew to orbit to confirm sightings if desired, which is the normal procedure during NSW aerial beach patrols. The third helicopter trial was conducted at an increased speed of 100 kts without stopping or deviating from their flightpath to allow direct comparison with the fixed-wing aircraft. The order in which the trials were undertaken changed each day, and the order in which each aircraft flew alternated each day. The order in which transects were flown was also varied between trials.

The six flight transects lay 150 m apart, running in an east-west orientation to minimise sun glare to the sideways-looking observers. Two transects (E-F and G-H) lay within the deployment grid, while the other four lay outside (Fig. 2B). For each trial, the aircraft flew all six transects at 500 ft (~150 m), in the directions that ensured the observer was always facing towards the centre of the grid. When a shark analogue was sighted, the observer would notify the rest of the aircrew, signalling the pilot to mark a GPS waypoint, and the recorder to note both the GPS waypoint number and the observer's estimate of the angle relative to the aircraft and distance to the analogue. Unless permitted, the aircraft would not deviate from its flightpath. Pilots would radio the number of analogues seen at the end of each transect, which was later verified against the datasheets. Datasheets were faxed by aircrew at the end of each day, with the latitude and longitude of each GPS waypoint included.

On a number of occasions, analogues were deployed on the far northern or southern edge of the grid. In these cases, the individual analogues were outside the viewing area of observers on transects E-F or G-H, respectively (Fig. 2B). These analogues were therefore not included when calculating sighting rates of those transects.

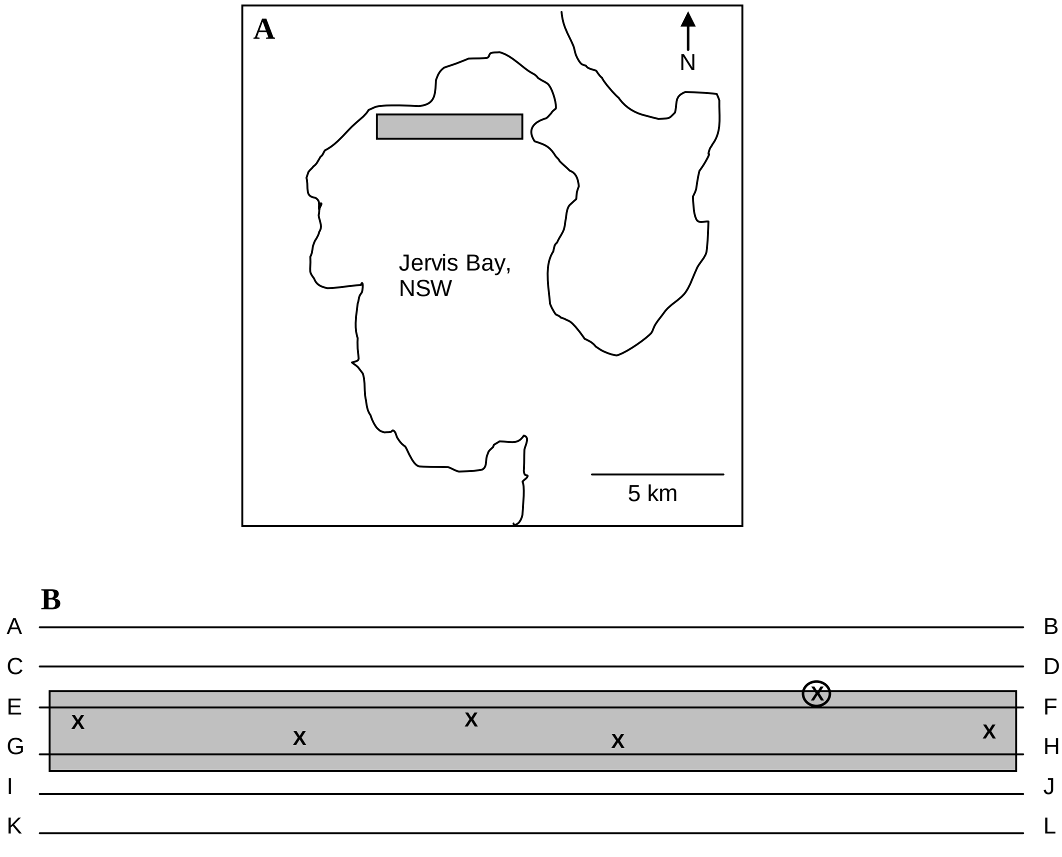

Figure 2. (A) Study location on the NSW coast showing the position of the survey grid in Jervis Bay. (B) Representation of the deployment grid (grey shading) showing the six 5 km-long transects flown by each aircraft per trial (not to scale). Letters represent transect coding given to aircrews. "X"s represent hypothetical analogue deployments. Observers faced southwards in transects A-B, C-D and E-F, and northwards in G-H, I-J and K-L. In this example, the circled analogue could not be seen on transect E-F and would not be included in that transect's calculations. All other analogues could potentially be seen during each transect (up to six sightings per trial).

To allow for human errors and aircraft yaw during analogue sightings, three additional positions were calculated for each given GPS waypoint:

a) the position at the far side of the deployment grid using the angle the observer recorded, with a 30º leeway;
b) the position of the aircraft a maximum of 2 sec prior to the GPS waypoint. This allowed for delays in the pilot responding and marking the point; and
c) the position at the far side of the deployment grid 2 sec prior to the GPS waypoint using the angle the observer recorded, with a 30º leeway.

This produced the coordinates for a four-sided quadrilateral, the boundary of which accounted for any likely errors in marking the position or estimating the angle to a sighted analogue (Fig. 3A). Using Earth Point online software (https://www.earthpoint.us), the quadrilateral coordinates for each reported sighting were uploaded in Google Earth, along with the position of each deployed analogue. If an analogue lay within the area bounded by the quadrilateral, it was counted as a genuine sighting. If not, it was counted as a false sighting. This procedure was repeated for leeways of 15º and 22.5º to examine the accuracy of the observers' angle estimates (Fig. 3B). Straight-line distance from the aircraft to each validated analogue sighting was then calculated. Here, half the maximum delay (1 sec) was subtracted from each given GPS position to allow for the delay in the pilot reacting, locating and pressing the GPS button following the observer's announcement of a sighting.

The proportion of deployed analogues sighted was calculated in MS Excel. To calculate the number of potential sightings at each distance, the minimum distance the aircraft passed by the analogue was used if the analogue was not seen, while the straight-line distance from the analogue to the aircraft was used if the analogue was sighted. For example, if the aircraft flew within 100 m of an analogue without it being seen, it was counted as a potential 100 m sighting. However, if the same analogue was sighted from 130 m distance, it was counted as a 130 m sighting. Results were binned into 50 m categories (0 – 49 m, 50 – 99 m, etc.) for analysis and plotting. Standard errors of sighting rates were calculated using the formula:

$$\text{SE} = \sqrt{\frac{p \times (1 - p)}{n}}$$

where:

p is the proportion of analogues sighted; and
n is the number of analogues deployed (Zar 1996).

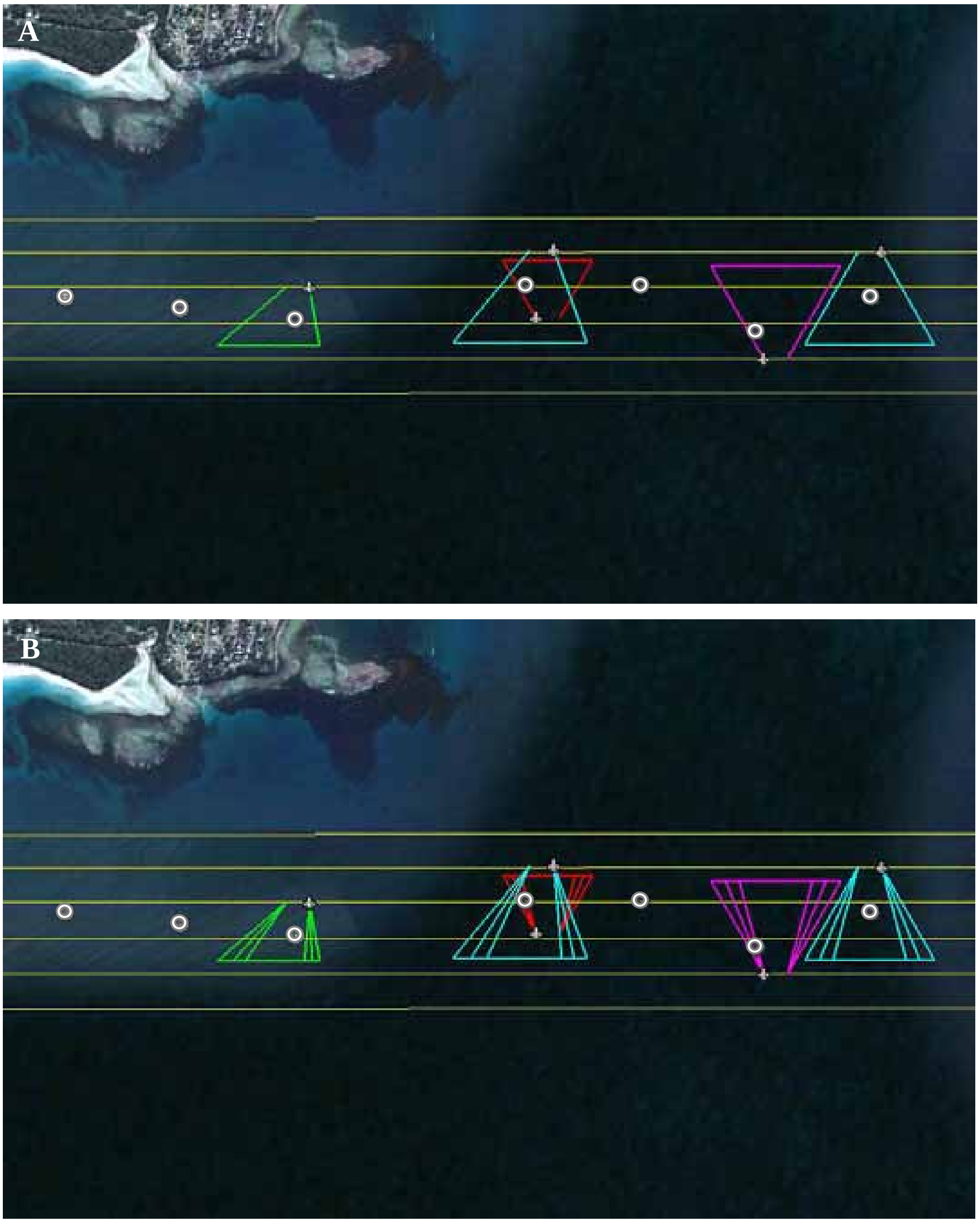

Figure 3. (A) Google Earth image of 30º quadrilaterals accounting for likely errors in shark analogue sightings. Parallel lines indicate the six transects flown per trials. Circles indicate deployed shark analogues. Aeroplane symbol marks the GPS position given. (B). The same sightings as (A), with additional quadrilaterals showing reduced 15º and 22.5º leeways.

2.5. Environmental correlations

Aircrew and boatcrew would estimate the wind speed, sea state (Beaufort scale) and cloud cover when possible for each trial, with the average of both crews' readings used in analyses. Water turbidity was also measured by the boat crew deploying a secchi disk in the shade of the boat at the start, middle and end of each day's sampling, at both ends and in the middle of the grid. These values were averaged to provide a daily water turbidity estimate.

2.6. Coastal aerial patrols

Both aircraft undertook a series of genuine beach patrols as part of this study. Aircraft flew between South Wollongong (34.4240ºS, 150.9103ºE) and Stockton Beach (32.9074ºS, 151.7956ºE), surveying the region encompassed by the NSW DPI Shark Meshing (Bather Protection) Program. Each flying day consisted of a north-bound and south-bound flight, resulting in the area being surveyed twice. Each flight was considered to be 225 km long, calculated by measuring the coastal distance between the start and end beaches using a GPS mapping program. Flights searched the area approximately 500 m seaward of the rear of the surf zone (surf backline), recording all sharks and other marine life seen. The helicopter flew behind the fixed-wing aircraft to allow direct comparisons of sightings. Both aircraft flew at their cruising speeds of 100 knots and 60 knots, respectively, with the fixed-wing aircraft periodically orbiting out to sea to allow the helicopter to catch up. Aircrews did not contact each other during flights, nor was the fixed-wing aircraft permitted to orbit to verify sightings. This prevented the helicopter aircrew from being alerted that an object had been seen by the fixed-wing observers. Aircraft refuelled at separate aerodromes between north- and south-bound surveys due to logistical reasons, however this also ensured no discussion of sighting records could take place. Results of each day's flights were faxed immediately upon return to the contracting company bases. Data analysis was conducted using ANOVA in SPSS 17. Data were log(x+1) transformed when necessary prior to analyses. Direction and aircraft type were treated as fixed factors, with day included as a random factor.

3. RESULTS

3.1. Depth experiment

Depth trials were conducted between 0800 hr and 1600 hr over two days, encompassing an equal proportion of sunny and overcast conditions. The order of aircraft participation alternated between the two days, with equal replicates conducted each day. Water clarity as measured by secchi disk fadeout was good, with turbidities of 2.9 – 3.5 m (day 1) and 4.5 – 6.1 m (day 2). Wind strength was under 10 kts each day.

No significant differences were found between aircraft types, indicating that observers in each aircraft had comparable ability to sight the shark analogues (Table 1). The maximum depth at which the 2.5 m-long analogues were observed was shallow, averaging 2.5 ± 0.1 m (SE) for the fixed-wing aircraft, and 2.7 ± 0.1 m (SE) for the helicopter (Fig. 4). The maximum depth of any individual sighting was 4.3 m (fixed-wing) and 3.7 m (helicopter). Although the deeper water at the 12 m stations created a darker background, this had no significant effect on analogue sighting depths (Table 1, Fig. 4). Observers therefore appeared to be sighting the analogues based on their appearance below the water surface, rather than through secondary effects such as shadows cast onto the substratum, or increased silhouetting of the analogues in shallower depths. The lack of effect of water depth on analogue sightability allowed the subsequent distance trial to be undertaken across the width of northern Jervis Bay, including varying (9 – 15 m) substratum depths.

Changes in the head shape of analogues also had no significant effect on their sightability (Table 1, Fig. 4). The increased surface area visible on the hammerhead analogues did not increase their sighting depth, nor did the decreased surface profile of the white shark make them more difficult to detect. Equal vertical detection probabilities enabled deployment of all three analogue types in the subsequent distance trial.

Table 1. Analysis of variance examining the effects of aircraft type, substrate depth and shark analogue type on sighting depth.

Factor	**SS**	***df***	***F***	***P***
Aircraft	0.009	1	1.921	0.40
Depth	0.016	1	9.561	0.20
Analogue	0.003	2	0.610	0.62
Aircraft x Depth	0.000	1	0.010	0.94
Aircraft x Analogue	0.002	2	2.271	0.31
Depth x Analogue	0.008	2	2.341	0.30
Aircraft x Depth x Analogue	0.008	2	0.434	0.70

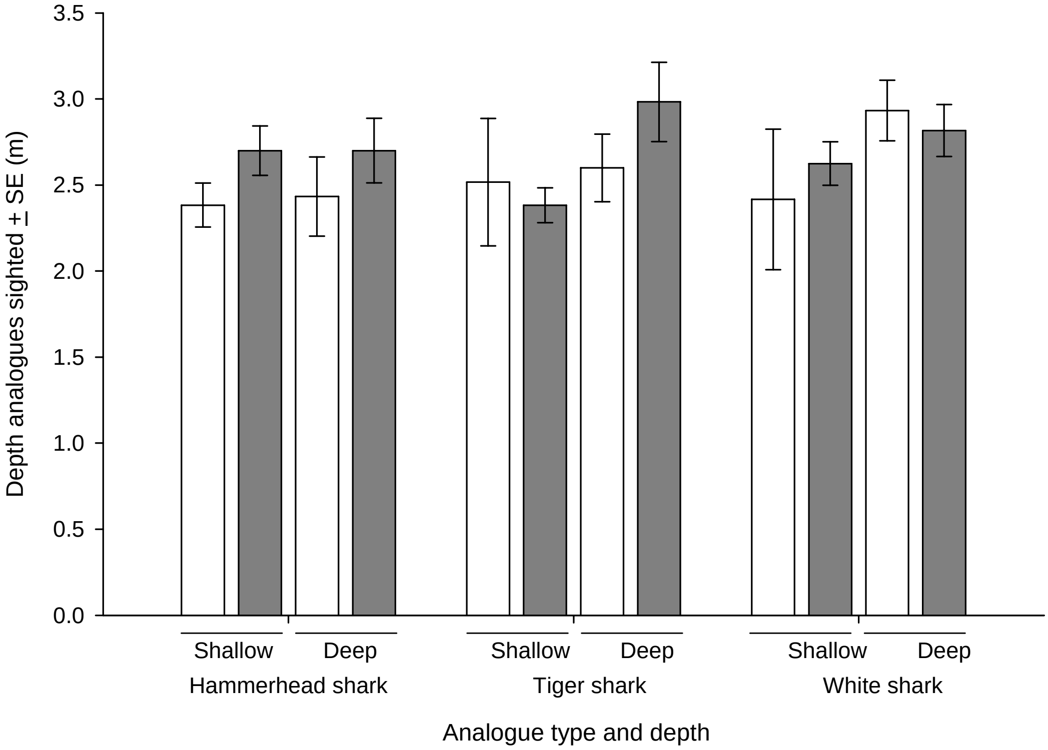

Figure 4. Depths at which shark analogues were sighted by fixed-wing and helicopter observers maintaining their position at 500 ft (~150 m) around a known position. Open (white) bars indicate fixed-wing sightings, closed (grey) bars indicate helicopter sightings.

3.2. Distance experiment

Distance trials were conducted between 0940 hr and 1605 hr over six non-consecutive days. Each aircraft undertook three trials per day, with the exception of two fixed-wing trials being cancelled due to adverse weather on the first day. A total of 96 fixed-wing transects (66 transects at 100 kts plus 30 transects at 100 kts with orbiting permitted), and 108 helicopter transects (72 transects at 60 kts plus 36 transects at 100 kts) were flown. There were 230 analogue deployments (107 during fixed-wing trials, 123 during helicopter trials) positioned 0 – 500 m from the transect paths. These provided 617 potential sighting opportunities for fixed-wing aircraft observers and 709 opportunities for helicopter observers.

Overall sighting rates were quite low, with only 12.5% and 17.1% of all deployments detected by the fixed-wing and helicopter observers, respectively (Table 2). These rates declined sharply with distances greater than 150 m (Table 2, Fig. 5). Although a proportional increase in sightings was apparent at distances over 450 m (Table 2, Fig. 5), this was an artefact of the relatively low number of deployments at this distance. Validated analogue sightings were identified at distances up to 506 m (fixed-wing) and 755 m (helicopter). Of the 305 sighting events reported, 198 were validated analogue sightings (77 fixed-wing, 121 helicopter), 50 were sightings of the floating analogue used for comparing distance estimates, 10 were reports of real sharks and dolphins and 47 were cases of false sightings. Although they had only 15% more analogues deployed, the helicopter aircrew recorded 57% more validated analogue sightings than the fixed-wing aircrew.

Table 2. Percentage of validated shark analogue sightings with cumulative distance. Number of analogue deployments shown in parentheses.

	Percentage of analogues sighted	
Distance	**Fixed-wing**	**Helicopter**
All	12.5 (617)	17.1 (709)
>50 m	13.2 (583)	17.7 (672)
>100 m	13.9 (533)	17.0 (268)
>150 m	11.5 (459)	11.8 (542)
>200 m	7.9 (392)	8.5 (469)
>250 m	6.8 (325)	4.3 (373)
>300 m	4.8 (251)	2.8 (287)
>350 m	3.3 (181)	1.9 (209)
>400 m	3.6 (111)	1.6 (124)
>450 m	1.7 (60)	2.9 (70)
>500 m	3.8 (26)	6.3 (32)

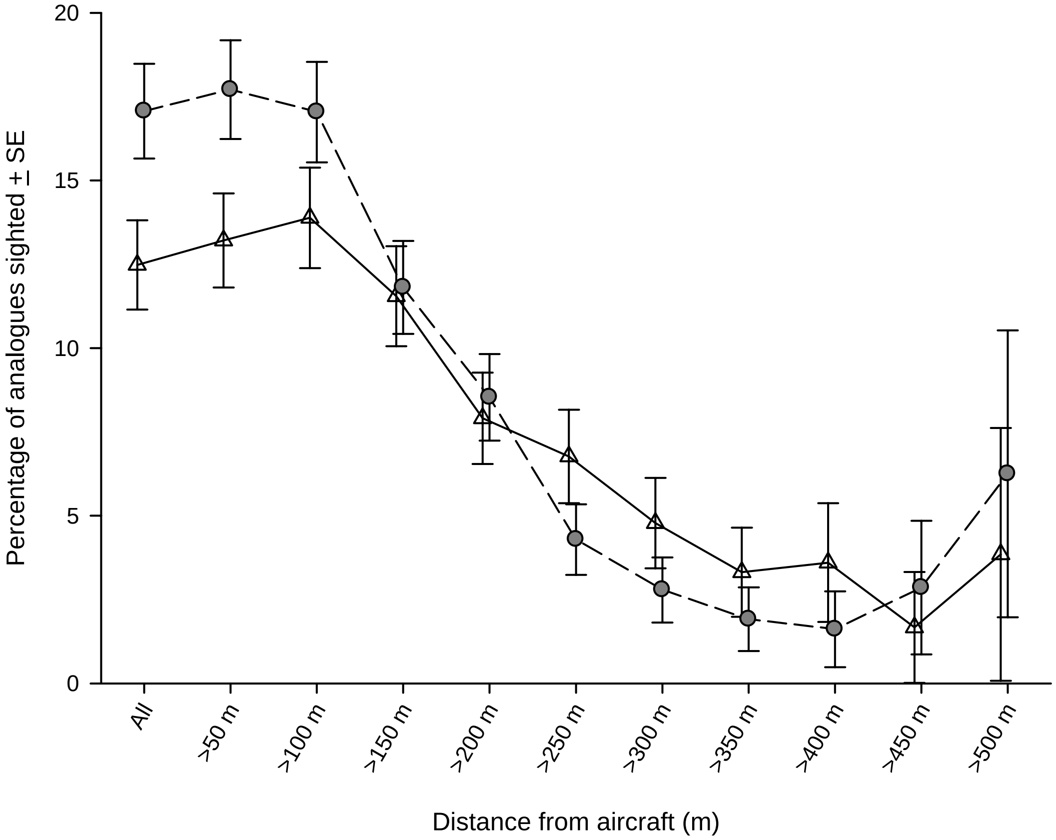

Figure 5. Percentage of validated analogue sightings with cumulative distances. Solid line (Δ) represents fixed-wing aircraft sightings, dashed line (●) represents helicopter sightings. Data points are offset for clarity.

The breakdown of sighting rates by individual distance reveal that the fixed-wing observers had the greatest success at sighting analogues deployed 100 – 200 m from their flightpath (Fig. 6). Here, they successfully sighted up to 33% of deployed analogues. This rate reduced to 13 – 14% at distances of 200 – 300 m from the aircraft. All analogues deployed outside these ranges were sighted less than 9% of the time.

Helicopter observers consistently saw a greater proportion of deployed analogues than the fixed-wing observers at distances up to 250 m from the aircraft (Fig. 6). The optimal sighting range for the helicopter was 100 m from the flight path, at which half the deployed analogues were sighted. However at least 25% of analogues were sighted at each distance between 50 – 250 m from the flight path. The higher visibility of the helicopter cockpit also enabled observers to see analogues within 50 m of their flight path. Similar to the fixed-wing observer sightings, distant analogue deployments (more than 250 m from the flight path) were sighted less than 10% of the time (Fig. 6).

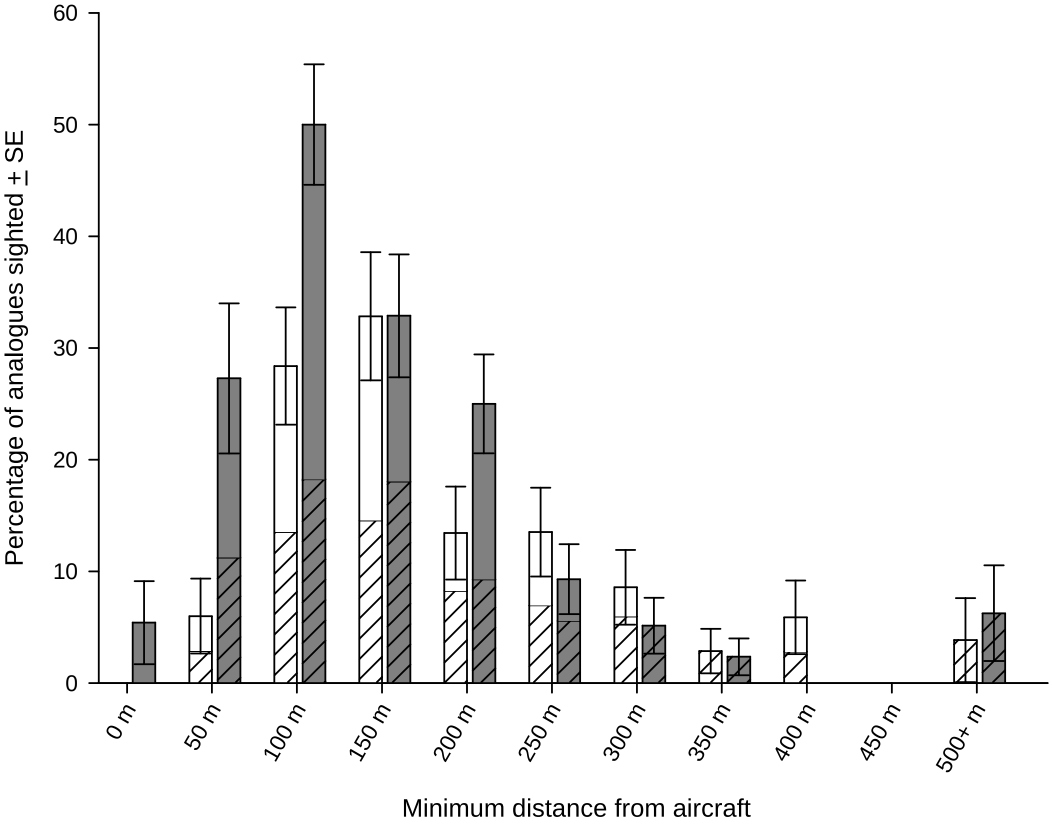

Figure 6. Percentage of validated analogue sightings per aircraft with relative contribution of different trial treatments. Open bars indicate fixed-wing data, closed bars indicate helicopter sightings. Hashed bars indicates contribution of trials undertaken using standard methodology (cruising speed, no orbiting), non-hashed bars indicates contribution of alternative trials (orbiting permitted (fixed-wing), 100 kts airspeed (helicopter)). Contribution of each treatment type has been scaled to account for differences in sample size.

Minimal differences were seen in fixed-wing sighting rates for trials where the pilots were permitted to orbit to verify sightings, compared with non-orbiting flights (Fig. 6). In fact, more sightings occurred on flights where circling was not permitted. Although the predisposition of the observers to expect large shark-like objects in the deployment grid may have contributed to their rapid identification, the sighting cue to perform the verification check (i.e. the decision that a submerged object is likely to be a shark) was sufficient in itself to successfully identify deployed analogues. This suggests there was no ambiguity in the identification of shark analogues during these experiments, nor any disadvantage to the fixed-wing aircrew when not permitting them to orbit suspected sightings as per the normal routine on aerial beach patrols.

Airspeed made minimal difference to the sighting ability of helicopter observers when flying within 250 m of deployed analogues (Fig. 6). However, trials conducted at the faster airspeed (100 kts) failed to produce detected analogues at distances over 300 m from the helicopter flight path. Sighting rates over 300 m were however, comparable between helicopter observers flying at 60 kts and the fixed-wing observers at 100 kts once sample size was accounted for (Fig. 6). This indicates that the helicopter observers had equivalent, albeit low, capacity to detect distant analogues when their aircraft was travelling at cruising speed.

Observers were requested to identify the deployed analogues to body-type (white shark, tiger shark or hammerhead shark) for all sightings during the last four days of the trials. However, identifications were made for only 34% and 55% of sightings for the fixed-wing and helicopter observers, respectively. Although the accuracy of identified analogues was relatively high (77% and 98%), the low rate of attempts meant that overall only 26% and 55% of deployments were correctly identified to ‘species’ for the fixed-wing and helicopter observers, respectively. Importantly, none of the 38 white shark or tiger shark deployments were successfully identified, with only hammerhead shark analogues correctly identified as such.

Estimates of distance to the high-visibility surface shark analogues showed no correlation with the actual deployment distance for fixed-wing observers (regression analysis: $n = 23$, slope = 0.05, $F = 0.45$, $p = 0.51$). A significant relationship was found between the helicopter observer distance estimates and actual deployment distances (regression analysis: $n = 26$, slope = 0.48, $F = 41.67$, $p < 0.001$), however estimates were 52% lower than the real distances. Both aircraft maintained altitudes of 500 ft (~150 m) throughout the experiments, eliminating vertical variations as a confounding effect. Instead, it appears that reliable distance estimates are extremely difficult to obtain while travelling aerially at speed.

The accuracy of the observers’ angle estimates was relatively high for both aircraft. There was only a 5% decrease in the number of validated analogue sightings if the leeway was reduced to 22.5º, and 14% less sightings if only 15º leeway was given (Fig. 7). Neither angle change significantly altered the sighting rates of either the fixed-wing (*k-s* tests; $z = 0.426$, $p = 0.993$; $z = 0.426$, $p = 0.993$, respectively) or helicopter observers (*k-s* tests; $z = 0.213$, $p = 1.000$; $z = 0.426$, $p = 0.993$, respectively).

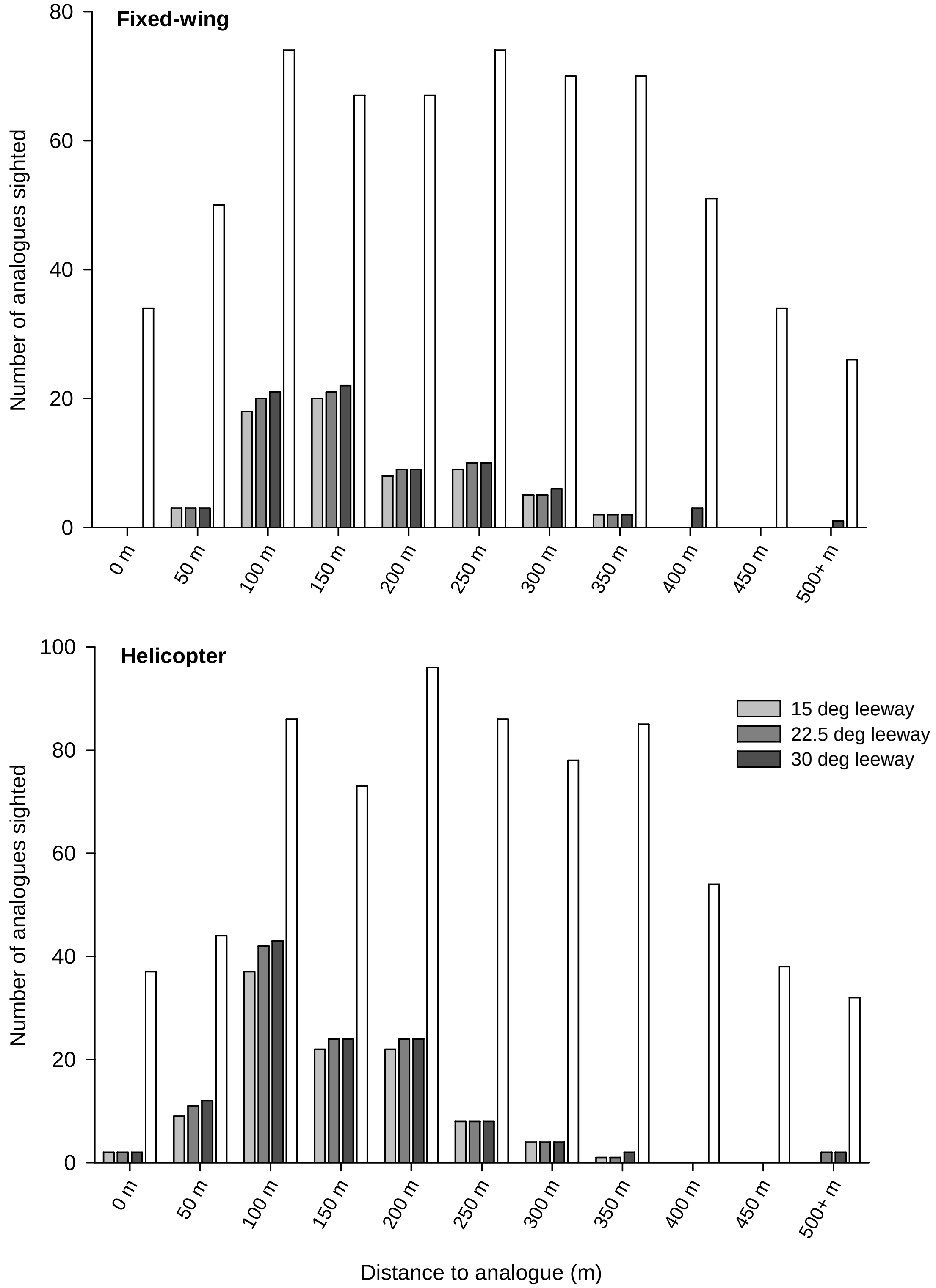

Figure 7. Number of validated shark analogue sightings with three levels of sighting angle leeway across all trials for each aircraft (closed bars). The total number of analogues deployed at each distance from the flight paths is indicated by open bars.

3.3. Environmental correlations

Water clarity increased during each day of sampling, however there was no correlation with analogue sighting rates for either aircraft type (Fig. 8). The 2.5 m shark analogues were deployed in much shallower depths than those in which the 25 cm secchi disk faded out. Thus it is possible that further sampling in more turbid waters may alter this finding.

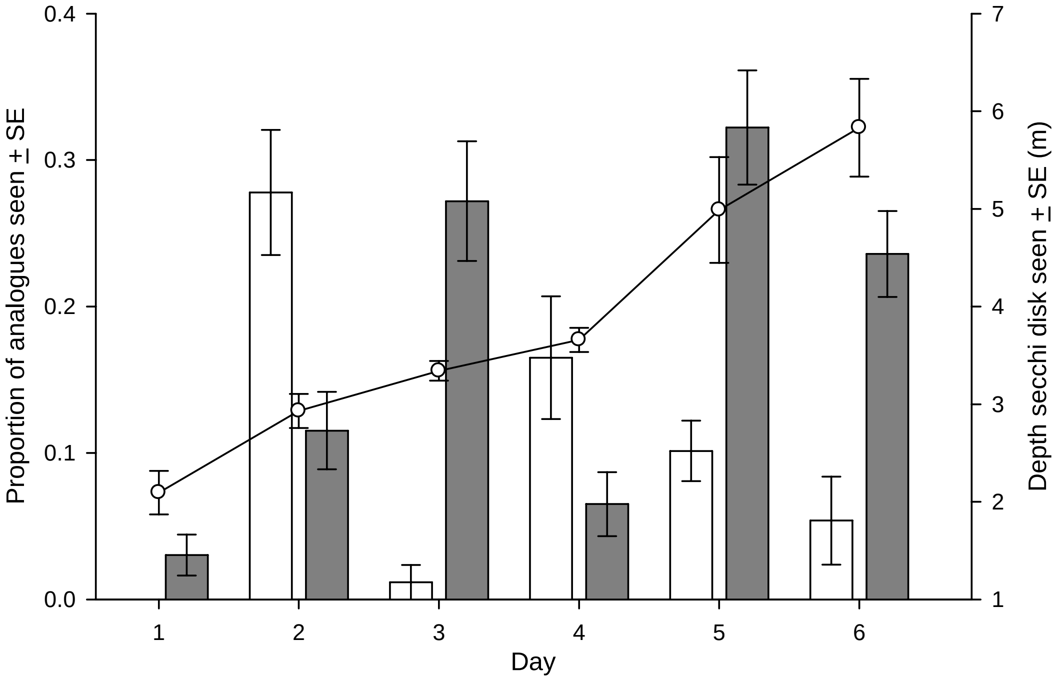

Figure 8. Proportion of validated shark analogue sightings per aircraft per day, with secchi disk measurements overlayed. Open bars indicate fixed-wing sightings, closed bars indicate helicopter sightings.

Environmental factors were compared with analogue sighting rates for each trial, and the results pooled by day for plotting. The sighting ability of helicopter observers was significantly correlated with sea surface conditions (Table 3, Figs. 9A & B). Higher sea states were recorded in conjunction with increased wind strengths, with a reduced proportion of analogues seen as these two environmental parameters increased. The magnitude of this relationship was stronger with respect to sea surface conditions than for actual wind speed (Table 3), however neither relationship was predictable with different proportions of analogues sighted among days with comparable wind or sea conditions (Figs. 9A & B). Correlations between environmental factors and analogue sightings were confounded by variations in the distance at which analogues were deployed from the transect lines among trials. This no doubt increased the variability in these results. The proportion of analogues sighted by the fixed-wing observers showed no significant correlation with wind and sea surface conditions (Table 3, Figs. 9A & B). This may reflect the lower overall rate of analogue sightings by the fixed-wing observers, suggesting they had more difficulty sighting analogues, even in better sea conditions.

Table 3. Regression analysis of environmental factors on fixed-wing and helicopter observer sighting rates.

Aircraft	**Factor**	**MS**	r^2	***F***	***P***
Fixed-wing	Wind speed	0.015	0.10	1.314	0.274
Fixed-wing	Sea state	0.015	0.09	1.283	0.278
Fixed-wing	Cloud cover	0.008	0.05	0.659	0.432
Helicopter	Wind speed	0.127	0.47	14.057	0.002
Helicopter	Sea state	0.175	0.64	28.723	<0.001
Helicopter	Cloud cover	0.089	0.33	7.719	0.013

With the exception of the first day's sampling, most days were heavily overcast (Fig. 9C). Nevertheless, cloud cover influenced helicopter observer sighting rates, but not sightings by fixed-wing observers (Table 3). As with sea state and wind strength, this relationship was neither strong, nor predictable. Cloud cover *per se* will not necessarily influence sighting ability, as clouds may be present, although not obscure the sun. Transect-by-transect recording of cloud position relative to the sun was attempted, however due to the high proportion of clouds present, this often changed within a single transect. As such, analysis at this scale was not viable.

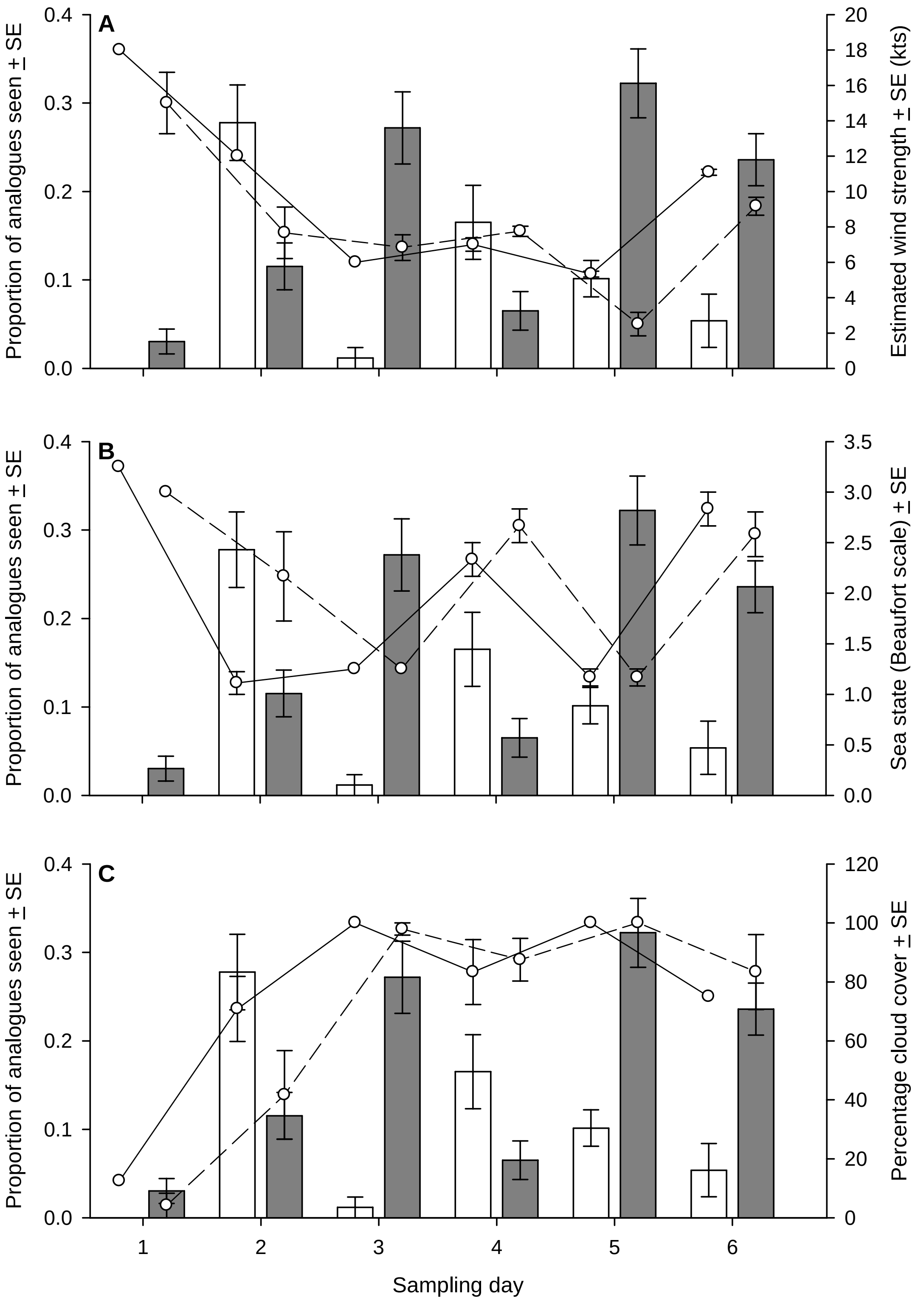

Figure 9. Proportion of validated analogue sightings per aircraft per day, with wind, sea state and cloud cover overlayed. Open bars indicate fixed-wing sightings, closed bars indicate helicopter sightings. Solid lines indicate environmental parameters during fixed-wing flights, dashed lines indicate those experienced during helicopter flights.

3.4. Coastal aerial patrols

Coastal aerial patrol flights were conducted between the 22nd Dec 2010 and 30th Jan 2011, between 0725 hr and 1456 hr. Flights were undertaken between South Wollongong and Stockton Beach, encompassing the area covered by the NSW DPI Beach Protection (Shark Meshing) Program. Due to inclement weather, the fixed-wing aircraft flew on 13 days, and the helicopter on 11 days. To allow direct comparisons, data analysis was only undertaken on the 10 shared flying days.

Each aircraft flew a northwards flight first, covering the same area on their return flight. As such, the fixed-wing observers always faced east (into the sun) on the first flight of each day. However, flight direction had no effect on the number of sightings reported by either the fixed-wing or helicopter observers (Table 4). Having risen hours earlier, it appears that the Austral summer sun was sufficiently high so as to not disadvantage the fixed-wing observers on these early morning flights.

Table 4. Analysis of variance examining the effects of aircraft type and flight direction on coastal sightings.

Factor	**SS**	**MS**	***F***	***P***
Aircraft	0.342	0.342	3.023	0.12
Direction	0.027	0.027	0.276	0.61
Aircraft x Direction	0.009	0.009	0.053	0.82

There were 84 reported shark sightings across all shared flying days (Table 5). Fixed-wing observers reported 31 sharks, while helicopter observers reported 53 sharks. The majority of shark sightings were hammerhead sharks (83%), which are not regarded as dangerous. Two individuals were thought to be whaler (carcharhinid) sharks, while the identities of the remaining 12 sharks were unknown. Because our Jervis Bay experiments showed observers were unable to identify the ‘species’ of non-hammerhead silhouettes in the water, the two whaler sharks were grouped with the “unidentified” sharks for analyses. Sightings of rays (17) exceeded the number of unidentified shark sightings, with almost 65% of ray sightings identified as manta rays. There were 13 reports of “other” sightings, the identity of which could not be determined by observers. Reports of fish schools and dolphins far exceeded the total shark sightings, with 149 schools and 783 individuals sighted, respectively.

Table 5. Number of reported sightings by fixed-wing and helicopter crews during 10 days of joint coastal patrols. North-bound and south-bound flights have been pooled for each day. "Other" category comprises rays and unidentified objects.

Date	Aircraft	Total shark	Hammer head shark	Unidentified shark	Fish school	Dolphin	Other
22/12/2010	Fixed-wing	0	0	0	4	4	0
	Helicopter	0	0	0	2	30	0
25/12/2010	Fixed-wing	8	5	3	14	39	1
	Helicopter	1	1	0	19	67	1
28/12/2010	Fixed-wing	1	0	1	1	18	0
	Helicopter	1	1	0	5	2	3
29/12/2010	Fixed-wing	0	0	0	6	0	6
	Helicopter	2	2	0	15	22	3
01/01/2011	Fixed-wing	16	13	3	2	14	5
	Helicopter	24	23	1	3	20	1
05/01/2011	Fixed-wing	0	0	0	8	45	0
	Helicopter	5	5	0	9	65	3
08/01/2011	Fixed-wing	6	2	4	5	101	0
	Helicopter	8	8	0	28	68	1
15/01/2011	Fixed-wing	0	0	0	2	63	0
	Helicopter	0	0	0	2	106	0
22/01/2011	Fixed-wing	0	0	0	11	47	0
	Helicopter	8	8	0	3	14	1
29/01/2011	Fixed-wing	0	0	0	1	15	0
	Helicopter	4	2	2	9	43	5
	Total	**84**	**70**	**14**	**149**	**783**	**30**

Larger groups of animals were sighted at the most frequent rate. Surface-oriented pods of dolphins were sighted most often, followed by fish schools (Fig. 10). Sightings of individual animals however, were extremely low. On average, a total of only 0.69 sharks were seen per 100 km flown by fixed-wing observers, and 1.18 sharks by helicopter observers covering the same area (Fig. 10). The fixed-wing observers did see three times as many unidentified sharks as the helicopter observers, although this was the lowest category of sightings.

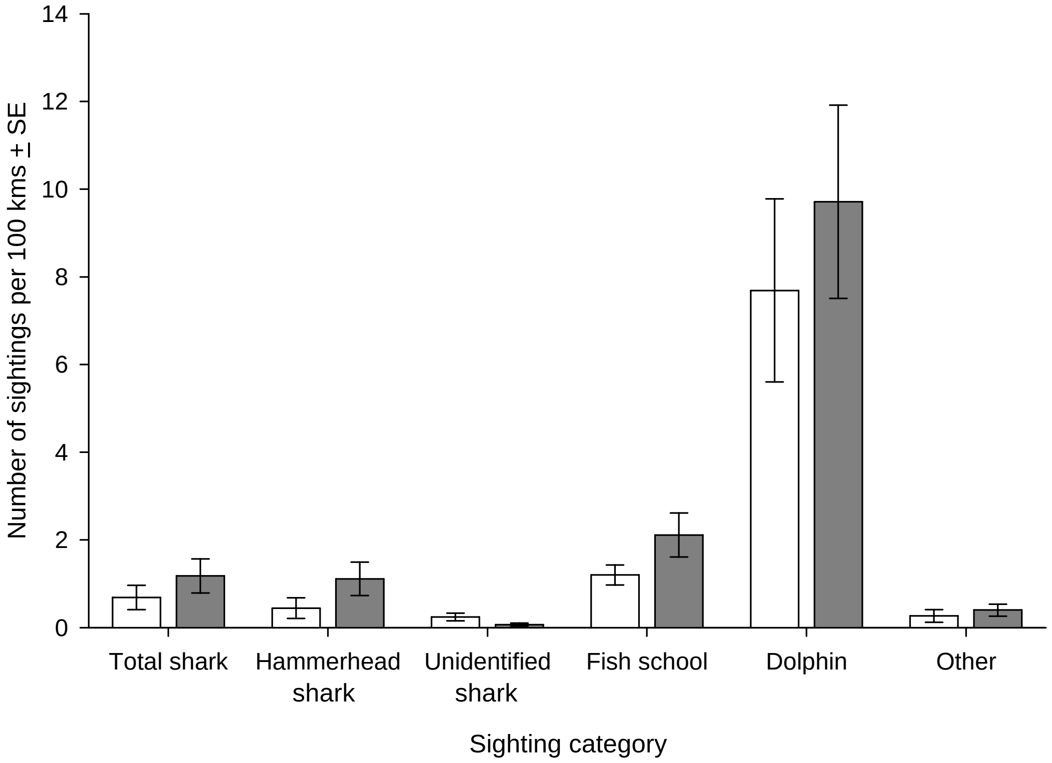

Figure 10. Reported numbers of sightings per 100 kms during coastal patrols of NSW beaches. Open bars represent fixed-wing sightings, closed bars represent helicopter sightings. “Other” category comprises rays and unidentified objects.

Only three of the 149 fish schools were identified as having sharks associated with them. Furthermore, on only 14 occasions were sharks recorded within two minutes flying time (~6.2 kms travelled for the fixed-wing aircraft and ~3.7 kms for the helicopter) of a fish school sighting (5 fixed-wing sightings, 9 helicopter). It is clear from these results that the presence of a fish school is not indicative of sharks present in the area.

4. DISCUSSION

4.1. Aerial shark detection

Aerial beach patrols are often presented as an effective preventative measure against shark attack. They receive considerable public support in Australia, but until now their efficacy in sighting potentially dangerous sharks has not been tested. Undercounting is one of the biggest problems associated with aerial surveys, with considerable effort taken to convert the numbers of animals sighted to realistic abundance estimates (Marsh & Sinclair 1989a, Cockcroft *et al.* 1992, Vrtiska & Powell 2011). Although aerial beach patrols are not formal surveys for quantifying the abundance of sharks, they are meant to successfully detect a high proportion of sharks present in the area surveyed. Operators cite themselves as having high sighting abilities, as they have "developed and proven and (sic) accurate system for predicting and monitoring the movement of dangerous sharks along our beaches" (www.surfwatchaustralia.com; accessed 03.11.2011). However, the overall sighting rates quantified in the present study of 12.5% and 17.1% for fixed-wing and helicopter observers, respectively, suggests that the actual rates of aerial shark sightings falls well short of this claim.

The size of the shark analogues used in this study (2.5 m) were the approximate size at which white sharks change their diet from teleosts to larger prey such as other sharks and mammals (Bruce 1992). Sharks of this size can be a threat to humans (West 2011), thus our findings estimated the sighting ability of aerial patrols for potentially-dangerous sharks. We had expected that the greater experience of the fixed-wing aircrew would have resulted in them achieving better sighting rates, but this was not the case. Although observer experience can influence terrestrial aerial sighting rates by as much as 9% (Ayers & Anderson 1999), no such advantage was apparent for the aircrews in this study. It is possible that an experience effect may have become apparent had we deployed smaller, less-visible analogues, however this was not examined due to the low (<10%) distant sighting rates seen with the full-sized analogues

Although not tested, it is unlikely that live, moving sharks would be sighted at higher rates, or at deeper depths than our static analogues. Many sharks swim at under 0.9 ms^{-1} (Sundstrom & Gruber 1998, Nakano *et al.* 2003, Nakamura *et al.* 2011), so their relative movements are negligible compared to that of an aircraft travelling at 100 kts (51 ms^{-1}). The difference between these relative movements is magnified the further the shark is from the aircraft's flightpath. Similarly, the body movement of a live shark is unlikely to contribute greatly to its sightability. A beating tail represents only a small proportion of a shark's body area, and species such as the tiger shark may beat their tail less than once every two seconds, or occasionally undertake "powerless" glides, with the tail held stationary (Nakamura *et al.* 2011).

Interestingly, the depth of the substratum did not influence the sightability of the shark analogues. The aerial observers instead identified the analogues' presence by their lighter colour against the water background. Secondary cues such as shadows cast, or increased contrast against the substratum in shallower water were not apparent at the depths trialled. The detection of analogues based solely on their distance from the water's surface increases the applicability of the data presented here, allowing these findings to be applied to aerial surveys over a range of water depths.

Our findings confirm that sighting marine animals is very difficult from the air. Marine aerial surveys can potentially miss over two-thirds of surface-oriented fauna, even when animals are travelling in groups (Cockcroft *et al.* 1992). Sighting submerged animals is more difficult, possibly accounting for a high proportion of under-reporting (Barlow *et al.* 1988, Ross *et al.* 1989). Marine animals located within sighting distance of aircraft observers can be missed if they are swimming too deep, or are in water conditions which mask their presence. Potentially dangerous species such as white sharks and tiger sharks often orient themselves close to the substratum when inshore (Holland *et al.* 1999, Bonfil *et al.* 2005). Considering the shallow detection depths found in this study (2.5 – 2.7 m from the water surface), such sharks may be well inshore of the surf backline before being detectable aerially. With inshore white sharks preferentially inhabiting water depths shallower than 15 m deep (Bruce 1992), individuals could remain undetectable to aerial surveys when in close proximity to surfers and swimmers at many of the beaches in NSW.

The high rate of hammerhead sightings found on commissioned coastal aerial beach patrols supports the hypothesis that deeper shark species are being overlooked. Hammerhead sharks comprise the largest catch of the NSW Shark Meshing (Bather Protection) Program, contributing 35% of total shark catch during the last decade (Reid *et al.* 2011). However, they comprised 83% of shark sightings by aerial beach patrols in this study. Hammerhead sharks spend time close to the substratum (Clarke 1971, Holland *et al.* 1993), although they are also found on the water surface. Hence they are represented in both the benthic shark meshing nets and aerial beach patrols. The disproportionately high abundance of hammerhead sharks in aerial patrol sightings suggests a substantial number of other sharks (including potentially-dangerous species) are being overlooked. Indeed, even if all unspecified sharks and unidentified objects seen on this study's aerial patrols were assumed to be non-hammerhead sharks, this still represents only 27% of sightings (compared with non-hammerhead sharks comprising 65% of the shark catch in NSW shark meshing nets).

Superficially, helicopters were more effective at sighting sharks than fixed-wing aircraft, even when using aircrew inexperienced in marine surveys. However there are a number of issues which must be considered when determining the usefulness of either aircraft for aerial beach patrols. Most importantly, neither aircrew sighted high proportions of deployed analogues, even at shallower depths than those at which potentially-dangerous sharks may inhabit (Holland *et al.* 1999, Bonfil *et al.* 2005). This is a clear concern when the purpose of these patrols is to provide a warning of shark presence to the beach-going public. Identifying larger, more visible targets such as baitfish schools did not provide any correlation with shark abundance, hence their sighting cannot be used as a proxy for sharks being in the area. Distance estimates of sightings were also highly inaccurate, making reported positions of sharks during such patrols potentially erroneous. Identification of shark type was also found to be inaccurate for any shark type except hammerhead shark analogues. Although any large shark close to swimmers should be treated seriously, accurate aerial identification of proximate sharks is important to allow accurate risk assessments by beach-based surf lifesavers.

The current NSW fixed-wing aerial patrols survey long distances (~285 km) on their regular flights (www.aerialpatrol.com.au). This, plus their average cruising speed of 100 knots, results in their ability to survey any individual beach for only a very limited period of time per day (minutes only). Although the public may feel safer knowing that aircraft are in the air, the tangible difference these flights make to an individual's safety from shark attack at any one of these beaches is likely to be small. While the use of coastal aerial patrols can provide benefits in terms of other surveillance, such as locating vessels in distress, these benefits remain secondary to their primary task of shark detection.

The risk of shark attack is thought to be heightened during conditions of low visibility, such as at dawn and dusk. During these times, the low angle of the sun can increase sun glare, which can significantly reduce marine aerial sightings (Lowry & Forney 2005). Observers in our study reported sun glare sometimes being an issue in this study, even during the middle of the day. Low sun angle also limits light penetration into the water, which is likely to further reduce the visibility of sub-surface sharks to aircraft.

In addition to favourable light levels, aerial patrols depend on suitable weather conditions to fly. Environmental conditions affected helicopter sightings more than fixed-wing sightings, although the helicopter observers still saw a greater proportion of deployed analogues. The dependence on favourable weather for aerial patrols can also severely affect their efficacy by reducing the number of days flown. This was particularly apparent during the summer of 2010/11 when 33% of scheduled flights were cancelled due to inclement weather conditions. Such environmental conditions are unlikely to reduce predatory shark behaviours, although inclement weather may coincide with a reduced number of beach users. If however, environmental conditions such as fog lift during the course of the day, this may result in perfect beach weather yet aerial observers will not have flown.

4.2. Alternatives to aerial beach patrols

Arguably the best alternative to aerial beach patrols is to bolster existing beach surveillance programs. Alongside the NSW Shark Meshing (Bather Protection) Program, the primary NSW beach safety programs are operated by members of the Australian Lifeguard Service and Surf Life Saving Australia. Collectively they patrol hundreds of NSW beaches each year, performing thousands of rescues per year (Anon 2010a). An alternative option to increase bather safety may therefore be to increase funding to such organisations to assist with equipment such as observation towers, binoculars and jet skis to investigate and deter sharks sighted by patrolling staff and beachgoers.

The utility of lifeguards in sighting sharks has been demonstrated internationally with sharks identified up to 300 m offshore by lifeguards atop 3 m beach towers around Oahu, Hawaii (Parrish & Goto 1997). Similarly, a very successful shark detection program has been developed in Cape Town to sight and immediately report the presence of potentially dangerous sharks approaching local beaches (Kock *et al.* 2012). The “Shark Spotters” program uses trained observers on vertically-elevated structures such as surrounding cliffs and buildings to alert the public when a shark is seen. The higher elevation increases sighting rates, and the observers can also give the “all clear” signal once the shark has left the area (Kock *et al.* 2012). With nearly 40 coastal drownings per year in NSW, compared with 2 shark fatalities over the last 35 years (Green *et al.* 2009, Anon 2010a), directing funding towards existing lifesaving programs may ultimately reduce fatalities from both sources. Increased funding for such organisations will further assist with the treatment of non shark-related injuries and medical emergencies on beaches, neither of which can be aided by aerial beach patrols.

Within NSW, expansion of the existing State Government shark awareness program, *Shark Smart* (www.dpi.nsw.gov.au/fisheries/info/sharksmart) should also be given a high priority. This program provides beachgoers with information such as the times of day, types of habitat, weather conditions etc. which can increase risk from shark attack. Although primarily a web-based information site, information packages could be distributed by NSW lifesavers and life guards, surf shops and tourist information centres. Aiding this program would be preferable to alternatives such as erecting shark advisory signs on NSW beaches as no NSW beach is an acknowledged ‘hotspot’ for shark attack (Green *et al.* 2009), thus any signage would rapidly lose impact with a gradual waning of public awareness.

4.3. Conclusion

Severe limitations were found in the ability of aerial observers in fixed-wing planes and helicopters to sight shark analogues, both in terms of depth and distance from the aircraft. Although it is acknowledged that aerial patrols will detect some coastal sharks, the rates of such detections are inconsistent with that required for an effective early detection system. Overall, the results from these experiments suggest that aerial patrols are extremely limited in detecting sharks in coastal NSW waters, while giving the public an inflated sense of protection against shark attack.

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