Non-destructive Techniques for Rapid Assessment of Shark Abundance in Northern Australia

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Bibliography.
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1. Sharks - Australia, Northern - Geographical distribution.
2. Underwater acoustics - Australia, Northern. I. Cappo, Mike.
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EXECUTIVE SUMMARY

This report describes research by the Australian Institute of Marine Science (AIMS) in June 2003 with funding co-investment from the Fisheries Resources Research Fund, administered by the Australian Government Department of Agriculture, Fisheries and Forestry. The aim of the project was to evaluate different non-destructive techniques to estimate shark abundance and to provide a census of sharks around two offshore reef systems in north-west Australian waters. These were Mermaid Reef in the Rowley Shoals (a Commonwealth Marine Protected Area closed to all fishing) and Scott Reef in the MOU 1974 Box. Scott Reef is one of the larger reefs within the MOU 1974 Box where access by Indonesians using traditional artisanal fishing techniques is permitted.

Our study used 2 non-destructive techniques to assess shark abundances in a variety of habitats at these oceanic coral reefs. In the first, an underwater speaker emitting broad frequency sound was deployed from a small vessel that was either anchored on the reef slope or allowed to drift in deep water off the edge of the reef drop-off. After a 5 min period of silence the speaker broadcast sound for 5 mins and the sharks that were attracted within a 30-40m radius of the speaker were recorded by a snorkeller at the surface. As a control, the same protocol was followed in another set of trials but the speaker was not switched on.

In the second technique we deployed Baited Remote Underwater Video Stations (BRUVS) in reef slope habitats in the lagoons (14-48 m depth), along the sides of deep drop-offs (58-72 m) and at 15m depth from a small vessel drifting off the edge of the reef drop-off over very deep (>300m) waters. One of the BRUVS used a pair of cameras in a stereoscopic configuration to allow precise and accurate measurement of sharks.

There was a striking difference in the species composition and abundance of sharks between Mermaid (closed to fishing) and Scott Reefs (open to fishing). Our acoustic techniques recorded a total of 153 sharks of 4 species in 72 deployments at Mermaid Reef, but only 12 sharks of 2 species in 46 deployments at Scott Reef. Similarly, BRUVS recorded 88 sharks from 8 species in 75 deployments at Mermaid, but only 14 sharks from 5 species in 28 deployments at Scott Reef. When corrected for sampling effort, our study shows that sharks were on average from 17 to 4 times more abundant at Mermaid Reef than at Scott Reef.

Analysis of BRUVS tapes also showed that it took twice as much time (50 min) at Scott Reef for sharks to appear in the video than at Mermaid Reef, further suggesting that they were much less abundant at Scott than at Mermaid Reef. Notably, the sharks more valuable for the trade in fins (Silvertip Whalers *Carcharhinus albimarginatus,* Scalloped Hammerheads *Sphyrna*

lewini) were not sighted at Scott Reef, but were relatively abundant at Mermaid Reef. One of the few Grey Reef sharks seen at Scott Reef had a wound in its left jaw that may have been caused by fishing gear.

Coarse comparisons of the length of shark images with scale grids on the bait arms indicated the possibility that Grey Reef and Silvertip Whalers seen on the surface baited hangs in very deep water were smaller than those seen on bottom-set BRUVS in 40-70m, but this requires further image analysis. Few sharks were seen on the stereo-video sets.

A range of evidence suggests that over-harvesting by Indonesian fishers is the most plausible explanation of these differences in abundance of sharks between Mermaid and Scott Reef. It is unlikely that the reduced number of sharks in the MOU Box is a function of differences in habitat, as Rowley Shoals and Scott Reefs are both isolated oceanic atolls that support comparable faunas. Furthermore, Australian commercial shark fisheries do not principally target the species that inhabit these reefs. However, we recommend that further studies of Scott Reef and Rowley Shoals, and other localities within and outside the MOU Box, be undertaken to confirm these results and ascertain the importance of habitat and effects of fishing in determining shark abundance.

The results of our attempts to use acoustic techniques to attract and count sharks were inconclusive. While 165 sharks of 4 species were observed in the vicinity of the speaker, there were no differences in the numbers of sharks recorded in “silent” and “sound” periods of the trials. Our observations of sharks suggested that they were strongly attracted to the noise produced by the outboard motor and anchoring of the boat, resulting in a confounding of our experiments. This could be overcome by fitting timers to acoustic gear so that it could operate independently of surface support vessels, or by testing the technique at a location where sharks are habituated to vessel noise and movement. Given the recognised need for non-destructive techniques to sample shark populations, we recommend that further research is undertaken to refine the acoustic technique.

Despite this problem, both acoustic and BRUVS techniques provided good relative estimates of shark distribution and abundance and found clear differences in species composition among habitats. Silvertip whalers (*Carcharhinus albimarginatus*) were seen only in deeper waters, and White-tip Reef sharks (*Triaenodon obesus*) were only seen on the seabed, mostly in the lagoons and reef edges. The Grey Reef Shark (*C. amblyrhynchos*) was seen in all habitats sampled, at the surface and on the bottom, but more commonly outside the lagoons. The largest (~3m) Tiger (*Galeocerdo cuvieri*) and Great Hammerhead (*Sphyrna mokarran*) sharks were sighted on one BRUVS in Mermaid Reef Lagoon.

The northern section of Mermaid Reef had an abundant and diverse fauna of Grey Reef, Silvertip and Scalloped Hammerhead sharks that were associated with schools of Rainbow Runners (*Elegatis bipinnulatus*), pelagic surgeonfish (*Naso hexacanthus/lopezi*) and long-toms (*Tylosurus* spp).

Single individuals of the poorly known Thresher Shark (*Alopias pelagicus*), Sicklefin Hound Shark (*Hemitriakis spA*) and Fossil Shark (*Hemipristis elongata*) were sighted on BRUVS tapes, with the remaining species comprising Tawny (*Nebrius ferrugineus*) and Leopard (*Stegastoma fasciatum*) sharks. Few sharks fed on the bait canisters. It is possible that multiple sightings of up to 6 *S.lewini* at one time are evidence for aggregations of these Scalloped Hammerheads occurring at Mermaid Reef, similar to the large aggregations known elsewhere in the Indian Ocean.

INTRODUCTION

Sharks have a unique combination of life history characteristics. Unlike bony fishes, they tend to have strong stock-recruitment relationships, low biological productivity due to late sexual maturity, low rates of reproduction (i.e. few offspring) and complex distributions that include ontogenetic and sexual segregation and seasonal migrations. Together, these traits mean that shark populations cannot withstand high rates of exploitation and are very susceptible to overfishing. Increasing global shark catches are thus a cause for concern and have prompted development by the FAO of an International Plan of Action for the Conservation and Management of Sharks.

In Australia, sharks form an important part (5%) of wild fisheries. They are caught by commercial, indigenous and recreational fishers and are also killed in bather protection programs. In response to the issues identified by the FAO, a National Plan of Action (NPOA) has been formulated to ensure the conservation of these animals. This plan recognises that there is a need for a significant improvement in the management of many species, particularly in situations where the stocks are shared with other nations, as is the case in northern Australia.

Information on distribution and abundance of sharks forms the most basic part of any stock assessment or management plan. Traditionally, this has been derived from catch and effort statistics provided by logbook and observer programs in commercial fisheries. The use of this type of data brings with it a number of problems that will bias abundance estimates, such as differences in vulnerability to fishing techniques among species and non-random distribution of fishing effort. Furthermore, this approach seldom provides accurate information on species that are not direct targets of the particular fishery, such as by-catch, or rare and threatened species. It also provides no information on shark distribution and abundance in areas where fishing is prohibited (eg marine parks) or on sharks that are inaccessible to fishing gear. Due to these limitations, the NPOA recommended there is a need to develop fishery-independent techniques for assessment of shark numbers.

For centuries artisanal fishermen have been aware that sharks are attracted to underwater sounds and have used this behaviour to target and capture these animals throughout the Indo-Pacific. In the late 1960's, experiments funded by the US Navy compared the attractiveness of different types of sounds to sharks and found that the greatest response was elicited by pulsed low-frequency signals (Richard 1968, Myerberg et al 1969, Nelson and Johnson 1972). Our proposal developed and tested systems that combined underwater video with a speaker emitting underwater sounds as a new, non-destructive technique for estimating the abundance and distribution of sharks.

Over the last five years, the Australian Institute of Marine Science (AIMS) has refined the use of a fleet of 6 baited remote underwater video stations (BRUVS) to quantify the relative abundance of marine fishes (Cappo et al., 2003). These have been very successful, particularly in deep-water (30-1000m) habitats beyond the range of divers, and in inter-reefal areas (see the AIMS website www.aims.gov.au for video footage of sharks recorded by BRUVS and for details of the method). It is possible to obtain accurate and reliable estimates of not only the identity and number of teleosts (fin fishes) and elasmobranchs (sharks) recorded by baited video, but also their size if stereo-video pairs are used, which can then be converted to biomass using length-weight regressions (see Harvey et al 2003). The fleet of AIMS BRUVS now offer a field-proven platform for the development of a shark acoustic-video system.

The localities chosen to test several approaches using video and olfactory/acoustic attractants were Mermaid Reef in the Rowley Shoals and Scott Reef in northern Australia. Both these reef systems are isolated oceanic atolls that are remote from coastal regions. At Scott Reef, fishermen from Indonesia are permitted to harvest sharks using traditional artisanal techniques, while they (and all other fishers) are excluded from Mermaid Reef in the Rowley Shoals. Anecdotal evidence suggests that there are relatively few reef and pelagic sharks at Scott Reef and nearby shoals, while sharks are very abundant at Rowley Shoals. This situation offered the opportunity to assess the status of sharks in a locality where stocks are shared with Indonesia, and to compare these data with an area not subject to fishing pressure. Such information contributes to the goals of the NPOA, particularly the need for better management of shark populations in this region of northern Australia.

The specific aims of the project were as follows:

1. To develop and test rapid, non-destructive techniques for assessment of shark abundance that can be used in marine habitats throughout Australia.
2. To provide a preliminary assessment of shark abundance on oceanic reefs in northern Australia that are protected and unprotected from shark fishing.

METHODS

Acoustic System

The acoustic system consisted of an underwater speaker linked to an amplifier with a power source of 12 Volt lead acid batteries. A portable compact disc player provided the sound source by playing a broad frequency, intermittently pulsed sound in a continuous loop. The frequency spectrum of the broadcast sound, the ambient spectrum and calculations on the area the sound was audible above ambient are shown in Appendix 1. In total, the system weighed approximately 30kg and could be handled by one person in a small inflatable vessel (zodiac).

The system components are displayed in Figs. 1-3. The amplifier, power source and player were housed in a splash proof case. Photos are shown with this equipment removed from the housing. The speaker (Fig. 3) is shown within its "shark proof" mesh cage. The speaker and surface components of the system were linked by 100m of cable, allowing the speaker to be deployed in water of this depth. A compensation bladder was deployed with the speaker to allow the in-water weight of the speaker system to remain at 6 kg irrespective of depth. The speaker could be joined to BRUVS (Baited Remote Underwater Video Stations, see below) so that the acoustic and video components could deploy together.

Baited Remote Underwater Video Stations (BRUVS)

The BRUVS consisted of a galvanized roll-bar frame enclosing a simple camera housing made from PVC pipe with flat acrylic front and rear ports. Stabilizing arms and bait arms (20mm plastic conduit) were attached before deployment. The bait arm had two 50mm square scale grids either end of a 35 cm plastic mesh bait canister containing 1 kg of crushed pilchards (Fig. 4). BRUVS were deployed with ropes and surfaces floats bearing a flag and were retrieved with an hydraulic pot-hauler wheel. Sony TRV18E MiniDV Handicams with wide-angle lenses (0.6 X) were used in the housings. Exposure was set to "Auto", focus was set to infinity/manual, standard or long-play mode was selected, and date/time codes were underlaid on footage. The BRUVS were deployed to provide 60-90 minutes of film recorded at the seabed.

Figure 1. Upper view of acoustic system showing CD player (removed from waterproof housing).

Figure 2. Side view of system showing amplifier and power source (removed from waterproof housing).

Figure 3. Underwater speaker, housing and compensation bladder

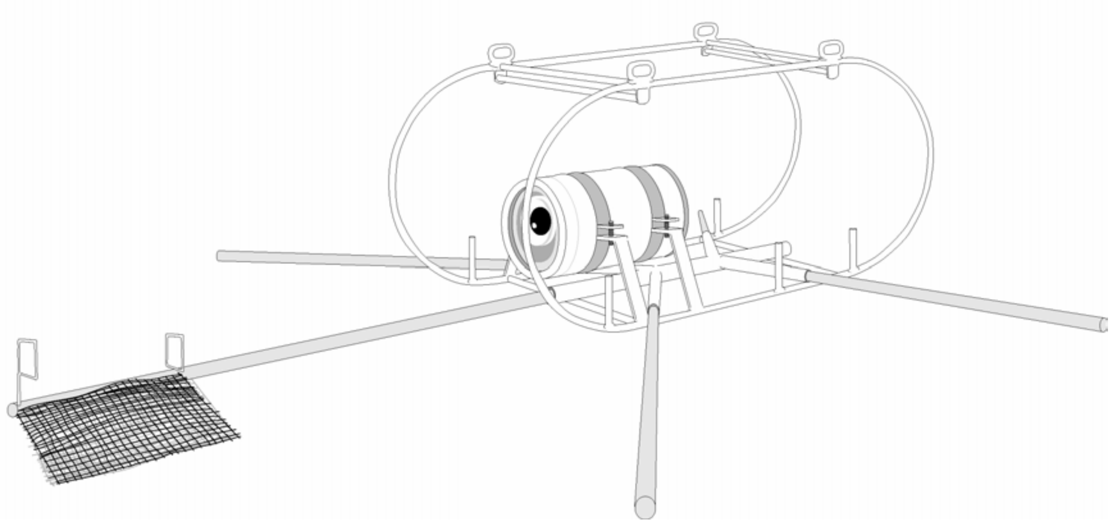


Figure 4. BRUVS unit with bait arm, stabilising arms and bait canister. These were set on the seabed or hung from the tender vessel.

Deployments

A) ACOUSTIC SYSTEM

The acoustic system was deployed from the zodiac in 2 different modes. Firstly, the zodiac was anchored on the reef crest or reef slope and the sound system hung from the side of the boat in mid-water at 3-10m depth. After a 5 min period of silence, the speaker broadcast broad frequency noise for 5 min. A snorkeller circled the zodiac recording the arrival time and identity of sharks that approached within 30-40m of the zodiac (the approximate limit of visibility) during the "silent" and "sound" periods. Acoustics were deployed in this fashion in a wide range of shallow reef habitats both in the lagoon and along the backreef. Sampling sites are shown in Figure 5. Secondly, the zodiac was allowed to drift in deep (300m+) water 500m off the edge of the reef and the sound system hung from the side at 15m depth. After a 5 min period of silence the speaker broadcast sound for 5 mins and a snorkeller recorded sharks as described above (Fig. 5).

B) ACOUSTIC SYSTEM + BRUVS

Acoustics and BRUVS were deployed together from a zodiac in 2 modes. Firstly, the zodiac was allowed to drift just off the reef drop off and the speaker and a BRUV hung from the zodiac at 15m depth. After a 5 min period of silence the speaker broadcast sound for 5 mins. In addition to obtaining a count of sharks from the BRUVS tapes (see below) a snorkeller recorded sharks arriving within 30m of the zodiac as described above. Secondly, the zodiac was again allowed to drift just off the reef drop off and the sound system hung from the side along with the BRUVS. However in this mode, the speaker was not switched on. A snorkeller recorded sharks during for 10 min after deployment. Habitats and sites where these deployments occurred are shown in Figure 5.

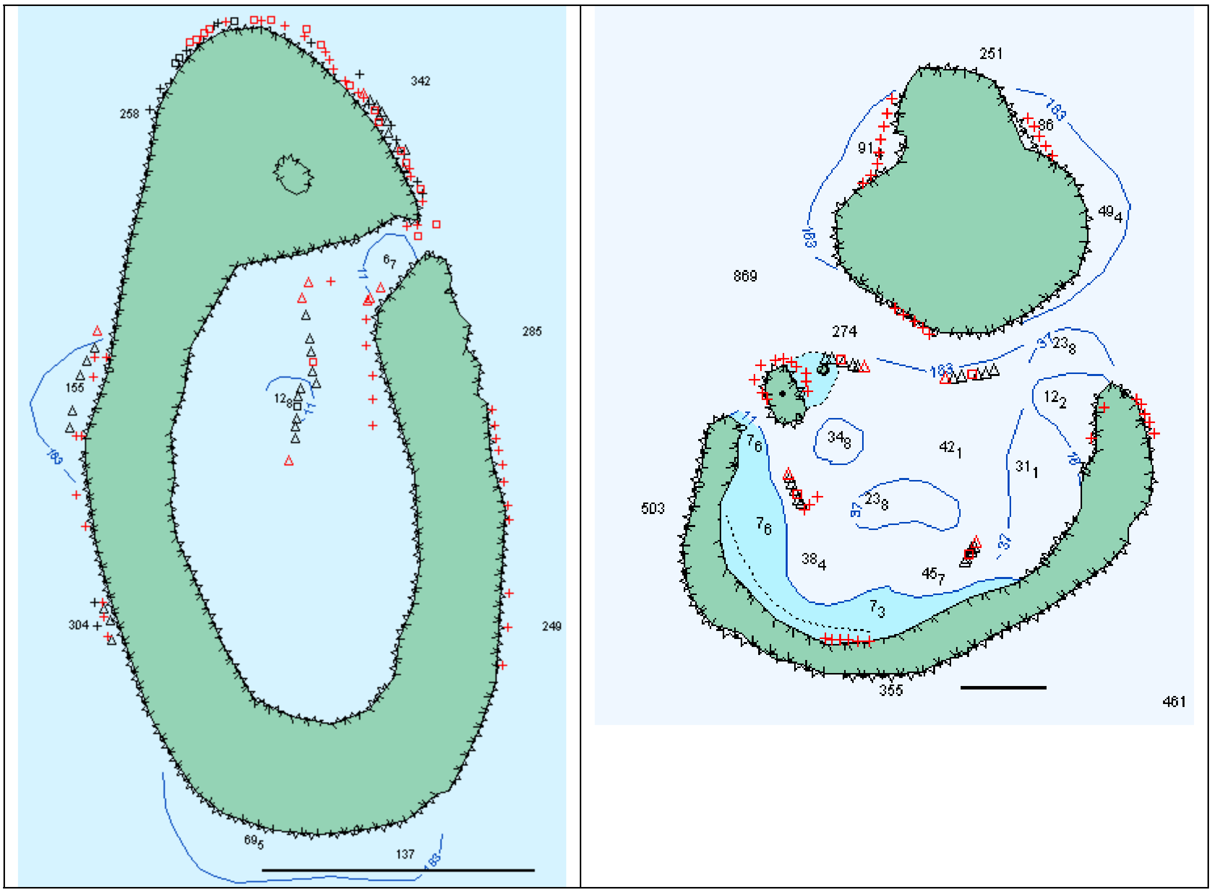
C) BRUVS

To assess microhabitat variation in shark numbers and species, BRUVS were deployed along depth contour lines with each unit separated by approximately 400m in the shallow (<10m) reef crest and deeper reef slope (50-70m) on the outside of reefs, and on the lagoon floor (20-30m) within the both reefs (Fig 5).

Interrogation of each tape provided the time the BRUVS settled on the seabed and, for each shark: its species; the time of first sighting; time of first feeding at the bait; a coarse initial estimate of length; and a list of fish species. This enabled the identification of different sharks on each tape for cumulative summaries of shark visits (*Nsharks*, see Table 1) to be developed for each BRUVS set. Coarse measurements of the total length of the largest individuals of some species were made by comparing them with the scale grids on the bait arm. These measurements could be made only when the sharks were perpendicular to the camera and immediately next to, or between, the scale grids (see Harvey et al., 2002a).

D) STEREO-BRUVS

A single stereo-BRUVS was used to obtain targets for accurate and precise measurements (Harvey et al., 2003). It comprised 2 housings set 700 mm apart with an angle of convergence of 12 degrees (Fig. 6). The stereo-BRUVS was hung from the RV "Cape Ferguson" or deployed on the seabed with float ropes in the normal run of BRUVS sets on the reef slopes and in the lagoons (Fig 5).



A. Mermaid Reef B. Scott Reef

Figure 5. Locality map showing deployments at Mermaid Reef (A) and Scott Reef (B). Black triangles = BRUVS, red triangles = stereo-BRUVS, black cross = acoustics drifting, red cross = anchored acoustics, black squares = BRUVS drifting, red squares = Acoustics+BRUVS. Scale bar in each map is equivalent to 5km.

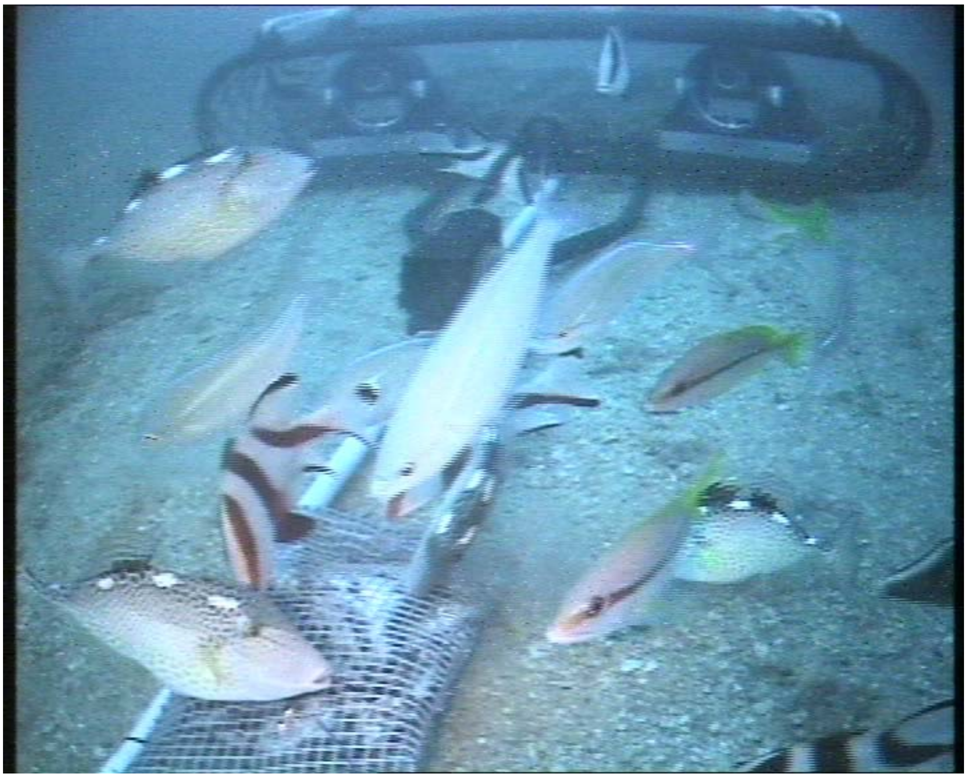


Figure 6. Stereo-BRUVS set on the seabed off Townsville. This unit was set on the sebed or hung from the mothership RV Cape Ferguson.

Table 1. Summary of results of BRUVS deployments. Number of sharks by location, habitat, depth (under the ship's hull) and method of sampling. AB=Acoustics and BRUVS, B=BRUVS and stereo-BRUVS NE=north east, E=east, W=west

	Nsets	total nbr tape hrs	Min depth (m)	*C. amblyrhynchos*	*C. albimarginatus*	*T. obesus*	*G. cuvieri*	*S. lewini*	*S. mokarran*	*Hemipristis elongata*	*H. emitriakis spA*	*S. fasciatum*	*N. ferrugineus*	*A. pelagicus*
				Grey Reef shark	Silvertip Whaler	White-tip Reef shark	Tiger shark	Scalloped Hammerhead	Great Hammerhead	Fossil Shark	Sicklefin Hound shark	Leopard shark	Nurse shark	Thresher shark
Mermaid Reef														
Mouth lagoon AB	2	0.445	100	0	0	0	0	0	0	0	0	0	0	0
N Top close AB	11	2.502	100	17	8	0	0	3	0	0	0	0	0	0
N face close AB	3	0.638	100	2	0	0	0	0	0	0	0	0	0	0
NE face wide AB	8	1.3	>300	0	0	0	0	0	0	0	0	0	0	0
NTop wide AB	9	1.856	10	8	1	0	0	0	0	0	0	0	0	0
W face wide AB	2	0.488	>300	0	4	0	0	0	0	0	0	0	0	0
Entrance B	7	3.817	11	2	0	0	0	0	0	0	0	0	0	0
NE face close B	3	3.325	6	5	0	1	0	0	0	0	0	0	0	0
Lagoon B	13	12.982	14.1	1	0	1	1	0	1	0	0	0	0	0
W face close B	3	3.132	5	3	0	3	0	0	0	0	0	0	0	0
W face dropoff B	7	9.87	61.9	7	3	0	0	0	0	0	1	0	1	0
NE face close B	7	6.87	60	3	3	0	1	8	0	0	0	0	0	0
Scott Reef														
SE lagoon B	7	10.089	43	0	0	0	0	0	0	0	0	0	0	0
E Hook dropoff B	7	9.795	58	0	0	2	0	0	0	0	0	0	0	1
W Hook lagoonB	7	10.032	41.6	0	0	4	0	0	0	1	0	1	0	0
W Hook dropoffB	7	9.937	65	5	0	1	0	0	0	0	0	0	0	0
TOTALS	103	87.078		53	19	12	2	11	1	1	1	1	1	1

RESULTS

Comparison of Techniques to Assess Shark Abundance

As relatively few sharks were recorded at Scott Reef, technique comparisons were limited to data sets collected at Mermaid Reef, Rowley Shoals.

A) ACOUSTIC SYSTEM

The results of acoustic deployments in both anchored and drifting modes on Mermaid Reef are summarised in Figure 7. A total of 65 sharks were seen in 29 deployments of anchored acoustic gear. These included reef whitetips (*Triaenodon obesus*), grey reef (*Carcharhinus amblyrhynchos*), silvertip whaler (*C. albimarginatus*) and one tawny nurse (*Nebrius ferrugineus*) sharks. These appeared in similar numbers during both silent and sound periods. Our observations of sharks suggested that they were strongly attracted to the noise produced by the zodiac motor and anchoring of the boat. Thus our "silent" and "sound" treatments were confounded and for this reason, we did not attempt any statistical analysis of these results. In the drifting mode, only 7 sharks were seen in 12 deployments, a number that was considered insufficient for further analysis (Fig. 7C). These low abundances probably reflect that fact that the deployments occurred in a habitat well off the reef edge (approximately >500m) in very deep water (>300m) where there were relatively few sharks.

B) ACOUSTIC + BRUVS

A total of 40 sharks were seen by snorkellers in 18 deployments when the acoustic system and BRUVS were hung below the zodiac drifting off the reef edge at Mermaid Reef. Grey reef and silvertip whalers dominated counts. A few scalloped hammerheads (*Sphyrna lewini*) were also recorded. Sharks were seen in similar numbers during both "silent" and "sound" treatments (Fig. 8). We believe that this result is due to boat noise confounding our treatments and for this reason we did not attempt any statistical analysis of these results.

When the BRUVS and acoustic system were deployed together but the speaker was not switched on, snorkellers recorded a total of 41 sharks in 13 deployments. Grey Reef and Silvertip Whalers were again the most abundant sharks. There was a significant difference (t-test, $p<0.05$) in the mean numbers of sharks seen in the first and second halves of the 10 min sampling period, with the majority of sharks recorded within the first 5 min (Fig. 8).

Analysis of the videotape obtained from the BRUVS in both deployment modes is detailed below (Section d, BRUVS).

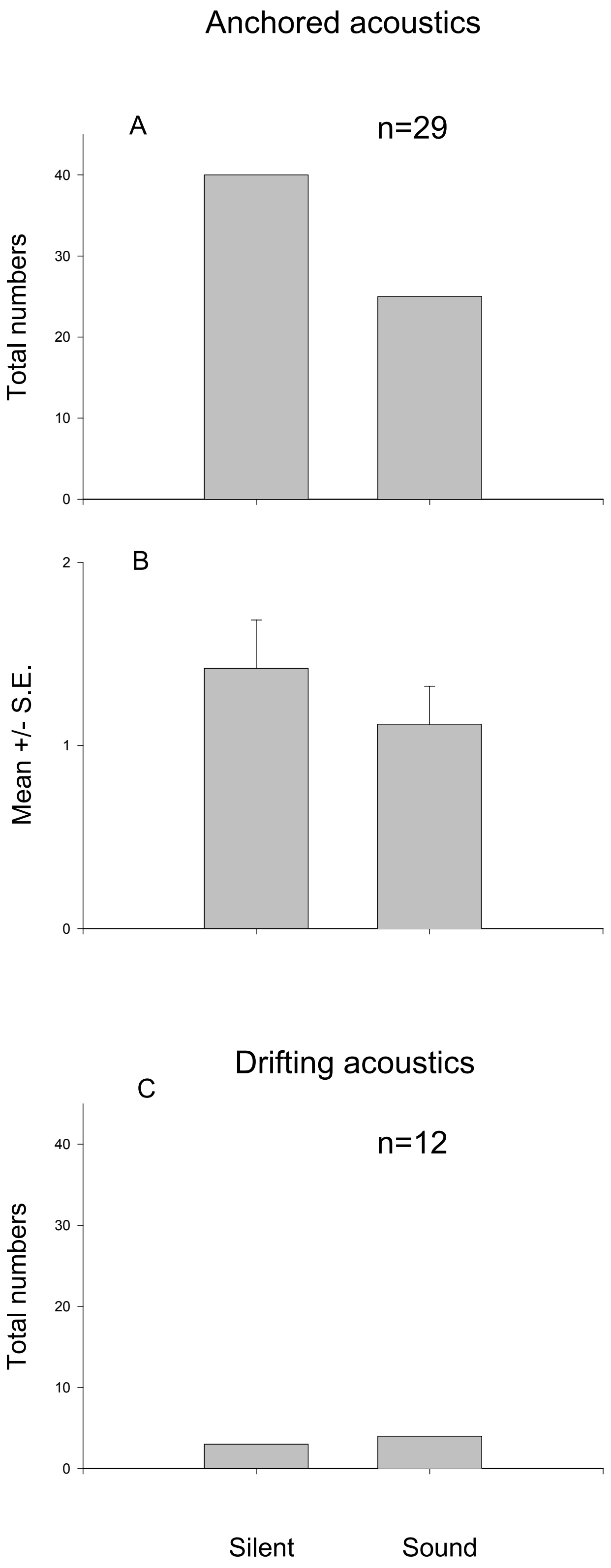


Figure 7. Comparison of total numbers (A), and mean numbers (B) of sharks (all species pooled) recorded in silent and sound treatments in anchored (A, B) and drifting (C) modes of deployments of gear. n=total number of deployments.

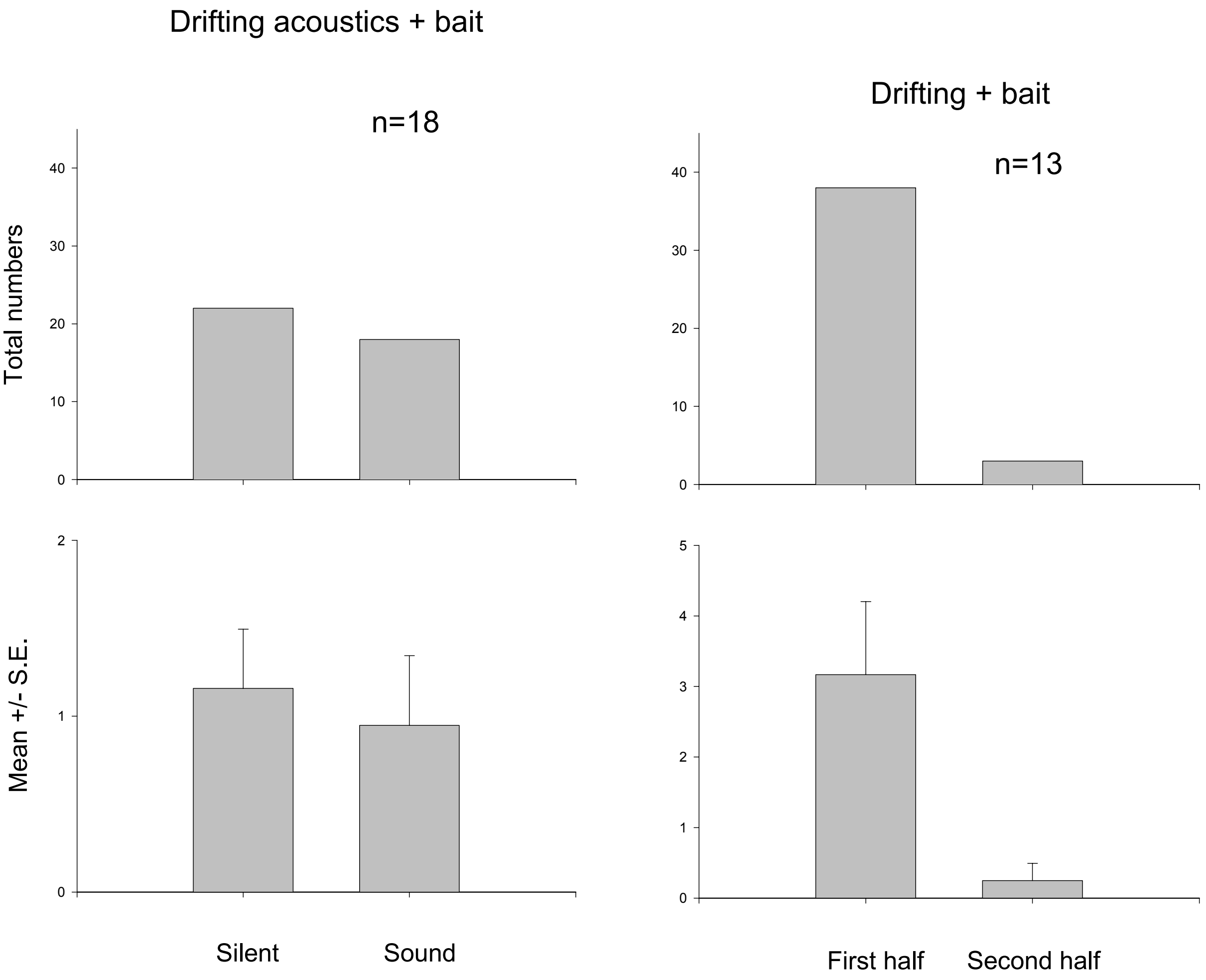


Figure 8. Total and mean numbers of sharks ±SE counted by snorkellers in drifting deployments of acoustics and BRUVS. The left panel shows counts during "silent" and "sound" treatments, while the right panel shows numbers counted in the first and second halves of the 10 minute sampling period (see Methods for sampling details). n=total number of deployments.

C) COMPARISON OF TECHNIQUES

Where a snorkeller was used to count and observe sharks the mean numbers of sharks recorded by each technique could be compared statistically. "Silent" and "sound" treatments were pooled for this analysis. A one-way ANOVA showed that the mean number of sharks (per 10 min) differed among deployment techniques (f=3.622, p=0.017), with the drifting acoustics recording significantly lower numbers than all other techniques (Fig 9). The remaining techniques recorded similar numbers of sharks.

D) BRUVS

At Mermaid Reef, a total of 72 sharks were seen in 75 BRUV deployments that recorded approximately 47 hrs of video. These sharks included 8 species (Table 1) but were dominated by Grey Reef and Silvertip Whaler sharks. Significantly greater numbers of sharks per hour were recorded in the deployments that hung the BRUVS with the acoustic system from the zodiac while drifting off the edge of the reef than in deployments on the bottom along the reef slope or crest (t-test $p<0.05$, Fig. 10). As there was no difference in abundances of sharks when BRUVS hung from the zodiac were deployed with or without broadcast sound (t-test $p<0.05$) these data sets were pooled for this analysis.

Where BRUVS were deployed and sharks were also counted by a snorkeller at the surface the efficiency of the visual and video techniques could be compared. When the acoustic system and BRUVS were hung below the zodiac drifting off the reef edge at Mermaid Reef and sharks counted during a 5 min period of silence and a 5min period when the speaker broadcast sound, snorkellers recorded on average 2.8 times the numbers of sharks than were seen in the video from the BRUVS. A similar result occurred when the gear was deployed in the same manner but the speaker was not switched on. In this case, snorkellers saw twice the number of sharks that were recorded by the BRUVS.

E) STEREO BRUVS

Relatively few sharks were seen on the four sets of the stereo-video system, consequently none were measured with Vision Metrology Software.

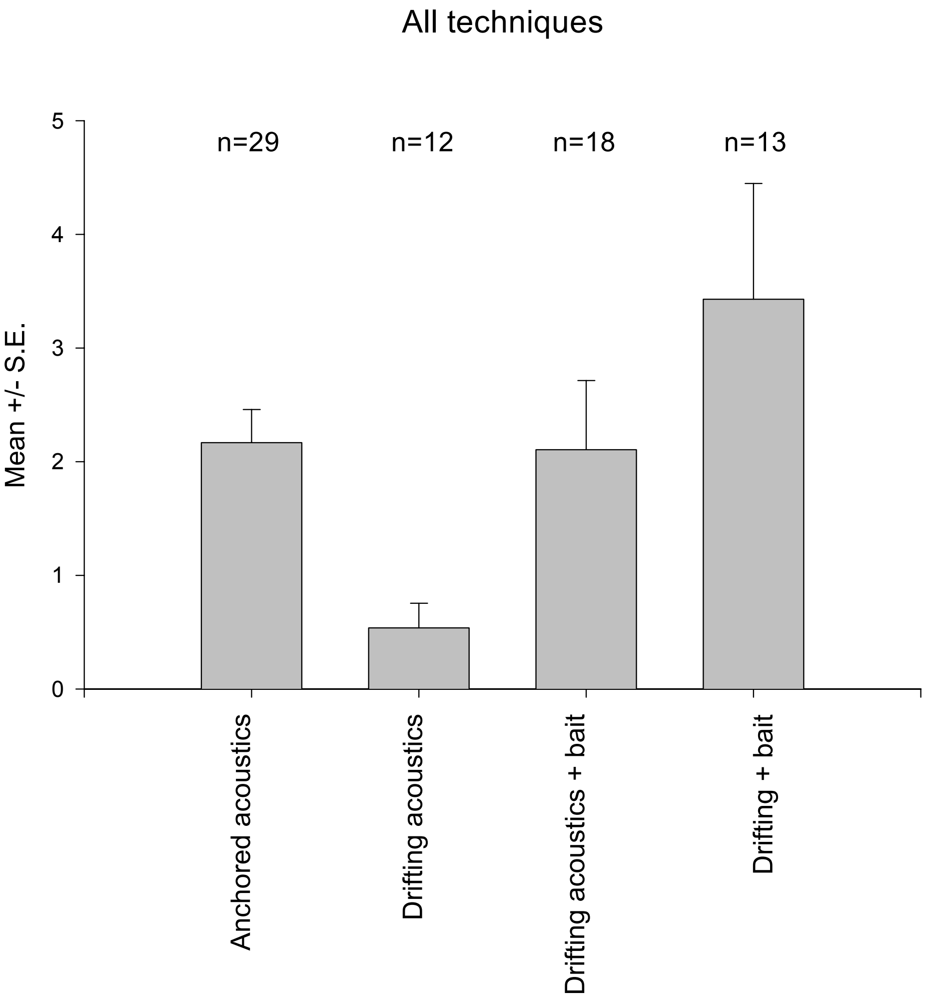


Figure 9. Comparison of mean numbers of sharks ±SE counted by snorkellers using 4 different sampling techniques. n=total number of deployments.

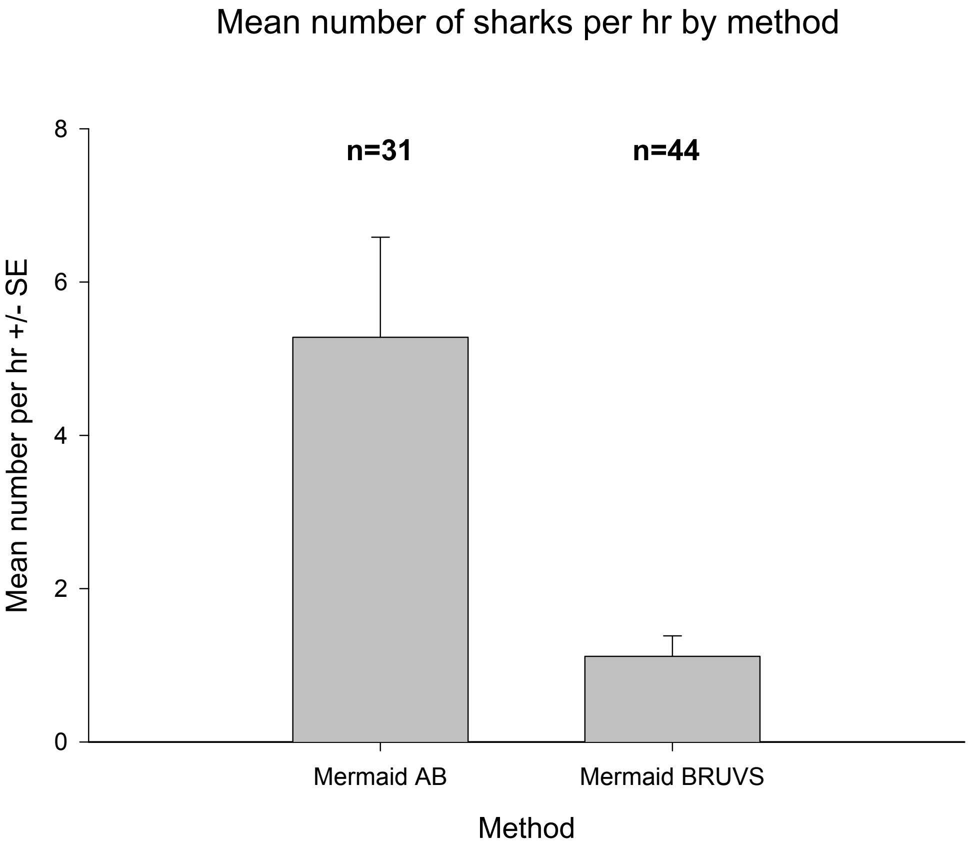


Figure 10. Average number of sharks ±SE (all species pooled) per hour sighted on each video set, pooled by location, habitat and method at Mermaid Reef. AB=Acoustics and BRUVS, B=BRUVS. n=total number of deployments.

Comparison of Shark Abundance at Mermaid and Scott Reefs

A) ACOUSTICS

Acoustic gear was deployed at Scott Reef in a similar manner to Mermaid Reef. A total of 11 sharks were recorded in 35 deployments of acoustic gear from a zodiac anchored on the reef crest and slope. All these sharks were reef whitetips. Only a single shark was seen in 11 deployments of acoustic gear from a zodiac drifting off the reef edge. Due to these low numbers, the data sets from anchored and drifting deployments could not be analysed statistically and were pooled for the between reef comparison. For Mermaid Reef, counts from drifting acoustics were excluded and data sets from the remaining techniques (anchored, acoustics + BRUVS) were pooled. Shark abundances were compared from a total of 60 deployments of acoustic gear at Mermaid Reef and 41 deployments at Scott Reef (Fig 11). There was an order of magnitude difference in the mean numbers of sharks recorded using these techniques between Mermaid and Scott Reefs. A greater diversity of sharks was also recorded at Mermaid (5 species) than at Scott Reef (2 species).

B) BRUVS

BRUVS recorded a greater number of species of sharks at Mermaid Reef (8) than at Scott Reef (5). At Scott Reef, counts included single individuals of some rarely seen species, such as Fossil (*Hemipristis elongata*), Thresher (*Alopias vulpinus*) and Sickle-Fin Hound shark (*Hemitriakis spA*). Silvertip whalers (the preferred targets of shark fishing) and hammerhead sharks were common at Mermaid Reef but absent from Scott Reef, while Grey Reef sharks were markedly less abundant on Scott than Mermaid Reef. At Mermaid reef, Grey Reef sharks were seen in all drifting BRUV deployments and in over half the sets deployed on the reef, while at Scott Reef only 5 Grey Reef sharks were sighted (all on the reef slope) on only four of the 28 demersal BRUVS deployments.

Similar to acoustic techniques, BRUVS recorded a major difference in the abundance of sharks between Mermaid and Scott Reefs. On average, the mean number of sharks at Mermaid Reef seen per hour of drifting BRUVS and BRUVS deployed on the reef was 17 and 4 times greater, respectively, than the mean number seen in BRUVS sets on Scott Reef (Fig 12). There was also a greater lag in arrival time of sharks to the BRUVS at Scott than at Mermaid Reef (Fig. 13). At the latter reef, sharks appeared on the video mostly within a few minutes of deployment in drifting mode and on average within 25 min of deployment on the reef, while at Scott Reef, sharks were not recorded by the BRUVS until almost 50 min after deployment on the reef. This implies that there was a far lower density of sharks at Scott than Mermaid Reef, and as a consequence, sharks had to travel a greater distance to arrive at the BRUVS.

Comparisons of shark images with scale grids on the bait arms in average size of sharks seen by BRUVS deployed on the reef at Scott and Mermaid Reefs were skewed by the presence of large hammerhead and tiger sharks at Mermaid Reef, and the data were too few to comment on the difference in sizes of Grey Reef sharks seen at both reefs (Fig 14). There was some suggestion that the Grey Reef and Silvertip Whalers seen on the drifting deployments off the reef edge at Mermaid Reef were smaller than those seen on bottom-set BRUVS in 40-70m, however this result must be treated with caution as the measurement technique was prone to major error (see Harvey et al., 2002a,b).

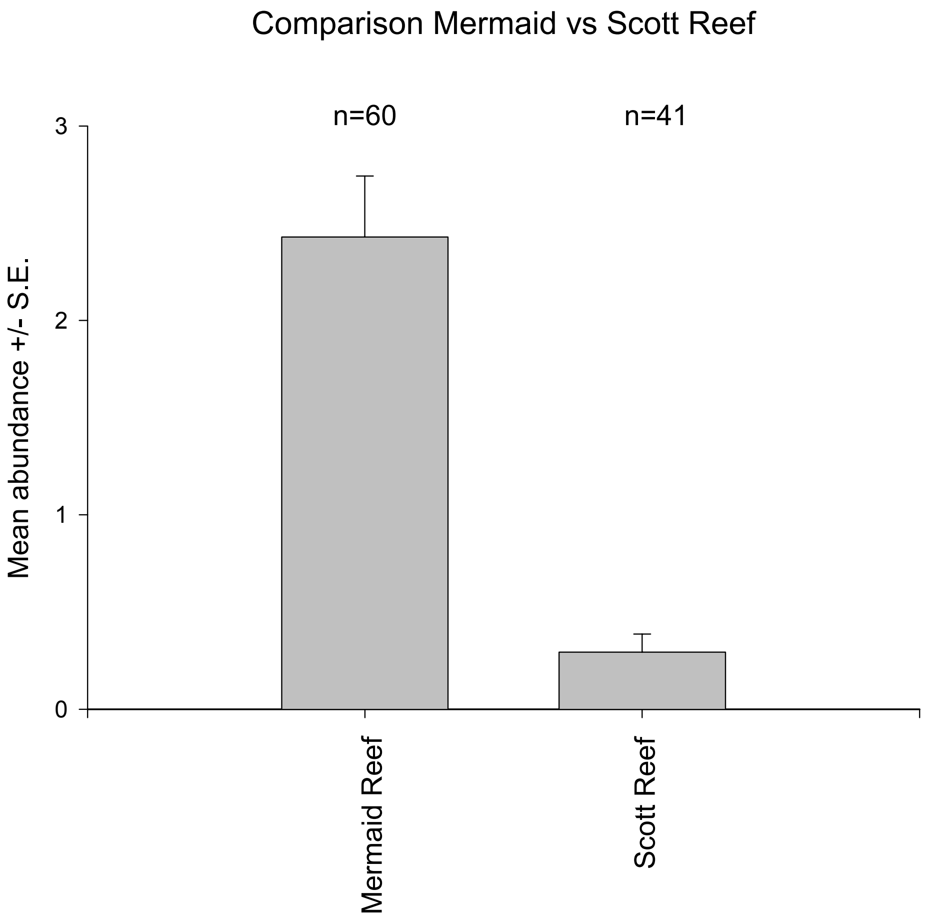


Figure 11. Comparison of mean numbers of sharks ±SE recorded by snorkellers (all species pooled) at Mermaid and Scott Reefs. Counts pooled among techniques within reefs, but excluding drifting acoustics at Mermaid Reef. n=total number of deployments.

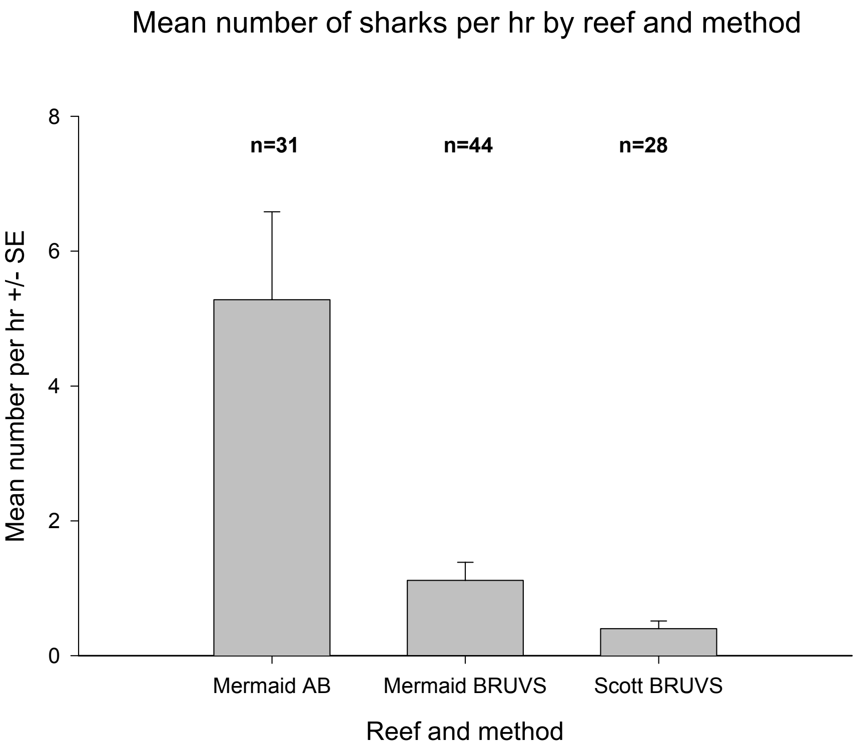


Figure 12. Comparison of average number of sharks ±SE (all species pooled) sighted per tape hour on each video BRUVS set, pooled by habitat and method at Mermaid and Scott Reef. AB=acoustics+BRUVS. n=total number of deployments.

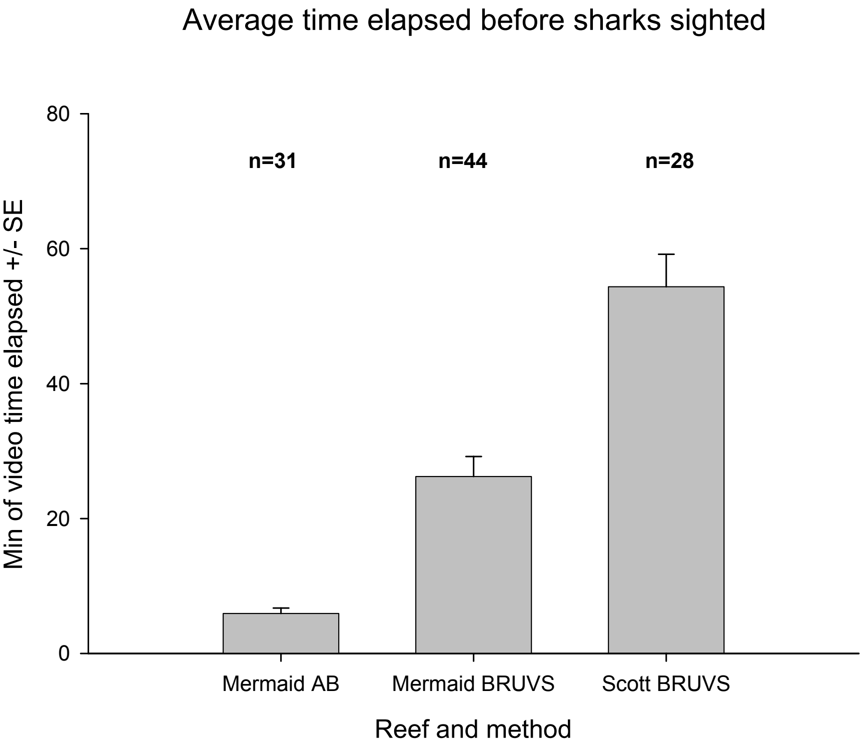


Figure 13. Average position of the sharks ±SE (all species pooled) sighted within each video tape, pooled by habitat and method for each reef. AB=acoustics+BRUVS, n=total number of deployments.

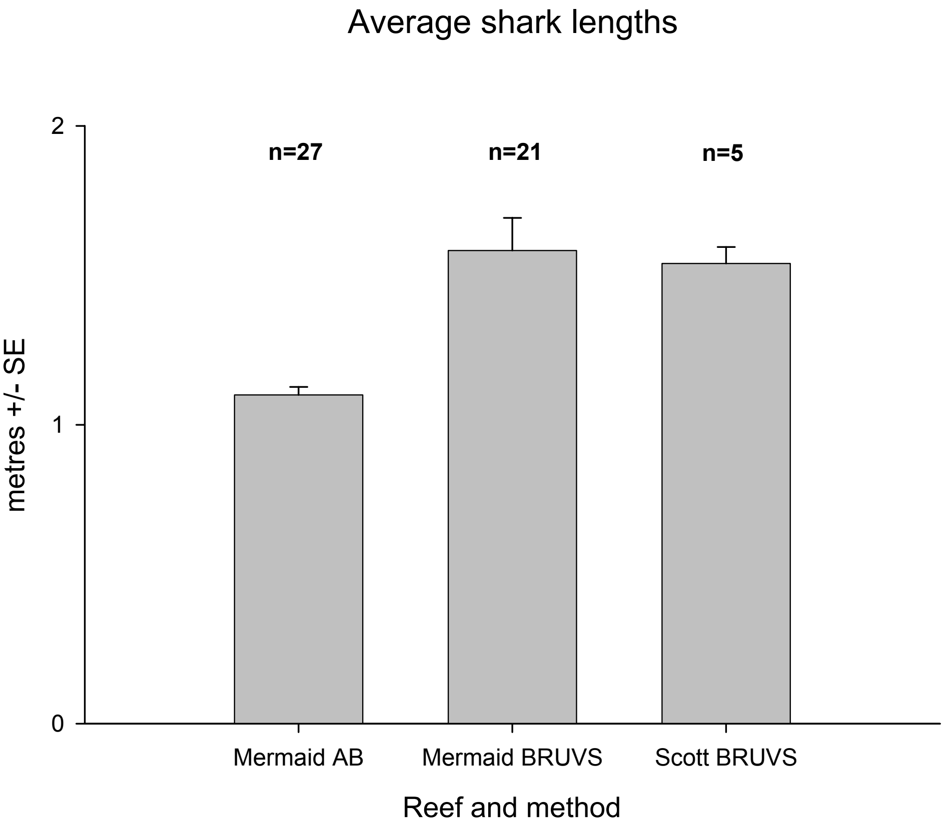


Figure 14. Average length of the sharks ±SE (all species pooled) sighted within each video tape, pooled by habitat and method at Mermaid and Scott Reefs. These estimates are coarse and not reliable. AB=acoustics+BRUVS, n=total number of sharks

DISCUSSION

Technique Comparison

Our study aimed to develop and compare non-destructive techniques for estimating the abundance of sharks. We proposed that acoustics could be used to attract sharks so that they could be counted by an observer, or recorded on video. Unfortunately, our experimental design did not take into consideration the possibility that the noise and activity of the boat would also attract sharks, confounding our results. This problem probably accounts for the fact that we recorded similar numbers of shark in our "silent" and "sound" treatments in both anchored and drifting modes of deployment. However, some evidence from a comparison of trials still supports the idea that sharks were attracted to the broad frequency noise produced by our speakers. In both drifting and anchored deployments, similar numbers of sharks were counted in the silent and sound treatments, but in trials where sound was not broadcast, the numbers of sharks attracted to the vicinity of the zodiac declined rapidly in the second half of the trial (Fig. 8). We suggest that this reduction in numbers may be due to the lack of a sound stimulus to retain or further aggregate sharks in the local area.

Rowley Shoals are a remote group of reefs that are rarely visited by fishermen and divers and any fishing activity is prohibited at Mermaid Reef by Commonwealth legislation. The novel nature of the stimuli probably accounts for the intense interest shown by sharks in our activities and their attraction to boat noise. Such behaviour appears to be a feature of shark populations in isolated regions of the Indo-Pacific (Nelson and Johnson, 1972). It is not possible however, to simply use boat noise rather than broadcast sound from a speaker to attract sharks. Different boats and motors are likely to produce a variety of sounds making standardisation of trials difficult. Furthermore, sharks rapidly habituate to sounds (Nelson and Johnson 1972), so that in areas where there is regular boat traffic, the noise produced by boats is unlikely to be attractive.

A solution to the problem of the confounding of the acoustic technique and boat noise might involve a redesign of the acoustic system so that a timer was incorporated. This would allow the gear to be deployed and then to operate independently of any disturbance or noise at the surface. A drawback is that this would also require a video to be deployed for surveillance of the acoustic device, as an observer could not be left in the water without vessel support. Surveys of large areas or reefs might thus require multiple systems, which could increase costs. An alternative approach might be to develop and refine an acoustic system in places where large numbers of sharks are habituated to human activity and boat noise, such as harbours or research stations (eg. Lizard Island, northern GBR). Rather than using broad frequency sound, work could then focus on determining a particular part of the sound spectrum most attractive to sharks. Previous studies suggest that this is likely to be within the low frequency part of the spectrum (Richard 1968).

Irrespective of the problems encountered in our study, we demonstrated that non-destructive techniques are capable of assessing relative patterns in the distribution and abundance of sharks on coral reefs. Traditionally, such methods have involved visual census by divers along transect lines. Our results suggest that this method is unlikely to document the range of species present on a reef since divers are typically confined to shallow (<30m) waters. The BRUVS used in our study recorded many shark species such as Tiger, Great Hammerhead, Fossil and Sicklefin Hound sharks in deeper (20-70m) areas beyond the range of SCUBA. Furthermore, attempts to count sharks using SCUBA ignore the possibility that there may be active avoidance (or attraction) by sharks. Divers rarely encounter species such as Hammerheads and Tigers, while these are often recorded in BRUVS sets (Cappo unpubl data). However, like all sampling techniques, BRUVS also have limitations. Since the area from which sharks are attracted to the bait bag and camera is unknown (but could be modelled), BRUVS can presently provide only a relative estimate of abundance. Despite this problem, our study has shown that BRUVS can provide a cost-effective and rapid means to estimate the relative abundance patterns of sharks (including rare species) over a wide range of habitats, such as open water beyond the reef drop off and deeper reef outside the range of SCUBA divers.

Comparison of Shark Assemblages at Mermaid and Scott Reefs

There was a striking difference in the diversity and abundance of sharks between Mermaid and Scott Reefs. More species of sharks were seen at Mermaid Reef than at Scott Reef and both acoustic and BRUV techniques provided evidence that sharks were more than an order of magnitude more abundant at Mermaid Reef than Scott Reef. Other evidence suggesting that there was a marked difference in abundance was provided by the time taken for sharks to appear on the BRUVS videos. On average, in benthic deployments at Mermaid, sharks appeared within range of the BRUVS video within 25 mins after the start of sampling, while the time of appearance in video at Scott Reef was over twice as long, with most sharks not arriving until 50 mins after deployment of the BRUVS. This implies that due to the low numbers of sharks, the attractant cue (sound of the BRUVS being deployed and scent of the bait bag) must travel much greater distances at Scott Reef than at Mermaid Reef before being encountered by sharks.

As we surveyed only one reef within and outside the MOU74 Box, we cannot discount the possibility that our results reflect a local pattern in shark distribution, and are not representative of the region as a whole. This seems unlikely, given that underwater visual count (UVC) surveys of 7 reefs within the MOU74 Box (Ashmore, Browse, Cartier, Hibernia, Scott North, Scott South and Seringapatam) also found very few sharks (Russell and Vail 1988, Dennis et al. in press). However, no study has surveyed multiple reefs outside the MOU74 Box and increasing the numbers of reefs used as a baseline for any comparison is an important priority for future work. Anecdotal evidence suggests that Mermaid Reef is typical of at least the other reefs within the Rowley Shoals, where any diving activity rapidly attracts numerous sharks to the local area (pers obs).

Over-fishing is the most plausible explanation of differences in the composition and abundance of shark assemblages between Mermaid and Scott Reefs. Sharks preferentially targeted by fishermen, such as Hammerheads and Silvertip Whalers were absent from counts at Scott Reef. Furthermore, catches of sharks in the MOU74 Box declined throughout the early 1990s'(Wallner and McLoughlin 1996) to the point that Indonesian shark fishing vessels have been relatively uncommon in this area in recent years (Fox and Sen 2002). Over-fishing was also conceded to be the factor most likely factor to account for the low numbers of sharks recorded by the Russell and Vail (1988) and Dennis et al. (in press) in surveys of reefs within the MOU74 Box. Dennis et al (in press) did suggest, however, that the lack of sharks recorded by their study might be due to diurnal movement patterns, where species migrated to deep water during the day and up to shallow water at night, thus were not recorded by the UVC technique, which was conducted in shallow water during the day. While diurnal movements may influence the total numbers of sharks counted by observers, this cannot account for our results, as we found sharks to be abundant in counts in shallow reefs at Mermaid Reef, but virtually absent from counts in the same habitat at Scott Reef.

The extirpation of sharks from coral reefs by fishing is not an unusual event. Recent studies have shown that this has been occurring over enormous areas of the tropical Pacific and Western Atlantic in recent years (Baum et al 2003, Myers and Worm 2003). We have very little idea what influence removal of this top order predator will have on reef ecosystems and fish communities. There have been relatively few studies (but see Friedlander and DeMartini 2002) and most of our knowledge of the effects of shark removal comes from computer simulations, rather than field data (Stevens et al. 2000). The oceanic reefs within and outside of the MOU74 Box offer great potential to directly compare the fish communities of reefs that strongly differ in shark abundance, but are otherwise very similar in geographic location and faunal characteristics (Allen and Russell 1986). Such a study could advance our knowledge of the ecosystem and food chain effects of shark removal.

The loss of sharks (and other top order predators such as billfish) from many tropical marine ecosystems has been occurring for a number of decades (Myers and Worm, 2003). Given this scenario, one of the major problems for management is the issue of "shifting baselines" (*sensu* Jackson et al. 2001), where original standing stocks of fishes are unknown, since exploitation commenced well before record keeping of catches in a fishery. This means that managers wishing to undertake remedial action to reduce fishing pressure and increase stocks may lack a baseline target to return stocks to. If Mermaid Reef is typical of other reefs in the Rowley Shoals, then these reefs may offer an appropriate baseline should any remedial management of shark populations in the MOU74 Box be attempted at some future time.

REFERENCES CITED

Allen GR, Russell BC (1986) Fishes. Part 7. In: Berry PF (ed) Faunal surveys of the Rowley Shoals, Scott and Seringapatam Reef, north-western Australia. Rec West Aust Mus Supplement No. 25

Baum JK, Myers RA, Kehler DG, Worm B, Harley SJ, Doherty PA (2003) Collapse and Conservation of Shark Populations in the Northwest Atlantic. Science 299:389-392

Cappo M, Harvey E, Malcolm H, Speare P (2003) Potential of video techniques to design and monitor diversity, abundance and size of fish in studies of Marine Protected Areas. In: Beumer JP, Grant A, Smith DC (eds) "Aquatic Protected Areas - what works best and how do we know?" World Congress on Aquatic Protected Areas Proceedings, Cairns, Australia, August 2002, p 455-464

Dennis DM, Milton DM, Skewes TD, Taranto TJ, Haywood MDE (in press) A rapid assessment of the fin-fish and shark resources on the shallow reefs in the Timor Sea MOU74 Box. The Beagle

Fox JJ, Sen S (2002) A study of socio-economic issues of traditional Indonesian fishers who access the MOU Box. Report for Environment Australia, Canberra, 56 pp.

Friedlander AM, DeMartini EE (2002) Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian islands: the effects of fishing down apex predators. Mar Ecol Prog Ser 230: 253-264

Harvey ES, Shortis MR, Stadler M, Cappo M (2002a) A comparison of the accuracy and precision of measurements from single and stereo-video systems. J Mar Tech Soc 36(2): 38-49

Harvey ES, Fletcher D, Shortis MR (2002b) Estimation of reef fish length by divers and by stereo-video. A first comparison of the accuracy and precision in the field on living fish under operational conditions. Fish Res 57(3): 257-267

Harvey ES, Cappo M, Shortis MR, Robson S, Buchanan J, Speare P (2003) The accuracy and precision of underwater measurements of length and maximum body depth of southern bluefin tuna (*Thunnus maccoyii*) with a stereo-video camera system. Fish Res 63(3): 315-326

Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Hunter SL, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR, (2001) Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629-638

Myers RA, Worm BR (2003) Rapid worldwide depletion of predatory fish communities. Nature 423(6937): 280-283

Myrberg AA, Banner A, Richard JD (1969) Shark attraction using a video acoustic system. Mar Biol 2:264-276

Nelson D, Johnson RH, (1972) Attraction of Pacific reef sharks: effect of pulse intermittency and variability. Com Biochem Physiol 42a:85-95

Richard JD (1968) Fish attraction with pulsed low frequency sound. J Fish Res Bd Canada 25:1441-1452

Russell BC, Vail LL (1988) Report on traditional Indonesian fishing activities at Ashmore Reef Nature Reserve. Australian National Parks and Wildlife Service. Canberra, 179 pp

Stevens JD, Bonfil R, Dulvy NK, Walker PA (2000) The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J Mar Sci 57: 476-494

Wallner BK, McLouglin K (1996) Review of Indonesian fishing in the Australian fishing zone. Report for Fisheries Policy Branch, Department of Primary Industries and Energy, Canberra, 37 pp

APPENDIX 1
SPECTRAL ANALYSIS OF BROADCAST AND AMBIENT NOISE

A fish was caught on site with a fishing line and as it was pulled to the surface, its struggles were recorded using a Clevite CH-17 hydrophone, pre amplifier and a Sony DAT deck from a distance of approximately two meters. The fish was then successfully released.

The DAT recording was copied into the Cool Edit program. The best sections of the sample were copied and pasted to make a random 3 min recording. This was then filtered with an 18th order Butterworth low pass with a 250Hz cutoff. The noise was then copied onto a DAT tape for playback and then onto a CD.

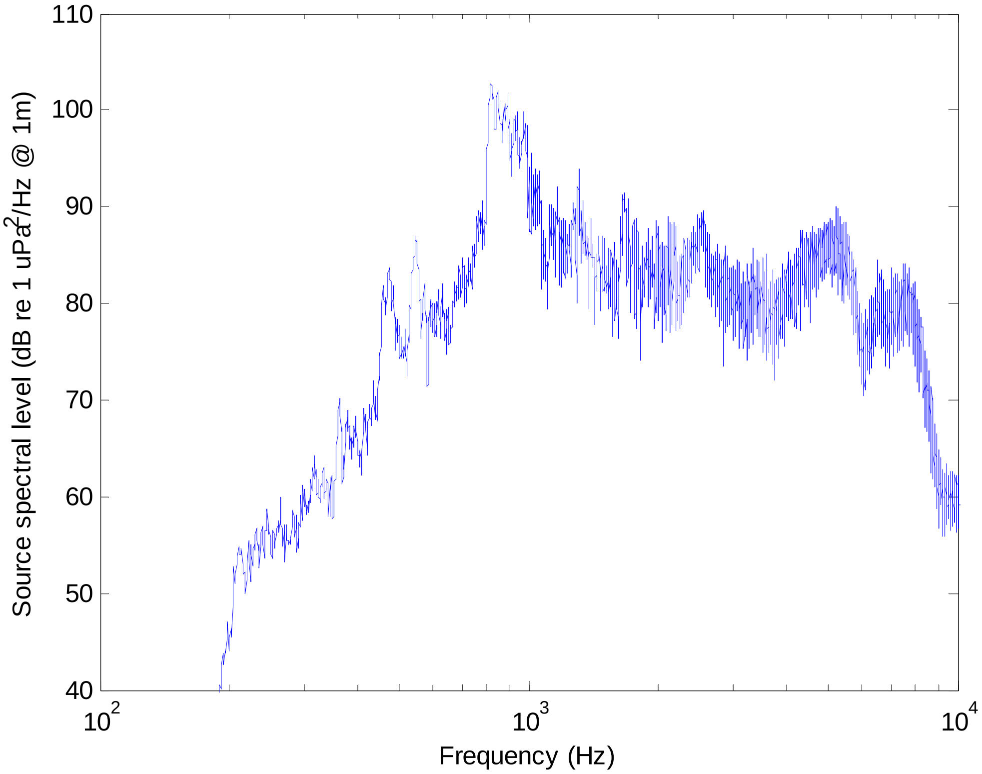


Figure A1. Source spectrum for 'distressed fish' noise

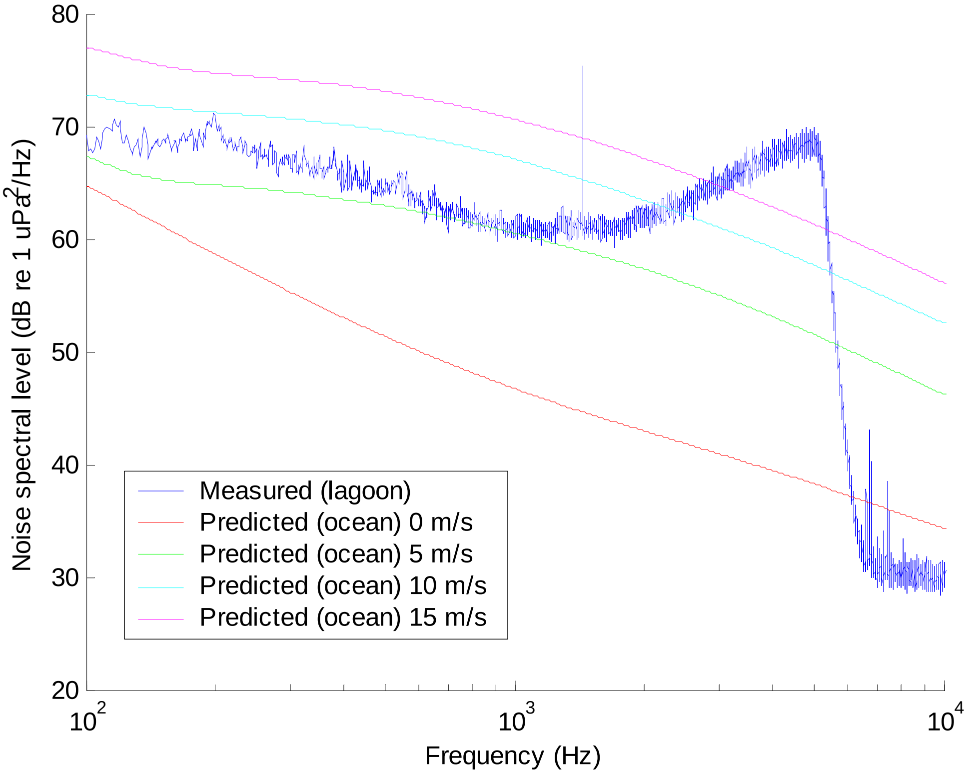


Figure A2 Background noise measured in Mermaid Reef lagoon at 2:10pm on 5/6/03 (blue). Spike at 1.25 kHz is due to electrical interference. Increasing trend of noise above 2 kHz is probably due to snapping shrimp. Rapid roll-off commencing at 4.5 kHz is due to response of anti-alias filters used in process of recovering signals from tape. Other curves are predictions for the open Indian Ocean for various wind speeds and include wind-dependent and traffic noise but do not include the effects of biological noise, which may be significant near a reef. These curves come from the Low frequency ambient sea noise prediction curves – Australian waters, Douglas H Cato, 1997, Maritime Operations Division, Defence Science and Technology Organisation.

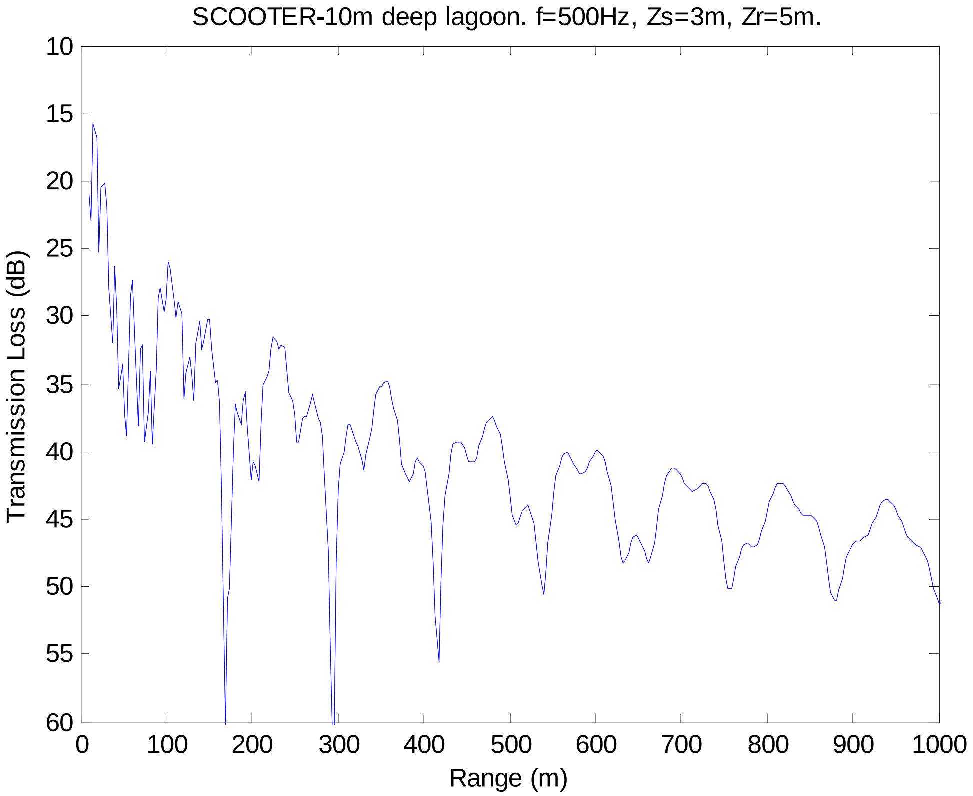


Figure A3. Predicted acoustic transmission loss versus range at 500 Hz for a 10m deep lagoon with a layered seabed comprising 2m thick sand, 24m thick partially consolidated limestone and a half-space of solid limestone. Source depth = 3m, receiver depth = 5m, frequency = 1000 Hz. Calculated using the Fast-field program Scooter contained in the Acoustics Toolbox (M Porter, SAIC).