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DSTO

Site Survey for an Ocean Engineering Project in Spencer Gulf November 1993

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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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Maritime Operations Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

Environmental surveys were made by DSTO at three sites in Spencer Gulf in South Australia in November 1993 to assess their suitability for an Underwater Radiated Noise Range for the Royal Australian Navy. Acoustic ranges are required to measure the noise radiated from ships and submarines. Salient factors for range design and performance include ambient noise, currents, internal waves, topography and nature of the seafloor, water properties, and wind and weather conditions. Measurements of these parameters indicate that the shallow waters of Spencer Gulf are particularly quiet compared with the open ocean around Australia. Swell is significantly less than in the ocean to the south where it originates, due to attenuation by passage through shallow water, and the sheltering effect of islands at the gulf mouth. Currents are predominantly tidal and thus predictable, with periods of up to 5 days at neaps with speeds less than 0.4 knot. The main disadvantage of the shallow waters is the continual noise background of snapping shrimp. Spencer Gulf appears to be suitable for the placement of a shallow water acoustic range. A Thistle Island site was marginally more suitable than a site near Wedge Island, and both were significantly better than a site near Corny Point.

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Executive Summary

Following DSTO's recommendations of potentially suitable sites for an acoustic range, the RAN requested DSTO to conduct a survey of the most promising shallow water site: the region inside the mouth of Spencer Gulf, South Australia, water depth 40 m. An acoustic range is designed to measure the noise radiated from ships and submarines. The site must be sufficiently quiet to allow the signals to be adequately measured, while the currents, the surface wave field, the nature of the sea floor, and the topography need to be known for the engineering design of the system. Also of importance are the prevailing weather conditions and the water properties. The survey thus involved the collection and interpretation of data to assess these environmental parameters.

Three sites were surveyed, one 7 miles NE of Thistle Island, one 5 miles NE of Wedge Island and one 5 miles WNW of Corny Point.

Currents are predominantly tidal and thus predictable. Current speeds predicted from harmonic constants are in good agreement with values measured for short intervals of 7 to 10 days. Peak speeds in the semi-diurnal cycle vary over a period of about two weeks, from negligible to almost 1 knot, with periods of up to five days at neap tides with speeds less than 0.4 knot. Current directions near surface and near bottom were generally similar for speeds over 0.4 knot.

Spencer Gulf is particularly quiet compared with the open ocean around Australia. The noise of distant shipping is very low. Biological noise is evident only for limited periods apart from the continuous noise of snapping shrimp which is significant above about 2 kHz. The ambient noise is dominated by wind dependent surface generated noise. For 40% of the time the noise is expected to be less than that indicated by the 10 knots curve of the summary graph over page (by comparison, the wind is less than 10 knots off Perth, which has also been considered for this facility, for only 14% of the time). The "noise floor", the quietest conditions, is 10 to 15 dB less than off Perth between 20 Hz and 2 kHz. For wind speeds less than 10 knots, the noise is 7 to 20 dB less than off Perth or Sydney for frequencies between 20 and 100 Hz, and 0 to 15 dB less between 200 Hz and 5 kHz. The effect of these lower noise levels on system performance is comparable to or greater than the gain achievable by a complex hydrophone array system. Sites off Thistle and Wedge Islands show comparable ambient noise. The site off

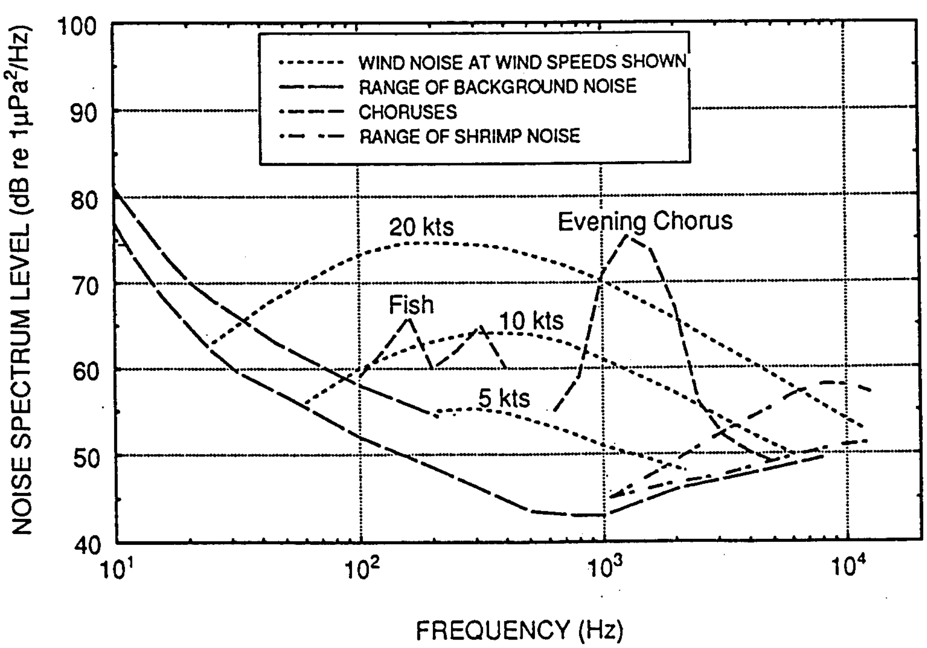
Corny Point tends to be significantly noisier for a significant proportion of the time.

Significant transient noise was evident at low frequencies from movement in the vicinity of the hydrophones on the sea floor. The transients occurred intermittently over periods of a few hours but did not appear to be correlated with the tidal currents. Since this is thought to be due to movement of debris against the recording system it is not considered to be part of the ambient noise and so not included in the summary graph. The design of an acoustic range would need to include isolation of the hydrophones from such motion. It is recommended that this effect be investigated further at the site.

Swell in Spencer Gulf is significantly less than in the ocean to the south where it originates, due to attenuation by passage through the shallow water. The direction is predominantly from south to south west. The Thistle Island site is the most sheltered, and showed little evidence of swell during the survey. The significant wave height over four weeks was almost always less than 2 m, and less than 1 m for 35% of the time.

The analysis of the currents, noise, and swell indicates that the site off Thistle Island is marginally more suitable than the site off Wedge Island, and both are significantly more suitable than the site off Corny Point for the siting of an acoustic range.

SUMMARY OF SEA NOISE RESULTS: SPENCER GULF SURVEY



CONTENTS

ANNEX A

1 INTRODUCTION

The RAN requires an Under Way Radiated Noise Range site for their vessels. Following an examination of existing data, Spencer Gulf (Fig 1.1) (overleaf) was recommended by DSTO as a potential site for shallow ranging. The RAN then requested DSTO to carry out a site survey of Spencer Gulf. Three sites were chosen as potentially suitable for noise ranging in Spencer Gulf based on the criteria (a) adequate depth (40 m) for boat manoeuvring over an area 5 miles by 2 miles with no shoals; (b) close to shore to minimise cable runs; (c) the presence of conspicuous land marks for navigation. The sites, shown in Fig 1.2 (on page 9), are listed below :

Site A:	BERRY.	5 miles WNW of Corny Point	34°52.6'S, 136° 55.2'E
Site B:	WEDGE.	5 miles NE of Wedge Is.	35°06.6'S, 136° 33.6'E
Site C:	THISTLE.	7 miles NE of Thistle Is.	34°56.8'S, 136° 17.2'E

The purpose of this survey is to provide the following data to determine the suitability of each site for noise ranging, and particularly to compare sites.

(a) Ambient Noise. This provides the main acoustic limit on system performance. Measurements need to be related to wind speed statistics and shipping movements to allow noise to be forecast in terms of the long term wind statistics and projected shipping movements.

(b) Wind Speed measurements are needed at each site for correlation with the ambient noise measurements and the wind measurements at weather stations.

(c) Swell And White Cap Coverage. The swell affects the handling of the submarines and stability of acoustic systems. The white cap coverage relates to the ambient noise since the white caps are the main source of wind generated noise for frequencies above about 5 Hz.

(d) Currents limit the extent that acoustic arrays will maintain their geometry and the accuracy that boats can maintain the required path during the sound ranging runs. High currents have the potential to damage arrays, and to cause unacceptable levels of flow noise. It is desirable to relate currents to tide and other sources to allow forecasts to be made.

(e) Bottom Samples provide mechanical information about the bottom needed to design system moorings. The nature of the bottom also affects the acoustic bottom reflectivity, which in turn affects the acoustic propagation. (Text cont'd page 8)

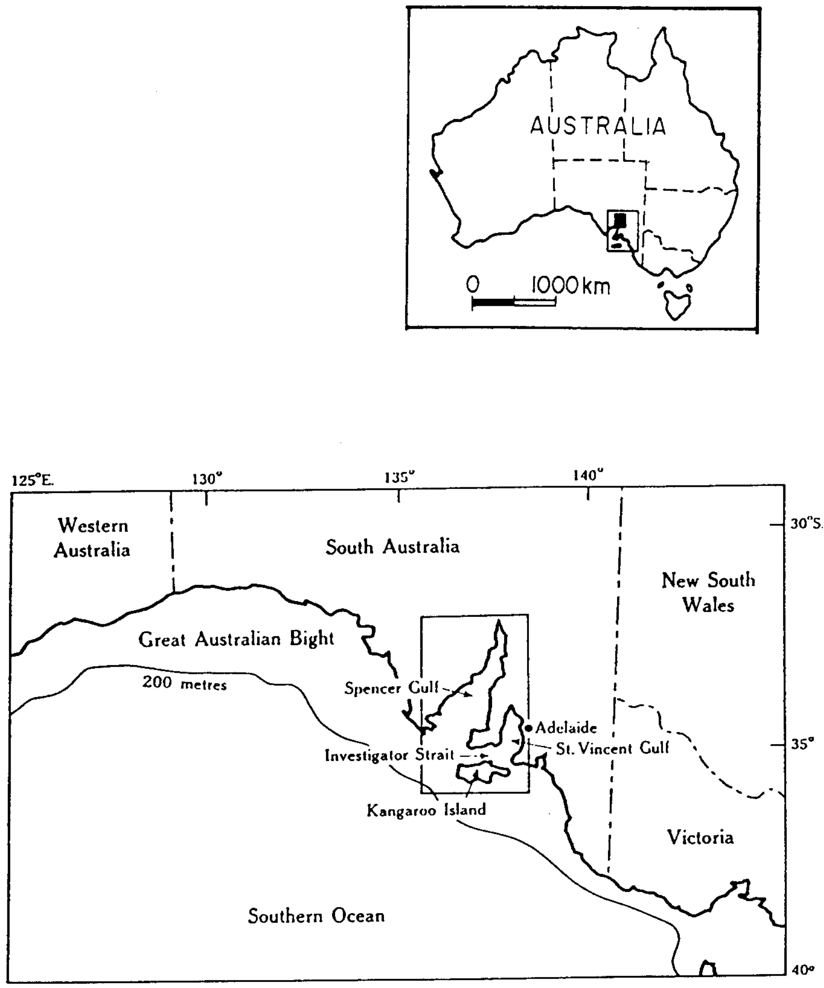


Fig. 1.1(a). The location of the South Australian gulf system.

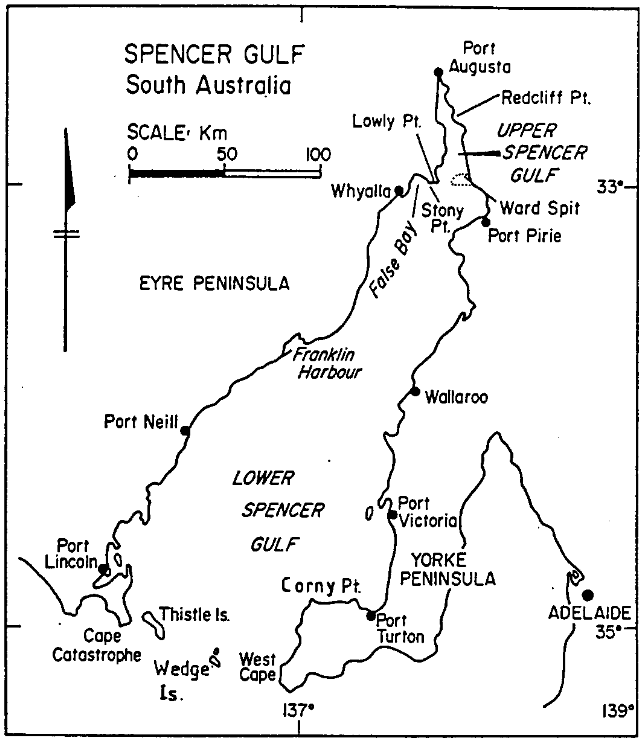


Fig. 1.1(b). Map of Spencer Gulf with selected place names.

(f) Vessel Movements through the Gulf during the period of noise recording are needed to relate to the noise measurements.

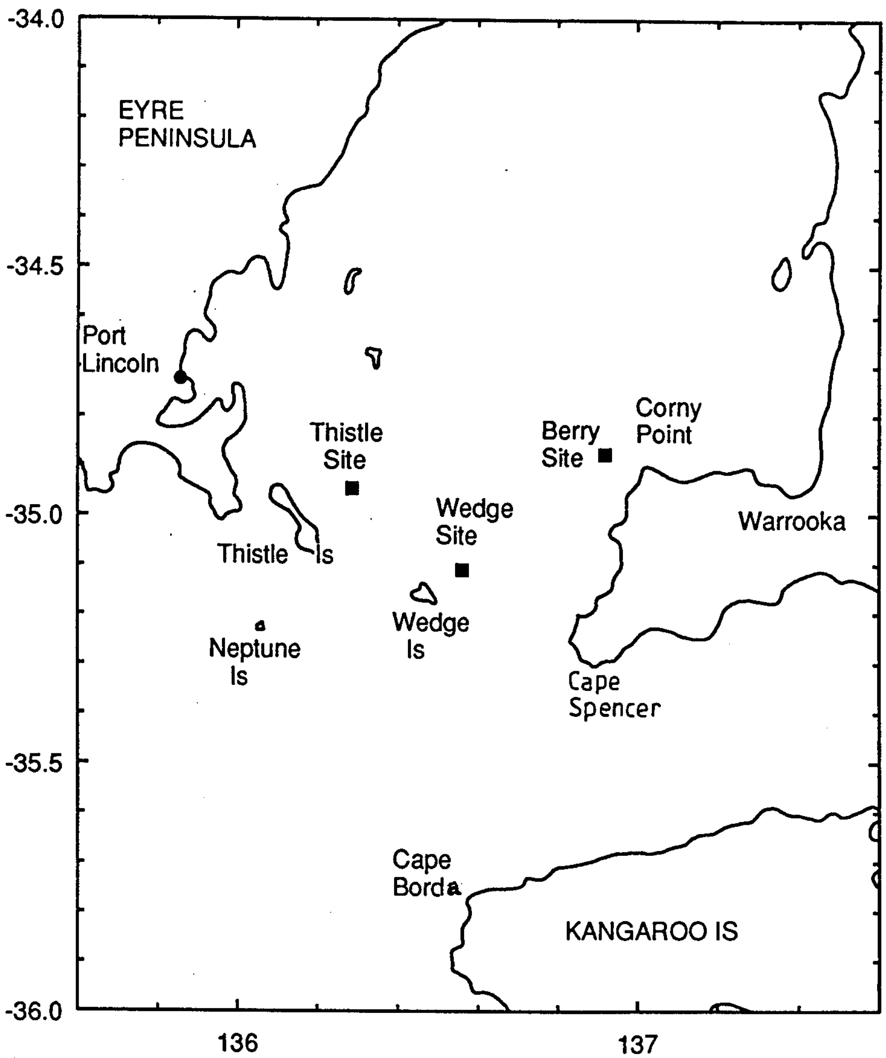


Fig. 1.2. Locations (■) of the Thistle Island, Wedge Island, and Corny Point sites selected for the survey.

2 TOPOGRAPHY AND SEA FLOOR TYPE

"Spencer Gulf is the larger of two shallow gulfs on the southern coast of the Australian continent (Fig. 1.1). *It has an irregular triangular shape, is some 300 km long, and about 90 km wide at its southern end where it merges into the continental shelf* (Fig. 2.1). *The climate is warm temperate, with low rainfall and high evaporation resulting in an hydrological inverse estuary. The average depth at the entrance to Spencer Gulf is 45 m and large areas of its floor are at depths of less than 25 m". "The Gulf essentially trends north-south and for the most part is lined with a complex sequence of unlithified sediment". "Tidal flows in and out of the Gulf are restricted because of its entrance width of 79 km, and partial blockage caused by a series of small islands."* (Hails and Gostin 1984).

From Fig 2.1 it can be seen that the required depths of 40 m are found in the south of Spencer Gulf, north of the gulf mouth and a series of islands.

Bottom Samples and Nature of the Sea Bed

The propagation of sound in shallow water depends critically on the acoustic properties of the sea floor, because of the reflection of sound from the bottom. This in turn depends on the thickness and nature of the sediment and on the depth and nature of the bed rock. The nature of the sea floor is also important in the mechanical design of a range system.

Samples of the sediment on the sea floor were taken at each site, obtained from the first few centimetres depth of sediment. A descriptive analysis is as follows. Details of grain size analyses are given next.

THISTLE SITE: Fine sand of angular grains poorly sorted in size. These appear to be mainly shell fragments. A few larger fragments (up to 1 cm) were also evident but form a very small proportion of the sample. Colour green-grey.

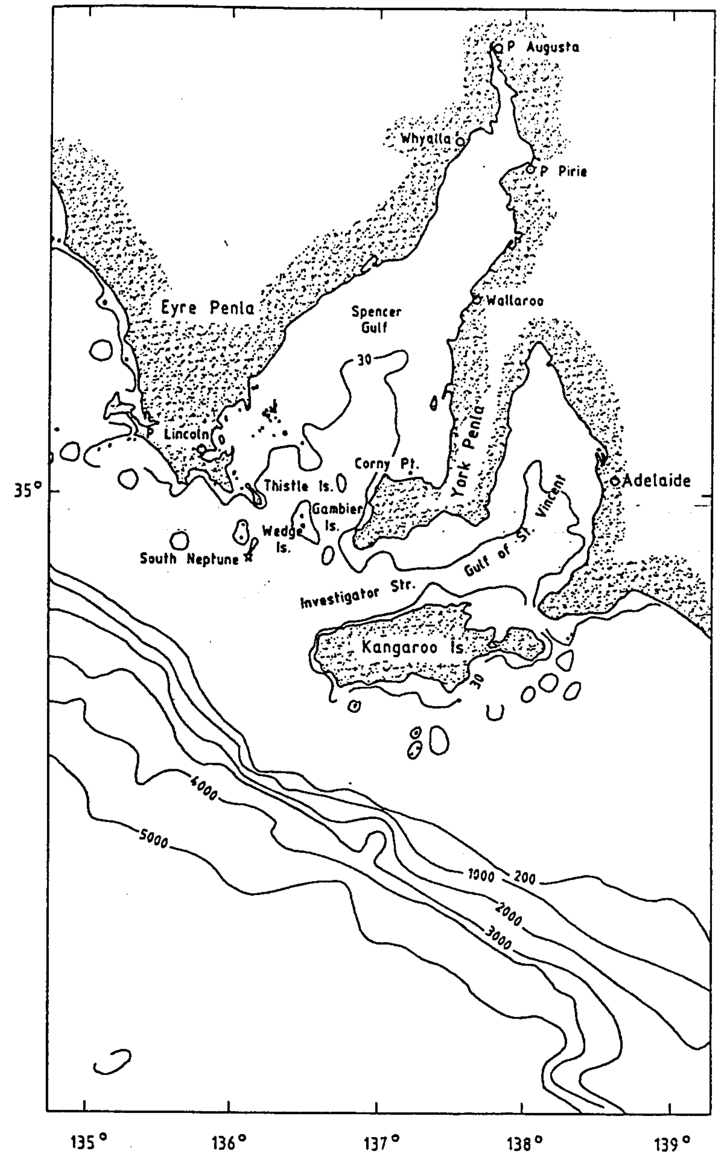


Fig. 2.1. Topography of the Spencer Gulf area. Contours are depth (m).

WEDGE SITE: Sand to coarse sand of shell grit with angular grains poorly sorted in size, with significant larger shell fragments up to 1 cm in size, and whole shells up to a few centimetres. Green-grey in colour.

BERRY SITE: Poorly sorted coarse sand of angular grains of shell fragments and what appears to be laterite. There are significant shell fragments up to 1 cm and some whole shells, with rounded pisolites of up to 1/2 cm in diameter. Colour is reddish brown due to the presence of the laterite.

Rock outcrops along the shore line of the Eyre Peninsula and the islands in the southern part of Spencer Gulf appear to be granitic or metamorphosed granitic rocks with some basaltic intrusions overlain by limestone.

This suggests that for the purpose of modelling bottom reflectivity and propagation loss, the bottom could be considered to comprise a layer of sandy sediment over granitic rocks.

Grain Size Analyses

The samples were wet sieved to obtain mud, sand, and gravel percentages by weight. Sand is defined as particles having diameter 0.063 - 2.0 mm (phi size 0 to 3), with mud having diameter less than 0.063 mm, and gravel having diameter over 2 mm (see Table 2.1).

From Thistle across to Berry the sediments were progressively coarser as a percentage by weight of total sediment. Thistle had 97 - 98% sand, 1% mud, and 1 - 1.6% gravel. The Wedge site had 81 - 87% sand, 0.1% mud, and 13 - 19% gravel. Berry had 56 - 75% sand, less than 1% mud, and 26 - 44% gravel. The variation at Berry was caused by small sample sizes and the presence of some larger gravel pieces. The average for Berry was 64% sand, 35% gravel, and less than 1% mud. The sand fraction was then split into the 5 sub-classes of Table 2.1. See Table 2.2. The small mud fraction indicates that sediments at all sites are not expected to be cohesive. This makes it easier to apply models of sediment movement for bottom stability considerations (see *Bell, Jones and Scott 1994* for a brief discussion).

Class		Particle Diameter (mm)	Acronym
GRAVEL		greater than 2.0	G
SAND			
	Very Coarse Sand	2.0 - 1.0	VCS
	Coarse Sand	1.0 - 0.5	CS
	Medium Sand	0.5 - 0.25	MS
	Fine Sand	0.25 - 0.125	FS
	Very Fine Sand	0.125 - 0.062	VFS
MUD			M
	Very Coarse Silt	0.062 - 0.031	
	Coarse Silt	0.031 - 0.016	
	Medium Silt	0.016 - 0.008	
	Fine Silt	0.008 - 0.004	
	Very Fine Silt	0.004 - 0.002	
	Clay	Less than 0.002	

Table 2.1. Particle-size classification by diameter.

	Thistle	Wedge	Berry
G	1-1.6	13-19	35±9
VCS	0.7	13	8
CS	8	26	21-26
MS	45	36-42	20-28
FS	40	6	8
VFS	4	0.3	1
M	1	0.1	<1

Table 2.2. Sediment size distributions as percentage of sample by weight at the Wedge, Thistle, and Berry sites. The values are averages of three samples. See Table 2.1 for acronyms.

3 CURRENTS IN SPENCER GULF

3.1 General

From a survey of the literature the main influences on currents are expected to be tides, winds, storm surges, resonances, and exchanges with shelf waters. Without tides the residual circulation is estimated to be less than 0.1 to 0.2 m/sec. This residual circulation tends to be clockwise, and may be induced by winds, or as a result of saltier, denser Gulf waters exiting the gulf on the southeast side at the bottom as a gravity current. Tides generally far outweigh the small residual circulation, with tides in some northern Gulf areas said to be as high as 3 knots. Near the Gulf entrance tides are estimated at about 1 to 2 knots. Faster tidal currents occur in the north because of an amplification effect as the gulf both narrows and shallows. Tidal currents around neap periods may drop to near zero for 1 to 3 days (dodge tides), so reasonable windows are expected to occur when tides will not influence site operations. However it is at this time when conditions are most suitable for the slower gravity currents to occur. These are thought to occur preferentially in winter months.

There are five reported records of time series of current measurements near the site location(s) (Fig 3.1), made in 1983 and 1989. Because of a local peculiarity in tides along the Great Australian Bight, leading to the dodge tides, it does not seem feasible to estimate tidal current strengths from tidal heights, so that direct current measurements are necessary before tidal strength predictions can be made. It is a relatively easy matter to predict the strengths of tidal streams at a location, once a time series record has been acquired over a period of 4 to 6 weeks. Ideally a six monthly or longer record is required to account for most tidal constituents.

3.2 Currents (other than tides)

Non-tidal currents are presently thought to have strengths of less than 0.2 m/sec. These are caused by winds, including remotely induced storm surges, and by gulf-shelf exchanges. *Radok and Raupach (1977)* indicated that sea-level variations in neighbouring St. Vincent Gulf caused by long period sea level oscillations were stronger than wind effects. What effect this has on current strengths is unknown. Residual circulation in Spencer gulf appears to be clockwise, and is stronger on the eastern side. A numerical model of wind-driven circulation *(Noye and Tronson 1978)* indicates this motion may be caused in the main basin of the gulf in response to winds with westerly components. However, *Nunes and Lennon (1987)* proposed that at least part of the clockwise circulation is caused by

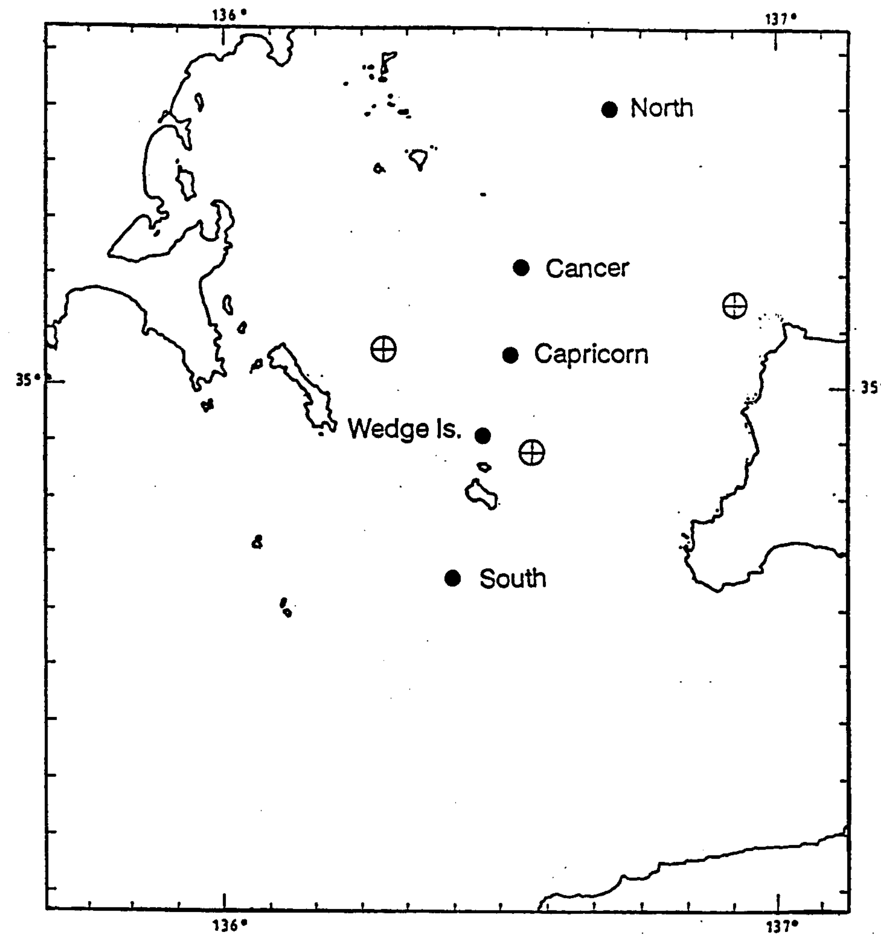


Fig. 3.1. Locations ⊕ of the Thistle Island, Wedge Island, and Corny Point sites selected for the survey. Also shown are the locations of current meter moorings (●) to 1989 from which tidal harmonic data are available. Limited current meter data were also obtained at the Wedge Island site in October 1993 on 29-30 October by Steedmans.

marine gravity currents. High salinity waters formed by evaporation at the head of the gulf during summer are cooled in autumn to become denser than gulf waters. This denser water then flows out along the bottom, tending to follow the central channel, but with a preference for exiting on the eastern side of the gulf mouth (Fig 3.2). According to Fig 3.2, all three sites could be affected by the density current.

Such outflow tends to occur at winter neap tides, when tidal currents may fall to zero for 2 to 3 days *(Lennon et al 1987)*, and may be unsteady in character, and possibly released in regular pulses, a fortnight apart. *Noye (1984)* modelled a wind-driven flow northwards along the Gulf margins with return flow down the centre.

3.3 Tides

The tides are the dominant source of currents. However virtually all tidal movements cease in Spencer Gulf at neaps for a period of approximately one day, with only weak movements for up to three days. This local anomaly is known as a dodge tide *(e.g. Nunes and Lennon 1986)*.

Harris et al (1991) report that tidal currents are maximum approaching high water, and that currents decrease away from the centre of channels. In lower Spencer Gulf (north of the proposed sites) rectilinear currents of 1 m/sec have been recorded *(Noye 1984)*. Tides are predominantly semi-diurnal in the Gulf, with a mean spring range at the entrance of about 1 m. However diurnal tidal currents may occur near the mouth, where the surface elevation variation is mostly semi-diurnal, according to simple modelling done by *Easton (1978)*. Storm surges may enhance or reduce the tidal heights e.g. by 0.5 m extra at Port Lincoln (and 2 m at Redcliff in the north). Locations of tide gauges (which record sea-level height variations) are shown in Figure 1 of *Easton (1978)*.

The positions and lengths of time for current records near the proposed sites were determined for DSTO by Steedman Science and Engineering *(Provis 1993)*. Tidal ellipse parameters are available for the 5 sites shown in Fig 3.1, based on about 50 days of tidal stream data. See Table 3.1 (on page 26) for the current meter positions and Table 3.2 (on page 27) for the ellipse parameters. "*In general, these data show that tidal currents can be expected to reach a maximum of just over 0.5 m/sec at spring tides. The variations between locations show that there will be local effects due to the bathymetry, but in general there is relatively little variation in phase across the* (study) *area." (Provis 1993).*

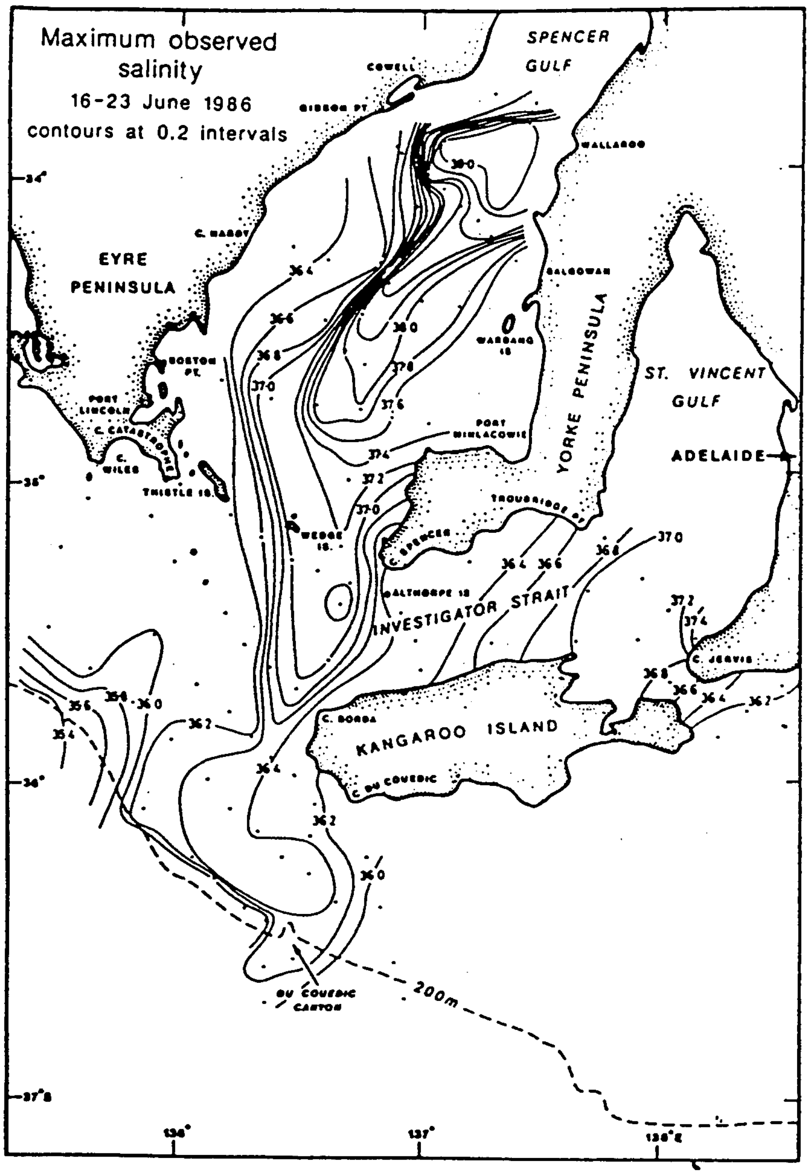


Fig. 3.2. Maximum observed salinity in Spencer Gulf 16-23 1986, corresponding to bottom salinity. The salinity contours show denser waters exiting the east side of Spencer Gulf as a gravity current. From Lennon et al (1987).

The Australia Pilot (1973) reports tidal streams of north-west and south-east going speeds from 1/2 to 3/4 knot (25 to 38 cm/sec), at Spencer Gulf entrance. Between C. Catastrophe (34°59'S, 136°E) (Fig 1.1b) and Williams Isle (about 6 miles south-west of the cape) 'tidal waves' may occur which are dangerous to small vessels. *"The north and south going streams sweep round Waterhouse Point (the south east extremity of Thistle Island) at a rate of 2 knots. The south going streams, meeting the south west swell, causes, with south winds, a dangerous race, which is felt up to 2 miles from the point." "In the vicinity of the islands between C. Catastrophe and Thistle Island, there are tide-rips which are so violent at times as to swamp a boat."* Speeds of over 3 knots are quoted *(the Australia Pilot 1973).*

3.4 Measurement Plan For Currents

Since the literature survey showed that tides were the dominant source of currents, measurements were planned to sample the expected maximum currents at the spring tides. Maximum ranges of tidal elevations were determined from tide tables for various locations around Spencer Gulf for the proposed survey period. Optimum sampling times were determined as 1930 hours 30 October to 0833 hours 31 October 1993. The next spring tide about 14 November was outside the original survey period, but 0043 to 0733 hours 12 November 1993 was selected as a compromise.

Initially a time series of measurements of current profiles from surface to bottom were to be made for a spring tidal cycle near each proposed site. The site(s) showing minimum currents, or most favourable currents based on other criteria such as shear or steadiness, were then to be further investigated over a longer period with moored current meters.

3.5 Results Of Profiling Current Meter Measurements

Steedmans *(Provis 1993)* have provided a short time series of seven current profiles (for speed and direction) at the Wedge Island location for a flood tide from 2250 hours 29 October to 0300 hours 30 October 1993 (see Fig 3.3a-d). The measurements were cut short by instrument problems and bad weather *(Provis 1993)*, and consequently no profiling measurements were made at the other sites. (Text cont'd page 22)

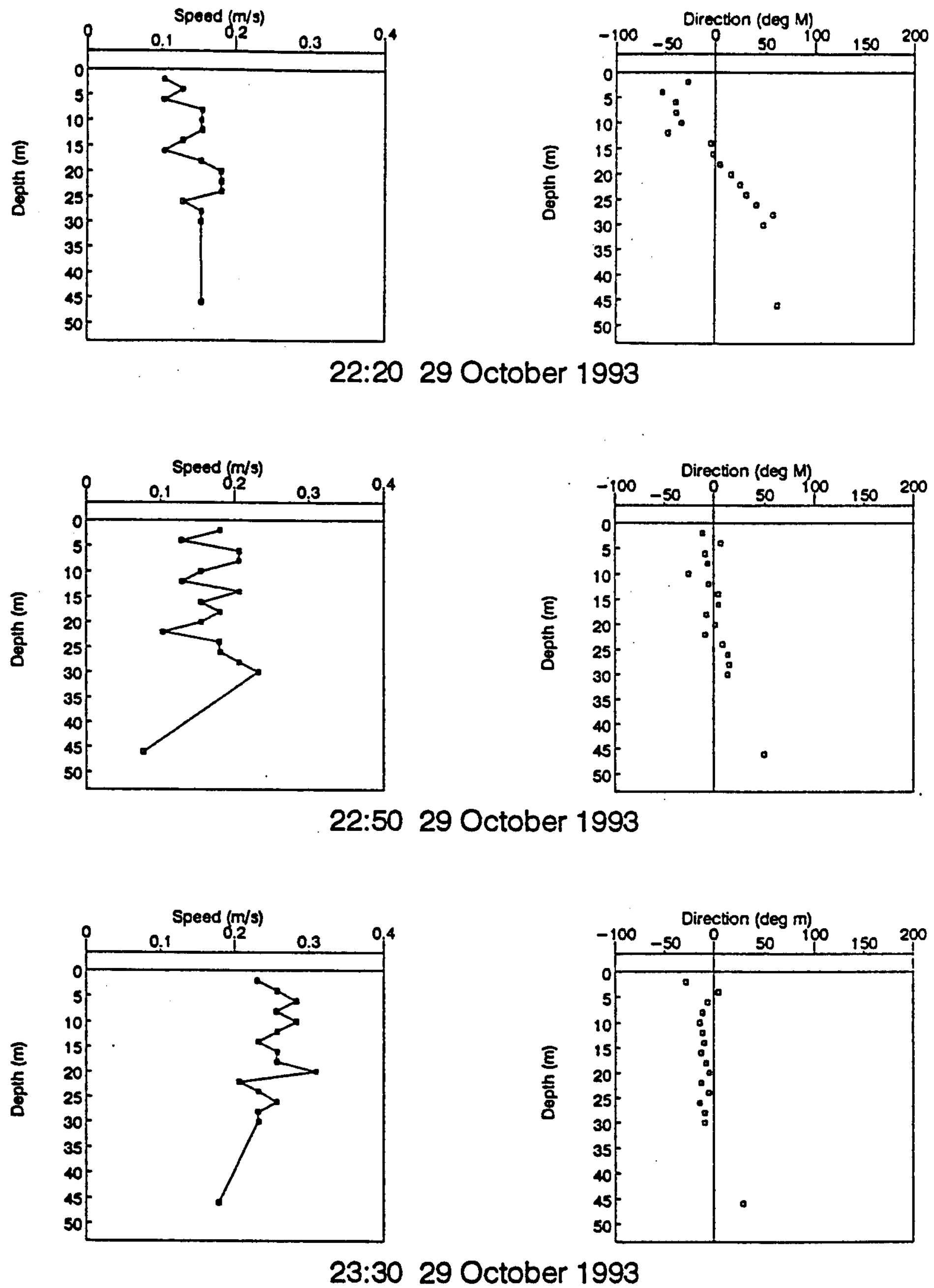


Fig. 3.3(a). Current profiles taken at the Wedge location 2220 to 2330 hours 29 October 1993 (From Provis 1993).

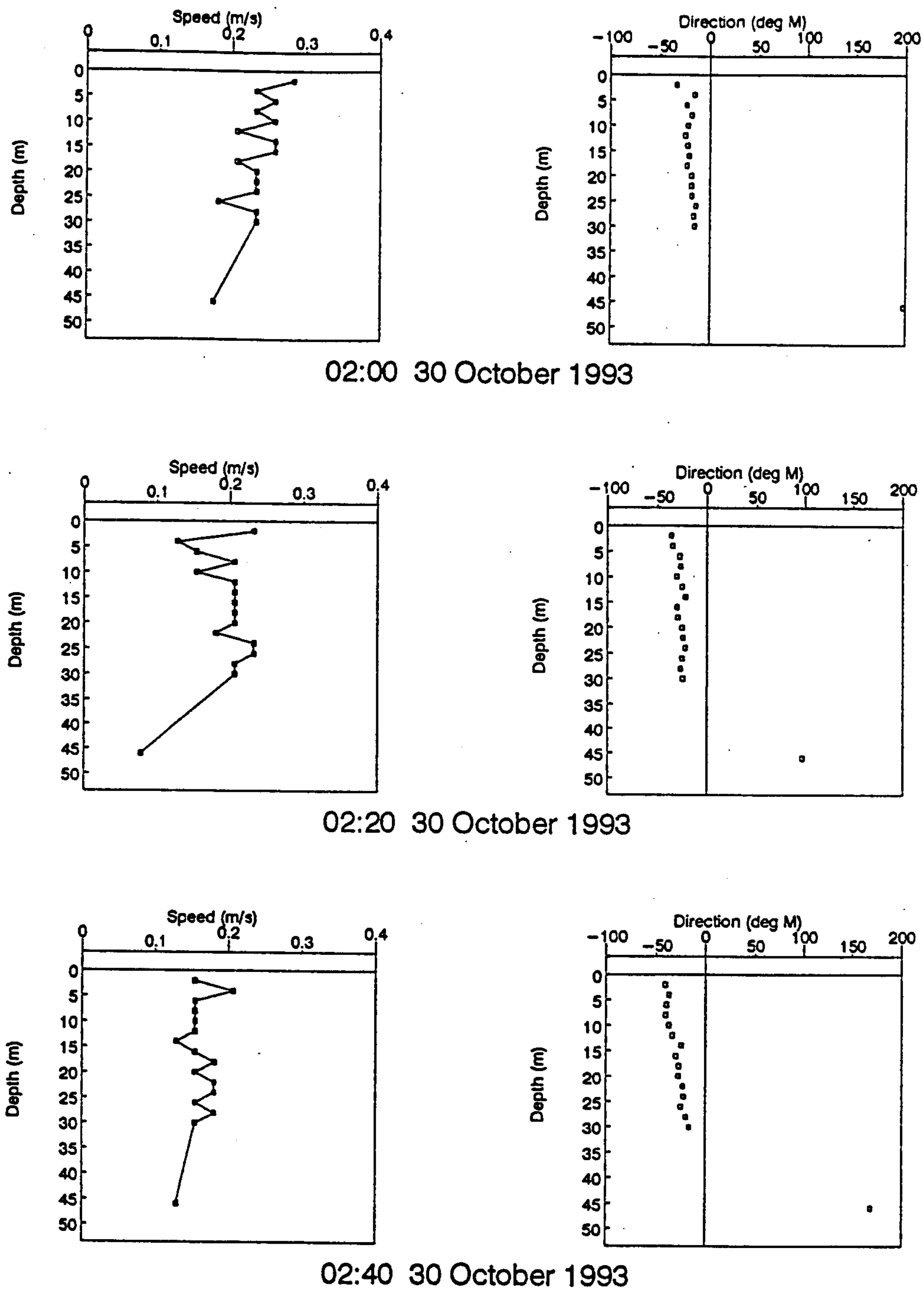


Fig. 3.3(b). Current profiles taken at the Wedge location 0200 to 0240 hours 30 October 1993 (From Provis 1993).

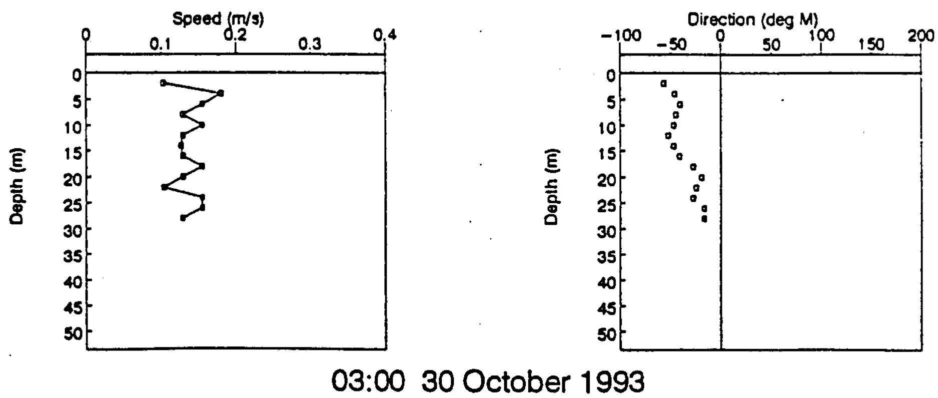


Fig. 3.3(c). Current profile taken at the Wedge location at 0300 hours 30 October 1993 (From Provis 1993).

Measurements were made at 2 m depth intervals to 30 m, with a single measurement 1 m above the bottom (46 m). Strongest average column currents to within about 1 m of bottom were about 25±5 cm/sec. Some profiles exhibited shear between 30 m and bottom. Time of measurement was selected according to tidal constants provided in *Steinberg (1983)*. The seven depth averaged speeds showed good general agreement with speeds predicted from the tidal constants, being about 5 cm/sec lower (Fig 3.4)(on page 28). Results displayed in Figs 3.3 and 3.4 are taken from *Provis (1993)*.

3.6 Results Of Moored Current Meter Measurements and Predictions of Current Speeds For 17 to 27 November 1993

Flinders University of South Australia were contracted to place two current meters at each site. Bottom depths at Thistle, Wedge, and Berry were about 40 to 43 m, with one current meter (the lower) positioned 2.5 m above bottom, and one (the upper) about 16 m below the surface. No data were returned from the lower current meter at the Thistle site, with 8 to 10 days data obtained for the other five instruments, between 18 to 27 November. Time series plots of speed and direction are shown in Figs 3.5 to 3.7 (on p29-33). Note that the plots do not all have the same scale. An analysis of the data proper is presented in *Andrew (1993)* (see next section).

To evaluate the usefulness of the harmonic constants of of *Steinberg (1983)* for predicting currents, predictions of tidal speeds and directions were made for the Wedge Island site for October and November, using the programs of *Foreman (1978)*. The constants were derived by *Steinberg (1983)* from a current meter 12 m below the surface. Plots of the predicted speeds were made using modified versions of the programs of *Tate (1988)*, and are shown in Fig 3.8 (on page 34). Peak predicted currents are about 45 cm/sec, with currents below 25 cm/sec for more than half of the time.

Peak current measured at Wedge Island was 40 cm/sec (Fig 3.5), compared to a predicted 38 cm/sec. Predicted speeds were usually within 10 cm/sec of peak speeds, perhaps tending to be higher, with predicted and measured currents approximately synchronized for peak events, with some anomalies. Predicted and measured directions were not compared. Speeds at the upper and lower meters were strongly in phase for peak events, for which the near bottom speeds were always lower than the upper speeds by 10 to 20 cm/sec. Currents were usually below 20 cm/sec. When the upper meter speeds were strongest at over 20 cm/sec, the lower current meter directions were 15 to

70° anti-clockwise of the upper directions. The period of measurement (19 to 27 November) commenced about two days after expected maximum speeds, but was quite representative of general conditions, according to predictions made for October and November (Fig 3.8). *Steinberg's (1983)* harmonic constants gave reasonable predictions of currents for both peak speeds and time of peak events. Tides are therefore the dominant driving mechanism for currents at this site, as expected.

Current speeds at Thistle Island 16 m below the surface (Fig 3.6) followed nearly the same pattern as the upper meter at Wedge Island, but were sometimes smaller at peaks by 5 to 10 cm/sec. Directions of flow were generally different from those at Wedge Island. Peak speed was 36 cm/sec.

Current speeds at Berry 16 m below the surface (Fig 3.7(a)) were similar to the other two sites. Upper and lower higher speed events were in phase. During periods of low current activity, episodes occurred when the lower current was stronger than the upper by up to 5 cm/sec (e.g. at times between 100 to 132 and 168 to 174 hours in Fig 3.7). Whether this was caused by the gravity currents, winds, or other effects, is not known. When upper speeds were over about 15 cm/sec, upper and lower current directions appeared similar. Peak speeds were 30 to 35 cm/sec.

Tidal currents predicted for November by the constants of *Steinberg (1983)* and *Bishop* (unpublished data) (Table 3.2) were compared for the Wedge and Capricorn sites (see Fig 3.1 for locations). The predicted currents for these different sites were in phase, but the currents predicted by *Bishop's* constants for Capricorn were up to 15 cm/sec lower than the Wedge Island values predicted by *Steinberg's (1983)* constants. Peak Capricorn predicted currents for November were about 32 cm/sec. The Capricorn meter was 5 m above a 45 m bottom, so speeds would generally be expected to be lower than the Wedge meter, which was 12 m below the surface in 43 m.

3.7 Results of Analysis by Flinders Institute for Atmospheric and Marine Sciences

The digital data recorded by the current meters were analysed by *Andrew (1993)*, allowing more quantitative results than those inferred from visual inspections of Figs 3.5 to 3.7. Scatter diagrams of current speeds with direction are shown in Figs 3.9 to 3.11 (p35-39). For the upper meter at Wedge Island the incoming tide was oriented at 60 to 70° clockwise from North, whereas the orientation of the outgoing tide was 240°. In the first half of the observation period the currents at the lower meter showed inflow at 30°, and outflow at 180°. In the second half, inflow-outflow took place from 0 to 330° True. The upper meter at Berry showed noisy speed and direction data, and may have been wind affected. Currents at the lower Berry meter also showed no preferred orientations.

At Thistle incoming flow was mostly northwards, and outgoing flow mostly southwards, although the currents still rotated through 360°. The weaker currents in the middle of the period showed a lack of preferred orientation.

3.8 Summary and Recommendations based on the information about currents.

Currents at the proposed locations were found to be tidally dominated, with predictions of current speeds from harmonic constants in good agreement with values measured for short intervals of 7 to 10 days. Peak speeds were less than 1 knot (50 cm/sec), with extended periods at about fortnightly intervals with currents less than 15 to 20 cm/sec, in a local phenomenon known as dodge tides. Current directions at near surface and near bottom were generally similar for speeds over 20 cm/sec, and different otherwise.

If the short measurements taken at the sites are representative, as indicated by limited comparisons with predicted currents, then the tides as the dominant source of currents are not expected to hamper operations at any of the three proposed sites for protracted periods. Peak measured and predicted speeds are less than 0.5 m/sec, and the currents will be less than this for a good proportion of the tidal cycle. Currents are less than 25 cm/sec away from peak events. As expected from the literature, tidal currents fell to low values for 1 to 3 days around neaps, which occur about once every two weeks, and some operations could be planned around these times. Because the sites lie in a tidally dominated current regime, it is possible to determine times of low current activity from tidal stream predictions, should this prove necessary. The predictions discussed were made from only the four major constituents, and use of more constituents should improve forecasts.

Currents at the three sites were broadly similar over the short measurement period. It is possible that Berry might be more affected by the slow gravity currents, due to its location on the eastern boundary where such currents are thought to be stronger for Spencer Gulf. Current speeds at the Berry site were noisy, with no preferred orientations, presumably making tidal predictions less reliable at this site, if the data were not affected by instrumentation problems. From this very limited data set, Wedge or Thistle would be preferred to Berry, in terms of more predictable current directions.

[Tables 3.1 and 3.2 are on pages 26 and 27]

[Figures 3.4 to 3.11 are on pages 28 to 39]

[Text continues on page 41 as Chapter 4 Water Properties]

STATION	Latitude South	Longitude East	Water Depth (m)	Depth of meter (m)
Wedge Island	35° 4'	136° 28'	45	12
North Upper	34° 35.1'	136° 42.2'	36	5
North Lower	34° 35.1'	136° 42.2'	36	31
Cancer Lower	34° 48.9'	136° 32.8'	43	38
Capricorn Lower	34° 57.1'	136° 31.9'	45	40
South Upper	35° 17.0'	136° 25.0'	79	5
South Lower	35° 17.0'	136° 25.0'	79	74

TABLE 3.1 Location details for current meter deployments from which tidal ellipse parameters are available. Data for Wedge Island are from Steinberg (1983), others are from Bishop (unpublished data). The table is from Provis (1993).

STATION	O_1		K_1		M_2		S_2	
Wedge Is.	0.084	70°	0.164	55°	0.128	45°	0.141	45°
	0.030	285°	0.070	324°	0.025	1°	0.020	62°
North Upper	0.082	350°	0.166	353°	0.110	1°	0.145	9°
					-			
	0.018	312°	0.058	328°	0.003	28°	0.008	102°
North Lower	0.043	18°	0.068	38°	0.077	9°	0.104	7°
	-		-		-			
	0.010	308°	0.030	343°	0.008	14°	0.002	79°
Cancer Lower	0.064	30°	0.087	39°	0.082	26°	0.100	19°
	-		-		-		-	
	0.002	294°	0.026	331°	0.014	1°	0.021	66°
Capricorn Lower	0.050	18°	0.083	42°	0.083	12°	0.121	11°
	-		-		-		-	
	0.014	301°	0.021	354°	0.003	356°	0.001	64°
South Upper	0.042	30°	0.101	3°	0.053	40°	0.067	37°
							-	
	0.008	299°	0.043	309°	0.003	352°	0.013	61°
South Lower	0.039	53°	0.065	61°	0.077	45°	0.095	42°
	-		-				-	
	0.004	314°	0.006	345°	0.001	354°	0.008	64°

Semi-major axis (ms^{-1})	Angle of major axis (°T)
rotation clockwise if -ve	
Semi-minor axis (ms^{-1})	Phase lag (g) relative to C.S.T.

TABLE 3.2 Tidal ellipse parameters for the major constituents from current meter deployments in southern Spencer Gulf for the positions shown in Fig 3.1 and Table 3.1. The lower box defines the entries in the main table. (°T is degrees True. C.S.T. is Central Standard Time). The table is from Provis (1993).

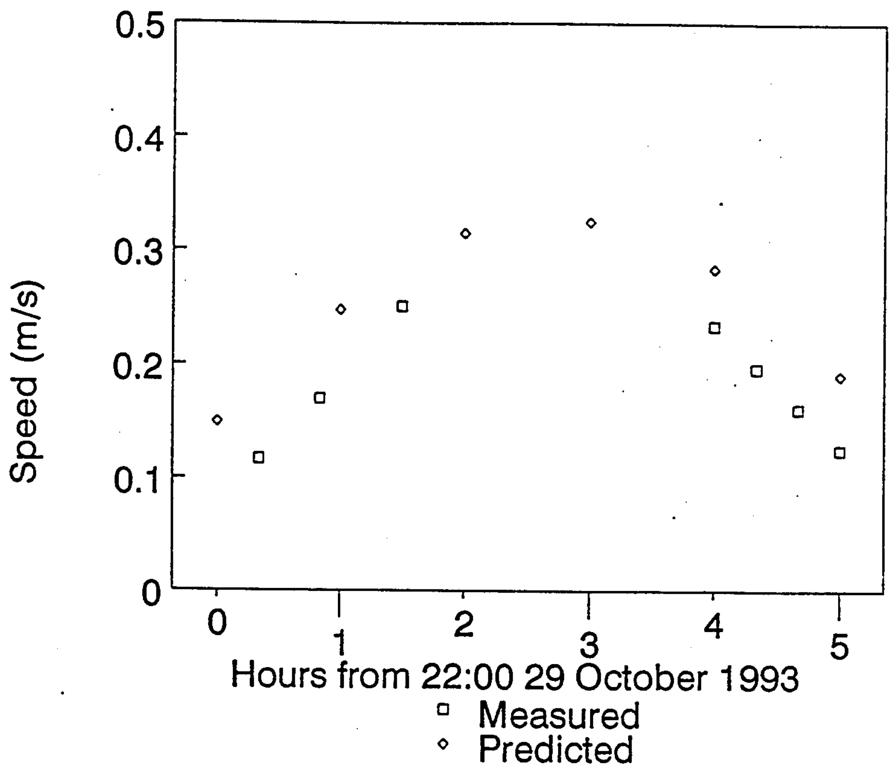


Fig. 3.4. Time series of depth-averaged currents taken at the Wedge Island location on 29 and 30 October 1993 compared with predicted current speeds based on tidal constants from Steinberg (1993). From Provis (1993).

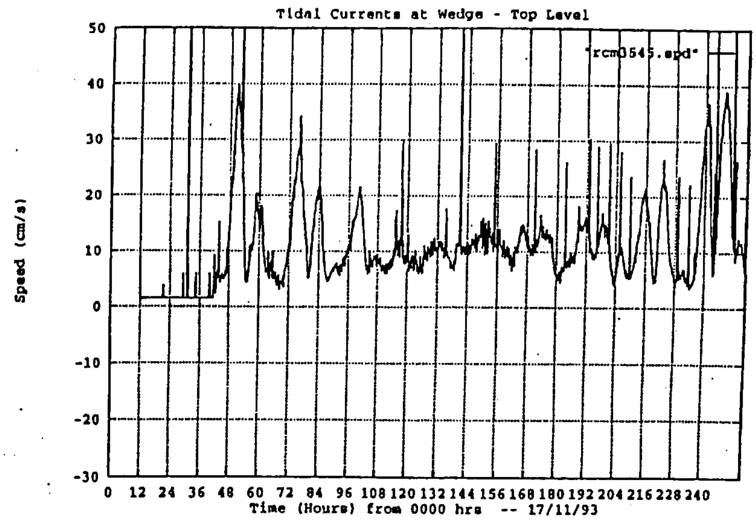


Fig. 3.5(a). Current speeds measured at the Wedge location 19 to 27 November 1993 by a current meter 16 m below the surface.

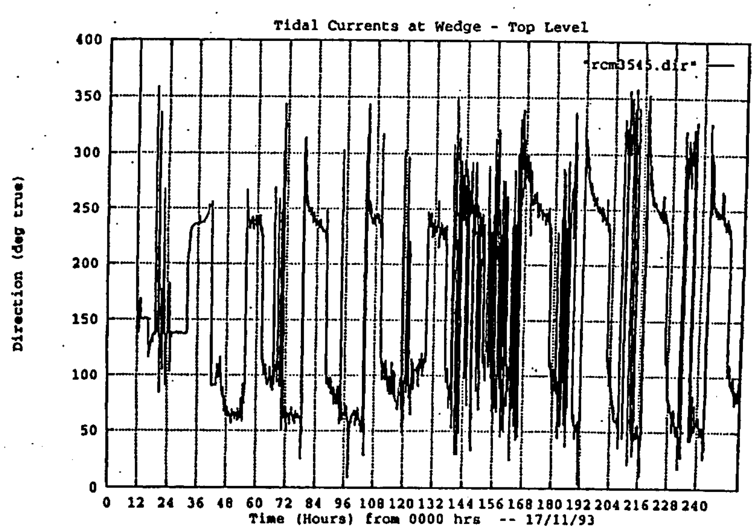


Fig. 3.5(b). Current directions measured at the Wedge location 19 to 27 November 1993 by a current meter 16 m below the surface.

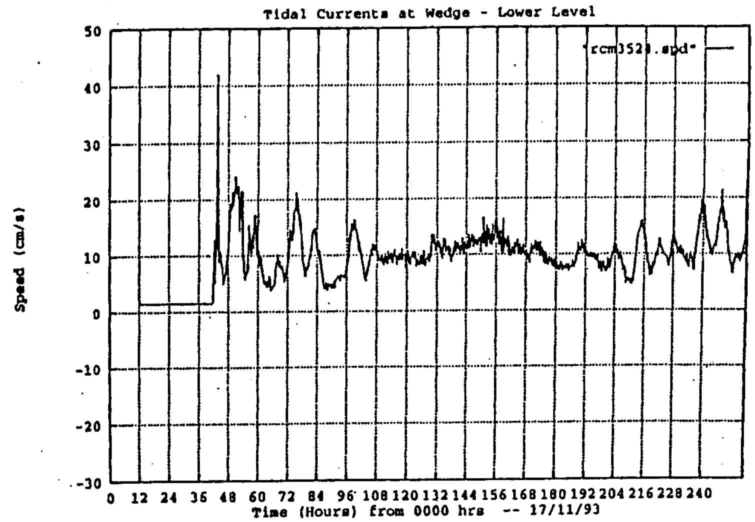


Fig. 3.5(c). Current speeds measured at the Wedge location 19 to 27 November 1993 by a current meter 2.5 m above the bottom.

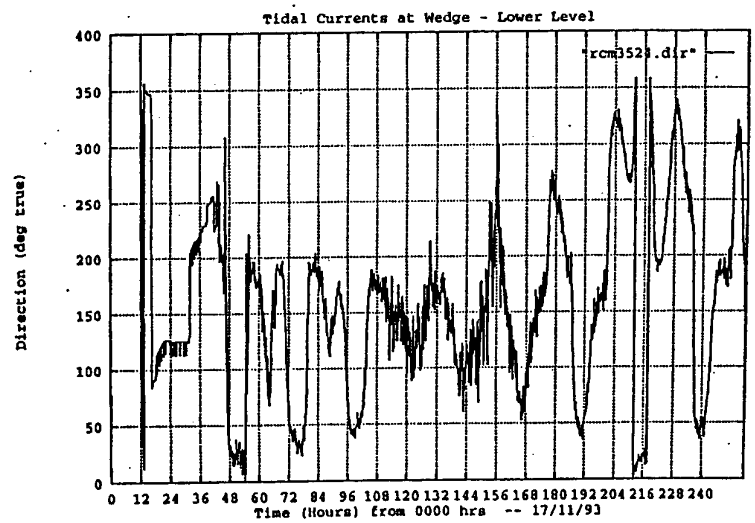


Fig. 3.5(d). Current directions measured at the Wedge location 19 to 27 November 1993 by a current meter 2.5 m above the bottom.

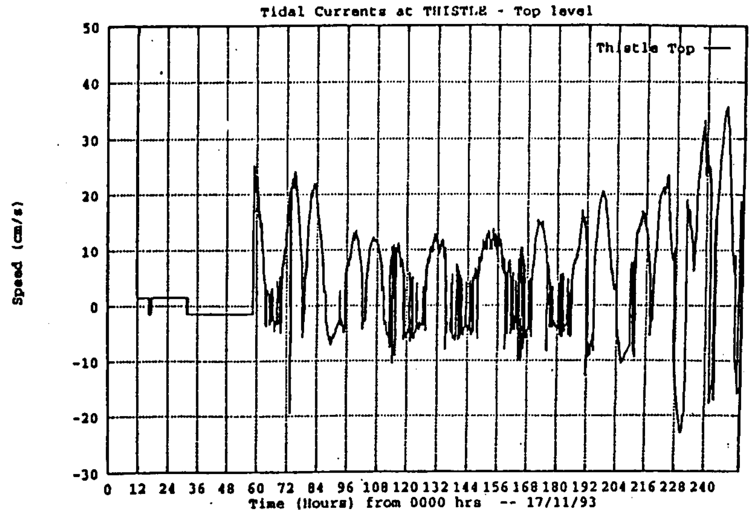


Fig. 3.6(a). Current speeds measured at the Thistle location 19 to 27 November 1993 by a current meter 16 m below the surface.

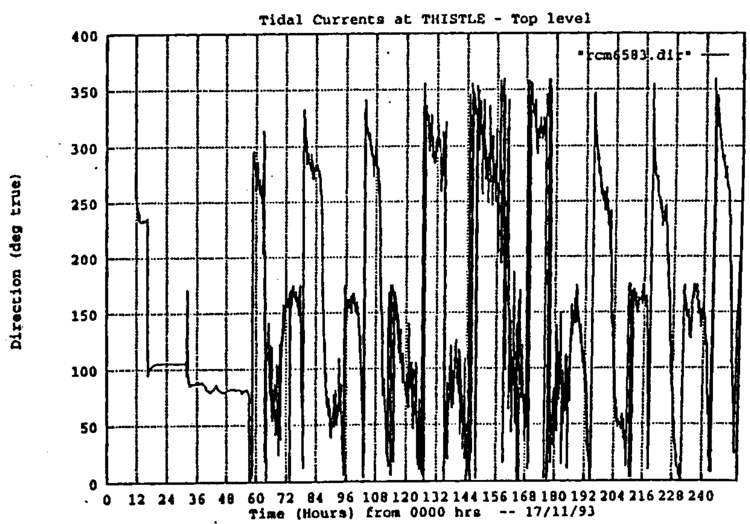


Fig. 3.6(b). Current directions measured at the Thistle location 19 to 27 November 1993 by a current meter 16 m below the surface.

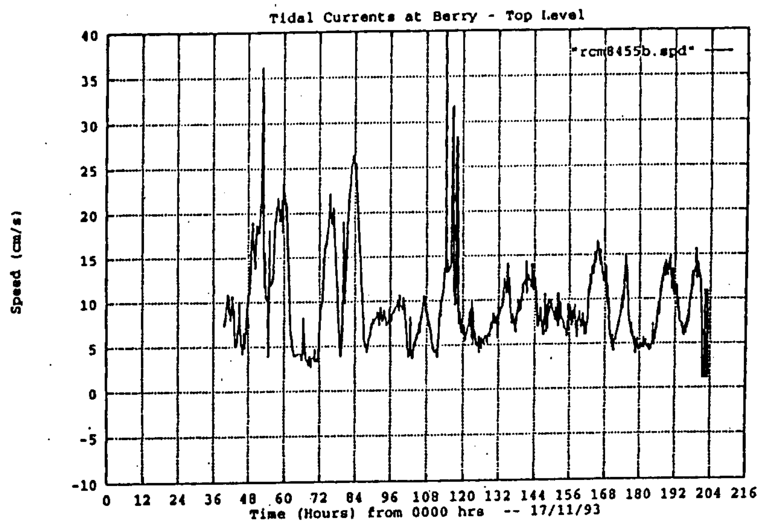


Fig. 3.7(a). Current speeds measured at the Berry location 19 to 27 November 1993 by a current meter 16 m below the surface.

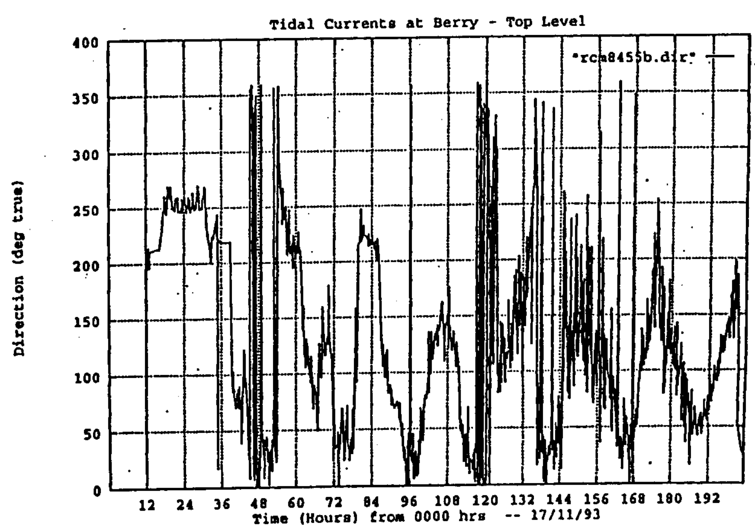


Fig. 3.7(b). Current directions measured at the Berry location 19 to 27 November 1993 by a current meter 16 m below the surface.

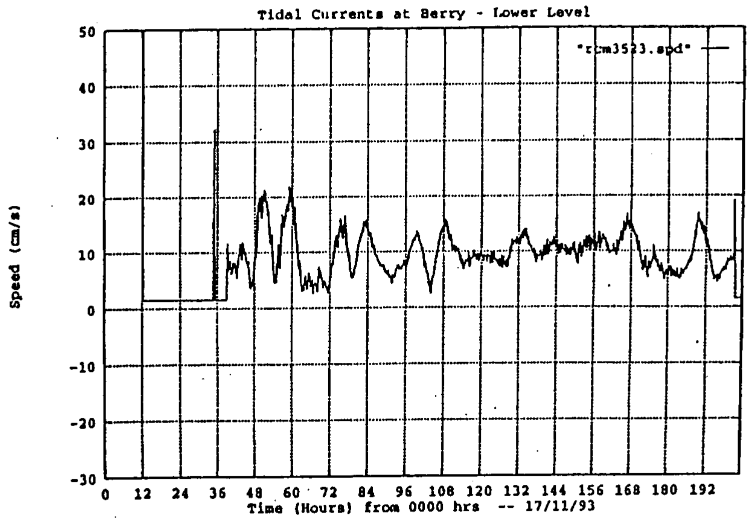


Fig. 3.7(c). Current speeds measured at the Berry location 19 to 27 November 1993 by a current meter 2.5 m above the bottom.

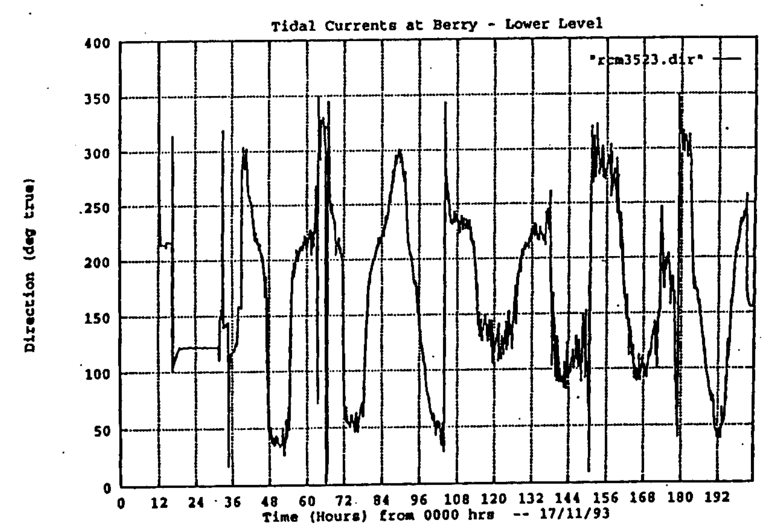


Fig. 3.7(d). Current directions measured at the Berry location 19 to 27 November 1993 by a current meter 2.5 m above the bottom.

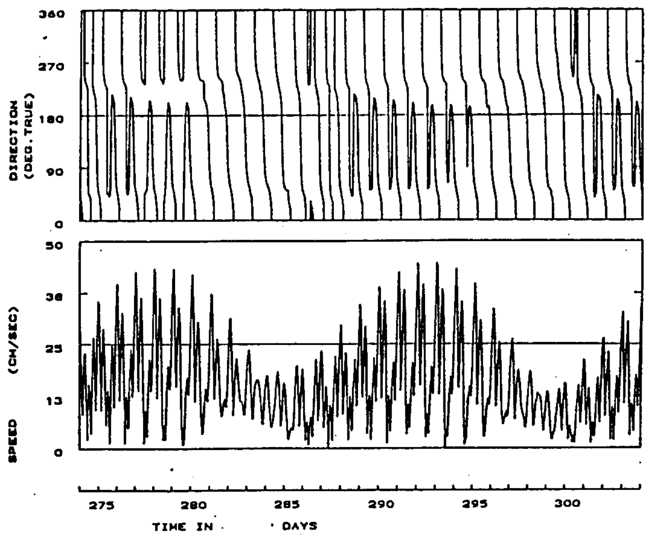


Fig. 3.8(a). Predicted current speeds and directions for the Wedge location for October 1993 using harmonic constants from Steinberg (1983).

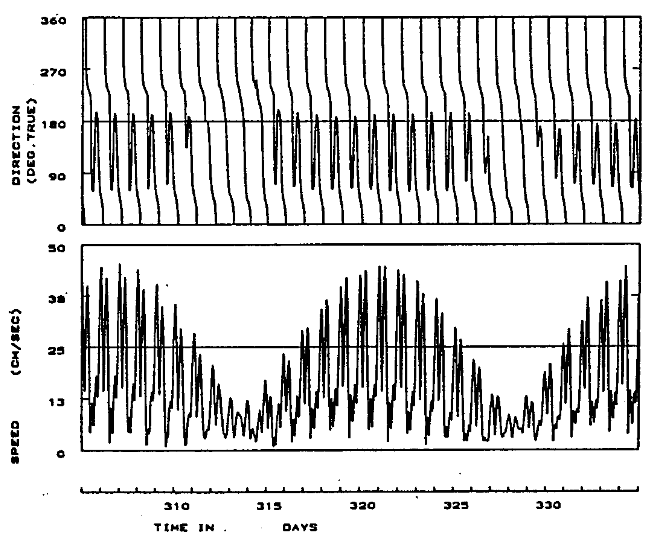


Fig. 3.8(b). Predicted current speeds and directions for the Wedge location for November 1993 using harmonic constants from Steinberg (1983).

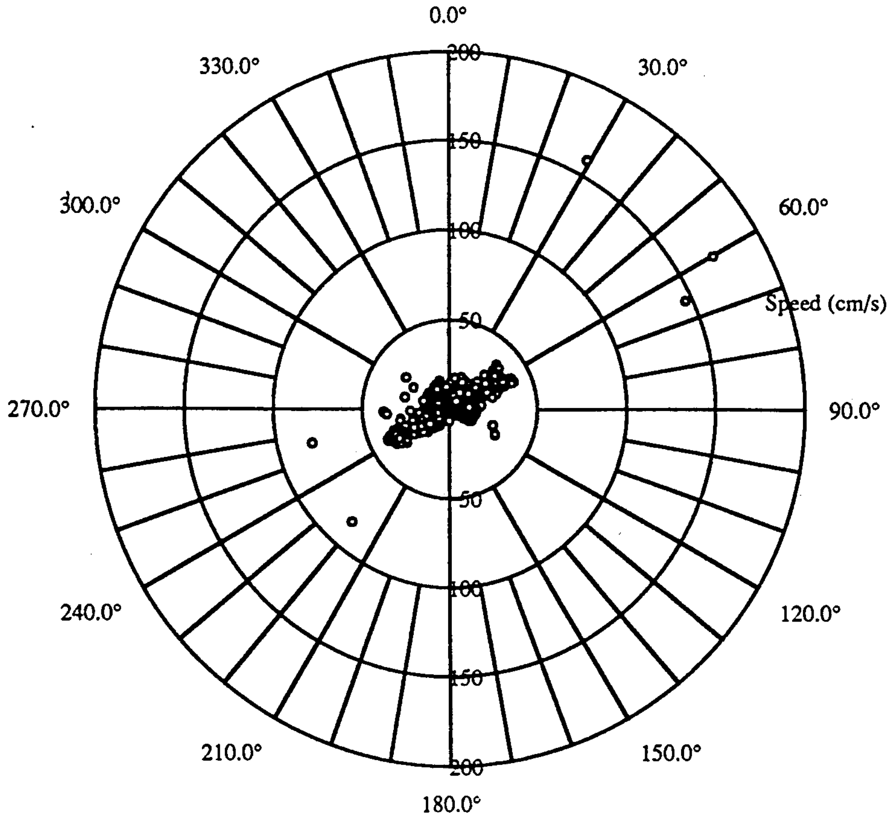


Fig. 3.9(a). Scatter diagram of current speed with direction for the upper current meter at the Wedge location for November 1993 (Andrew 1993).

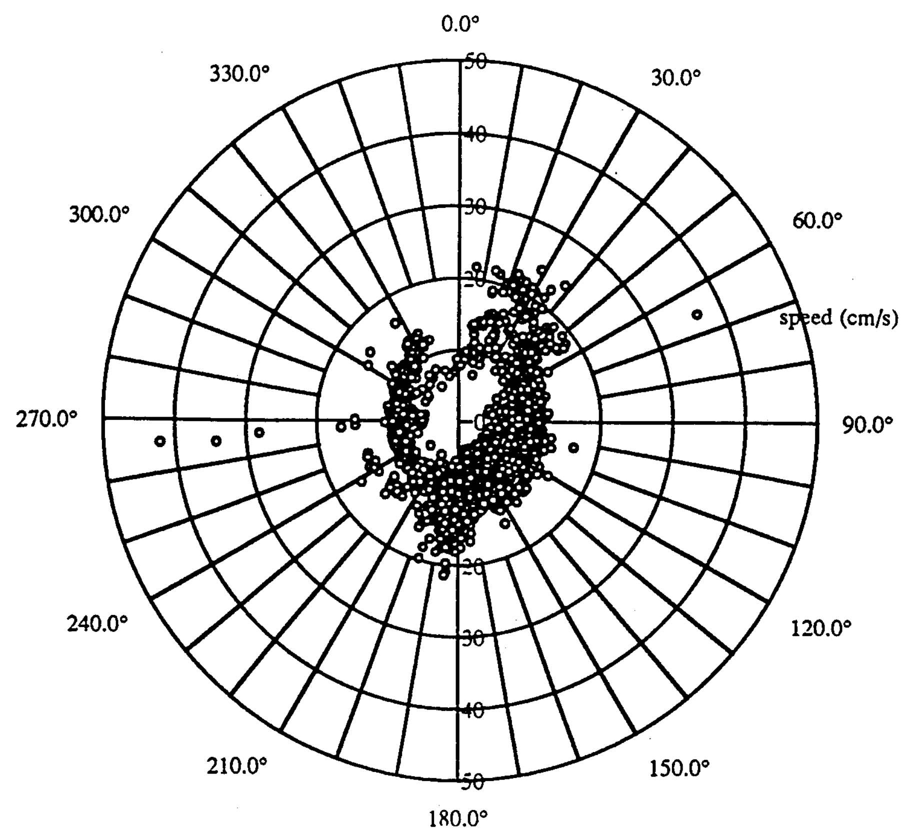


Fig. 3.9(b). Scatter diagram of current speed with direction for the lower current meter at the Wedge location for November 1993 (Andrew 1993).

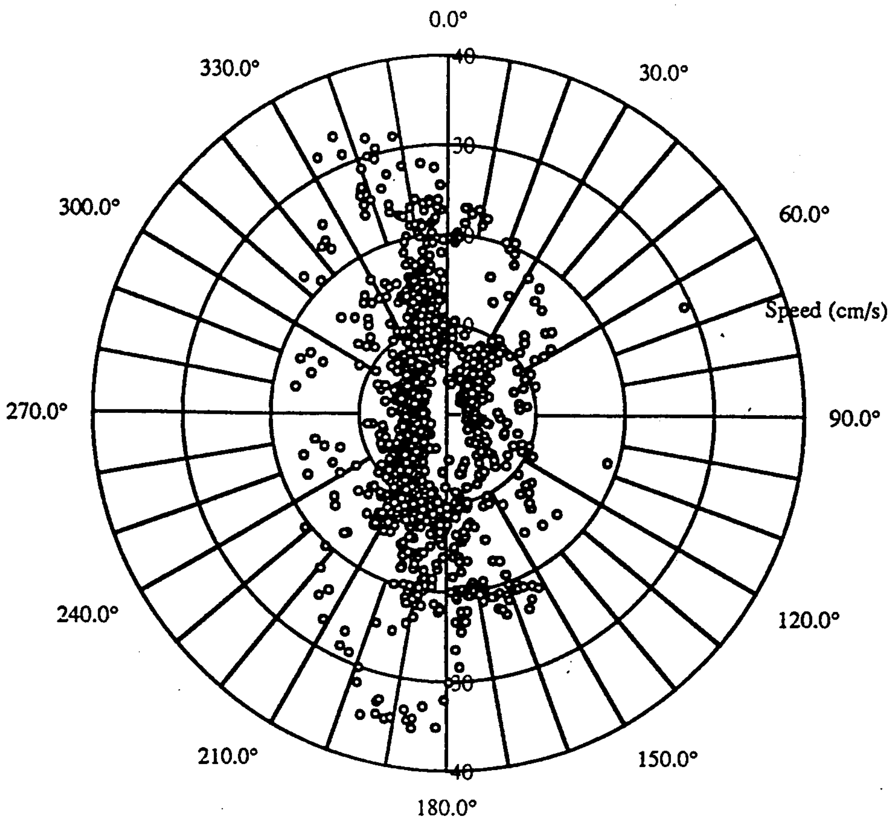


Fig. 3.10. Scatter diagram of current speed with direction for the upper current meter at the Thistle location for November 1993 (Andrew 1993).

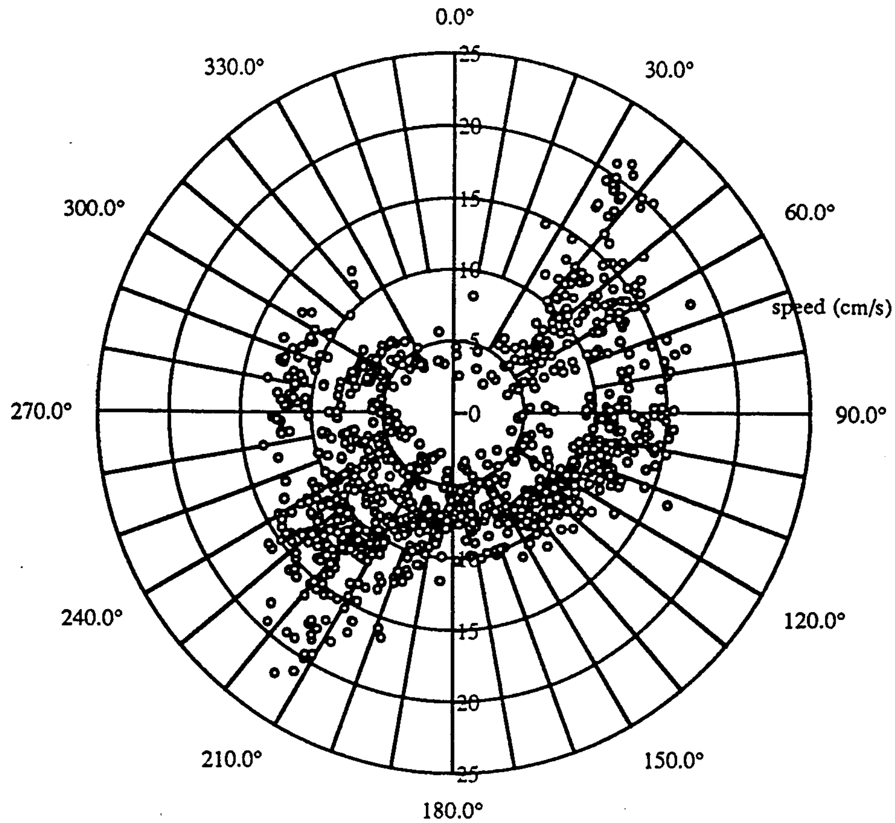


Fig. 3.11(a). Scatter diagram of current speed with direction for the upper current meter at the Berry location for November 1993 (Andrew 1993).

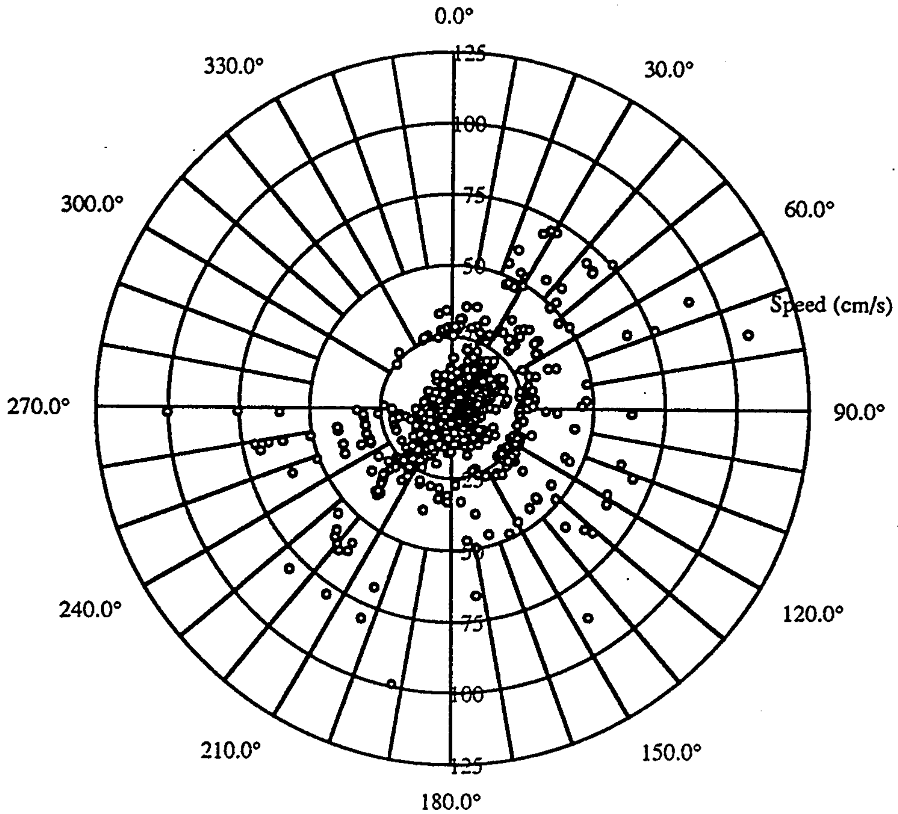


Fig. 3.11(b). Scatter diagram of current speed with direction for the lower current meter at the Berry location for November 1993 (Andrew 1993).

Fig. 4.1. An example of sea surface temperature patterns in Spencer Gulf shown by infra-red imagery. Red is warmest, and blue is coolest. Note the apparent temperature front across the mouth of Spencer Gulf.

4 WATER PROPERTIES

Water properties such as temperature and salinity are required for computation of sound-speed and density profiles. Sound-speed profiles are required to model acoustic propagation, and density profiles can be used to predict the presence of internal waves, and for buoyancy calculations for acoustic range array components.

4.1 Temperature

Seasonal temperature response within Gulf waters differs markedly from that of the shelf seas. In the far north of Spencer Gulf *"The seasonal response of gulf waters is substantial, changing typically from around 12°C in winter to around 24°C in summer"* . The behaviour of sea surface temperature (SST) is strongly seasonal, following a classic sinusoidal variation, allowing it to be modelled if necessary. Outside the mouth of Spencer Gulf the temperature range is much less, with temperatures from 15 to 20°C, and may also be modelled as a sinusoid, with the average maximum in March and the average minimum in August to September. The gulf waters are usually well mixed, with vertical and horizontal uniformity of temperature. During late summer and autumn there are large temperature gradients between the northern shelf and the Gulf *(Nunes and Lennon 1986).*

A daily heating/cooling cycle was seen in the temperatures at the upper current meter at all sites, the temperature change being about 0.3°C. Temperatures and salinities from the current meters do not appear calibrated, so no data on stratification is available. However the lower current meters at Wedge and Berry sometimes showed opposite trends to the upper current meter for temperature and salinity. At Berry the lower temperature occasionally rose when the upper temperature dropped, possibly indicating a vertical mixing event. On two occasions at Berry this event was marked by a spike in the upper current meter speed, seen once at the lower current meter, possibly supporting the mixing scenario.

4.2 Salinity

Salinity increases from the mouth to the head of the gulf, as a result of the high evaporation in this area and the lack of freshwater input by precipitation or riverine influxes. Salinity in shelf waters is about 35 to 36, but may reach 43 to 48 at the head of the Gulf. During the outflow of density currents, salinity between Wedge Island and Cape Spencer to the

4.3 Stratification and Internal Waves

Intense horizontal and vertical stratification may occur in the Gulf at certain periods. In the absence of tidal stirring during dodge tides at fortnightly intervals, the mixed conditions generally experienced may be changed to vertically stratified, in the absence of strong winds. The switch may occur rapidly in a time of hours *(Nunes and Lennon 1987)*. Enhanced gravitational circulation can then further increase the horizontal and vertical stratification.

During summer and autumn the entrance to Spencer Gulf is characterised by strong sea surface temperature (SST) fronts, which may be seen in satellite infra-red imagery *(Nunes and Lennon 1986)*. An example is shown in Fig 4.1 (p40). *Petrusevics (1993)* reports that the SST fronts (with maximum contrast of 3 to 4°C) overlie strong bottom temperature and salinity differentials of 7 to 8°C and 1.2 to 1.5 respectively. A thermocline and halocline were located between 30 to 40 m, midway between Wedge Island and Cape Spencer (35°18'S, 136°53'E) in March 1988, with temperature decreasing downwards by 2°C, and salinity increasing downwards by 0.4, in a vertical interval 10 m above the bottom. When the gravity current flows, lighter waters overlie saltier, denser waters. It is known that such a situation can lead to internal waves, but no measurements of internal waves have been reported. Since the tides virtually cease at neaps, a primary source of excitation for internal waves is possibly removed, leaving atmospheric forcing as a possible driving mechanism. If internal waves prove a problem, SST imagery could possibly be used to show up such fronts. The SST front has occurred in summer (December 1988) between Wedge and Thistle Islands. Its alignment was approximately west to east, following bathymetric contours near the Gulf entrance. Over September 1988 to April 1989 the front progressively moved 50 km in a north-east direction, and was stronger in the eastern regions.

It is not known if seiching, shelf, or other waves occur in this locality. On 26 September at Wedge Island, near bottom temperature dropped markedly and salinity decreased at a time of low currents when the lower current was greater than the upper current by about 5 cm/sec. Bottom directions were variable, turning anti-clockwise from 350° to 50° True. A similar but smaller event occurred at Wedge on 19 September, before the start of the neap period, when peak speeds were still high. More often at Wedge during the low currents of the neap period the bottom salinities increased, with the lower temperature near constant, and the upper temperature near constant or rising slightly.

5. WIND

Wind speed statistics are important for this survey because of the substantial variation of ambient noise with wind speed and the effect of the wind on general sea conditions.

5.1 Climatology.

Winds are often from the south west. *"From an analysis of wind data recorded at Adelaide airport it was found that the wind was from an arc of 45^o centred on south west for 25% of the time"*. This direction leads to maximum fetch along the gulf. Time scale of variations in weather conditions is of the order of 2 days *(Tronson 1974)*. *"South west winds are more frequent and stronger than other winds and are usually associated with weather conditions which may persist for up to 3 days. These winds generate considerable wave activity. In the shallow waters of the gulf, the waves increase the turbulent motion on the sea floor, enabling the bottom sediment to be more easily moved. .....the bottom sediment distribution partly reflects the circulation driven by south west winds"*.

Figures 5.1 to 5.4 (p44-47) show wind speed statistics from the following weather stations in the region: Neptune Island, Cape Borda (NW corner of Kangaroo Island), Port Lincoln and Warooka (E of Corny Point) (see Fig 1.2). The statistics are shown as the mean wind speed exceeded 50% of the time for each month of the year at 0900 and 1500 hours. The arrows in these figures give an indication of the most common wind direction for each month. Large differences are evident between the stations. Neptune Island and Cape Borda show much higher wind speeds throughout the year than at Port Lincoln or Warooka. Part of the reason for this is probably that the last two stations are more sheltered (for example by hills). However the differences are so substantial that they would translate into more than 10 dB difference in wind noise underwater, hence the importance of comparing the wind speed regimes at the proposed sites.

5.2 Site measurements.

A buoy with an anemometer at a height of 3 m was moored at each site and recorded wind speed every 20 s as the average of the wind speed over the preceding 20 s. In the results reported here, the measurements have been corrected to the equivalent for the standard height of 10 m using well established scaling laws for the wind profile. Figures 5.5 to 5.13 (p49-57) show a comparison between the wind speeds recorded on 19 to 27 November at the three sites. This period included a representative range of

(Text cont'd page 48)

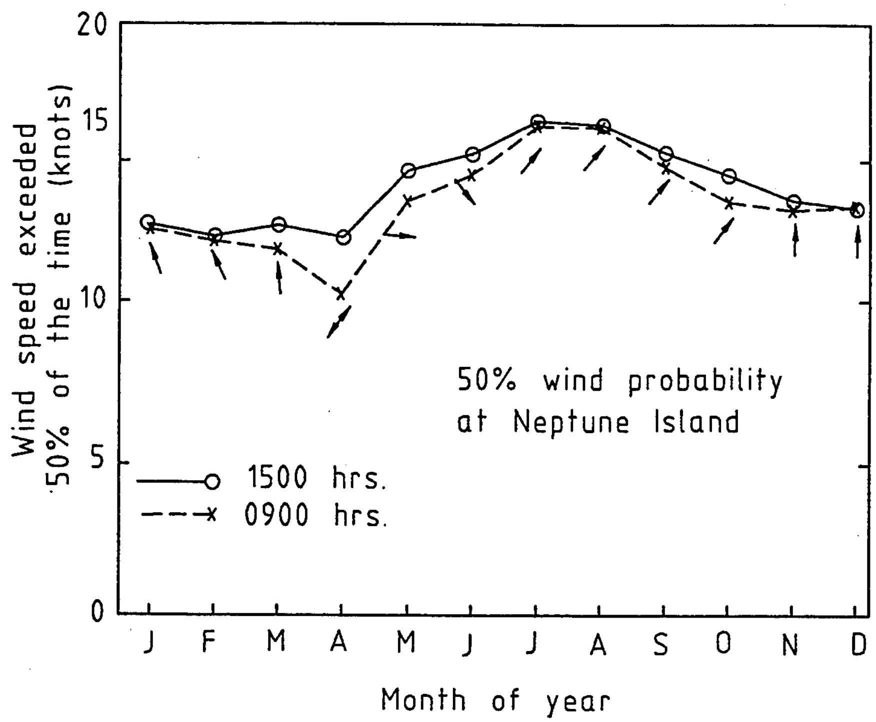


Fig. 5.1. Long term statistics of the wind speed exceeded 50 % of the time at Neptune Island.

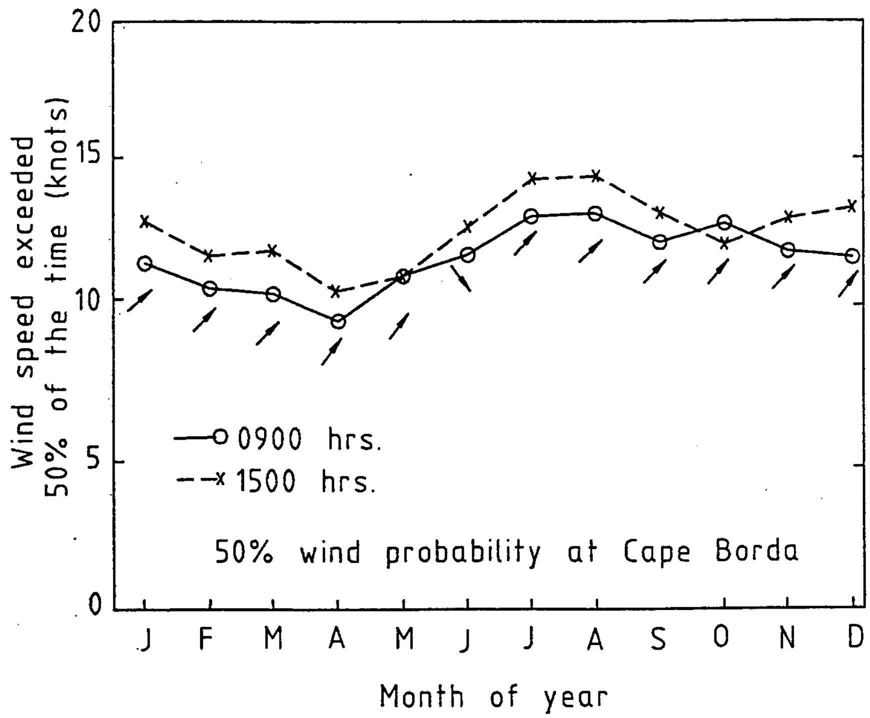


Fig. 5.2. Long term statistics of the wind speed exceeded 50 % of the time at Cape Borda.

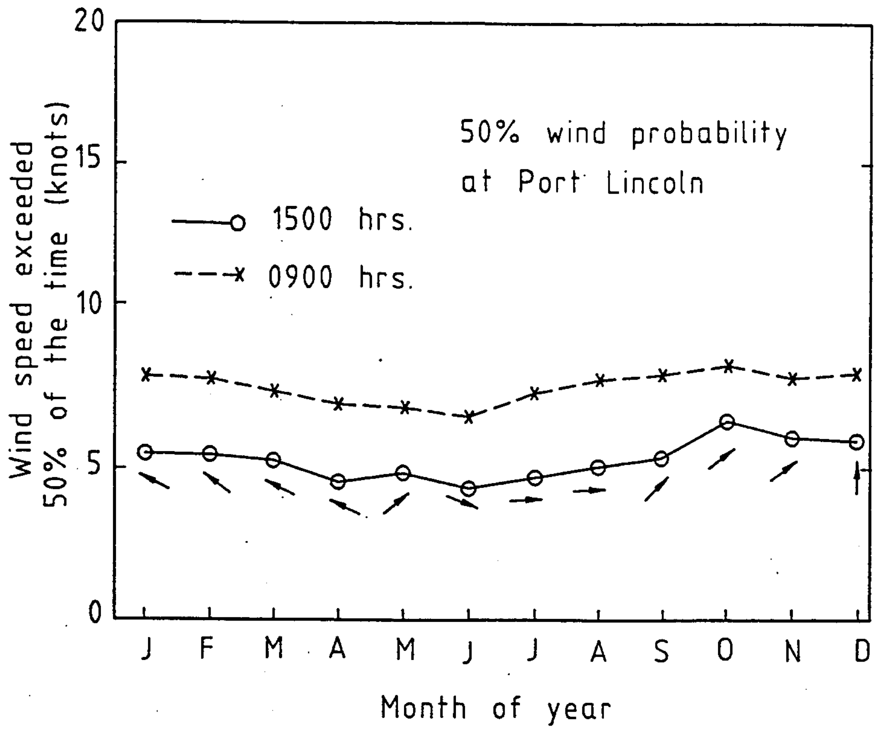


Fig. 5.3. Long term statistics of the wind speed exceeded 50 % of the time at Port Lincoln.

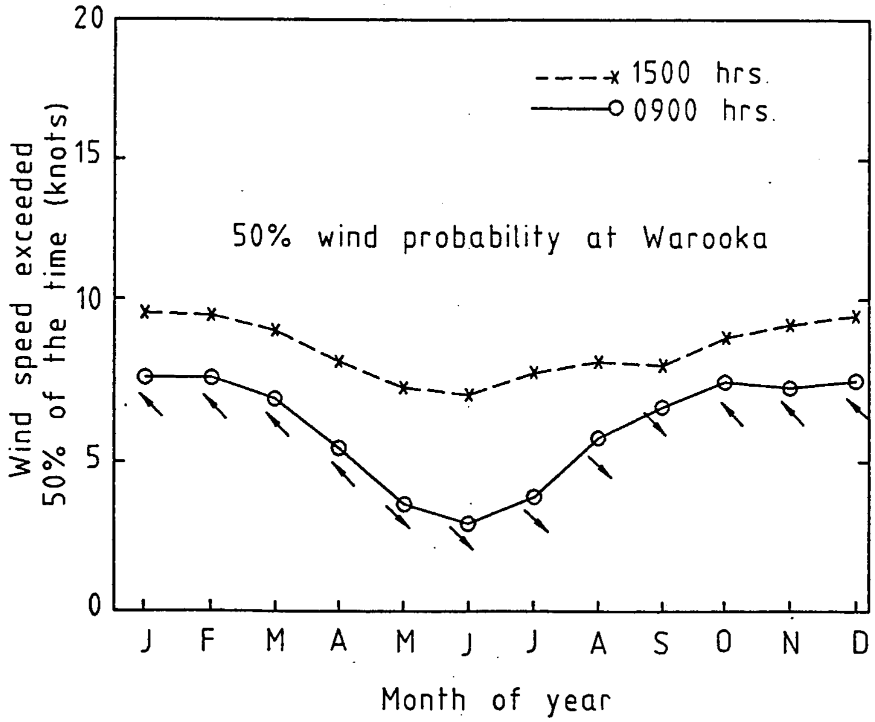


Fig. 5.4. Long term statistics of the wind speed exceeded 50 % of the time at Warooka (east of Corny Point).

wind speeds. It is evident that there is little difference between the wind speeds recorded at Wedge and Thistle, but there are times when the wind speed at Berry is significantly greater than at the other two sites. This appears to be related to the afternoon sea breeze. The Berry site is significantly more influenced by the presence of land, being closer to the Yorke Peninsula than the other two sites. For comparison, wind speed as a function of time for the same period at three of the weather stations referred to above is shown in Fig. 5.14 (p 58).

For the purpose of predicting the long term wind statistics at the sites, a comparison was made with wind speed recorded at Neptune Island for the period of the site recordings. Neptune Island was chosen as this is the most exposed of the four weather stations (least affected by the presence of land) and so could be expected to be the most indicative of open water wind speeds. The comparison between the winds speeds at Neptune Island and the buoy recordings at the Wedge site for the period 9 to 26 November is shown in Fig. 5.15 (p59). During this period, wind directions varied sufficiently for the data to be considered as representative of all significant wind directions. Although there is some spread in the data, the general trend is for the wind at the two sites to show similar speeds on average. It is reasonable therefore to use the Neptune Island long term statistics for predictions of wind speeds at the Wedge and Thistle sites.

5.3 Summary.
From this analysis, wind speeds would be expected to exceed about 15 knots in winter and 12.5 knots in summer for 50% of the time. Averaged over the year, the wind could be expected to be 10 knots or less for about 40 % of the time. During the period of recording, wind speeds were less than 10 knots for 33 % of the time at Wedge and 34 % of the time at Neptune Island. Although this is a lesser period than calculated from the long term statistics, it is probably too short a sample to be representative of the year. It does show the similarity of the Wedge and Neptune Island data. Winds speeds are estimated to be less than 5 knots for about 12 % of the time.

Comparison of wind speeds statistics in Spencer Gulf with those for the Indian Ocean off Perth, which has also been considered as a potential site for an acoustic range, show that wind speeds tend to be significantly lower in Spencer Gulf. Statistics from Rottnest Island off Perth show that wind speeds can be expected to be less than 10 knots for only about 13 % of the time compared with 40 % of the time in Spencer Gulf. (Text cont'd page 60)

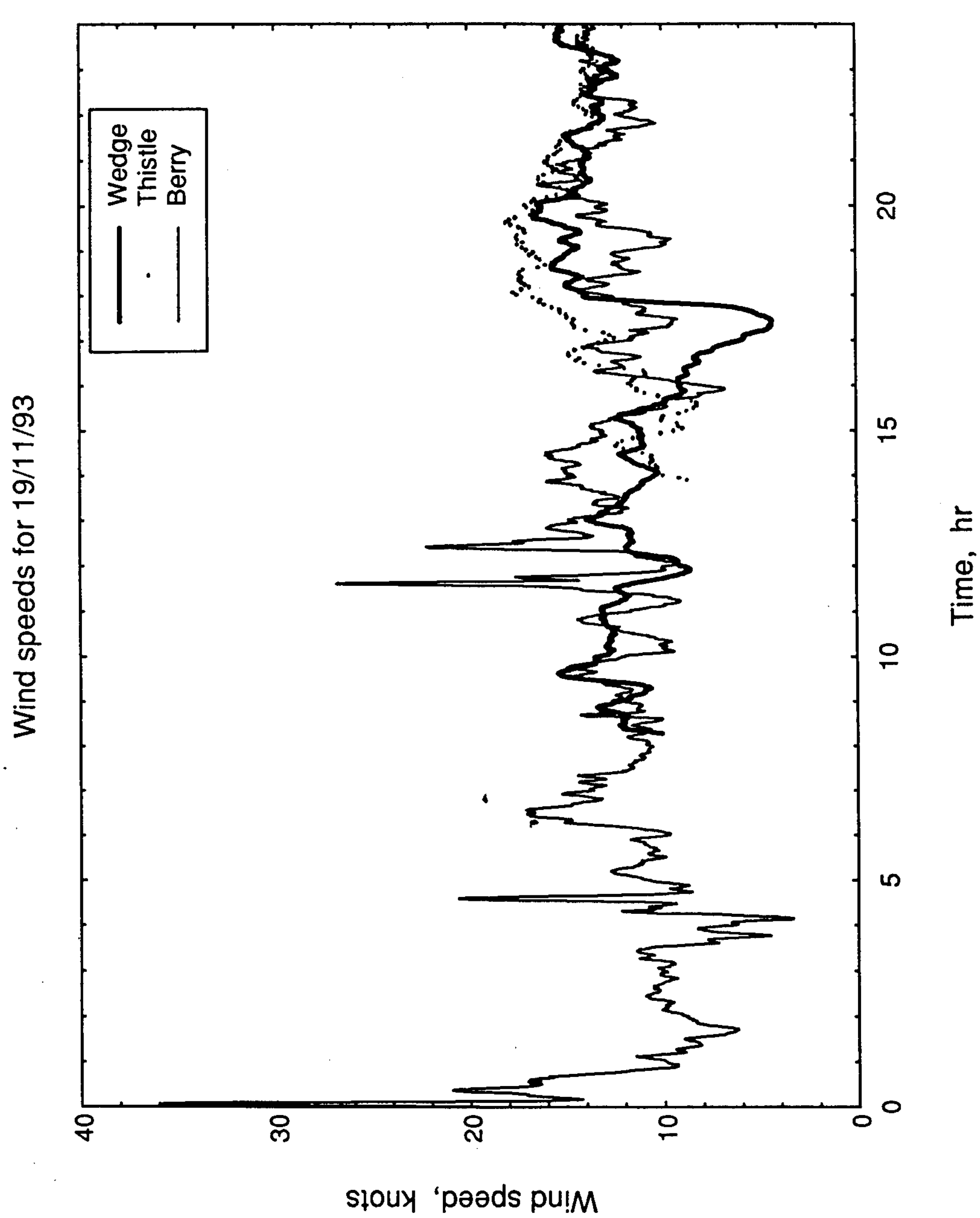


Fig. 5.5. Comparison of wind speeds measured using anemometer buoys at the Wedge, Thistle and Berry sites for 19 November 1993.

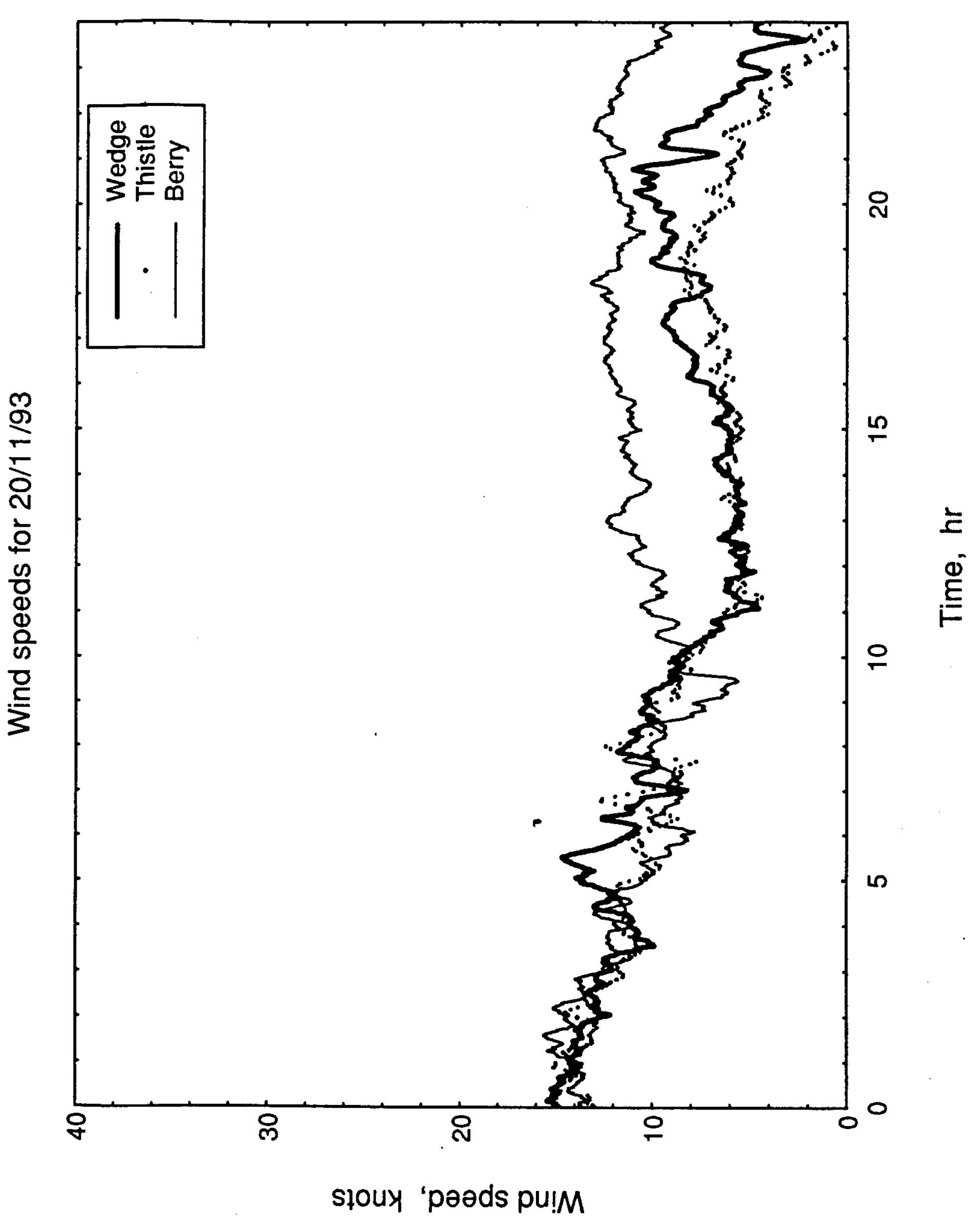


Fig. 5.6. Comparison of wind speeds measured using anemometer buoys at the Wedge, Thistle and Berry sites for 20 November 1993.

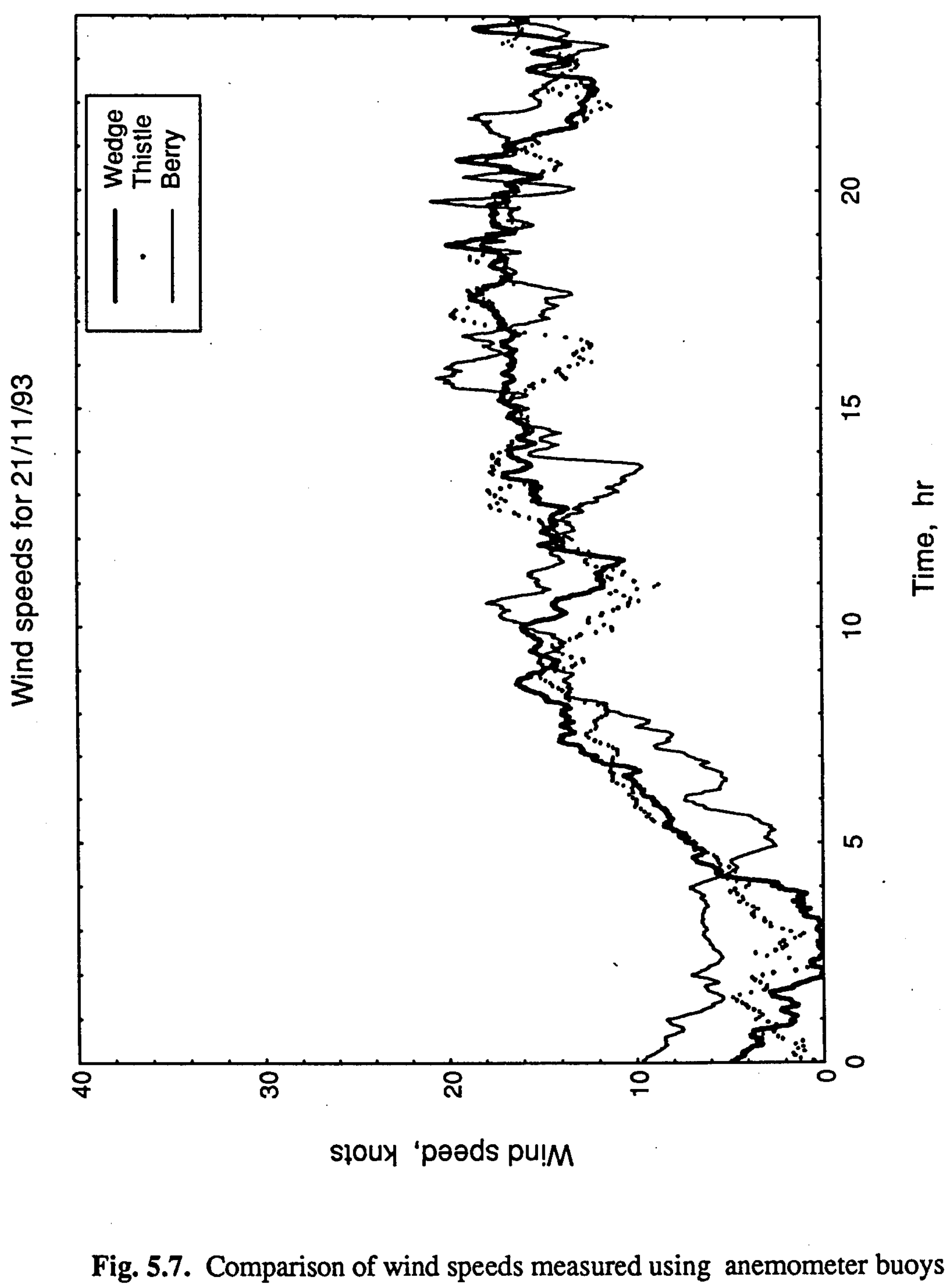


Fig. 5.7. Comparison of wind speeds measured using anemometer buoys at the Wedge, Thistle and Berry sites for 21 November 1993.

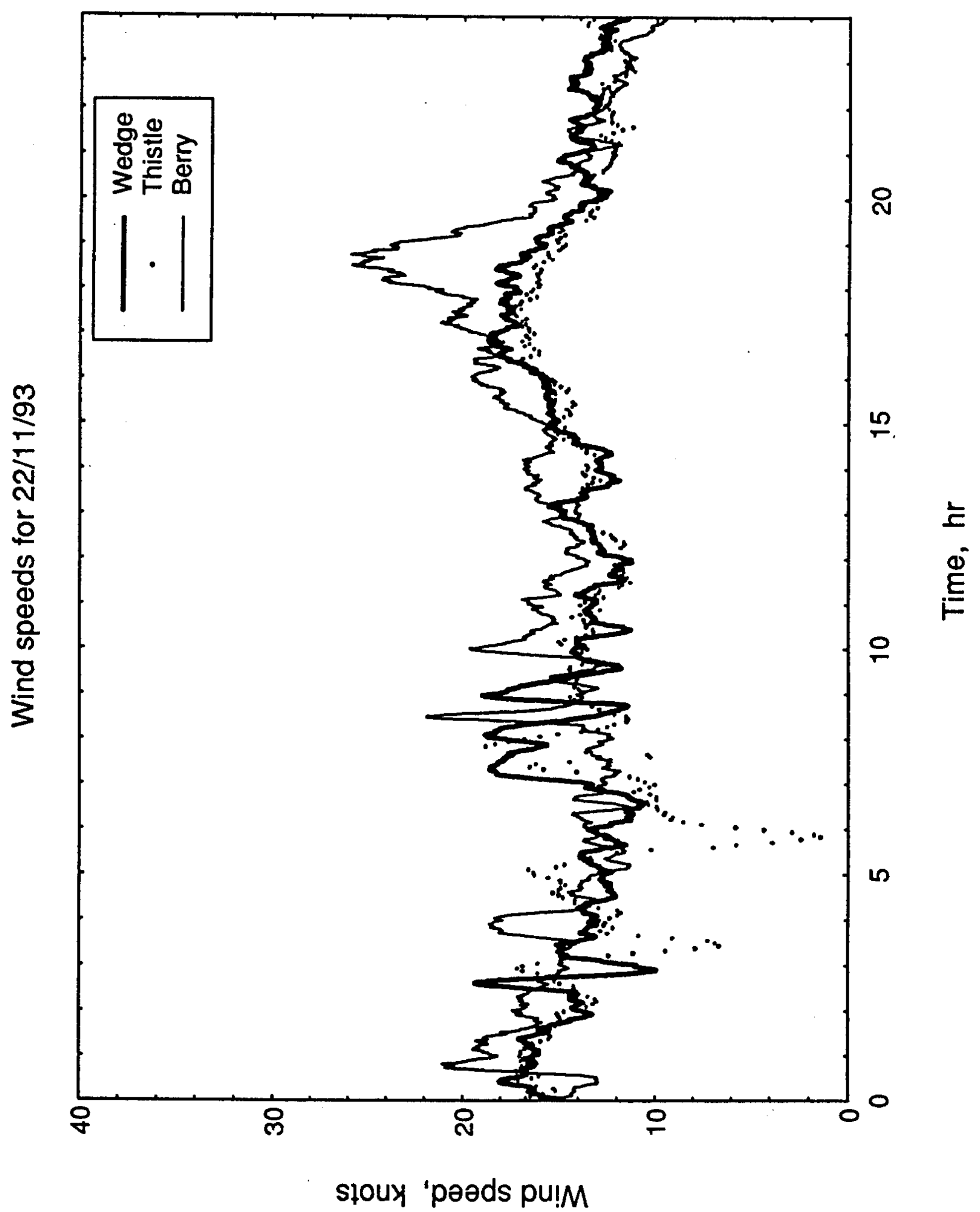


Fig. 5.8. Comparison of wind speeds measured using anemometer buoys at the Wedge, Thistle and Berry sites for 22 November 1993.

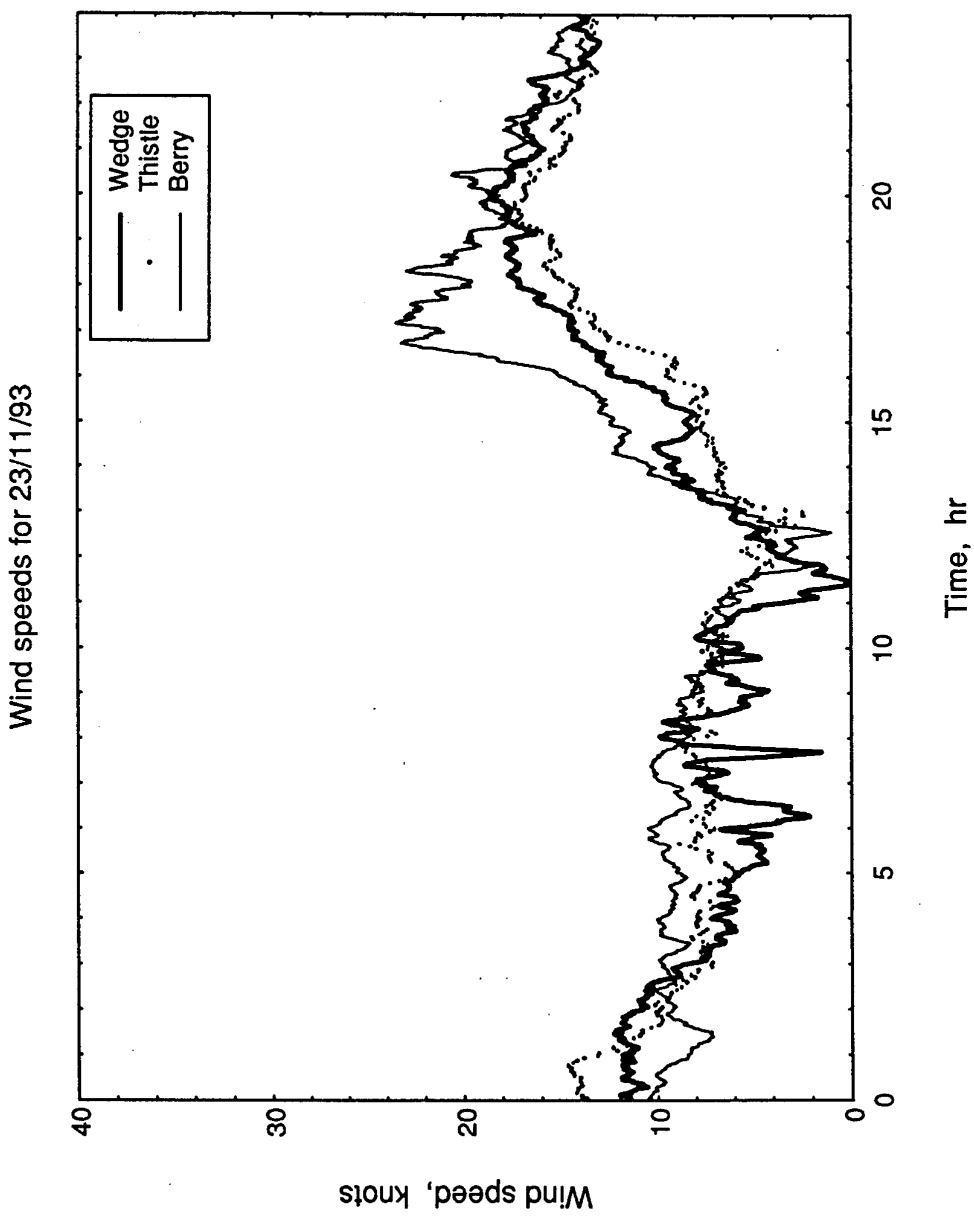


Fig. 5.9. Comparison of wind speeds measured using anemometer buoys at the Wedge, Thistle and Berry sites for 23 November 1993.

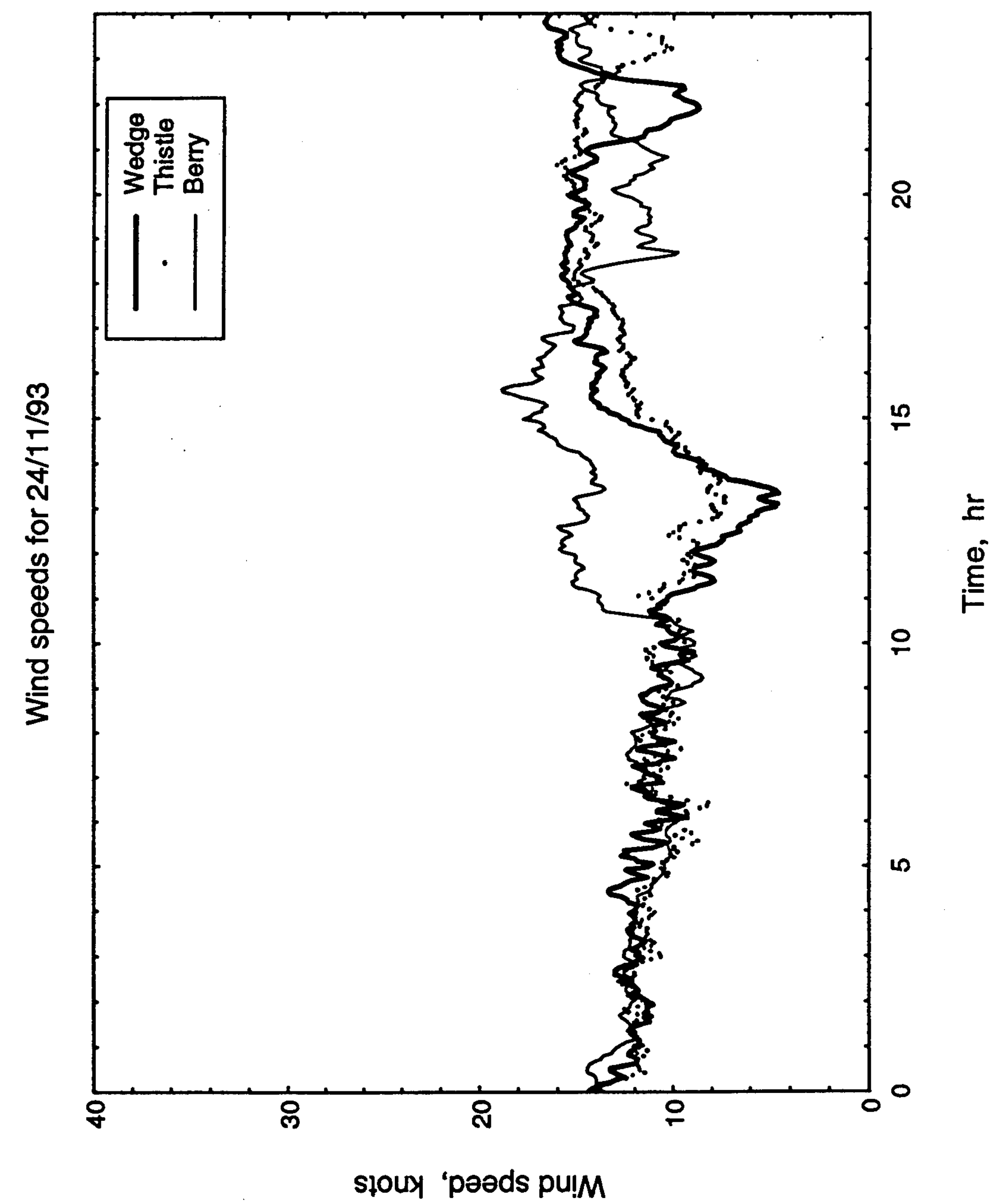


Fig. 5.10. Comparison of wind speeds measured using anemometer buoys at the Wedge, Thistle and Berry sites for 24 November 1993.

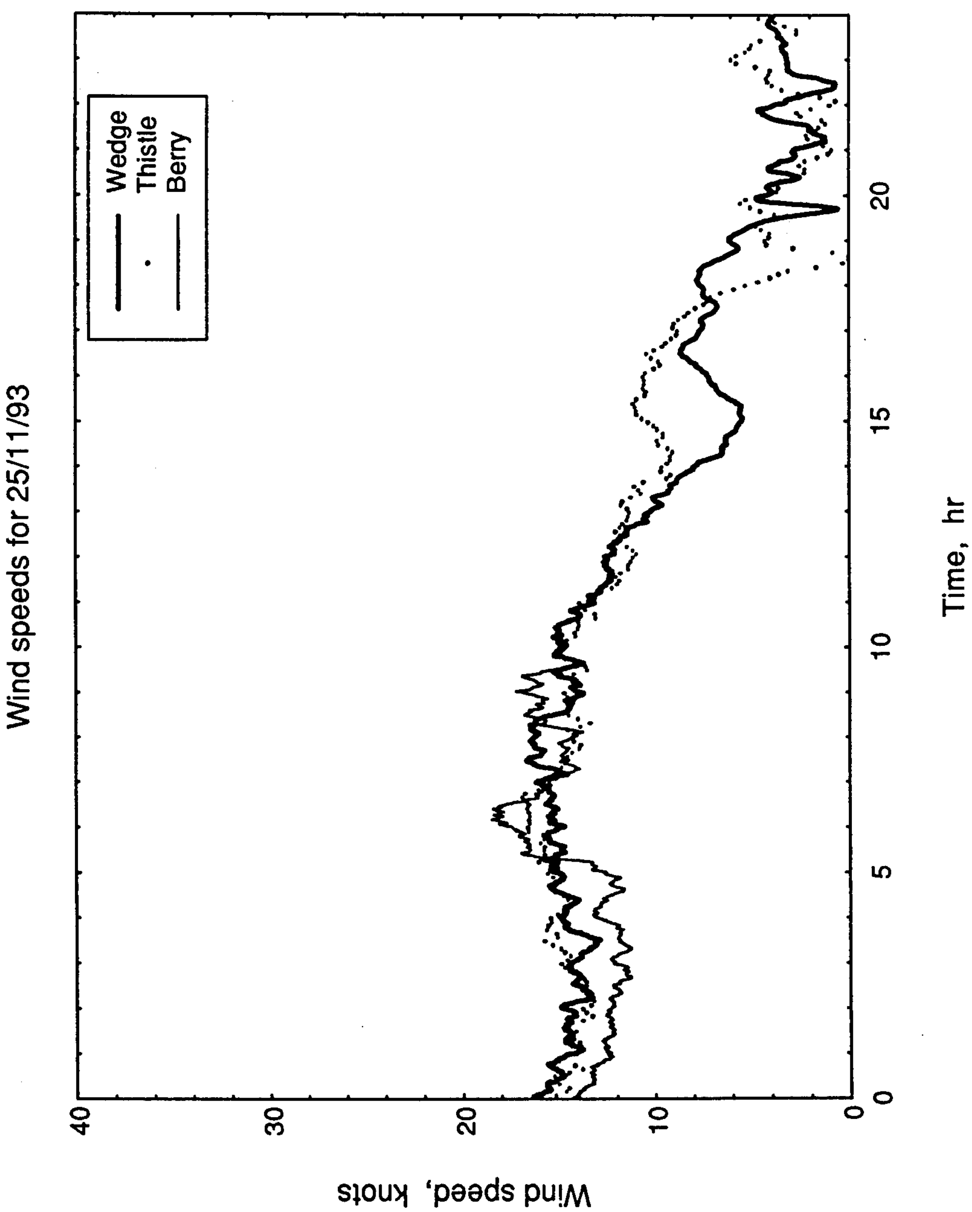


Fig. 5.11. Comparison of wind speeds measured using anemometer buoys at the Wedge, Thistle and Berry sites for 25 November 1993.

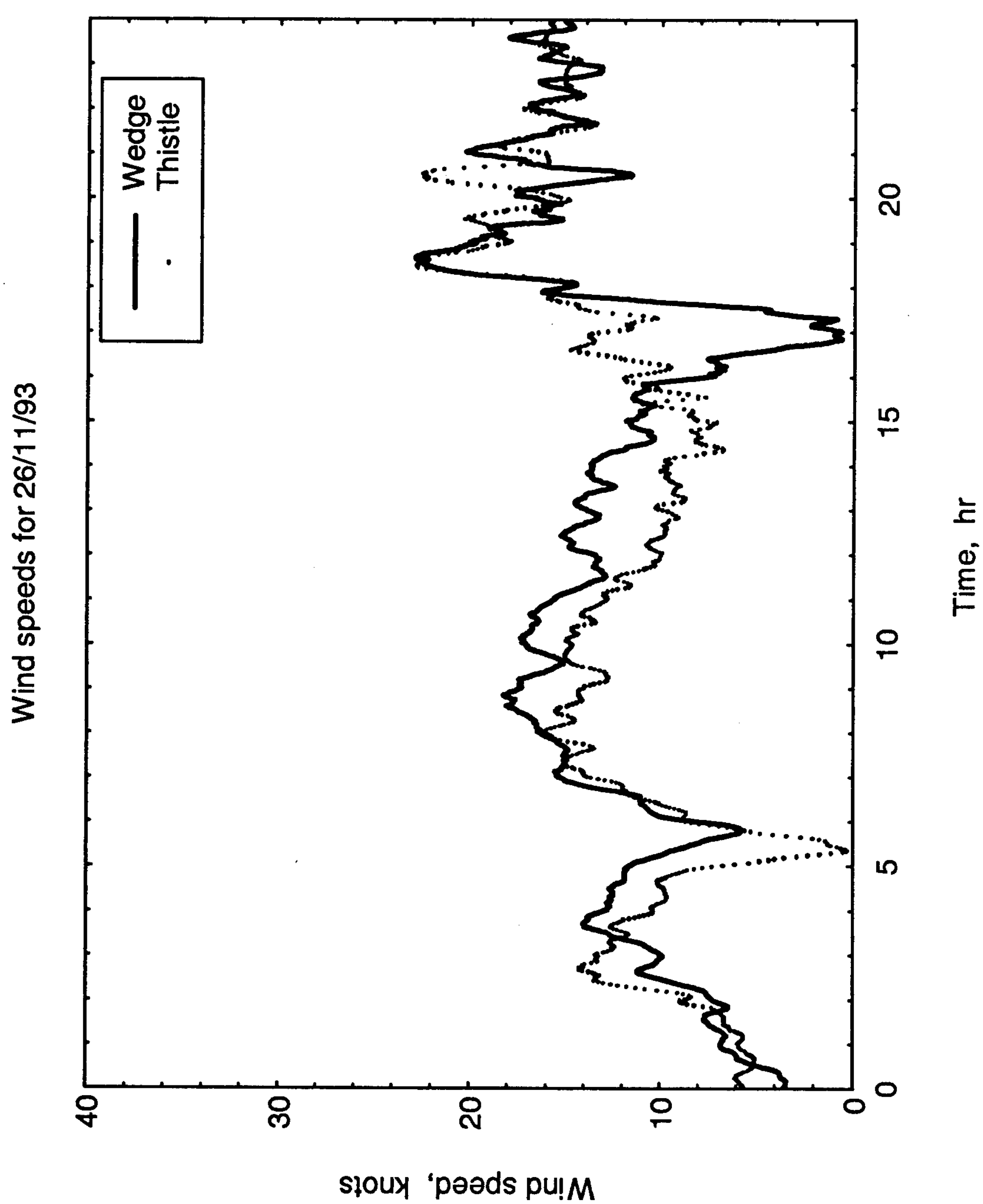


Fig. 5.12. Comparison of wind speeds measured using anemometer buoys at the Wedge, Thistle and Berry sites for 26 November 1993.

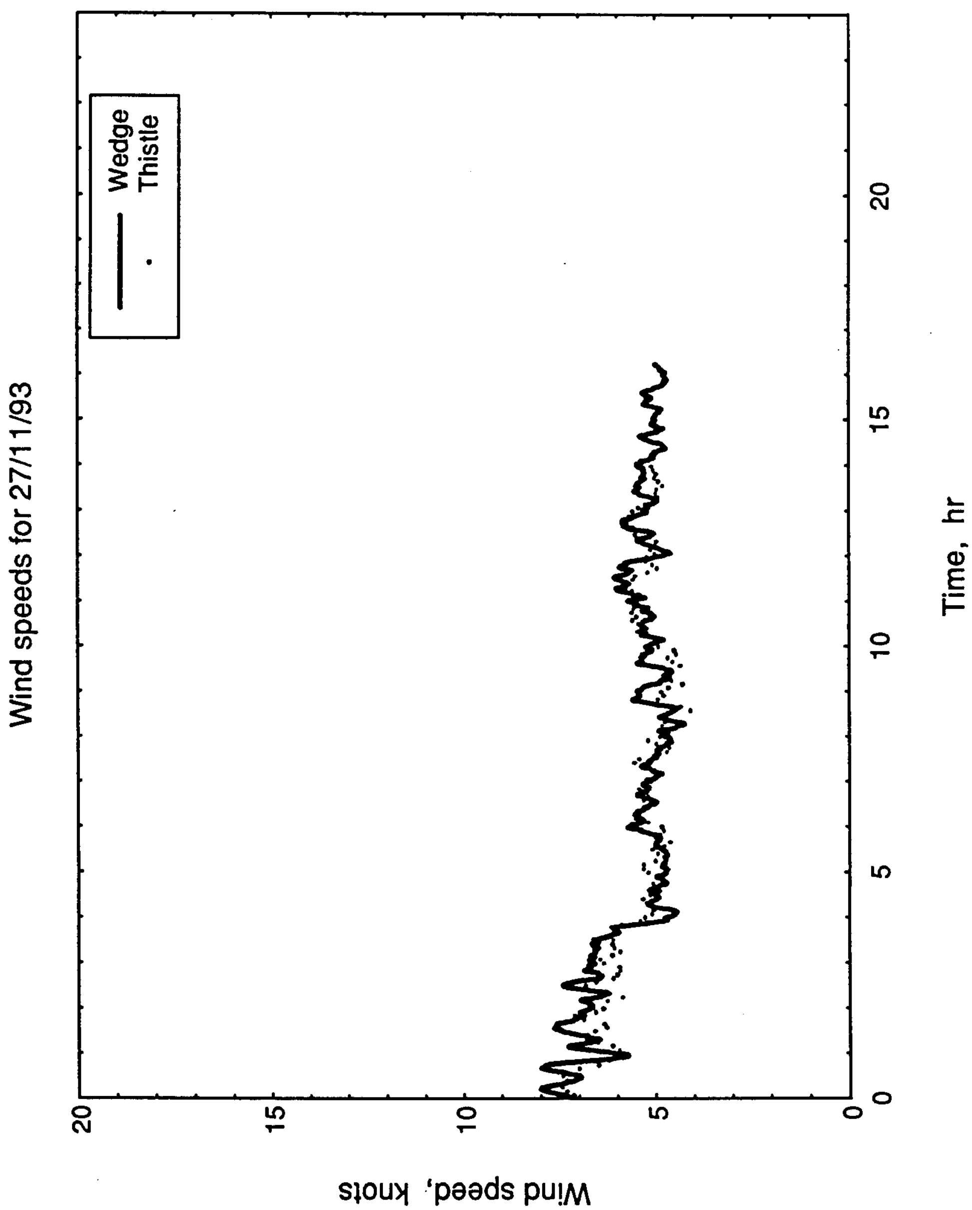


Fig. 5.13. Comparison of wind speeds measured using anemometer buoys at the Wedge, Thistle and Berry sites for 27 November 1993.

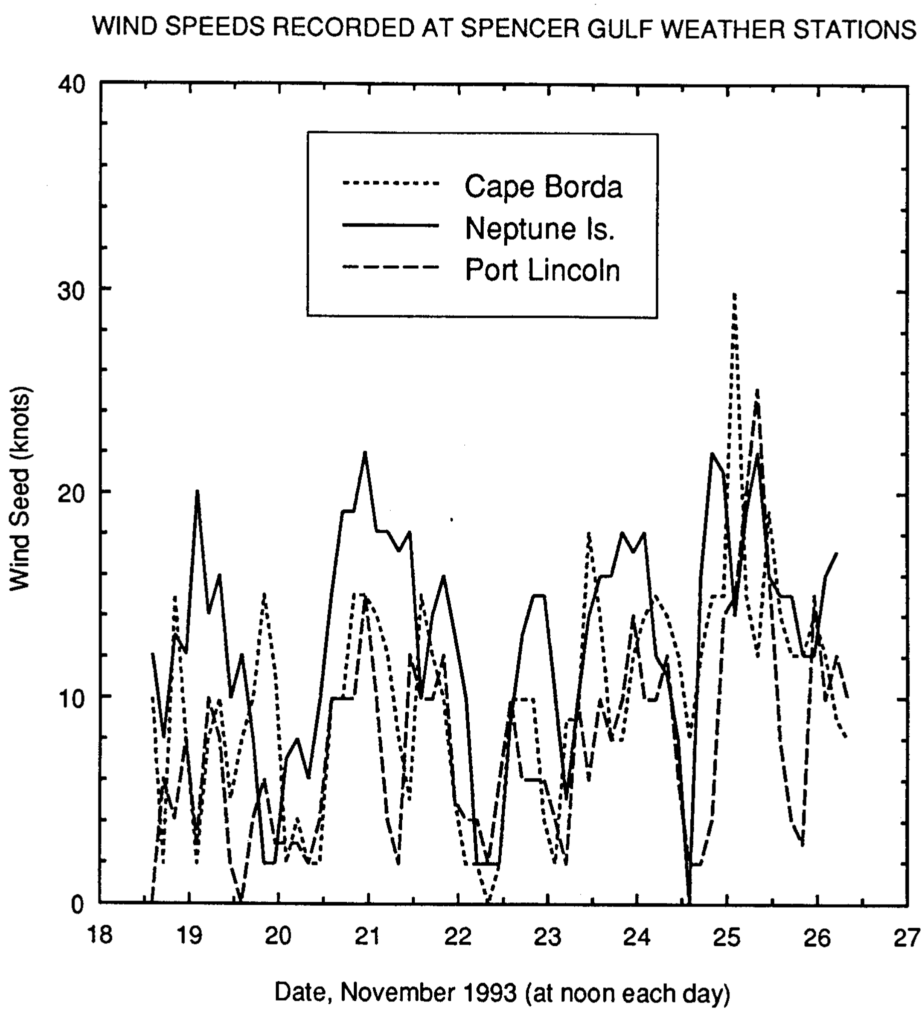


Fig. 5.14. Comparison of winds speeds at Neptune Is., Cape Borda and Port Lincoln over the same period as the buoy records.

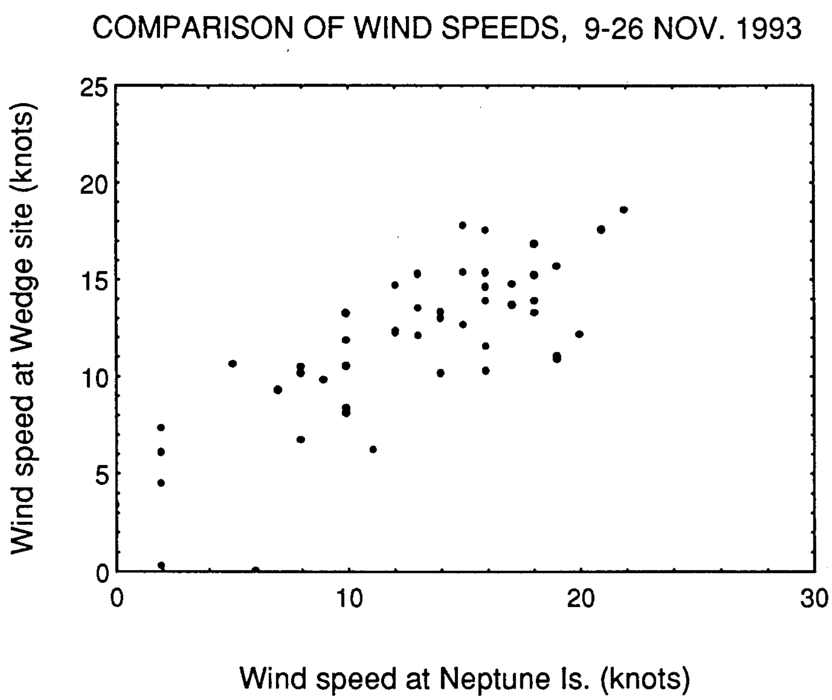


Fig. 5.15. Comparison of wind speeds at the Wedge site and at Neptune Is. for the period 9 to 26 November 1993.

6. WAVES AND WHITECAPS

Waves and whitecaps are an important source of ambient noise. Waves and swell also determine seakeeping abilities of vessels used on the acoustic range, and the design of engineering structures.

6.1 Waves

Because of the shape of the coastline, Spencer Gulf is protected from the effects of ocean waves and swell from all directions except the south to south west. *"The season with the greater wave energy is generally from March to October, while November to February is relatively less energetic, although calm water is rare. The two gulfs are protected from the Southern Ocean swell by islands in their entrances. The large size of the gulfs, however, allows 1.5 m waves to be generated locally." (Harris et al 1991).*

"Wave heights were recorded during 1965 by the Department of Marine and Harbours at Port Neill in the Lower Gulf. ....The height of the swell recorded was very small, of the order of centimetres." (Noye 1984).

Although Spencer Gulf has sufficient wind fetch to allow the generation of significant wind waves, it is insufficient for the generation of long wave swell. Ocean swell enters the Gulf from the south or southwest but suffers significant attenuation due to the passage through shallow water and the obstruction of the coastline.

6.2 Observations and measurements

Observations of the wave and swell pattern and white cap coverage were made by air using a small chartered aircraft flying at a height of 150 m and speed of 120 knots. Wave rider buoys were deployed at the Wedge and Berry sites for the period of noise and wind measurements.

During observation flights, the main swell pattern was observed to be generally from the south or the southwest. On some occasions there was evidence of a southerly swell superimposed on a southwesterly one. The swell height was small. West of a north south line through the east edge of Thistle Island the swell diminished becoming almost negligible.

An analysis of the wave heights measured at the Wedge site from 29 October to the 22 November is shown in Fig. 6.1. The significant wave height during this period was less than 2 m for 93% of the time and below 1 m for 35% of the time.

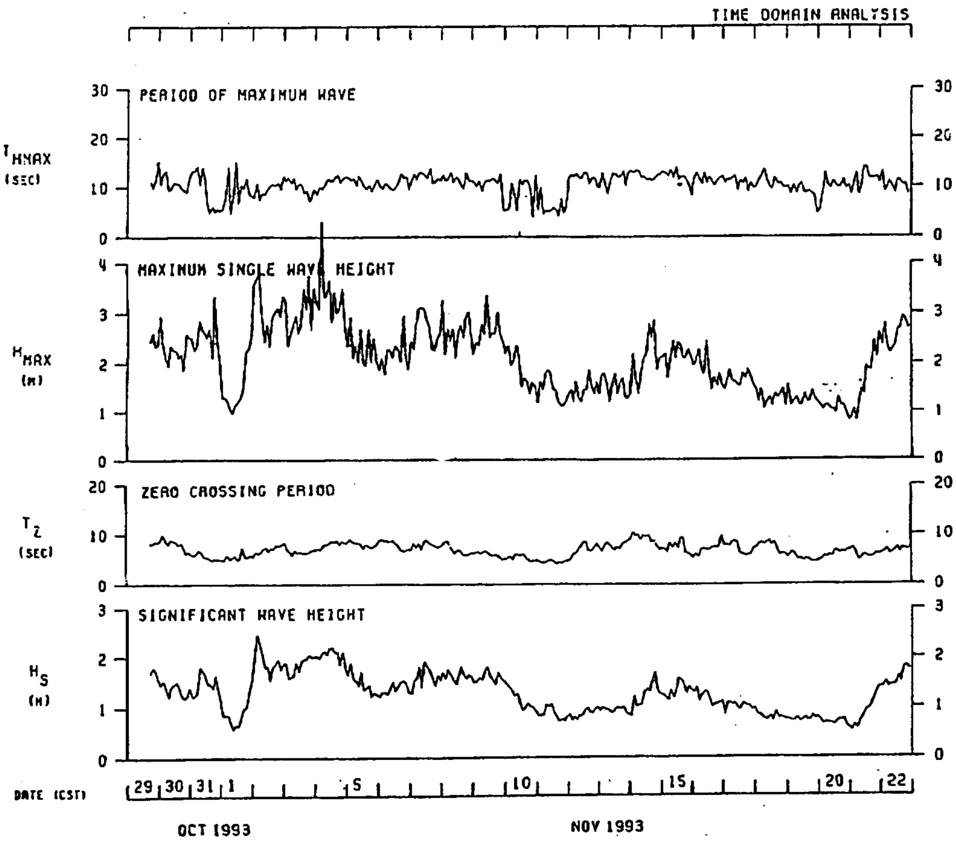


Fig. 6.1. Wave height measurements at the Wedge site for the period 29 October to 22 November 1993.

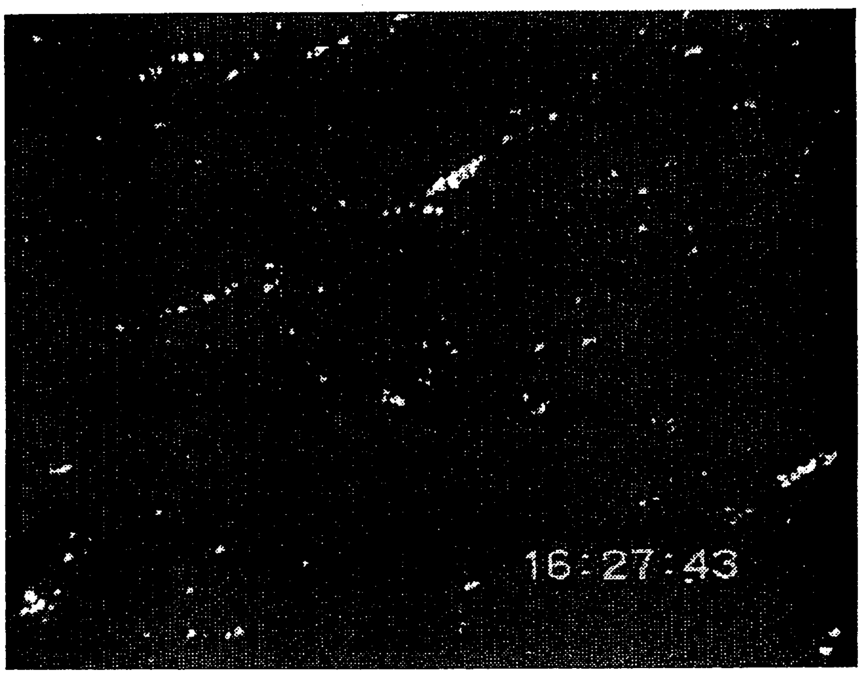


Fig. 6.2. Image of the sea surface captured with the video recorder showing typical white cap coverage.

6.3 Ocean Whitecaps (from Wong 1993)

During the observational flights, a high resolution video camera was used to photograph the sea surface for the purpose of measuring the white cap coverage, since wind dependent noise is caused directly by oscillation of the bubbles formed in whitecaps. Each frame enclosed an area of 10 m x 12 m of the sea surface. The recordings were analysed by computer by capturing and digitising individual frames. It was suspected that the percentage of whitecap coverage might be related to the fetch of a particular site. A total of 16 tapes were recorded in this experiment over the period between 11 to 25 November 1993. Flight details are shown in Table 6.1. An example of the image captured by the video recorder is given in Fig. 6.2.

Ta	Date	Take off	Thistle	Wedge	Berry	Land
1	11/11/9	09:20 PL →	09:46 est	09:55 est	10:08	C
2	11/11/9	11:31 C ←	12:01 est	11:52 est	11:39 est	12:20 PL
3	12/11/9	08:34 PL →	08:50:15	09:01:25	09:14:58	09:24 C
4	12/11/9	17:12 C ←	17:42:20	17:33:00	17:20:10	17:58 PL
5	13/11/9	08:26 PL →	08:39:40	08:48:20	09:00:40	09:31 PL
6	15/11/9	18:00 PL →	18:30 est	18:21 est	18:08 est	18:46 PL
7	16/11/9	16:20 PL →	17:14 est	17:05 est	16:52 est	17:30 PL
8	20/11/9	PL →	08:47:35	08:55:50	09:08:45	0918 C
9	20/11/9	C ←	17:24:30	17:16:00	17:02:40	17:40 PL
10	21/11/9	08:10 PL →	08:28	08:38	08:52	PL
11	22/11/9	08:37 PL →	08:51:55	09:00:15	09:14:00	09:24 C
12	22/11/9	14:22 C ←	14:52:55	14:44:05	14:30:55	15:08 PL
13	24/11/9	08:23 PL →	08:38:40	08:46	09:00	09:09 C
14	24/11/9	C ←	17:41:20	17:33:	17:19:30	PL
15	25/11/9	PL →	06:36:45	06:45:15	06:56:30	C
16	25/11/9	C ←	16:38:47	16:30:00	16:17	PL

Key: Direction of flight: → = E ; ← = W
est = times estimated from speed
appx. = approximate time read from watch
C = Corny Pt. PL = Pt. Lincoln Ta=tape

Table 6.1 Details of the flights showing times of take off, landing, and site crossings.

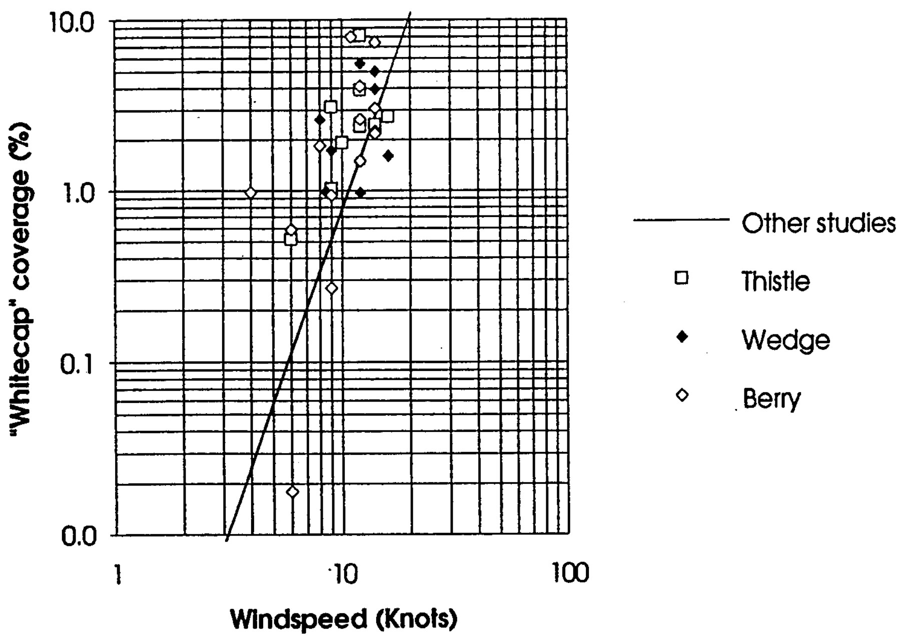


Fig. 6.3. White cap coverage as a function of wind speed at the three sites. Also shown is the relationship derived in other studies.

Figure 6.3 shows the whitecap coverage measured at each site as a function of the wind speed measured at the site. The straight line in the graph shows the relationship derived by *Wu (1979)* using data obtained by *Monahan (1971)* and *Toba and Chaen (1973)*:

$$w = 1.7U_{10}^{3.75}$$

where w is the whitecap coverage (ppm - parts per million) and U_{10} is the wind speed at a height of 10 m above sealevel.

The results show a general agreement in the wind dependence of white caps at the three sites.

7. SHIPPING

Shipping may be a significant source of ambient noise (traffic noise), and could also affect on site operations.

7.1 Commercial Shipping

The development of commercial shipping has continued in Spencer Gulf from the earliest years of settlement in the mid 1830's. The long swell-free waterway provided many convenient ports for the economical transport of wool cargoes by sailing ships to Europe. The importance of wool has decreased with time, but has been replaced in part by live sheep exports to middle east countries. Wheat growing commenced in the first years of settlement and from 1850 to 1880 the area surrounding the Gulf became Australia's granary, until railways from Melbourne and Sydney into the inland made other wheatlands more economical for Australian consumption. The major agricultural products exported through Spencer Gulf ports in recent years includes wheat, barley, peas and beans. Wheat ships are more frequent between November and March each year.

Mineral exports by sea commenced with copper ores and copper from the Wallaroo area in 1861, and ceased around 1920. Port Pirie because of its rail link with Broken Hill established around 1900, became a major port for the silver-lead-zinc ores, concentrates and smelted metals, and these exports continue although they are supplemented by imported metal concentrates due to the decline of Broken Hill mines. In 1915 iron ore from the Middleback Range was shipped from Whyalla to the steelworks in Newcastle. Although iron ore is no longer shipped interstate, steel is produced in Whyalla and mainly exported.

Liquid hydrocarbons piped from the Moomba field are shipped through the facility opened in 1984 at Port Bonython near Whyalla, which can handle ships of up to 110,000 tonnes capacity. Because of the economies of bulk sea transport many ships bring cargoes into Spencer Gulf. The main incoming cargoes are: coal; coke; limestone; dolomite; refined petroleum products; agricultural fertilizers; and metal ore concentrates. Further details of cargoes passing through the ports can be obtained from the S.A. Dept of Marine and Harbors, Commercial Division, 293 St Vincent St, Port Adelaide, 5015.

The increase in the tonnage of ships with time has led to the disuse of the smaller ports in the Gulf, leaving the five larger ports of Port Lincoln, Whyalla, Port Bonython, Port Pirie and Wallaroo.

7.2 Shipping statistics

Statistics of shipping entrances and exits to the ports in Spencer Gulf provide an estimate of the frequency of shipping through the site area. There are approximately 520 ship passages through the area per year, an average of 1.4 per day (a ship passing in and out of the Gulf would pass through the area twice and thus be counted as two ships for the purpose of these statistics). Although some ports show seasonal variation in shipping, overall this averages out and there appears to be little seasonal variation in total number of ships passing through the site area.

During the period of the acoustic measurements in the present investigation, a survey was conducted of the shipping passing through the area of the proposed acoustic range. The Daily Commercial News newspaper was used to compile the list of ships calling at the ports, which is shown in Table 7.1 (overleaf). The co-operation of the harbour managers was sought to distribute questionnaires to the masters of visiting ships. About a half of the masters replied to the questionnaire, and from these responses the ships' tracks through the research area in the Gulf are shown on the map of Fig. 7.1 (on page 69). This shows that ships pass near all sites.

Figure 7.2 (on page 71) is a map showing the observations of vessels from the air during survey flights crossing the Gulf from Port Lincoln to Corny Point and return, on 10 days between 11 and 25 November. Only four ships were seen, three of which were near the Berry site, though the sample is too small to draw any conclusions about ship distributions (Fig. 7.1 would be more reliable in this respect). Small boats cluster around Corny Point and trawlers/ large fishing boats around the entrance to Port Lincoln.

Date	Ship Name	Last Port	Next Port	Questionnaire Returned	
5 Nov	Iron Baron	Pt Kembla	Whyalla	yes	
5 Nov	Mun Kim	Indonesia	Whyalla		
5 Nov	Iran Saeidi	Indonesia	Pt Pirie		
8 Nov	Al Yasrah	Kuwait	Pt Lincoln	yes	
9 Nov	Al Yasrah	Pt Lincoln	Portland	yes	
9 Nov	Iran Saeidi	Pt Pirie	Albany		
9 Nov	Tasman	Melbourne	Pt Lincoln	yes	
10 Nov	Tasman	Pt Lincoln	Pt Stanvac	yes	
11 Nov	Iron Baron	Whyalla	Pt Kembla	yes	
11 Nov	Anagel Spirit	Panjang	Pt Pirie		
12 Nov	Iron Sturt	Pt Kembla	Whyalla	yes	
14 Nov	Iron Sturt	Whyalla	Ardrossan	yes	
14 Nov	Anagel Spirit	Pt Pirie	Burnie		
14 Nov	Global Ace	Portland	Pt Lincoln	yes	
15 Nov	Global Ace	Pt Lincoln	S. Korea	yes	
15 Nov	Mun Kim	Whyalla	P'pines		
15 Nov	Manisamut Naree	overseas	Pt Pirie		
16 Nov	Iron Sturt	Ardrossan	Whyalla	yes	
18 Nov	Manisamut Naree	Pt Pirie	Adelaide		
19 Nov	Iron Sturt	Whyalla	Ardrossan	yes	
19 Nov	Dolphin	Newcastle	Pt Lincoln		
19 Nov	Dolphin	Pt Lincoln	UAE		
19 Nov	Alaska Trader	Singapore	Pt Pirie		
19 Nov	Tanunda	Pt Adelaide	Pt Lincoln	yes	**
20 Nov	Alaska Trader	Pt Pirie	Adelaide		
22 Nov	Kelvin	Sydney	Pt Bonython	yes	
23 Nov	Kelvin	Pt Bonython	Sydney	yes	
23 Nov	Express	Adelaide	Wallaroo		
24 Nov	Express	Pt Pirie	Thevenard		
24 Nov	Steel Flower	overseas	Wallaroo		
25 Nov	Eclipse	Pt Stanvac	Pt Bonython	yes	
26 Nov	Eclipse	Pt Bonython	Pt Stanvac	yes	

Table 7.1. LIST OF SHIPS PASSING THROUGH PROPOSED RANGE AREA (as listed in the Daily Commercial News; except ** from returned questionnaire).

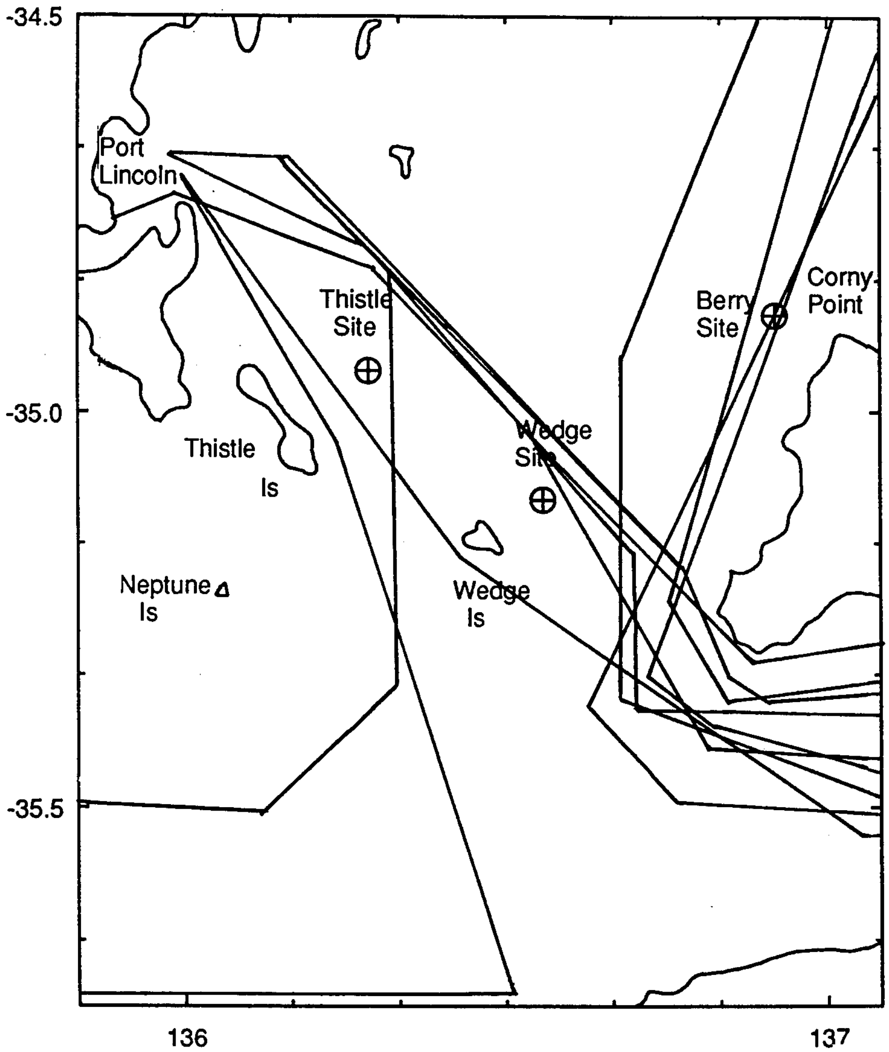


Fig. 7.1 Map showing the tracks of ships passing through the survey area from the reponses to the questionnaire by the ships' masters.

7.3 Commercial Fishing

Many fishing boats use Port Lincoln as a base but most of them are engaged in fishing in ocean and coastal waters to the west of Spencer Gulf, using Thorny Passage to the west of Thistle Island for the transit. The tuna season lasts from December to April each year, and other fish can be trawled throughout the year. Inside Spencer Gulf there are many boats from numerous ports engaged in netting fish close to the shore, generally some distance from the three proposed range sites.

Prawn trawling is another major activity, with about 39 boats of 16 to 20 metres LOA engaged in this work. About a half of the prawn trawlers tend to work in a single group, while the others operate singly or in small groups. The prawns are seasonal and are fished around the Thistle site from April to May, and around the Berry site from November to June. In other months the trawlers can operate further north in the Gulf. Prawning activity is not continuous within the permitted season because the fishery is regulated by the number of days in each month that they are permitted to trawl.

Crayfish are trapped throughout the area including the three range sites from November to May. There are about 40 boats of 12 to 16 metres LOA engaged in crayfish trapping, but they are dispersed over the lower Gulf area and seawards. Further details about the fishing industry in Spencer Gulf may be obtained from Mr John Johnson, SA Dept of Primary Industries, Fisheries Division, 135 Pirie St, Adelaide, 5000.

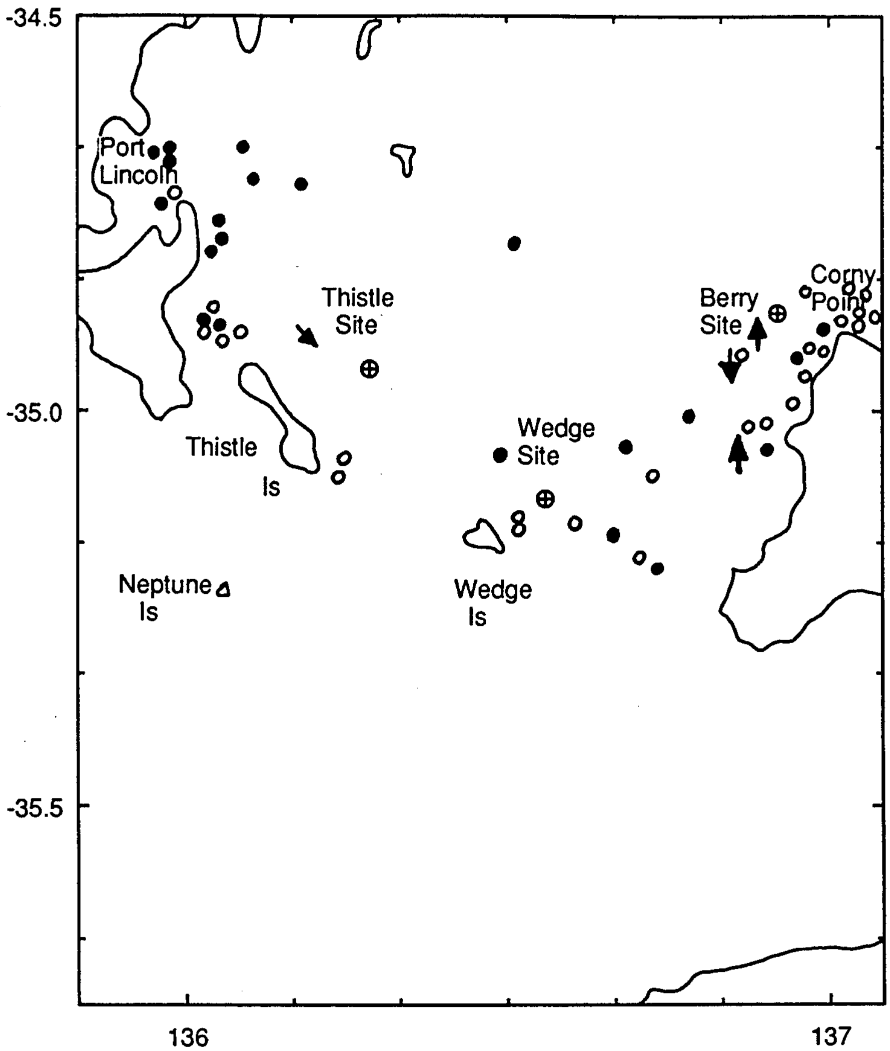


Fig. 7.2 Map showing the positions of ships (arrow heads indicating ship's direction), trawlers and large fishing boats (filled circles), and small boats (open circles) seen during the 10 days of flights across the Gulf.

8. AMBIENT NOISE FROM WIND AND SHIPPING

8.1 Introduction

This comprises the noise generated by various processes due to wind and wave action in the vicinity of the sea surface, and the noise generated by distant shipping. Wind generated noise is the prevailing noise against which the signals must be detected. At low wind speeds, it gives the noise floor - the minimum background noise, which determines best possible system performance. As a function of wind speed, it gives the range of wind speeds over which the system can be used, so that from known wind speed statistics we can determine the proportion of the year that the system would be useable. This is the crucial question that determines if the system will be viable.

Ambient noise ("sea noise"), is the general background noise from all sources, except those associated with our own vessel or recording system, and thus provides the limit on the detectability of underwater acoustic signals. It results from many different sources, and commonly varies over a range of about 20 dB as a result of varying weather conditions, shipping densities or biological activity. This variation may include temporal, seasonal or geographical factors. The full range of variation of ambient noise, however is more than 30 dB. An idea of the effect of this on system performance is that, under typical conditions, a variation of 20 dB would cause a variation of a factor of about 10 in the distance to which a source would be detectable, while a variation of 30 dB corresponds to a factor of about 30 in distance.

A comprehensive review of ambient noise in the context of acoustic ranges is given in *Jones, Cato, Hamilton and Scott (1992).*

The main components of ambient noise in the ocean are:-

a. Sea surface noise: the noise of wind and wave action at the surface, usually referred to as *wind dependent noise*, and rain noise

b. the noise of shipping, the contribution from distant shipping being distinguished by the term *traffic noise*; and

c. biological noise - the noise of fish, whales and invertebrates.

Wind dependent noise is the sum of the noise of large numbers of breaking waves across the sea surface. Wave breaking is directly related to wind speed (rather than to sea state), so the noise is usually given in terms of wind speed. Although it has been known for many years that the noise is generated at the sea surface *(Knudsen, Alford and Emling 1944, 1948; Wenz 1964)*, the actual source was not known and many prediction methods give the noise as a function of sea state, and are thus significantly less reliable than those that relate the noise to wind speed. *Banner and Cato (1988)* found that the noise of breaking waves was due to oscillation of bubbles formed in the process of air entrainment to make whitecaps. This has been confirmed in later studies (e.g. *Medwin and Beaky 1989*) and indicates that noise should be related to white cap coverage. Wind dependent noise has been observed throughout the whole frequency range considered in this study.

Traffic noise is the contribution from distant shipping and excludes the contribution of any ship that is individually detectable. It is significant because the good sound propagation in the ocean allows ships at great distances to contribute. It forms a general background noise usually dominant in oceanic waters at frequencies below 100 Hz when wind speeds are low to moderate. Its significance decreases above 100 Hz, but it contributes to a general background noise floor at higher frequencies. The noise of an individual ship passing close to a hydrophone may reach very high levels but is not considered to be part of traffic noise since it is a short term and clearly definable event associated with the passage of that particular ship.

Biological noise is more intermittent than the other two components, and may occur in any frequency range.

8.2 Prediction Of Ambient Noise.

Because the various components are relatively independent, each varying significantly in space and time, spot measurements of ambient noise are no more than snap shots, and have little value in predicting the noise. The only effective method is to establish the relative contributions of the components and their individual behaviour. This requires a series of controlled measurements which allows the behaviour of the individual components to be analysed and interpreted and related to other parameters for which statistics are available, such as wind speed. Noise predictions can then be made by combining the components.

8.3 Measurement plan for Spencer Gulf

The expectation in planning the survey was that the noise would be dominated by wind dependent noise, except on occasions when the noise of passing ships and fishing boats would be significant. Passing ships are expected to be sufficiently infrequent that it should be possible to plan ranging around them. Fishing boats may or may not be a problem depending on their seasonal and geographic distribution. The noise of distant shipping is expected to be low because ships would be well south of the gulf, in low concentration and the propagation loss through the shallow water to the site would be high (this was one of the reasons for recommending Spencer Gulf).

Because of the large differences in wind speed statistics between weather stations (Section 5), it was considered possible that significant variation might occur across the waters of the Gulf leading to significant variation in surface generated noise between the selected sites. Simultaneous recordings of noise and wind speed were therefore made at each site using a DSTO designed bottom moored hydrophone recording system for the noise and a buoy deployed recording anemometer. The recorders were set to sample noise at intervals of about 15 minutes and wind speed at intervals of 20 s. Systems were recovered and data extracted after the first recording period (10 to 18 November) and then redeployed for a further recording until the final recovery on 25 (Berry) and 27 November (Wedge and Thistle). Wind and rain data were obtained from weather stations in the region for the period of sampling. White cap coverage and wave height were also measured (Section 6).

A light aircraft was chartered to make flights over the sites to photograph the swell and white cap coverage using a still camera and a high resolution video camera, and to observe the presence of boats and shipping. Wave rider buoys were deployed at Wedge and Berry sites.

Measurements were made with hydrophones on the bottom to avoid the problem of "flow noise" contaminating the recordings. Flow noise is caused by pressure fluctuations in turbulence in the vicinity of the hydrophones, which are sensed in the same way as acoustic pressures. Vortex shedding by flow about any cylindrical cross section is a particular problem. Fairings were fitted to all vulnerable components and the recording systems separated from the moorings by long lines lying on the bottom and thus subject to minimum water motion.

The recordings of ambient noise were analysed in 1/3 octave bands using a Bruel and Kjaer spectrum analyser controlled by a PC using locally developed software *(Prenc 1993)*. The final results are presented as the spectrum level (the value in a 1 Hz band) averaged over the appropriate 1/3 octave.

8.4 Results Of Measurements

The measurements showed a general similarity between the three sites. The results will be presented for the Wedge site first, followed by a comparison with the results at the other sites. The results are also compared with measurements off Perth *(Jones, Cato, Hamilton and Scott 1992)* and other sites around Australia *(Cato 1976, 1978a, 1978b and 1980)*.

Figs 8.1 to 8.6 (see pages 76-81) show noise at frequencies 25 Hz, 100 Hz, 500 Hz, 1 kHz, 2 kHz and 8 kHz respectively as a function of wind speed measured at the Wedge site. The data include significant samples for winds from the E, SE, SW, W and NE. Variations with wind direction appear to be small if significant. It is evident that there is significant wind dependence at all frequencies except 25 Hz and 8 kHz. For wind speeds up to 20 knots, the noise from 500 Hz to 2 kHz varies over a range of 30 dB while at 100 Hz the range is about 20 dB. This is a substantially wider range of variation (at least 10 dB more) than observed in open ocean measurements, and results from the much lower "noise floor" (due to residual background noise) at this site. This would provide a gain in system performance at low wind speeds of 10 to 15 dB over open ocean sites — as much as could be achieved by a very complex array system.

Figures 8.1 to 8.6 also show the substantial variation in system performance that would result for the kind of wind speed variation that can occur over a period of a few hours. Figures 8.7 and 8.8 (p84-85) show just such variation over the course of a day (21 and 23 November, respectively) and may be compared with the wind speeds for the same period in Figs. 5.7 and 5.9. The wide variation is entirely due to variations in wind speed. Figure 8.7 shows the noise rising by about 20 dB over about three hours as the wind rises from almost still conditions to about 14 knots. Figure 8.8 shows the noise falling early in the day and rising later in the day with considerable fluctuation in response to varying wind speed.

At a frequency of 25 Hz (Fig. 8.1) there is little variation with wind speed, in contrast to the wide variation in the open ocean. Noise levels are low

(Text cont'd page 82)

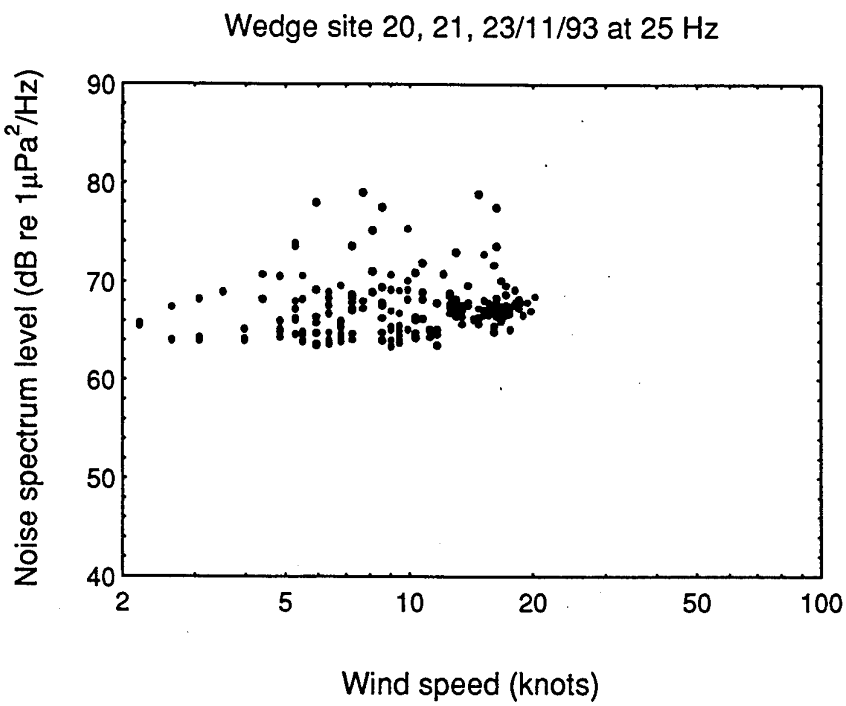


Fig. 8.1. Ambient noise at 25 Hz as a function of wind speed at the Wedge site.

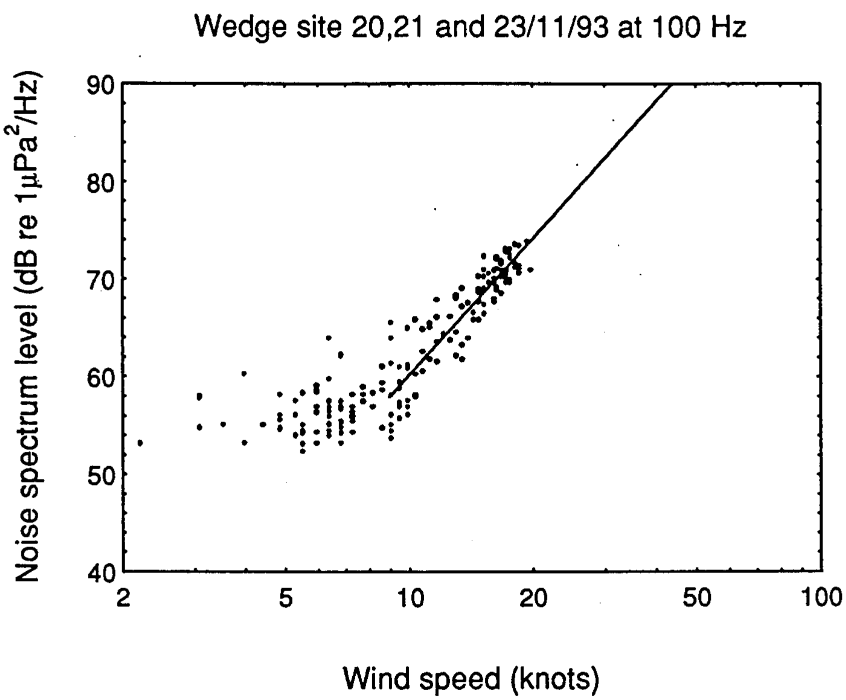


Fig. 8.2. Ambient noise at 100 Hz as a function of wind speed at the Wedge site.

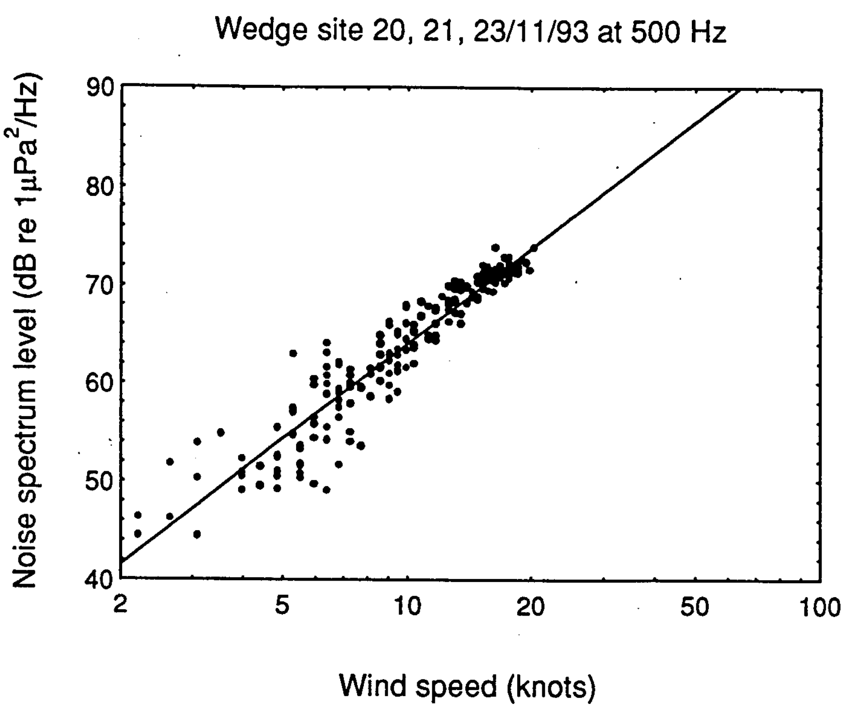


Fig. 8.3 . Ambient noise at 500 Hz as a function of wind speed at the Wedge site.

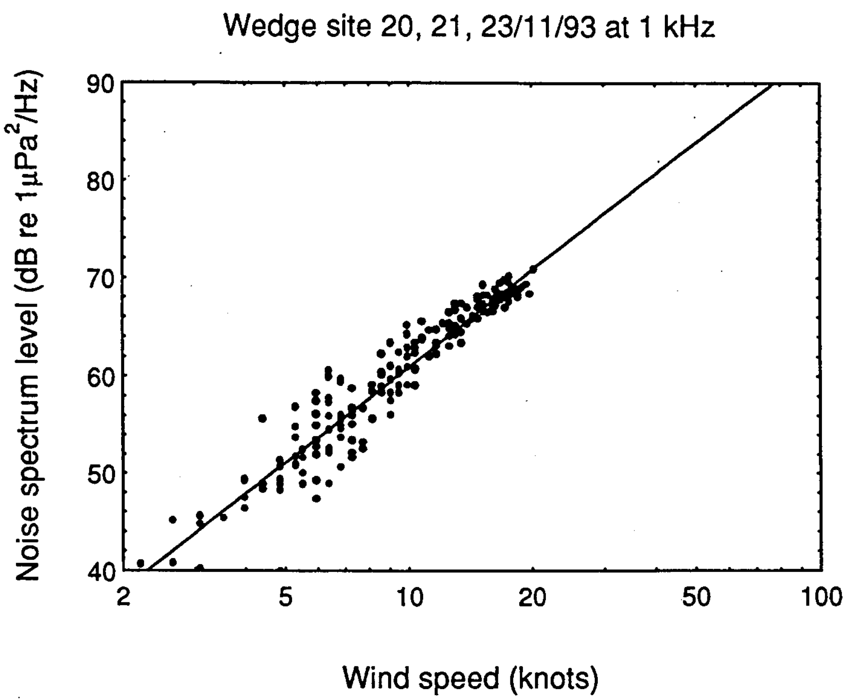


Fig. 8.4. Ambient noise at 1 kHz as a function of wind speed at the Wedge site.

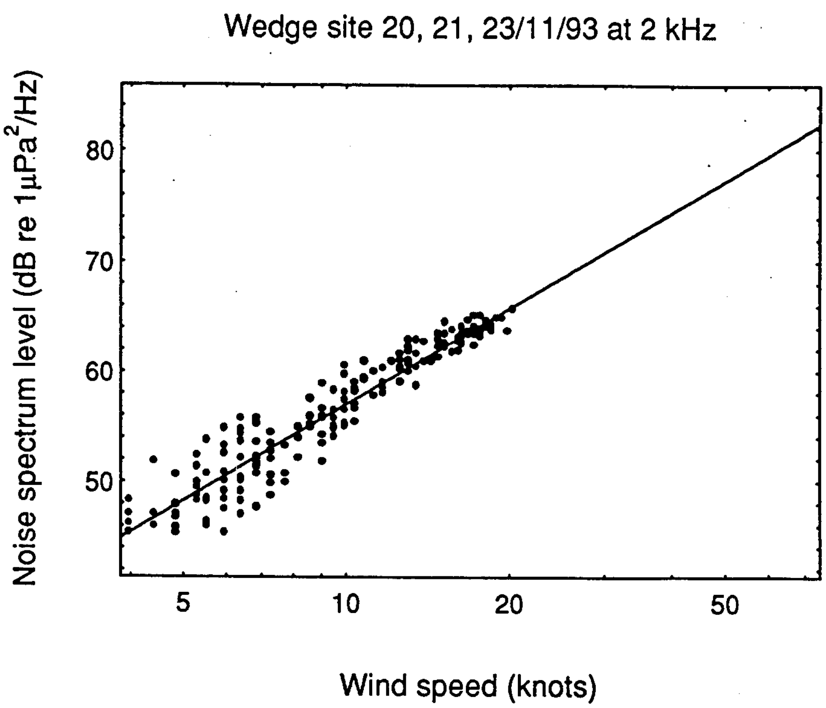


Fig. 8.5 Ambient noise at 2 kHz as a function of wind speed at the Wedge site.

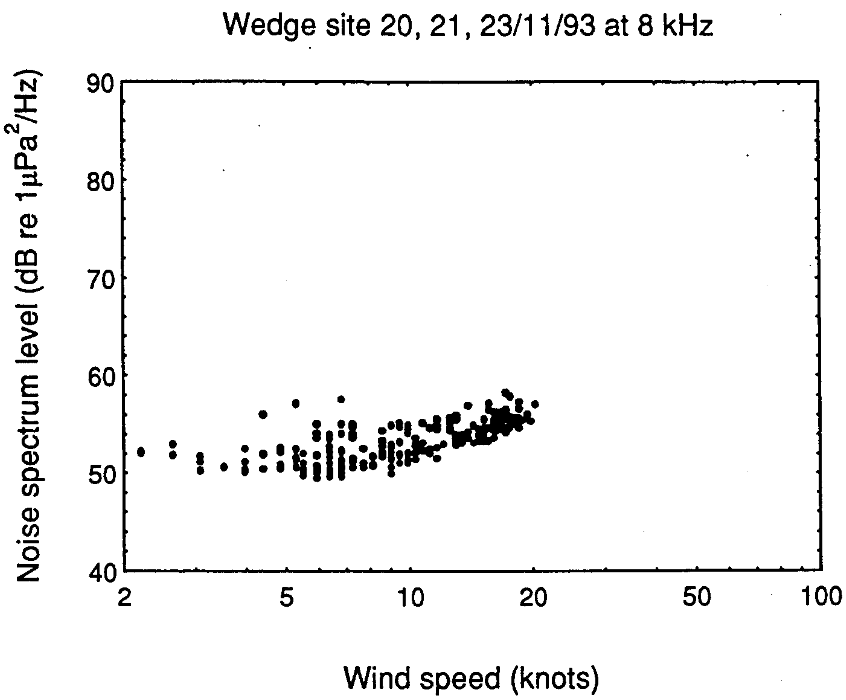


Fig. 8.6. Ambient noise at 8 kHz as a function of wind speed at the Wedge site.

compared to the open ocean. There is thus little wind dependence at this frequency, a result which seems to be a peculiarity of shallow enclosed waters, since similar behaviour has been observed in the few measurements in similar types of waters around Australia. Figures 8.9 and 8.10 (p86-93) show noise as a function of time at 25 Hz and 8 kHz respectively over four consecutive days (20 to 23 November) and little variation in level is evident compared with the wide variation evident at 500 Hz, 1 kHz and 2 kHz. Some of the samples at 25 Hz show higher levels due to noise from ships or movement in the vicinity of the hydrophone, but otherwise, levels are generally less than 65 dB re 1 $\mu Pa^2/Hz$, indicating that non wind dependent noise (presumed to be traffic noise) is very low at this site. The range of traffic noise at this site is 10 to 15 dB less than the range observed off Perth.

At a frequency of 8 kHz (Fig. 8.6) the noise shows little variation with wind speed until the wind exceeds about 10 knots, because it is dominated by the continuous background noise from snapping shrimps. It is only when the wind dependent noise rises above the shrimp noise that it becomes evident. Note that the levels indicated for wind noise are comparable to those observed elsewhere, so the dominance by shrimp noise results because of the high levels of shrimp noise, not low level of wind noise. The shrimp noise is discussed further in Chapter 9, and is to be expected in waters of this depth.

The graphs of noise level as a function of wind speed in Figs. 8.2 to 8.5 also show the regression lines drawn on the data. These were calculated to determine the dependence on wind speed for noise prediction purposes. At 100 Hz, the calculation of the regression line excluded data at low winds speeds where this appeared to show the contribution of non wind dependent noise. The regression line is terminated at the lowest wind speed for which data were included in the calculation.

The regression lines are somewhat steeper, (suggesting that noise rises more rapidly with wind speed) than those calculated for measurements in the open ocean. This results from the much lower non wind dependent noise at this site. In open ocean measurements, higher non wind dependent noise adds to the noise levels measured at low wind speeds, giving higher levels at these wind speeds than would be the case if the noise were predominantly wind dependent. This tends to reduce the slope of the regression lines resulting in an artificially low rate of increase of noise with wind speed. Because of the temporal variability of non wind dependent noise, it is difficult to separate it from the wind dependent noise. Apart from traffic noise, some of this non wind dependent noise may be due to noise at high wind speeds (e.g. storms) generated at considerable distances from the measurement site, where the wind speed is poorly correlated with the local wind speed. It is considered that the relationships measured for noise as a function of wind speed from Spencer Gulf are more accurate than those measured in the open ocean.

The graphs of noise as a function of wind speed in Figs. 8.2 to 8.5 show more spread in the data at low wind speeds than at high wind speeds where the spread is about ± 2 dB. The greater spread at low wind speeds is due to the variable contribution from non wind dependent noise sources.

Figure 8.11 (p96) shows three examples of sea noise spectra at the Wedge site: one for a wind speed of 4 knots (example of quiet conditions in low wind speeds), one for a wind speed of 18 knots (example of high wind speeds) and one demonstrating the choruses (discussed in chapter 9).

The Berry and Thistle sites generally show similar results to those of the Wedge site. There is little wind dependence at 25 Hz and 8 kHz and the wind dependence at 100 Hz, 500 Hz, 1 kHz and 2 kHz is similar to that observed at Wedge. As an example for the Berry site, the wind dependence at 1 kHz is shown in Fig. 8.12 (p97). The regression line on the data is remarkably similar to that for the Wedge site. Figure 8.13 (p98) shows an example for Thistle of noise as a function of wind speed at 1 kHz with the regression line for the Wedge site superimposed to show the similarity.

The main difference in noise level between sites is that Berry tends to be 5 to 10 dB higher than Wedge or Thistle at low to mid frequencies (from about 20 Hz to about 2 kHz). During the measurements, the noise floor at the Berry site was 5 to 10 dB higher between 50 Hz and 1 kHz than at the Wedge site. Because of the clustering of boats around Corny Point (Chapter 7), higher noise levels at low wind speeds could be expected at the Berry site. This could, however, be a seasonal effect.

Non wind dependent noise can be estimated from the graphs of noise as a function of wind speed from the data points at low winds that do not show wind dependence. The results show exceptionally low levels. While such non wind dependent noise at low frequencies in oceanic waters is usually due to distant ship traffic, the levels observed in Spencer Gulf are so low that the noise may comprise a mixture of traffic noise and other distant sources. Mean non wind dependent noise levels in Spencer Gulf are shown in the summary graph of Fig. 10.1 and are about 15 dB less than mean traffic noise levels off Perth. (Text cont'd page 94)

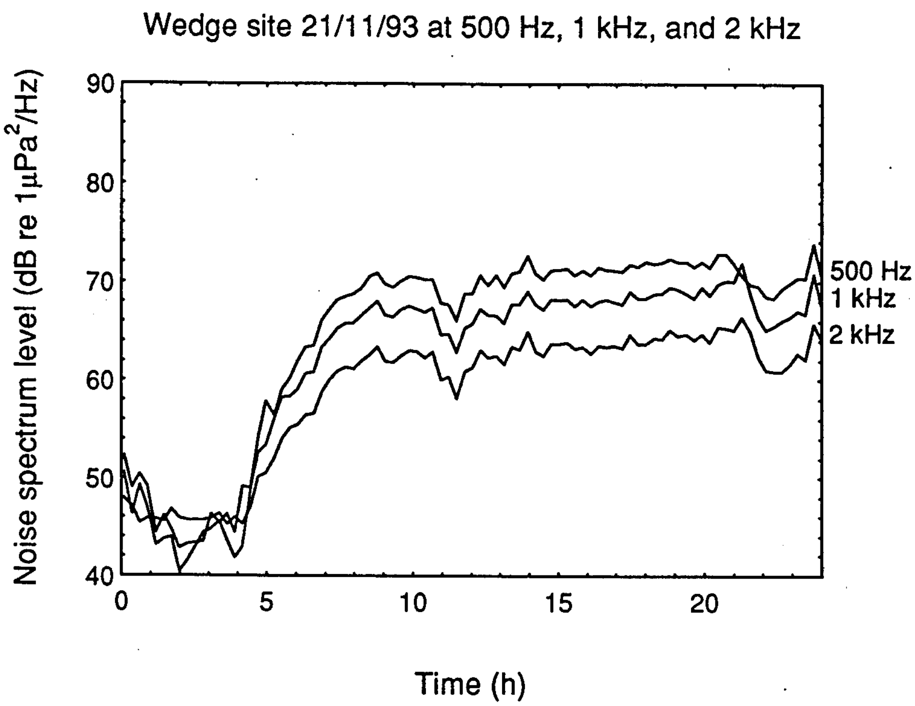


Fig. 8.7. Variation in ambient noise at 500 Hz, 1 kHz and 2 kHz at the Wedge site over the course of a day (21 November) due entirely to variation in wind speeds. The wind (Fig. 5.7) was almost still around 3 am and rose rapidly after 4 am to reach 18 knots later in the day.

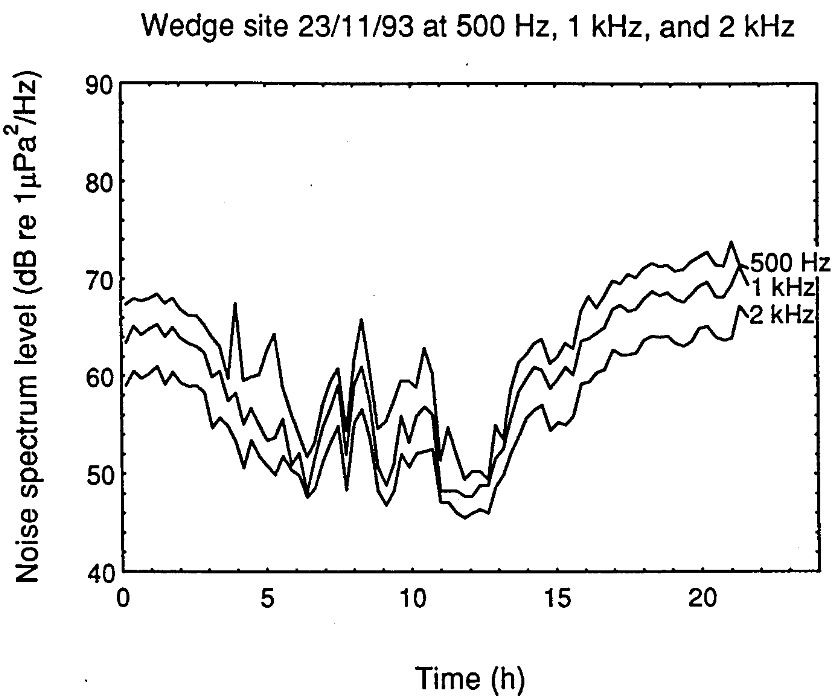


Fig. 8.8 Variation in ambient noise at 500 Hz, 1 kHz and 2 kHz at the Wedge site over the course of a day (23 November) due entirely to variation in wind speeds. The wind (Fig. 5.9) was about 12 knots early in the day, fell during the morning, and rose to about 18 knots in the evening.

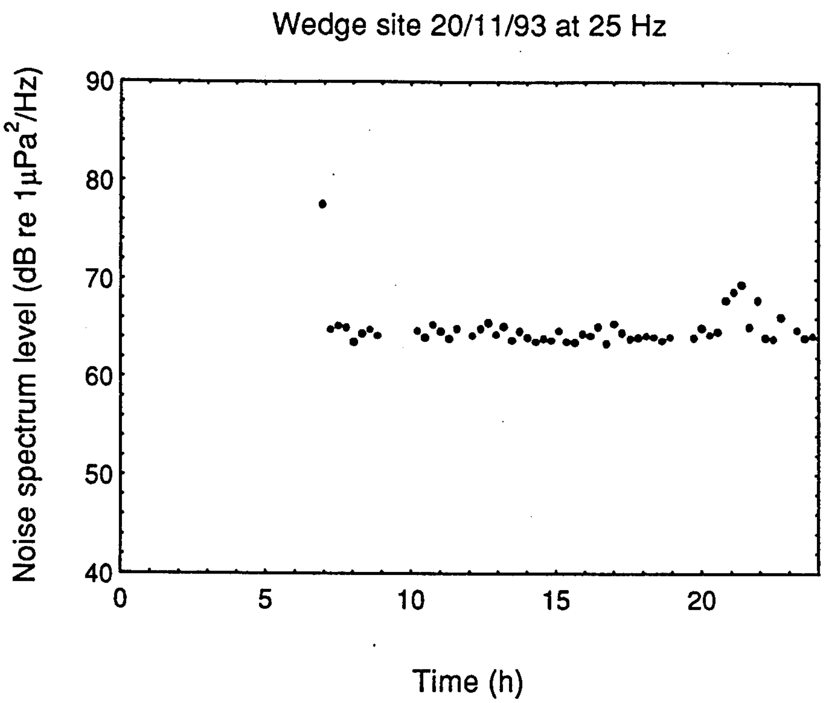


Fig. 8.9(a). Ambient noise as a function of time at 25 Hz at the Wedge site on 20 November 1993

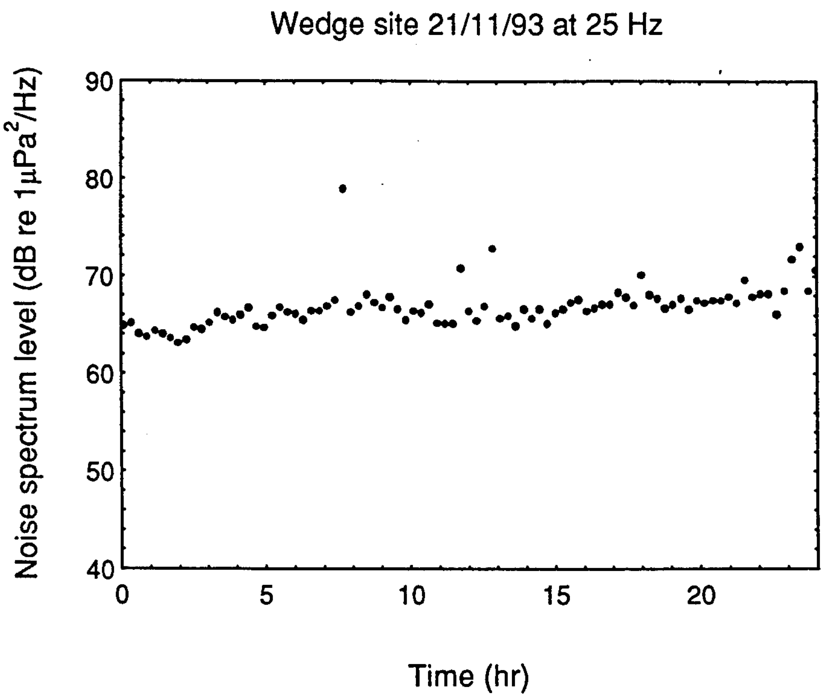


Fig. 8.9(b). Ambient noise as a function of time at 25 Hz at the Wedge site on 21 November 1993

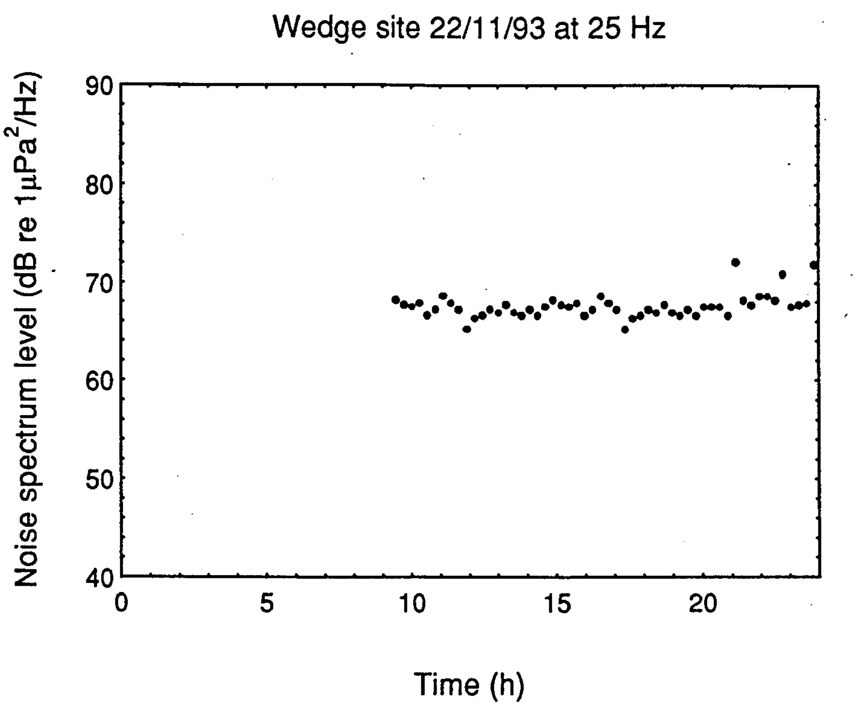


Fig. 8.9(c). Ambient noise as a function of time at 25 Hz at the Wedge site on 22 November 1993

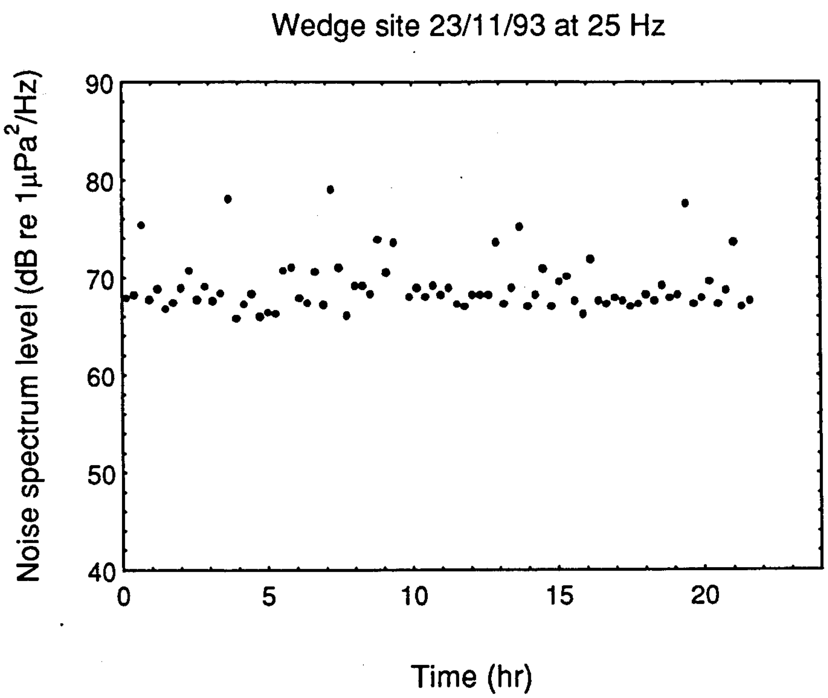


Fig. 8.9(d). Ambient noise as a function of time at 25 Hz at the Wedge site on 23 November 1993

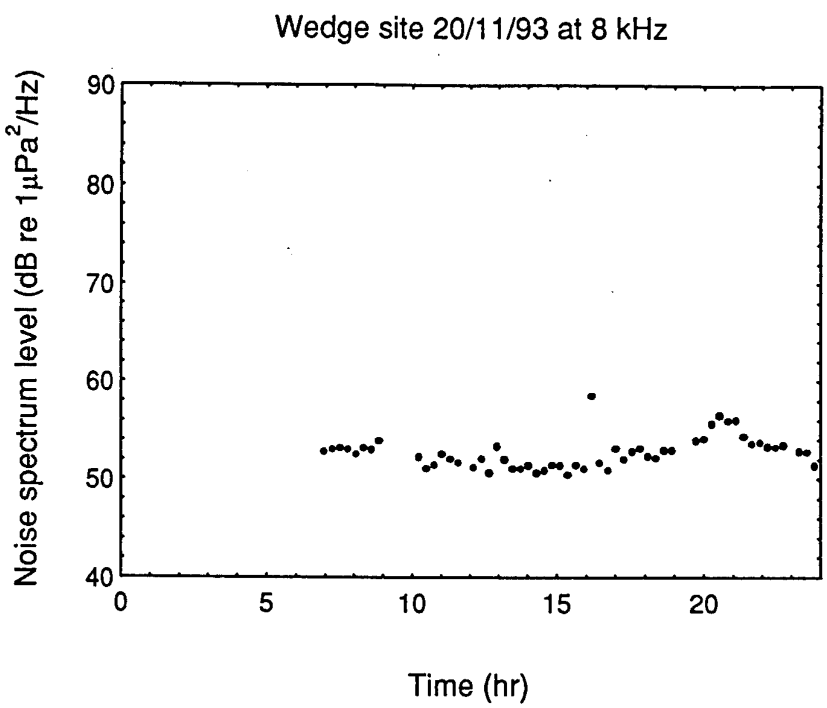


Fig. 8.10(a). Ambient noise as a function of time at 8 kHz at the Wedge site on 20 November 1993

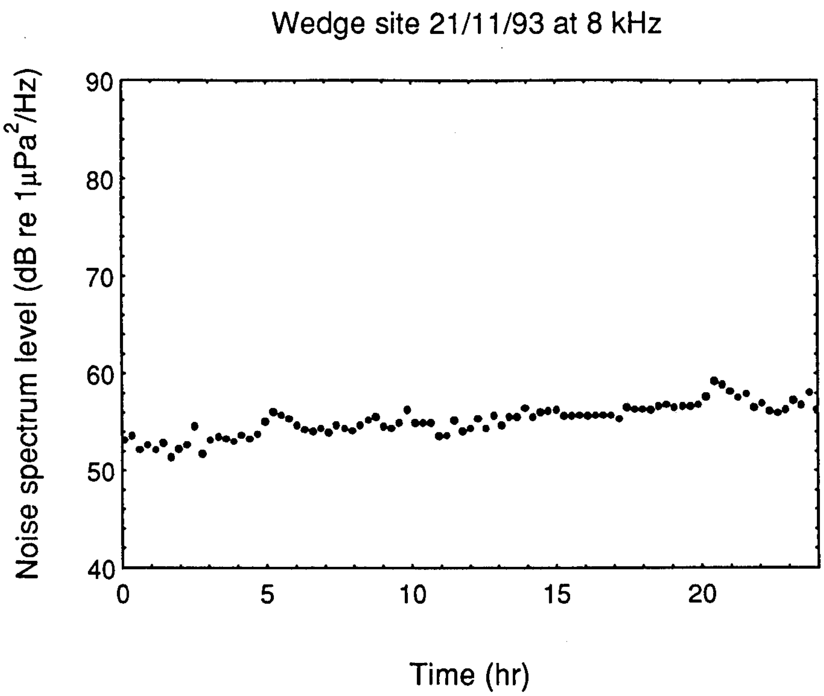


Fig. 8.10(b). Ambient noise as a function of time at 8 kHz at the Wedge site on 21 November 1993

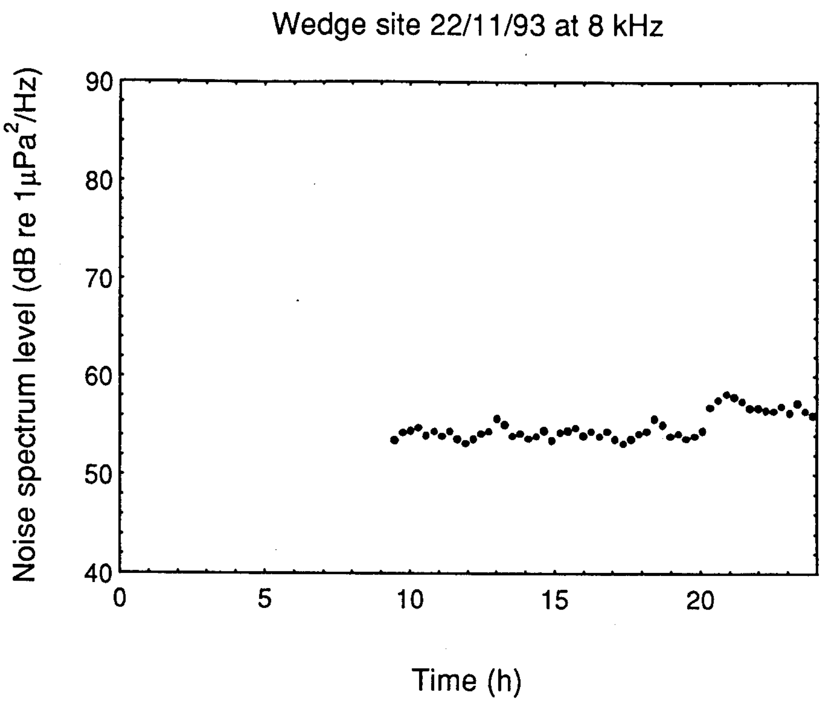


Fig. 8.10(c). Ambient noise as a function of time at 8 kHz at the Wedge site on 22 November 1993

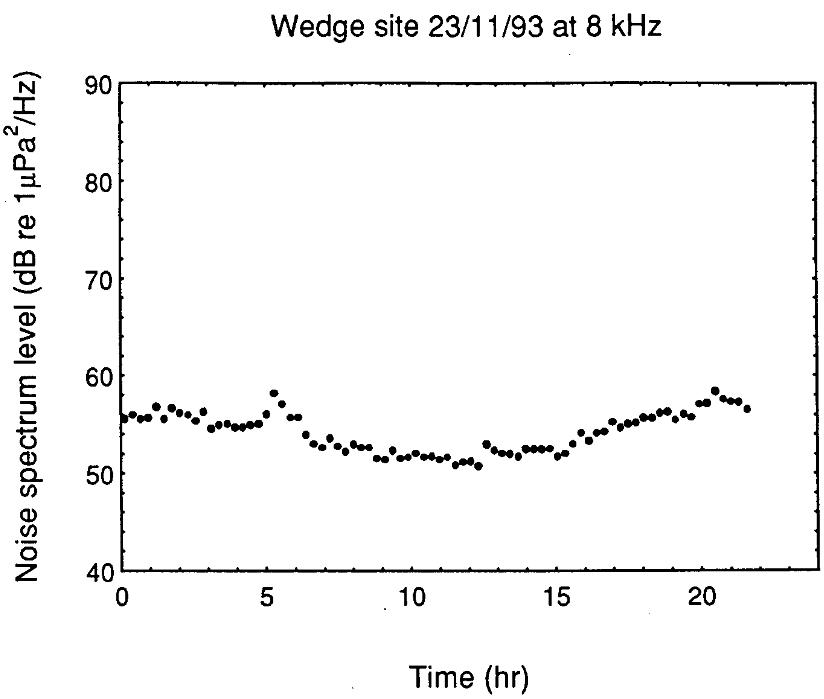


Fig. 8.10(d). Ambient noise as a function of time at 8 kHz at the Wedge site on 23 November 1993

A discussion of shipping movements through Spencer Gulf is given in Chapter 7. On average, 1.4 ships per day pass through the area, in addition to trawlers and fishing boats. Ship or boat noise was audible on the noise recordings for less than 2% of the time, and a ship audible on one noise sample was usually not audible on adjacent samples approximately 15 minutes before and after. With about 96 samples per day this is consistent with an average of 1.4 ships per day. At a speed of 20 knots, a ship would travel about 5 miles between noise samples, hence is not likely to be audible beyond about 5 miles. This suggests that the noise contribution from a ship is significant for much shorter ranges than in deep ocean areas, presumably because of poorer propagation in shallow water. An analysis for the site survey off Perth in 400 m of water *(Jones, Cato, Hamilton, and Scott 1992)* indicated that ships were audible for 20 to 30 miles and approximately 10 ships per day on average passed close enough to the site to be audible. Note that this is a simple comparison based on audibility.

The very low levels of traffic noise in Spencer Gulf compared with open ocean regions such as off Perth are therefore consistent with the small amount of shipping and the distance from the main shipping lanes which are well to the south of the gulf. The shallow water and presence of islands shield the gulf from significant contribution of long range shipping. Local shipping is too infrequent to produce a significant traffic noise background.

Noise from individual vessels passing near a hydrophone in Spencer Gulf could be expected to contribute to the noise for a relatively small proportion of the time.

8.7 Transients

Significant low frequency transient noise was evident at all sites intermittently. This included thumps and dragging sounds of the kind heard when there is motion of the hydrophone on a hard bottom. There were also somewhat metallic "clicks" and "clunks" which later tests on the equipment showed could have been produced by impact of objects with the metal canister containing the hydrophone electronics. The bottom at the sites comprised compacted shell fragments including whole shells, and showed evidence of scouring. The transients were audible at all sites at much the same times for periods of several hours but not synchronised as they would be if from a common source. The times of start and finish of the periods of transients were slightly different at each site and the sounds audible at one site were not correlated with those at another. This indicates that the sources were localised to each site but mechanism was initiated by an effect that was common to all sites and is consistent with movement in the vicinity of the hydrophones resulting from a current field that influenced all sites.

Examination of the current meter records does not reveal an obvious correlation of the occurrence of the transients with the speeds of the tidal currents. There is, however, some evidence of correlation with significant fluctuations in current direction. It is also possible that the generation of the transients is related to a bottom current not correlated with the tidal currents.

This type of bottom mounted recording system has been used at a number of sites around Australia and usually such transients are not observed except on rare occasions. The bottom conditions are usually muddy allowing the system to sink slightly thus securing it to the bottom. The compacted shell grit on the bottom in Spencer Gulf would not allow this and the hydrophones would be more vulnerable to movement.

A system for use in Spencer Gulf needs to be designed to isolate the hydrophones from the mechanical impact noise on the bottom. The precise nature of the causes of these transients needs to be investigated further at the chosen site to provide the information required for this.

An idea of the levels of the transients can be seen in Fig. 8.9 which shows noise as a function of time at 25 Hz . Most of the data points show similar levels throughout the day but there are some points especially on 23/11/93 (Fig. 8.9d) which are up to 10 dB higher. Some of these are due to the transients. The transients may contribute at frequencies up to some hundreds of hertz. (Text cont'd page 99)

EXAMPLES OF NOISE SPECTRA, WEDGE SITE

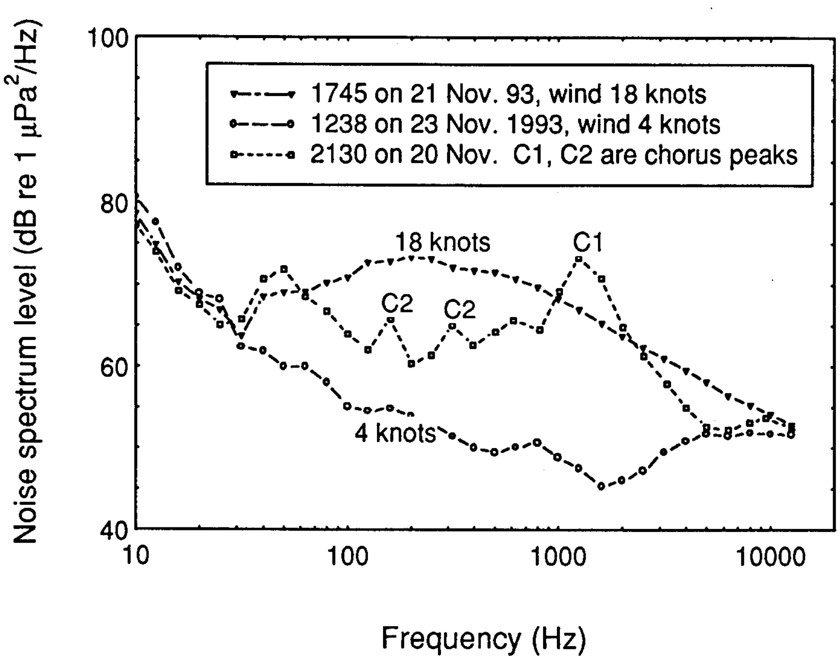


Fig. 8.11. Examples of ambient noise spectra at the Wedge site for high and low wind speeds.

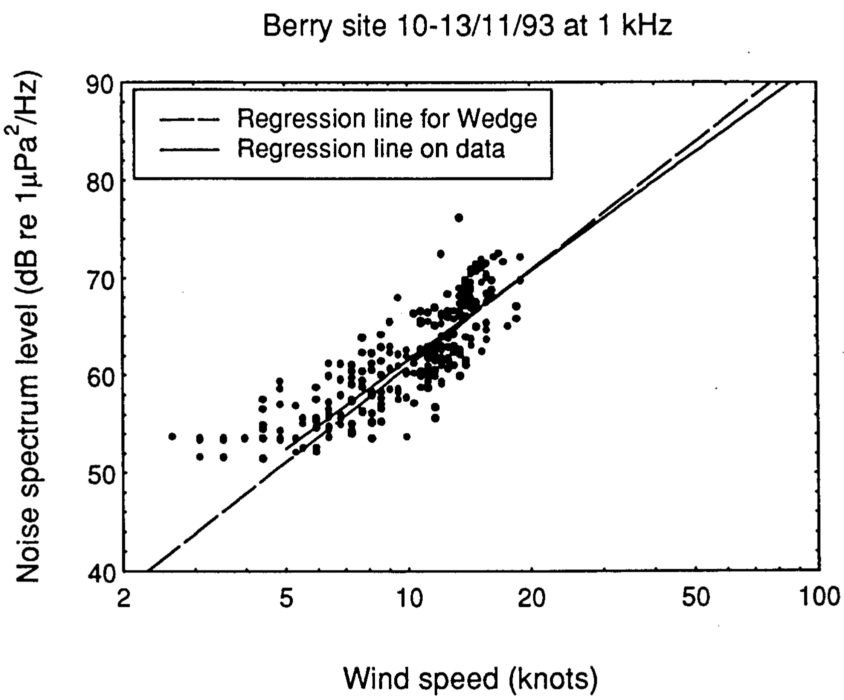


Fig. 8.12. Ambient noise at 1 kHz as a function of wind speed at the Berry site. The regression line on the data and that for Wedge are shown.

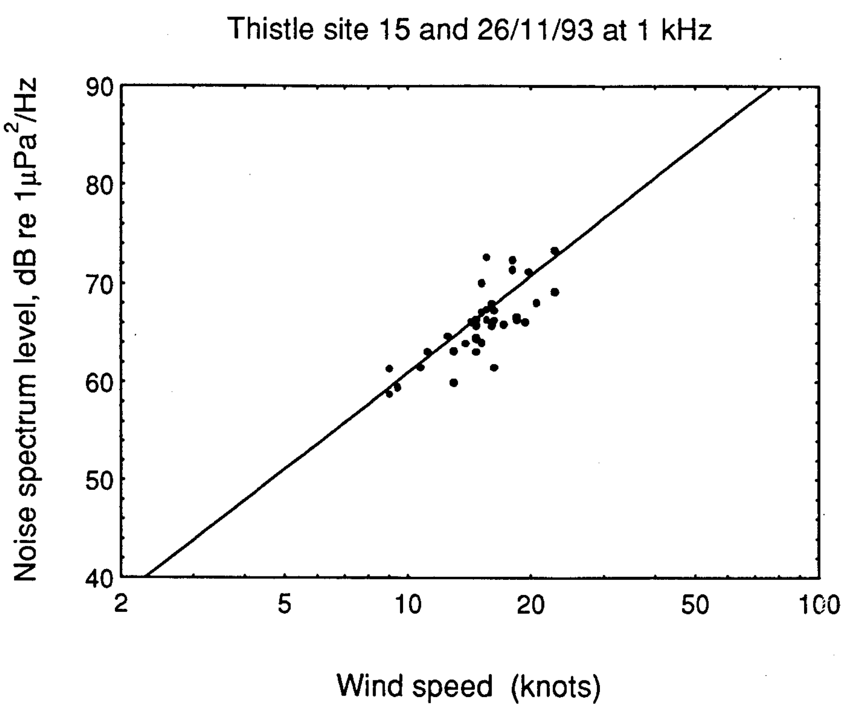


Fig. 8.13. Ambient noise at 1 kHz as a function of wind speed at the Thistle site. The regression line is that for the Wedge site.

9. BIOLOGICAL NOISE

9.1 Introduction

While a wide range of animals produce sounds, not all are important in terms of the contribution to the ambient noise. The most significant contributions are (a) the choruses, which result when large numbers of animals are calling and (b) the intense transients of the higher source level calls. The choruses increase the general background noise levels while the transients are evident as individual signals.

The term *Biological Choruses* is used here to mean the continuous noise (averaging time order of 1 s) produced when large numbers of individuals are producing sounds. So many sounds overlap that the noise level is far higher than that of an individual sound. In some choruses, the individual sounds may still be detectable, while in others they merge together.

Studies of ambient noise around Australia have shown the presence of a wide range of biological noise with substantial contribution to the ambient noise. A full review is given by *Jones, Cato, Hamilton and Scott (1992).*

9.2 Results Of Measurements

The characteristic noise of snapping shrimps was evident at all three sites throughout the period of recording. Snapping shrimps are found in shallow waters (less than about 60 m depth) at latitudes less than about 40° S and so are to be expected at these sites. Further details of the sound production, distribution and habitat are given by *Everest, Young and Johnson (1948)* and *Cato and Bell (1992).* The measured range of the spectra of snapping shrimp noise is shown in Fig. 10.1. An indication of the variation of shrimp noise as a function of time is given by the variation of the noise level at 12.5 kHz over several days at the Wedge site in Fig. 9.1a-d (overleaf). There is a rise in noise level of about 5 dB for about two hours near dawn and dusk, peak levels occurring at about 0530 (half an hour before sunrise) and 2030 (half an hour after sunset). Similar behaviour can been seen at 8 kHz in Fig. 8.10. Comparable levels of shrimp noise were observed at the Thistle site. At the Berry site, levels were about 3 dB higher. The relationships of the peaks to sunrise and sunset suggest that they are triggered by the change in light at dawn and dusk.

Snapping shrimp noise is usually evident throughout the year and shows only small seasonal variation. The shrimp prefer a habitat where bottom
(Text cont'd p104)

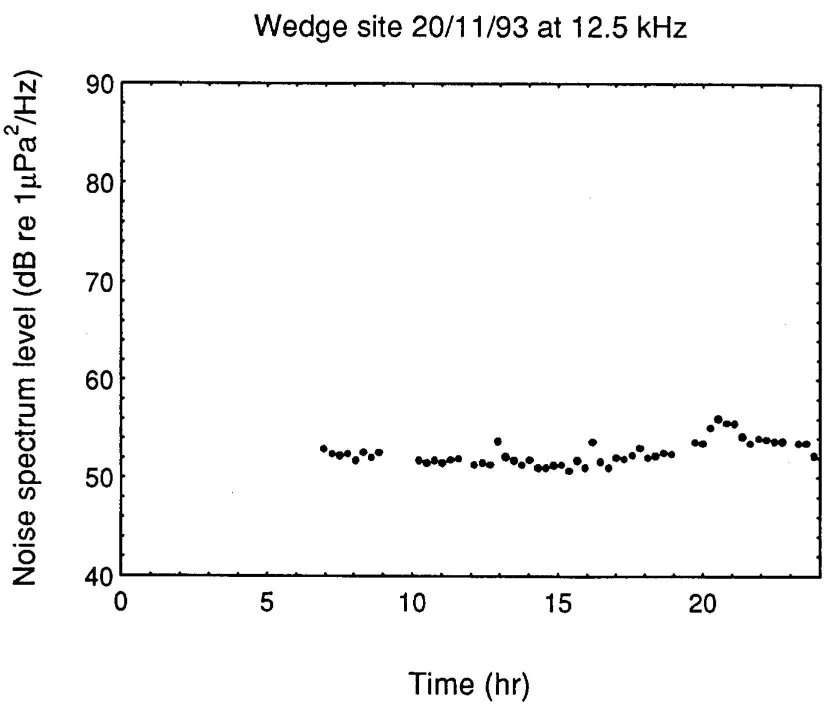


Fig. 9.1(a). Ambient noise as a function of time at 12.5 kHz on 20 November 1993 at the Wedge site showing the variation of shrimp noise.

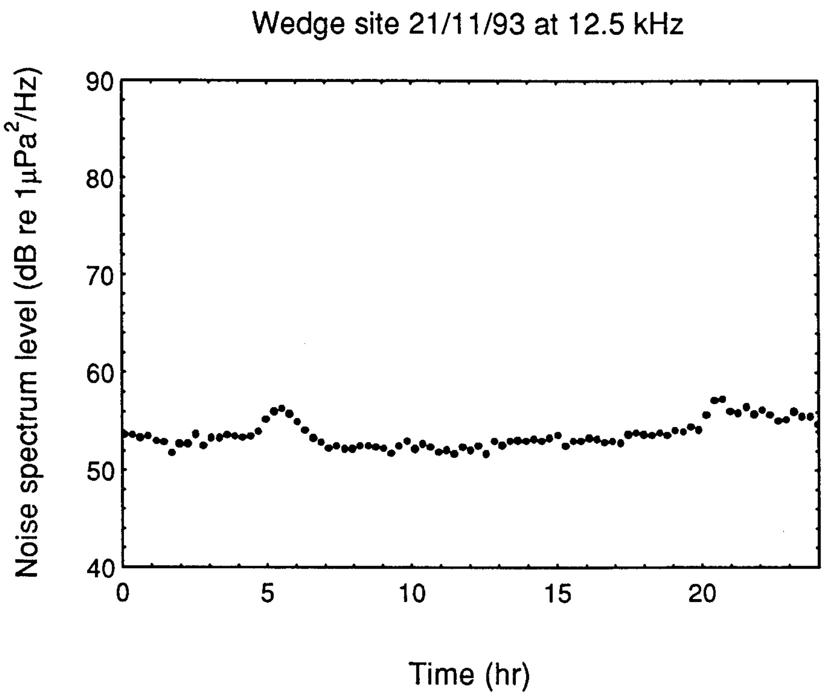


Fig. 9.1(b). Ambient noise as a function of time at 12.5 kHz on 21 November 1993 at the Wedge site showing the variation of shrimp noise.

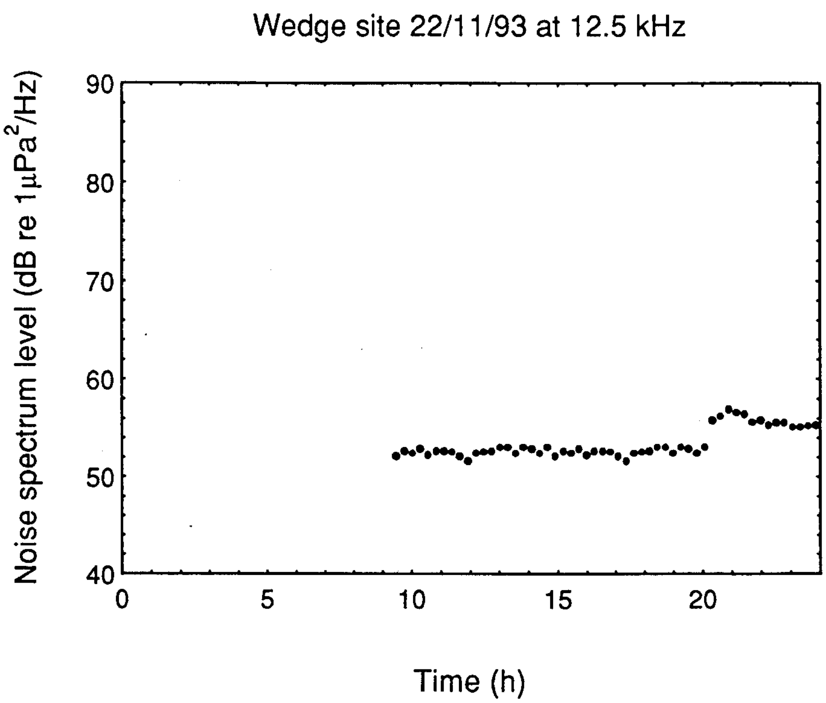


Fig. 9.1(c). Ambient noise as a function of time at 12.5 kHz on 22 November 1993 at the Wedge site showing the variation of shrimp noise.

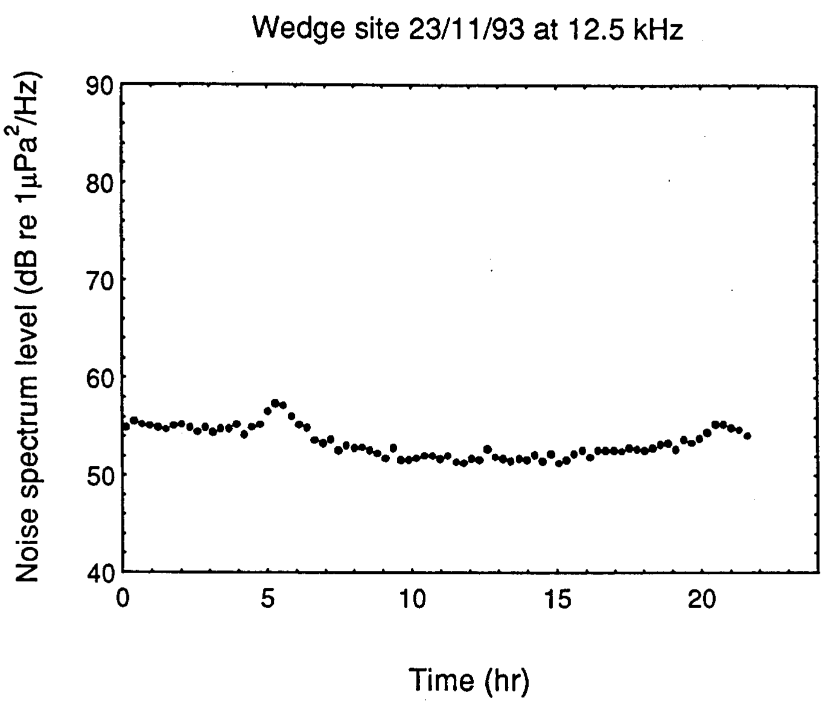


Fig. 9.1(d). Ambient noise as a function of time at 12.5 kHz on 23 November 1993 at the Wedge site showing the variation of shrimp noise.

conditions allow some shelter, e.g. the presence of debris, rocks, shells sponges, etc. Noise levels can vary significantly over short distances (hundreds of metres) where there are significant variations in bottom conditions.

A biological chorus similar to those observed in other waters around Australia was observed on all 15 evenings of recording at the Wedge site but not at the other two sites. Examples of the chorus spectra over several nights are shown in Fig. 9.2. The chorus spectrum peaks in the 1.25 kHz 1/3 octave band and is significant from about 800 Hz to about 2.5 kHz at low wind speeds. At high wind speeds, the wind dependent noise may mask the chorus except near the spectral peak. This is evident in Fig. 9.2 in the spectra on 23 and 26 November, for example, compared with the spectrum measured under low winds on 25 November. The chorus reached its peak at about 2130 each night and was evident for about one hour. The variation in the level of the peak each evening was about 3 dB. The evening chorus is the most common type of chorus observed in waters around Australia *(Cato 1978a)*. Its time of occurrence usually shows only a small variation so is quite predictable.

A chorus of "buzzing" sounds, typical of some sounds produced by fish strumming their swim bladders was heard on occasions at the Wedge site. A sample spectrum of this chorus is shown in Fig. 8.11 and indicated by the notation "C2". Choruses produced by fish using their swim bladders are common in tropical waters near Australia, but little is known of their occurrence in temperate waters. They are usually produced during spawning and are thus seasonal. The seasonal and diurnal dependence varies widely between species and some produce very high noise levels over frequencies in the range 50 Hz to 1 kHz (*McCauley 1989*; and *Cato 1992*). It is quite possible that similar choruses occur in Spencer Gulf at other times of the year and that the observed chorus may be significantly more intense and evident for a longer period of time at some other time of year.

The sonar clicks of dolphins were audible on a number of occasions. These clicks are intense transients with a very broad frequency band. The effect is usually a moderate contribution to the ambient noise for a short period (less than one minute to a few minutes). Several individuals of the so called common dolphin *Delphinus delphis* were seen from the boat during transits to the measurement sites. These are usually found in large schools (up to thousands of individuals) usually off shore. Although the better known bottlenose dolphin *Tursiops truncatus* was not seen during the measurement period, it seems likely that they also inhabit the gulf.

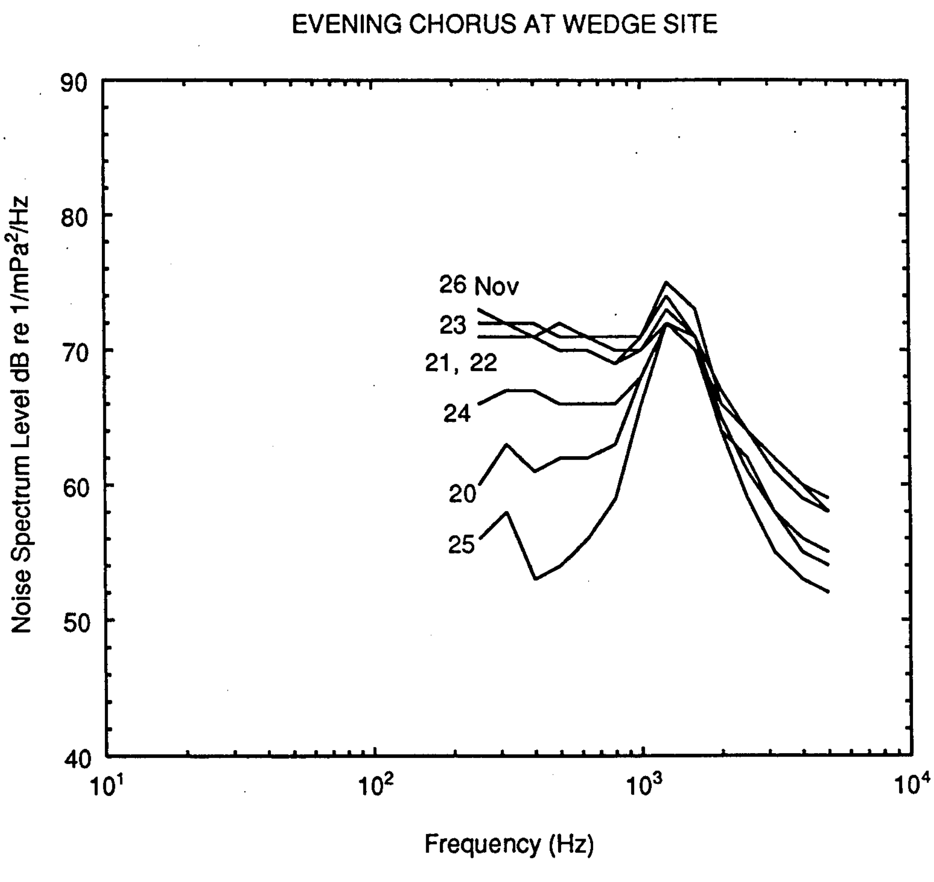


Fig. 9.2 Samples of the evening chorus at the Wedge site on different days at the dates shown.

No whale sounds were observed, however they are likely to be significant at certain times of year. Spencer Gulf is part of the region along the southern coastline that comprises the breeding grounds of the southern right whale, *Balaena glacialis*. There were small whaling stations in the Gulf early last century, but these closed following the substantial reduction in the number of right whales that occurred between 1830 and 1840. Although numbers are still low, there has been a significant increase in recent years, and they are commonly seen close to shore along the southern coastline between Cape Leeuwin and Warrnambool (Victoria) from July to September *(Bannister 1985)*. It is likely that some may enter Spencer Gulf during these months. Right whales produce intense sounds similar to those produced by humpback whales, for example moans and trumpeting sounds, covering a frequency range of about 100 Hz to 10 kHz. The sounds may exceed the background noise for distances of tens of kilometres. In contrast to humpback whales, the right whales produce sounds relatively infrequently. This and their relatively small numbers suggest that they are likely to contribute to the background noise in Spencer Gulf only very occasionally.

The pygmy right whale *Caperea marginata* may also be found in these waters. It is either elusive or rare, being rarely seen, but more than one third of all sightings world wide have been in the southwest corner of Australia. The sounds are intense thumps of about 1/4 second duration with energy extending from 50 Hz to about 300 Hz *(Dawbin and Cato 1992)*. The rarity of sightings suggest that it is unlikely to contribute to the background noise in Spencer Gulf except on rare occasions.

10. OVERVIEW OF AMBIENT NOISE RESULTS

10.1 General summary

Figure 10.1 (overleaf) summarises the components of ambient noise at the Wedge site, which may be taken as indicative of the general characteristics of the Spencer Gulf region. The total noise at any time is determined by summing the intensities of the components (not the decibel values).

In Fig. 10.1, averaged wind dependent noise spectra are shown for wind speeds of 5, 10, and 20 knots. These were determined from plots of noise as a function of wind speeds, as shown in Figs. 8.2 to 8.5, by calculating regression lines on the data. The range of variability about the averages shown in Fig. 10.1 can be seen in these figures. At high wind speeds, this variability is least and about ± 2 dB. It is greater at low wind speeds because of the variable contribution of non wind dependent noise to the data from which the regression lines were calculated.

Wind dependent noise is the dominant and prevailing component of the ambient noise over the mid frequency range. It shows a greater rate of change with wind speed than usually observed in the open ocean, probably because of the much lower levels of non wind dependent noise contribution at lower wind speeds. The shapes of the wind dependent noise spectra are somewhat different to those measured in ocean waters around Australia, which show evidence of two components - one with a broad peak at about 500 Hz and one dominant below about 100 Hz with noise level increasing with decreasing frequency *(Cato 1976 and 1978b)*. The latter component results in high noise levels at low frequencies. In Spencer Gulf this low frequency component appears to be absent or very low, resulting in significantly lower wind dependent noise levels at low frequencies. For example, it is about 15 dB lower at 30 Hz for a wind speed of 20 knots than off Perth *(Jones, Cato, Hamilton and Scott 1992)*.

Non wind dependent noise is the residual background noise from sources such as distant shipping and boats, biological noise, surf noise etc., when other identifiable noise components are absent. It is the dominant component at low frequencies (below 20 to 100 Hz, depending on conditions). Because traffic noise (the noise of distant shipping) is so low in Spencer Gulf it may not dominate the low frequency non wind dependent noise as it does in the open ocean.

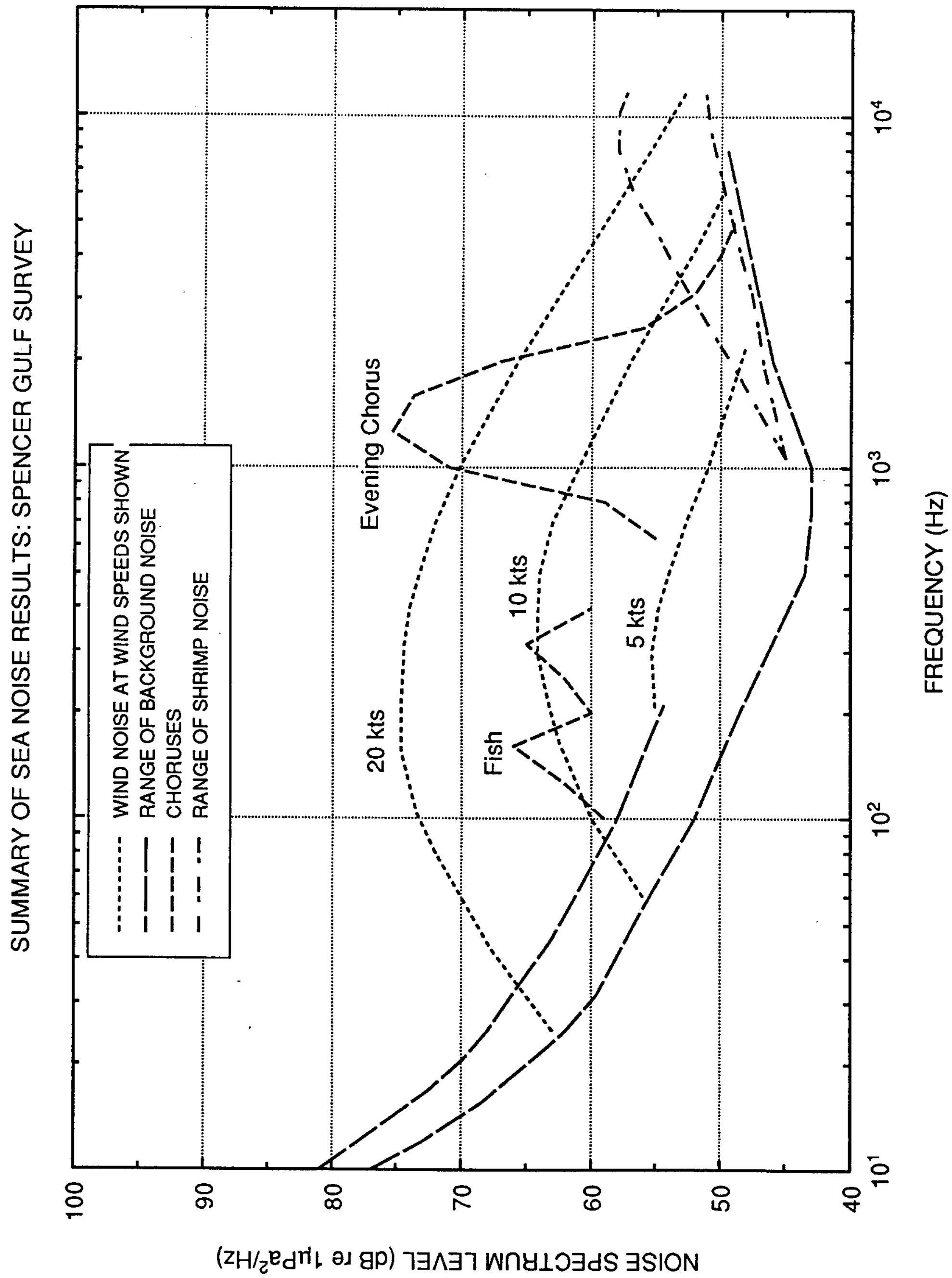


Fig. 10.1 Summary of sea noise results : Spencer Gulf survey.

The noise from snapping shrimps is always present and varies between the levels shown, dominating the ambient noise at frequencies above 2 to 10 kHz. The highest levels are reached only for a short period just before sunrise and just after sunset. Otherwise, the highest levels are about 3 dB lower than those shown.

The evening chorus was observed on all evenings at the Wedge site for about one hour, peaking at about 2130 hours. The peak levels varied from day to day by about 3 dB, the maximum values being shown in Fig. 10.1. Measurements at other sites around Australia show that choruses of this type occur for long periods, in some cases throughout the year. No such chorus was observed at the Thistle or the Berry sites.

The spectral peaks marked "fish" in Fig. 10.1 are indicative of a chorus typical of those produced by fish strumming their swim bladders. Such choruses are usually seasonally dependent since they are related to activities such as spawning. They may occur for weeks and in some cases months at a time at various times of day. Very much higher noise levels have been observed from such choruses in other areas, extending over frequencies from 50 Hz to 1 kHz. The present observations are too limited to give any indication of the likely occurrence of these choruses in Spencer Gulf other than to show that they do occur and it is possible that much higher levels over a broader frequency band may occur at other times of year. Although this chorus was observed at the Wedge site only, there is no reason to expect that such choruses would be confined to Wedge. They should be expected at all sites.

The contributions from passing boats or ships are not included in Fig. 10.1 and can be expected to produce high noise levels. These were, on average, audible on less than 2% of the noise samples, which is consistent with the numbers of ships passing through the area per day.

Significant intermittent noise from transients was evident at low frequencies at certain times. The times of occurrence were similar at all three sites. These are considered to be the result of movement at the bottom in the vicinity of the hydrophones, and caused by impact of bottom debris on the hydrophones and the underwater canister, and possibly movement of the hydrophones themselves. It is possible that some noise results from motion of shells and shell fragments on the bottom. These transients are not considered to be part of the ambient noise but interaction between the recording system and the environment, and so are not included in the summary graph of Fig. 10.1. The possible exception would be sounds generated by the motion of debris on the bottom. The sea floor at the sites appears to be relatively hard comprising compacted shell fragments. The hydrophone system would have been more vulnerable to movement than in many other areas where the bottom is muddy and the system becomes fixed in the mud. The design of a system to record sounds in Spencer Gulf needs to take into consideration the effects of the motion near the bottom, and the nature of the sea floor, adequately isolating the hydrophones. Further investigation of the nature of transient generation at the chosen site is required to provide the information needed to design the system.

10.2 Comparison of sites

The ambient noise at the Thistle site was found to be generally similar to that at Wedge, while Berry was found to be significantly noisier. Wind dependent noise was similar at all sites for the same wind speeds, but while winds speeds were comparable at Thistle and Wedge, there were significant periods of substantially higher wind speeds at Berry (due to sea breezes). Consequently, wind dependent noise can be expected to be higher at Berry than at the other sites for significant periods of time (particularly in the afternoon).

Non wind dependent noise was comparable at Wedge and Thistle but significantly higher at Berry due to clustering of boats around Corny Point, resulting in noise levels at low frequencies being 5 to 10 dB higher. Since this effect depends on boat movements, there may be significant seasonal effects.

Shrimp noise was similar at Wedge and Thistle, but about 3 dB higher at Berry. This difference is too small to be of practical significance. The evening chorus and the fish chorus were observed only at the Wedge site. There is no reason to suppose that fish choruses would be confined to Wedge. They are seasonal and may occur at the other sites at other times of year. The presence of the evening chorus is, however, significant because data from other areas suggest that it is less seasonally dependent. On the data sample available, it is not possible to state the relative occurrence of fish choruses at the sites and all should be considered to be equally likely to show significant choruses at certain times of year. It seems likely that the evening chorus is more prevalent at Wedge but it may also occur at the other sites. The evening chorus is significant for little more than one hour and its timing is very predictable.

10.3 Forecast

The following forecast is made in the absence of rain over the hydrophones which would contribute significant noise at higher frequencies. It also excludes the presence of close shipping since this is relatively infrequent. Since the main variation in noise level in the summary graph of Fig. 10.1 is wind dependent, a forecast of the ambient noise can be made from the wind speed statistics for Neptune Island and the Wedge site (see analysis in Chapter 5). For more than 90% of the time, the noise level will be less than that indicated by the "20 knots" curve in Fig. 10.1. For about 40% of the time it will be less than that shown by the "10 knots" curve, and less than the "5 knots" curve for about 12% of the time. At the Berry site the wind noise would be less than the curves shown for a significantly smaller proportion of time than at the Wedge or Thistle sites.

Shrimp noise can be expected to be in the lower half of the range shown except for about two hours near dawn and again near dusk when it would reach a peak near the highest levels shown.

The evening chorus at Wedge peaked at about 2130 in November. Its timing may be related to the time of dusk, and once established for a particular time of year would be expected to show relatively little variation from evening to evening. It is possible that a similar chorus could be evident at the other sites.

Insufficient is known about fish choruses in the region to predict their occurrence or their acoustical characteristics. It is likely that they occur at all sites at certain times of year, and could produce noise levels up to 15 dB higher than those shown in some part of the frequency band 50 Hz to 1 kHz. These choruses are intrinsically predictable in both their diurnal and seasonal occurrence from measurements made once in the appropriate season.

Dolphin and fish sounds can be expected to contribute to the noise but generally this contribution is covered by the non wind dependent noise. Whale sounds are likely to be significant for a sufficiently small proportion of the time to be negligible.

The Berry site is likely to be significantly noisier than the other two sites over most of the measured frequency band for much of the time.

10.4 Comparison with the ambient noise off Perth

Spencer Gulf is substantially quieter than the region investigated off Perth *(Jones, Cato, Hamilton and Scott 1992)* for a number of reasons. Noise as a function of wind speed is significantly less at low frequencies (less than about 100 Hz) because of the absence of the low frequency wind noise component. At 20 knots the noise at 30 Hz is about 15 dB lower. Winds in Spencer Gulf are on average significantly lower than off Perth. Traffic noise is very low and non wind dependent noise is substantially less than off Perth.

The Gulf wind noise at high frequencies is comparable with Perth up to wind speeds of 10 knots and a few decibels higher at 20 knots. It is difficult to determine if the difference at 20 knots is a real effect or due in part to the uncertainties of determining wind dependence given the spread of the data and the contributions from non wind dependent sources. Part of the difference may be real and due to differences in the acoustical characteristics of the sites. However the substantially greater occurrence of low winds speeds at this site compared to the waters off Perth ensure that, on average, wind dependent noise at high frequencies will be lower. The wind speed is equal to or less than 10 knots for 40% of the time in Spencer Gulf compared with 14% of the time off Perth.

The evening chorus at Wedge is comparable in level to that observed off Perth but about an octave lower in frequency and evident for a shorter period of time.

Whale sounds are likely to be a rare occurrence in Spencer Gulf whereas off Perth humpback whale sounds can be expected to contribute significantly for about four months of the year.

Snapping shrimps are significant in Spencer Gulf but not in deep water sites off Perth (where they would be expected to be of comparable levels in shallow water). This would result in higher levels in Spencer Gulf above 5 kHz compared with the noise for 10 knots wind off Perth.

At the Wedge site, the "noise floor" - the lowest levels of ambient noise measured (ie. very low winds speeds, lowest levels of non wind dependent noise) is 10 to 15 dB less than off Perth for frequencies between 20 Hz and 2 kHz, the greatest difference being at frequencies around 500 Hz. For wind speeds less than 10 knots, the noise at Wedge is from 7 to 20 dB lower at frequencies between 20 and 100 Hz, the variation depending on relative levels of both wind dependent and non wind dependent noise. It is 0 to 15 dB lower between 200 Hz and 5 kHz, the difference increasing as wind speed decreases below 10 knots.

11. ENVIRONMENTAL IMPACT

11.1 Environmental Impact

The (then proposed) Environmental Impact Statement legislation in South Australia requires developers to assess the effects of both direct and indirect factors in their proposals *(Stefanson 1977)*. Spencer Gulf is a shallow, semi-enclosed area subject to stress by industrial activity, particularly at Whyalla, Port Pirie, and Port Augusta, a fishing industry, and increased recreational activity. The Gulf experiences virtually no ingression of fresh water, and depends on oceanographic and meteorological factors for flushing. Seagrass and mangrove communities are believed to be the major productive base for the marine ecosystem.

Stefanson (1977) indicates that few environmental problems are likely to occur in southern Spencer Gulf, because of increased water movements in this area, and the large volumes of water involved, which aid dispersal and removal of pollutants. Seagrasses generally grow abundantly in subtidal waters of less than 10 m *(e.g. Harris et al. 1991)* and are not expected to be found in deeper waters, where light penetration is generally insufficient for photosynthesis.

Right whales come into the shallow waters of the southern coastline to breed from July to September. This species is the most depleted of all in the Australian region and would be considered to be the most vulnerable. Sightings attract considerable publicity. If right whales were to enter Spencer Gulf it would be in small numbers, and in view of the size of the Gulf it seems unlikely that they would be found in the vicinity of an acoustic range and very unlikely when the range is in use. There is no reason to suppose that an acoustic range would have any more impact than any other type of mooring, and ranging operations would have less impact than that of a passing ship.

11.2 Effects of environment on moored instruments

Nunes and Lennon (1986) report that loose strands of seagrass in the shallow depths of the far north of Spencer Gulf occasionally bound the rotors in current meters. Rapid marine growth in the high summer temperatures of 20 to 25° C caused many problems with temperature and current measurement sensors.

Significant low frequency transient noise was evident at all sites intermittently. These included thumps and dragging sounds of the kind heard when there is motion of the hydrophone on a hard bottom. There were also somewhat metallic "clicks" and "clunks" which later tests on the equipment showed could have been produced by impact of objects with the metal canister containing the hydrophone electronics. The bottom at the sites comprised compacted shell fragments including whole shells, and showed evidence of scouring. The transients were audible at all sites at much the same times for periods of several hours but not synchronised as they would be if from a common source. The times of start and finish of the periods of transients were slightly different at each site and the sounds audible at one site were not correlated with those at another. This indicates that the sources were localised to each site but mechanism was initiated by an effect that was common to all sites and is consistent with movement in the vicinity of the hydrophones resulting from a current field that influenced all sites.

Examination of the current meter records does not reveal an obvious correlation of the occurrence of the transients with the speeds of the tidal currents. There is, however, some evidence of correlation with significant fluctuations in current direction. It is also possible that the generation of the transients is related to a bottom current not correlated with the tidal currents.

This type of bottom mounted recording system has been used at a number of sites around Australia and usually such transients are not observed except on rare occasions. The bottom conditions are usually muddy allowing the system to sink slightly thus securing it to the bottom. The compacted shell grit on the bottom in Spencer Gulf would not allow this and the hydrophones would be more vulnerable to movement.

A system for use in Spencer Gulf needs to be designed to isolate the hydrophones from the mechanical impact noise on the bottom. The precise nature of the causes of these transients needs to be investigated further at the chosen site to provide the information required for this.

12 CONCLUSIONS

Spencer Gulf appears to be suitable for a shallow water acoustic range, and to be a substantially better site than off Perth.

The currents are low enough not to cause major difficulties in system design or stability. Currents are predominantly tidal and therefore predictable so that, if required, ranging times can be chosen to coincide with the very low currents that occur for periods up to five days in a fortnightly cycle, and also for other times of low currents. The currents are substantially less than off Perth.

Noise levels at low wind speeds in the Gulf are significantly lower than in the open ocean. For most of the frequency range measured, the noise in Spencer Gulf would be 10 to 15 dB less than off Perth for significant periods of time. At low frequencies the noise levels are much lower because of the absence of significant traffic noise and the low frequency component of wind dependent noise. At mid and high frequencies where the noise is predominantly wind dependent, noise levels are lower for substantial periods because the wind speeds in Spencer Gulf are on average significantly lower. For example, wind speeds are equal to or less than 10 knots for about 40% of the time compared with only 14% of the time off Perth. The effect on system performance from the substantially lower noise levels is comparable to or greater that achievable by a complex hydrophone array system over a single hydrophone.

The main disadvantage of a shallow water site from the noise point of view is the presence of a continual background from snapping shrimps. Above about 5 kHz, noise levels can be expected to be higher than at low wind speeds in the open ocean.

The Thistle and Wedge sites are significantly more suitable than the Berry site in having lower noise levels for a significant proportion of the time, and less variable currents. Boats were observed to cluster around Corny Point causing higher low frequency noise levels at Berry. Wind speeds, and thus wind noise level, are significantly higher at Berry for significant periods of time, usually in the afternoon. The Thistle site did not show evidence of the choruses observed at Wedge, and is more sheltered from swell, but otherwise the two sites are comparable. The differences are not major. The fish choruses are likely to occur at any site, and the evening chorus is predictable and significant only for about one hour per day. Swell at all sites is small compared to the open ocean. The Wedge and Thistle sites are thus recommended in preference to the Berry site off Corny Point. The margin of Thistle over Wedge is sufficiently small that both sites should be considered acceptable in terms of the considerations of this survey.

The noise recordings in Spencer Gulf showed evidence of movement in the vicinity of the hydrophones, causing significant transient noise at times. This is considered to be due to water flow over a relatively hard bottom resulting in motion of debris and possibly the hydrophone. An acoustic range would need to be designed with moorings and hydrophone suspension suitable to isolate the hydrophone. This will need to be based on more detailed information about the nature of the mechanisms causing the transients than is presently available. Further investigation at the chosen site is therefore recommended.

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ANNEX A

Brief Narrative of Site Survey

29/10/93
Current profile measurements at Wedge site and deployment of wave rider buoy (Steedmans)

30/10/93
Continuation of work of 29/10/93.

10/11/93
Deployed noise and wind recording systems at the three sites and a wave rider buoy at the Berry site.

11/11/93
Flights 1 & 2 Port Lincoln-Corny Point-Port Lincoln

12/11/93
Flights 3 & 4 Port Lincoln-Corny Point-Port Lincoln

13/11/93
Flight 5 Port Lincoln-Port Lincoln

15/11/93
Flight 6 Port Lincoln-Port Lincoln

16/11/93
Flight 7 Port Lincoln-Port Lincoln

18/11/93
Recovered noise and wind recording system at Berry site, changed data tapes and redeployed. Deployed current meters at site.
Recovered noise and wind recording system at Wedge site and changed tapes. Deployed current meters.

19/11/93
Redeployed noise and wind systems at Wedge. Recovered wind and noise systems at Thistle, changed tapes and redeployed. Deployed current meters at Thistle.

20/11/93
Flights 8 & 9 Port Lincoln-Corny Point-Port Lincoln

21/11/93
Flight 10 Port Lincoln-Port Lincoln

22/11/93
Flights 11 & 12 Port Lincoln-Corny Point-Port Lincoln
Weather
Lone Pine 11:45 Wind SSE at 12 kts
Port Lincoln 11:00 Wind SSW at 12 kts
Cloudy

23/11/93
Contacted Tony Santic (Santa Rosa) - recovery to be delayed until Saturday
27/11/93
Weather
Lone Pine 5 kts EES. Conditions sunny clear
Port Lincoln 12 To 16 kts East

24/11/93
Flights 13 & 14 Corny Point -Port Lincoln -Corny Point
Unloaded gear from lighthouse and transported to aircraft for transport
Weather
0700 07:00 4 kts southerly
Neptune Island 10 kts ESE

25/11/93
Flights 15 & 16 Port Lincoln -Corny Point -Port Lincoln
Left airport 0600
Boarded G Filmers boat at Corny Point for recovery at 0800
Proceeded to current meter position and recovered at 0900 approx
Recovered sea noise mooring etc at 0920 approx
Recovered wave rider at 10:00 approx
Returned to Corny Point at 1300 after stowing equipment
Returned to Port Lincoln at 1800

Weather Corny Point S/SE at 15 to 20 kts
Dropped off to 5 kts E as day progressed

26/11/93
Weather at Lone Pine
Wind 35 to 40 kts from N/NW Sea flat with considerable whitecaps
Port Lincoln
Wind 40 to 45 kts from North
Bay flat with considerable whitecaps
These conditions continued for rest of daylight hours

27/1/93
Boarded Santa Rosa at 0750 and rigged for recovery (block on boom and deck railing)
Ship rigged new lifting wire

Proceeded to Thistle site and recovered current meter mooring 1300 approx
Recovered Thistle sea noise mooring at 14:00 approx

Proceed to Wedge site and recovered sea noise mooring at 16:15 approx
Recovered Steedmans waverider at 1700 approx
Recovered current meter mooring at 17:45 approx
Stowed gear at sea and returned to Port Lincoln at 22:15
Weather
Wind S/SE at 15 kts
Sea 1 to 1.5 m swell with wind chop

28/11/93
Proceeded to unload Santa Rosa at 0715, commenced unloading at 0800
Using wharfside crane owned by port master
Continued to stow and pack equipment until 16:30

29/11/93
Continued to pack equipment including Steedmans waverider which was transported to fisheries compound in Port Lincoln.

Site Survey for an Ocean Engineering Project in Spencer Gulf November 1993

Ian S.F. Jones, Douglas H. Cato, L.J. Hamilton, Sandra Tavener and B.D. Scott

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ABSTRACT

Environmental surveys were made by DSTO at three sites in Spencer Gulf in South Australia in November 1993 to assess their suitability for an Underwater Radiated Noise Range for the Royal Australian Navy. Acoustic ranges are required to measure the noise radiated from ships and submarines. Salient factors for range design and performance include ambient noise, currents, internal waves, topography and nature of the seafloor, water properties, and wind and weather conditions. Measurements of these parameters indicate that the shallow waters of Spencer Gulf are particularly quiet compared with the open ocean around Australia. Swell is significantly less than in the ocean to the south where it originates, due to attenuation by passage through shallow water, and the sheltering effect of islands at the gulf mouth. Currents are predominantly tidal and thus predictable, with periods of up to 5 days at neaps with speeds less than 0.4 knot. The main disadvantage of the shallow waters is the continual noise background of snapping shrimp. Spencer Gulf appears to be suitable for the placement of a shallow water acoustic range. A Thistle Island site was marginally more suitable than a site near Wedge Island, and both were significantly better than a site near Corny Point.