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On the feasibility of using acoustic techniques to estimate orange roughy and oreo biomass on underwater hills

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1. Executive summary

NIWA, and previously MAF Fisheries, have used acoustic methods to provide abundance indices for spawning stocks of hoki, southern blue whiting, and orange roughy. Data have been collected using a variety of systems, with either a hull mounted transducer or a shallow-tow (down to about 200 m) towbody. These systems work well provided that most of the target fish are not too close to the seabed, in the "shadow" or "dead" zone, where acoustic targets are under-sampled because of the conical acoustic beam.

On underwater hills, where concentrations of orange roughy and oreos are often found, the sloping bottom leads to larger dead zones than on flat terrain. In this paper the feasibility of using acoustic techniques to provide abundance data for orange roughy and oreos on hills is investigated. Two major aspects are considered, the likely dimensions of dead zones on the type of hills where roughy and oreos are found, and whether roughy and oreos aggregate by species on the hills.

Acoustic data collected from the Graveyard complex of hills on the Chatham Rise were analysed to determine average slopes and dead zone dimensions. The estimated slopes of the hills range from 10 to 20°, typically being about 15°. With the shallow-tow system these slopes gave an average dead zone height at the centre of the beam of 7–24 m (18–52 m, at the edge of the beam). If a deep-tow system were used, the corresponding average dead zone heights would be about 2–6 m (at the centre) and 4–12 m (at the edge).

Anecdotal data, based on fishing experience, suggest that oreos tend to concentrate near the top of hills and that orange roughy tend to be found on the sides. An analysis of trawl survey data from the Chatham Rise gives a little support to this hypothesis. Trawls on hills were aimed to start at the top and go all the way down the side, but a low to moderate percentage of trawls do not land on the top. The data show some weak trends, including a larger proportion of orange roughy in the trawls that missed the top, and a larger proportion of smooth oreos in the trawls that hit the top.

It appears likely that the use of a deep-tow acoustic system on underwater hills will, in the future, be able to provide reliable abundance indices for orange roughy and oreos. The greatest challenge to the method will be on hills where there is low abundance and a lack of distinct marks. On hills where spawning plumes of orange roughy occur, precise absolute estimates of abundance should be achievable.

2. Introduction

Acoustic methods have developed during the last two decades and now routinely provide quantitative fish stock abundance estimates (Burczynski 1979, Simmonds & MacLennan 1996). At NIWA, and previously at MAF Fisheries, acoustic surveys have been made of spawning stocks of hoki, southern blue whiting, and orange roughy (Do & Coombs 1989, Hanchet *et al.* 1994, Coombs & Cordue 1995). A variety of acoustic systems have been used with hull-mounted transducers and shallow-tow towbodies. For deepwater species, which aggregate on underwater hills with tops anywhere from 600 to 1200 m below the surface, there are some problems in using acoustic methods which rely on hull-mounted or shallow-tow systems.

The main problem is that the slopes of hills at ranges of 500 m or more lead to large "shadow" or "dead" zones, where fish are under-sampled by the acoustic beam. The under-sampling can be compensated for by extrapolating observed fish densities into an estimated dead zone volume (Elliot & Kloser 1993, Ona & Mitson 1995), but this could produce large errors in abundance estimates. It is far better to reduce the dead zone as much as possible by using a deep-tow system (to get physically closer to the seabed), and if necessary correcting for the remaining dead zone (Kloser 1996).

In this paper, equations for the vertical dimensions of the dead zone are determined for an idealised beam shape. Acoustic data collected on a 1995 survey of the graveyard hills (TAN9509) are then analysed to estimate average dead zone heights on the hills when either a shallow-tow or deep-tow system is used.

The problem of species identification is also addressed. Data from three random trawl surveys of Chatham Rise hills (TAN9210, TAN9309, TAN9406) are analysed to see if they support the hypothesis that oreos and orange roughy aggregate by species on the hills.

3. Methods

3.1 Dead zone

A vertical, single beam echosounder has a downwards pointing transducer that generates a conical beam. (A real beam is only approximately conical, it has a strong central beam, and a number of weaker side lobes; a real beam is normally approximated with a single conical beam, *see* Burczynski (1979).) The apex of the cone is at the transducer and a spherical front travels from the transducer towards the seabed (Figure 1). If the seabed has a constant slope (β), then the dimensions of the dead zone can be derived using standard trigonometry (the formulae are given in Appendix 1). Some of these equations can be found in Do & Coombs (1989), but they concerned themselves only with the measurement D and the case where $\beta < \theta/2$ (where θ is the idealised beam angle).

Acoustic data from a survey of the Graveyard complex of hills were analysed to determine average hill slopes and dead zone dimensions. Bottom definition was done on transects in the usual manner (Cordue 1990) and the bottom ranges (for each ping or transmit) were exported to S (Becker *et al.* 1988). The bottom ranges were smoothed (using the S smooth function) and then for each pair of successive pings the slope of the bottom was estimated by:

$$\beta_i = \sin^{-1}\left[\frac{R_{i+1} - R_i}{d}\right]$$

where R_i is the range of the bottom on the ith ping, and d is the distance travelled between successive pings (a constant speed is assumed). For each pair of successive pings on each transect, the estimated bottom slopes and the given ranges were input into the formulae of Appendix 1 to calculate profiles of dead zone measurements. Estimated slopes greater than 45° were excluded because such angles are unrealistically large. For each transect, the profiles were delineated by eye, and the dead zone dimensions were averaged across the extent of the hill. A beam angle of 7° was used in the formulae (this is the effective beam angle of the transducer used during the survey).

3.2 Trawl survey data

The working hypothesis held by most experienced research staff is that oreos tend to be found near the top of hills and that orange roughy tend to be down the sides. The limited targeted trawling that has been done on research surveys tends to support this view, but the data are qualitative and not conclusive. To test the working hypothesis, trawl data and acoustic data collected from numerous Chatham Rise hills were collated. The hills surveyed and the estimated depths of their tops are given in Tables 1 and 2. The tops were estimated mainly from echograms collected during the trawl surveys (some data from the acoustic survey were also used).

The trawl survey data were analysed by extracting, for each trawl, the start and finish depths, the total catch, and the catches of orange roughy, smooth oreo, and black oreo. For total catches of at least 1 t, catches and proportions of orange roughy, black oreo, and smooth oreo in the catch were plotted against the mean depth of the trawls and the ratio of the starting depth to the depth at the top of the hill (the ratio being a measure of how far down the hill the trawl started).

4. Results and Discussion

Estimated bottom slopes for "flat" terrain, in orange roughy depths, from the shallow-tow system on the Chatham Rise, ranged from 0 to 4° (Figures 2 and 3). The corresponding estimates of dead zone height at the centre of the beam were 0–1.5 m (Figures 2 and 3). Typical profiles for a hill are shown in Figures 4 and 5. The hills appear to be far from constant in slope, having various bumps that often generate slopes of 10–30°, giving dead zone heights (at the beam centre) of up to about 30 m.

The average slopes on the graveyard hills were between 10 and 20°, typically being about 15° (Figure 6). With the shallow-tow system the average dead zone height at beam centre was typically 10–20 m (Figure 6), and at beam edge 20–40 m (Figure 7). A deep-tow system which could get down to within 100–300 m would reduce the dead zone height at beam centre to 2–6 m (Figure 8), and at beam edge to 4–12 m (Figure 9).

Orange roughy plume up during the spawning season, producing marks that can extend up to 100 m above the bottom: plumes 30–50 m high are perhaps more typical. A shallow-tow system could miss a large proportion of the biomass of such plumes if they occurred on a sloping bottom, particularly if they tended to be denser nearer the seabed. With a deep-tow system, the bias introduced by the dead zone is enormously reduced.

There has been limited experience of acoustically surveying orange roughy on hills, but some Australian surveys have been done, both with a hull-mounted system (Elliot & Kloser 1993) and a deep-tow system (Kloser 1996). Acoustic results have also been compared with an egg survey estimate; the point estimates were of a similar size, but both had large uncertainties associated with them (Koslow *et al.* 1995). That the two estimates were in the same "ball-park" is nevertheless encouraging for both methods.

The biomass of large spawning plumes of orange roughy can be reasonably accurately estimated using a deep-tow acoustic system (provided that a good target strength estimate is available). If necessary, a correction can be made for the small proportion of fish that are under-sampled in the dead zone. However, for hills that contain a mixture of species it is not conclusively known if oreos school separately from the orange roughy.

Most experienced scientific staff believe that there is some structure in the acoustic marks found on deepwater hills. The hypothesis considered in this paper is that oreos tend to produce marks near the tops of hills and that orange roughy tend to produce marks down the sides. The trawl survey data show only weak trends, but these trends lend the working hypothesis some support.

There is a slight increase in total catch, and the individual catches of orange roughy and oreos with increasing depth (Figure 10). Catches of all three species tended to be higher if the trawl landed near the top of the hill, but some large roughy catches were taken when the trawl landed well down the side of the hill (Figure 11). There were large variations in the proportions of the three species in the catches, ranging from 0–1 for roughy and smooth oreos. Black oreos only once made up most of the catch and normally never exceeded more than 60% (Figure 12). On average, trawls that landed near the top of the hill caught a greater proportion of smooth oreo and a lesser proportion of roughy (*see* the trend lines in Figure 13). The trends, although weak, are entirely consistent with the working hypothesis.

There have been no quantitative acoustic surveys of oreos on hills. Further data need to be collected to establish how structured the marks are, looking particularly at whether black and smooth oreos form separate marks.

5. Acknowledgments

Thanks to Di Tracey, Peter McMillan, and Alan Hart for help with data on the tops of hills, to Gavin Macaulay for trigonometric discussions, and to Sam McClatchie for a constructive review.

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Table 1: Hills surveyed on voyage TAN9406 which were used in the analysis of species composition. The name, or stratum name for unnamed hills, is given with the depth (m) of the top of the hill (SW = southwest, SE = south east, Char. Horse = Charlie Horsecock, Not til Sun. = Not til Sunday).

Name	Top	Name	Top	Name	Top
Jimmy	755	Fletchers	915	Condoms	860
Rachael	770	Trevs Pinni	880	Char. Horse	925
Possum Saddle	835	Mt. Nelson	830	Cotopaxi	935
Dickies	640	Hegerville	645	Mangrove	980
Sir Michael	880	Nielson	650	Big Chief	740
Diamond Head	605	Der Spriggs	635	Flintstones	810
Aloha	775	Paranoias	775	Lucky	955
No. 2557	555	SE28	540	Tomahawk	990
Mt. Sally	810	Featherlite	950	Teepee	985
SW06	635	Deadringer	815	Not til Sun.	740
SW07	735	Graveyard	750	Harrisville	630
SW09	890	Morgue	895	Smiths City	895
SW12	585	Mummy	1035	Camerons	780
SW13	605	Crypt	1145	Erebus	980
SW59	655	Zombie	890	Possum East	720
SW61	815				

Table 2: Hills surveyed on voyages TAN9210 and TAN9309 which were used in the analysis of species composition. The name is given with the depth (m) of the top of the hill (Char. Horse = Charlie Horsecock).

Name	Top	Name	Top	Name	Top
Condoms	860	Trevs Pinni	880	Char. Horse	925
Possum East	720	Mangrove	830	Cotopaxi	935

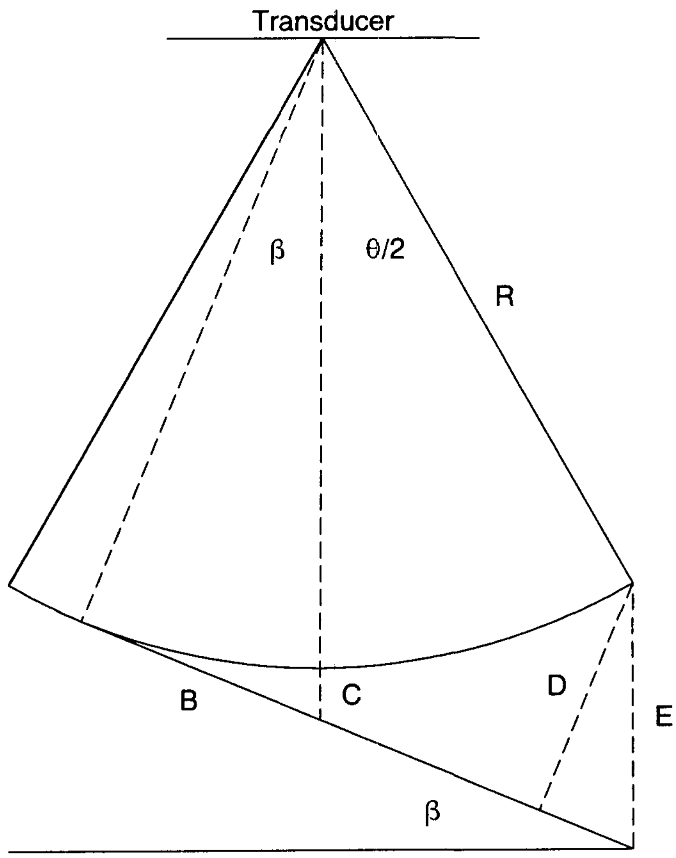

Figure 1: Diagram showing the definition of B, C, D, and E for an idealised beam (beam angle θ) and a sloping bottom (range R, angle β). The case where $\beta < \theta/2$ is shown.

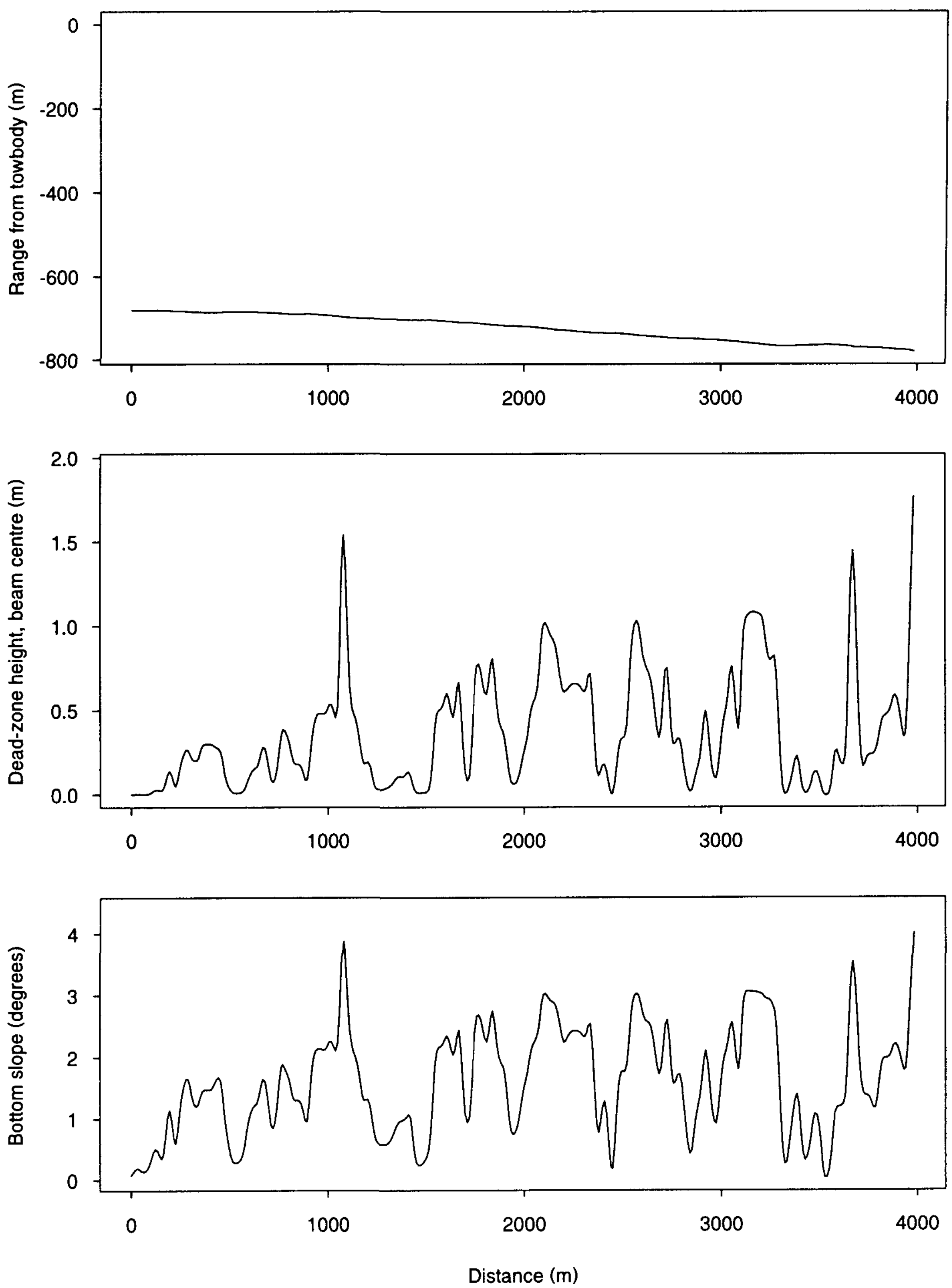

Figure 2: Smoothed plots for an acoustic transect recorded on the "flat": the estimated range of the bottom from the transducer; the dead zone height; and the bottom slope.

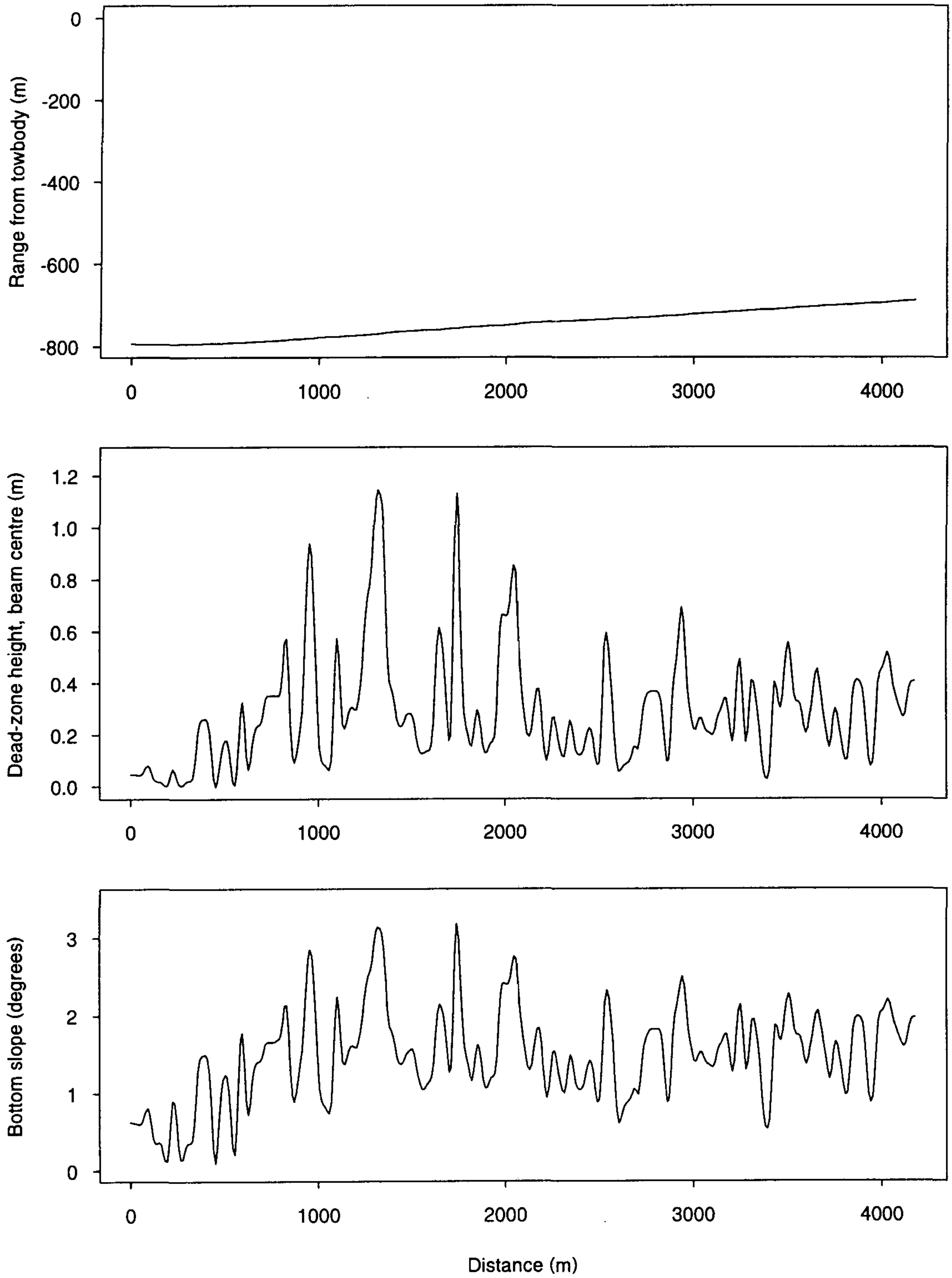

Figure 3: Smoothed plots for an acoustic transect recorded on the "flat": the estimated range of the bottom from the transducer; the dead zone height; and the bottom slope.

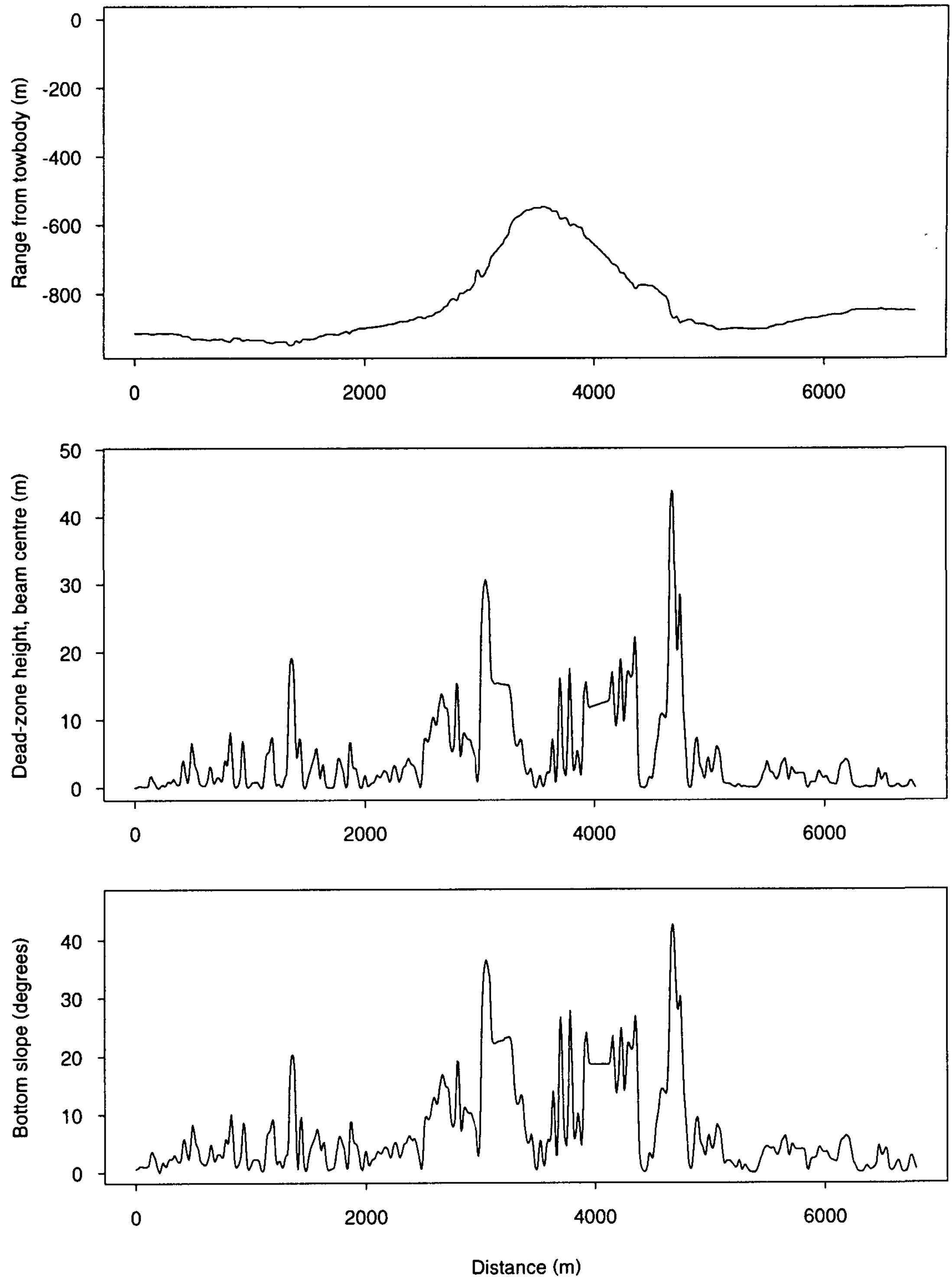

Figure 4: Smoothed plots for an acoustic transect recorded on the graveyard: the estimated range of the bottom from the transducer; the dead zone height; and the bottom slope.

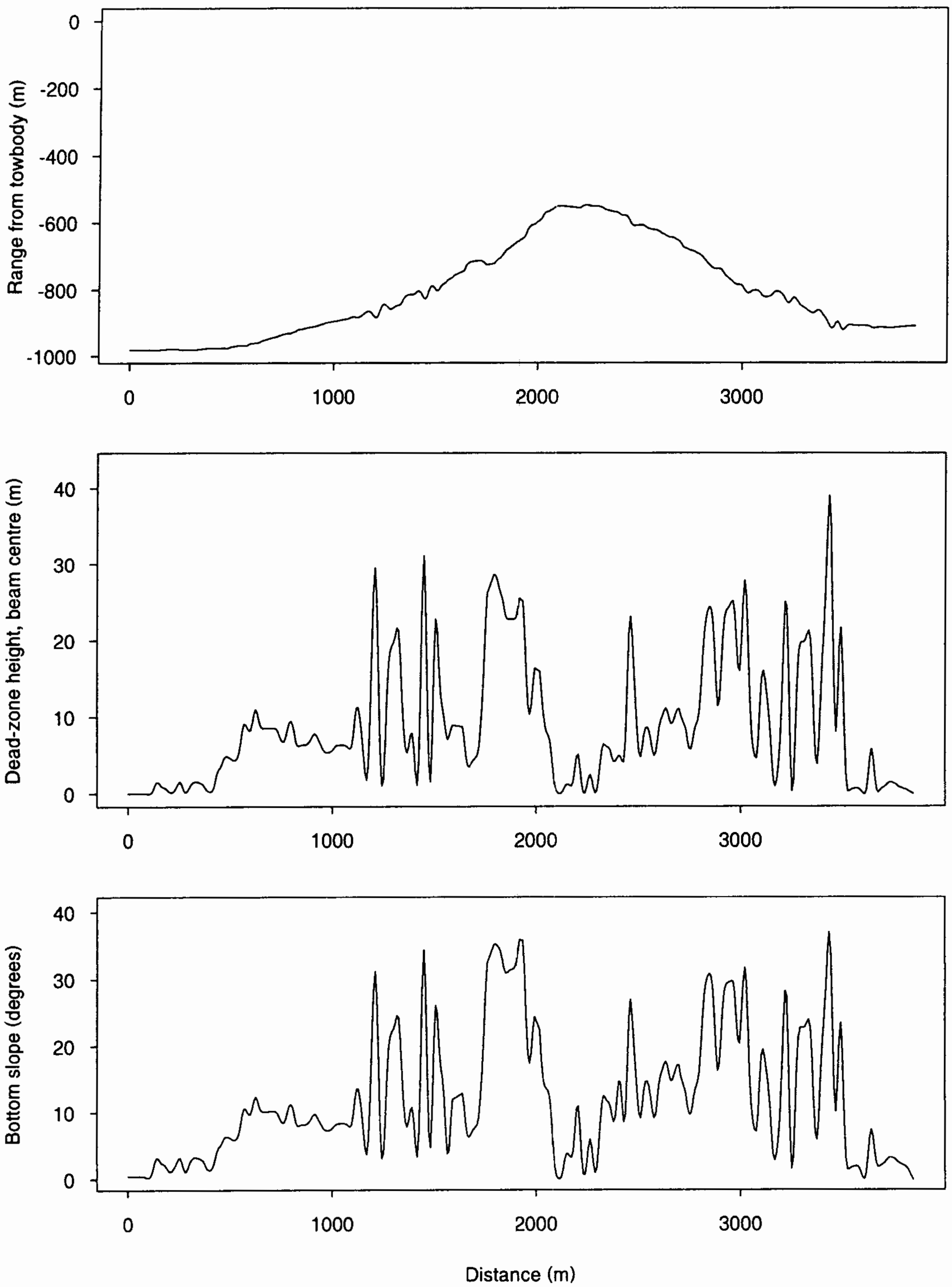

Figure 5: Smoothed plots for an acoustic transect recorded on the graveyard: the estimated range of the bottom from the transducer; the dead zone height; and the bottom slope.

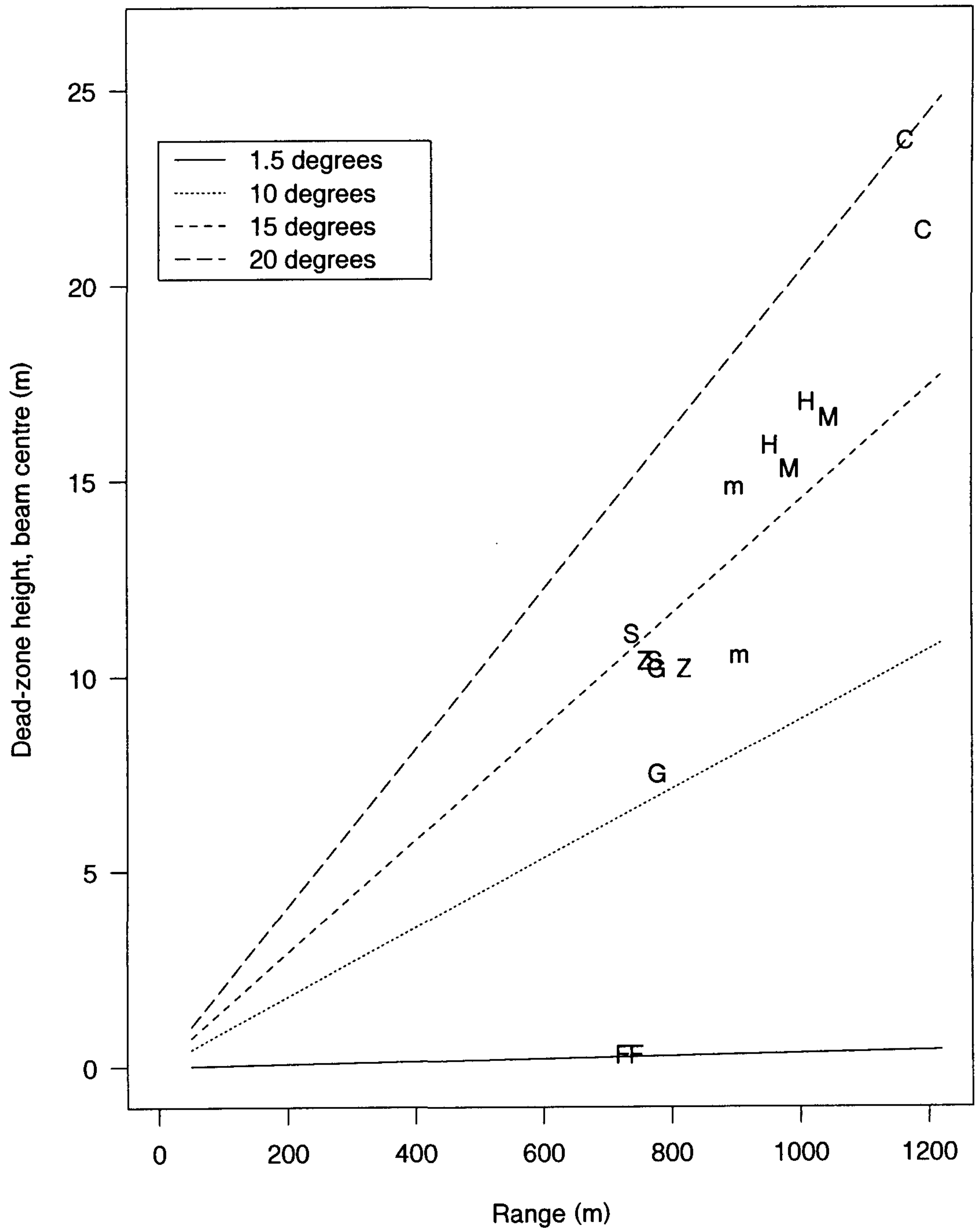

Figure 6 Estimated average dead zone height (centre) for acoustic transects on the "flat" (F) and on the hills (C = Crypt, G = Graveyard, H = Headstone, m = Morgue, M = Mummy, S = Scroll, Z = Zombie), with reference lines for average bottom slopes from 1.5 to 20°.

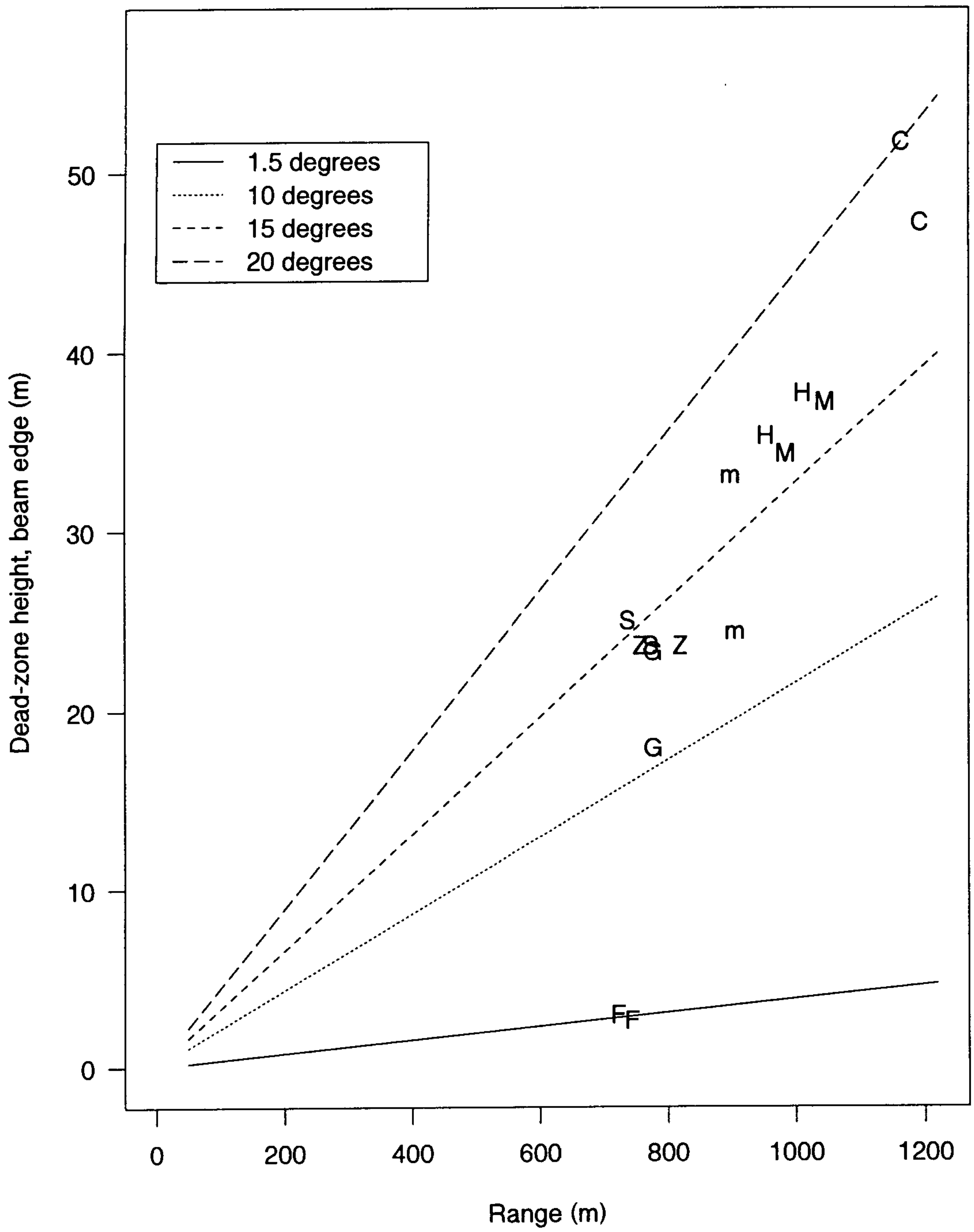

Figure 7 Estimated average dead zone height (edge) for acoustic transects on the "flat" (F) and on the hills (C = Crypt, G = Graveyard, H = Headstone, m = Morgue, M = Mummy, S = Scroll, Z = Zombie), with reference lines for average bottom slopes from 1.5 to 20°.

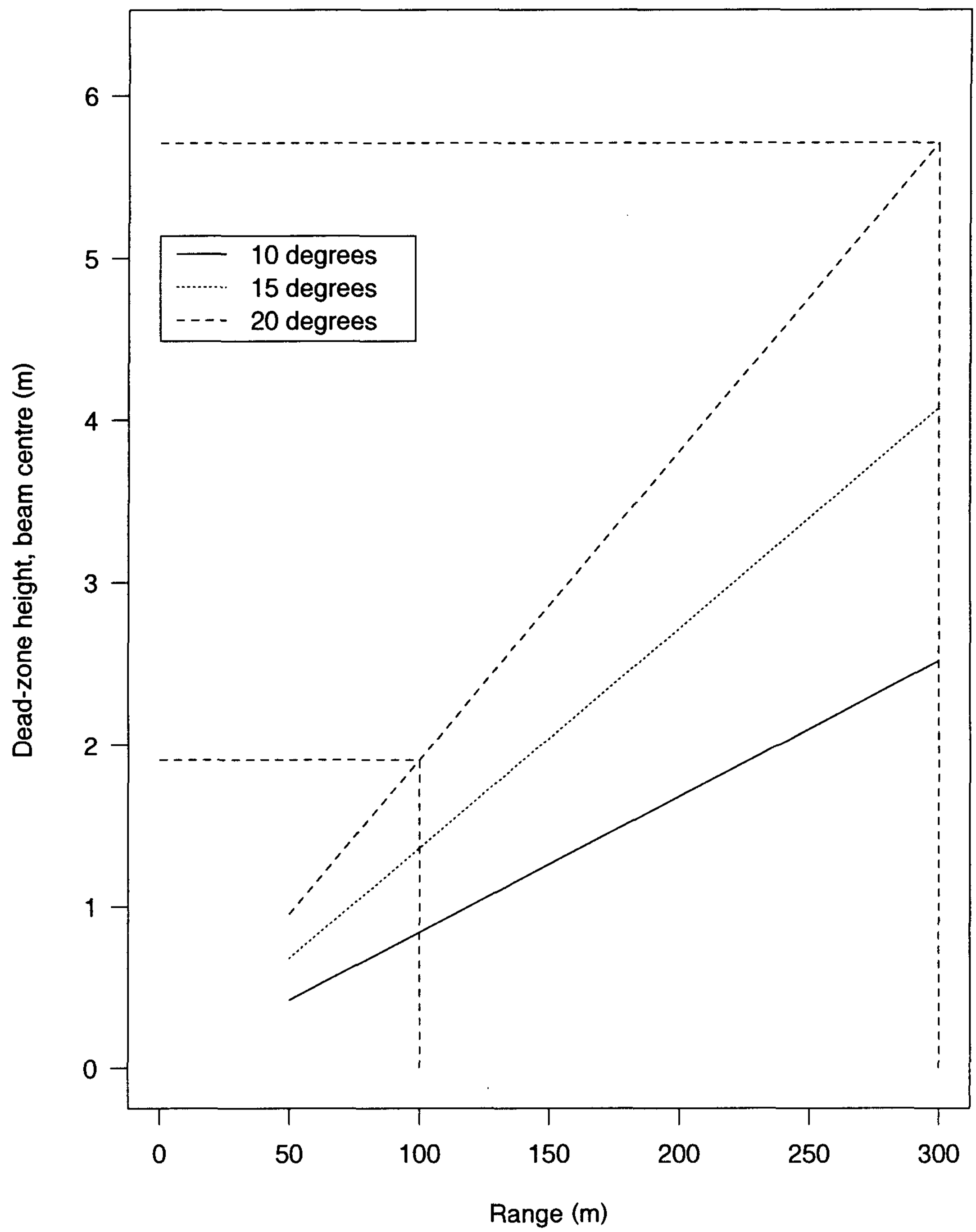

Figure 8: Approximate dead zone heights (centre) for hills with average slopes from 10–20° at ranges from 100 to 300 m.

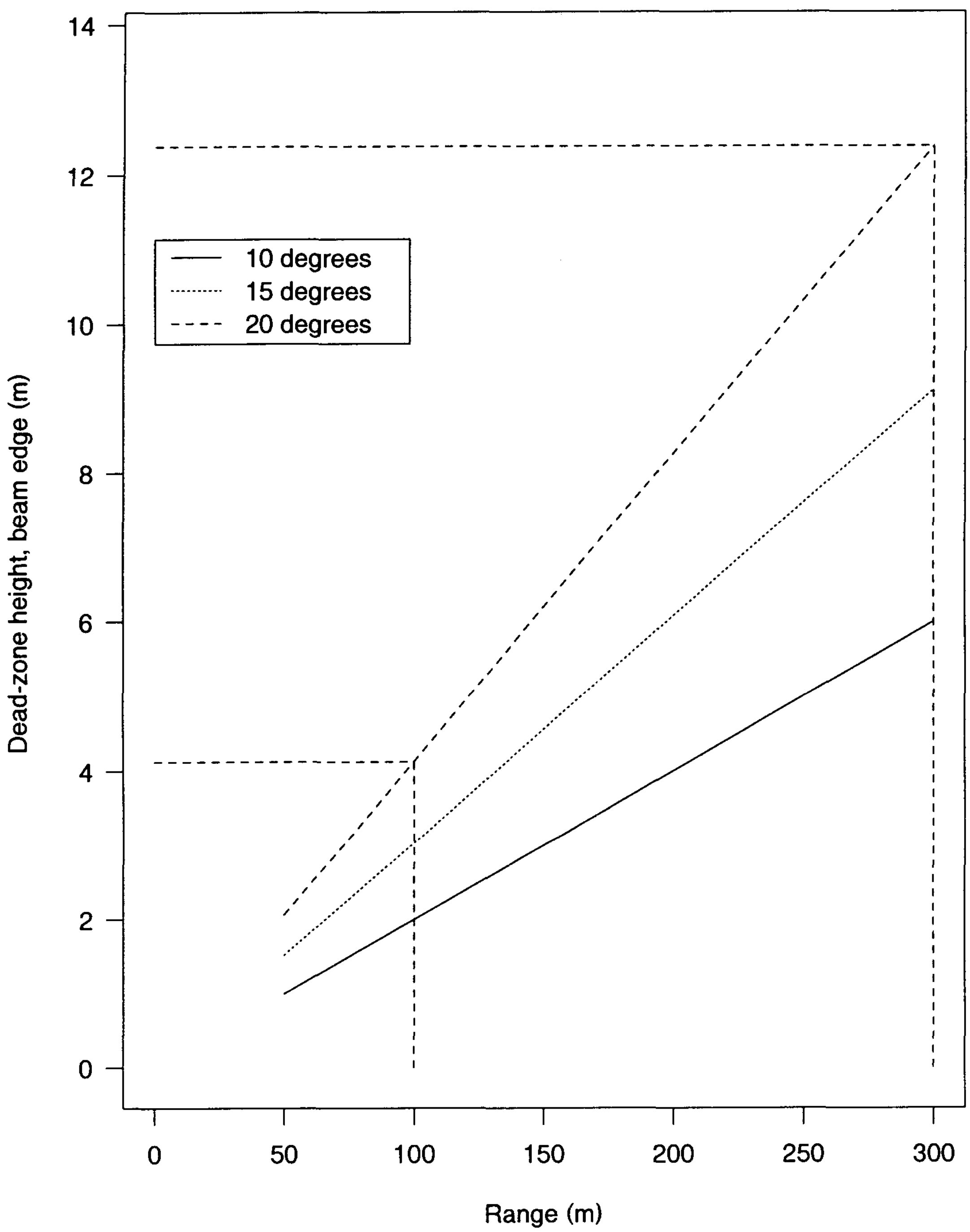

Figure 9: Approximate dead zone heights (edge) for hills with average slopes from 10–20° at ranges from 100 to 300 m.

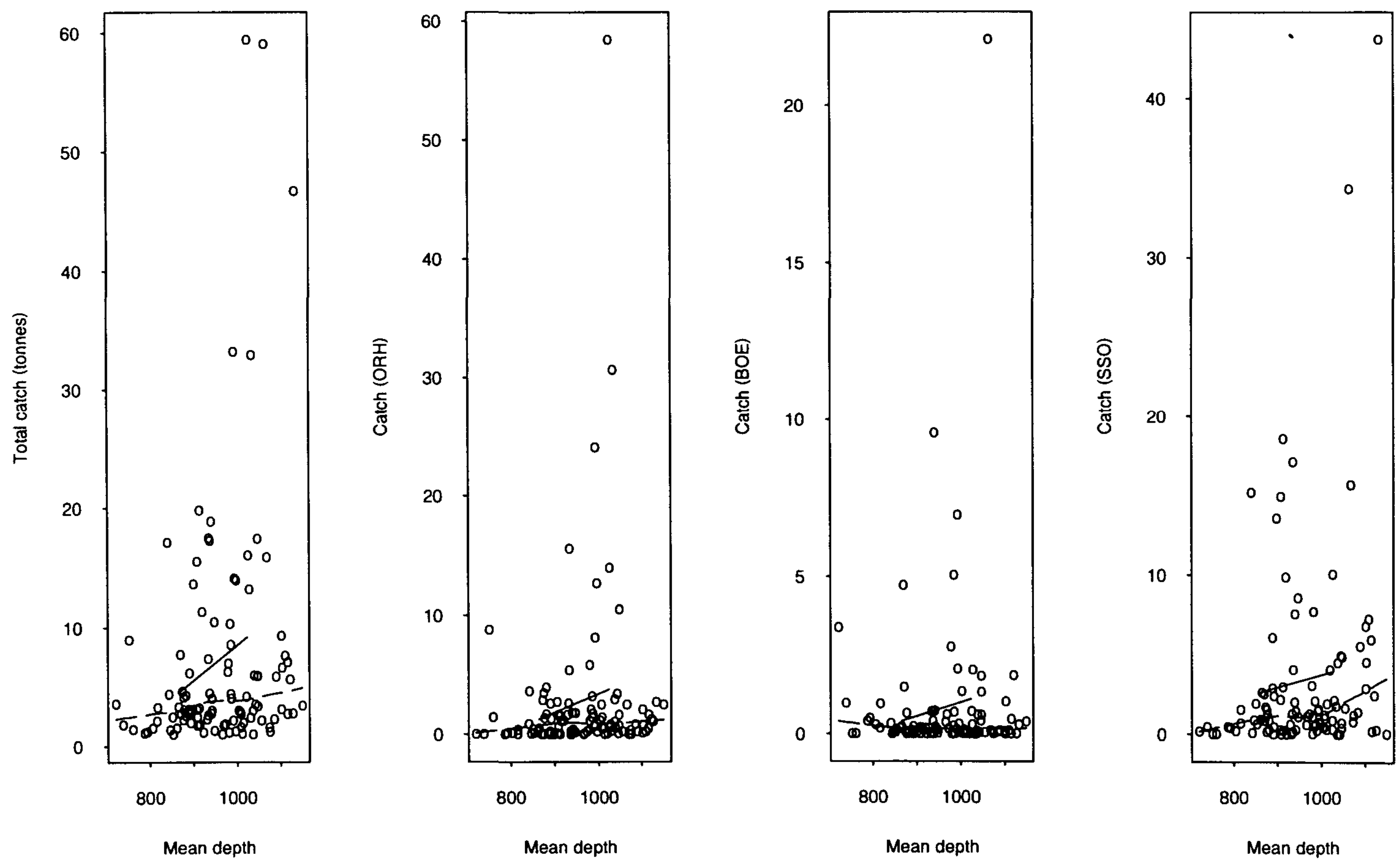

Figure 10: Scatterplot of catches vs mean depth of trawl. Two trend lines are shown (dashed line, lowess fit; solid line, 2-cell average)

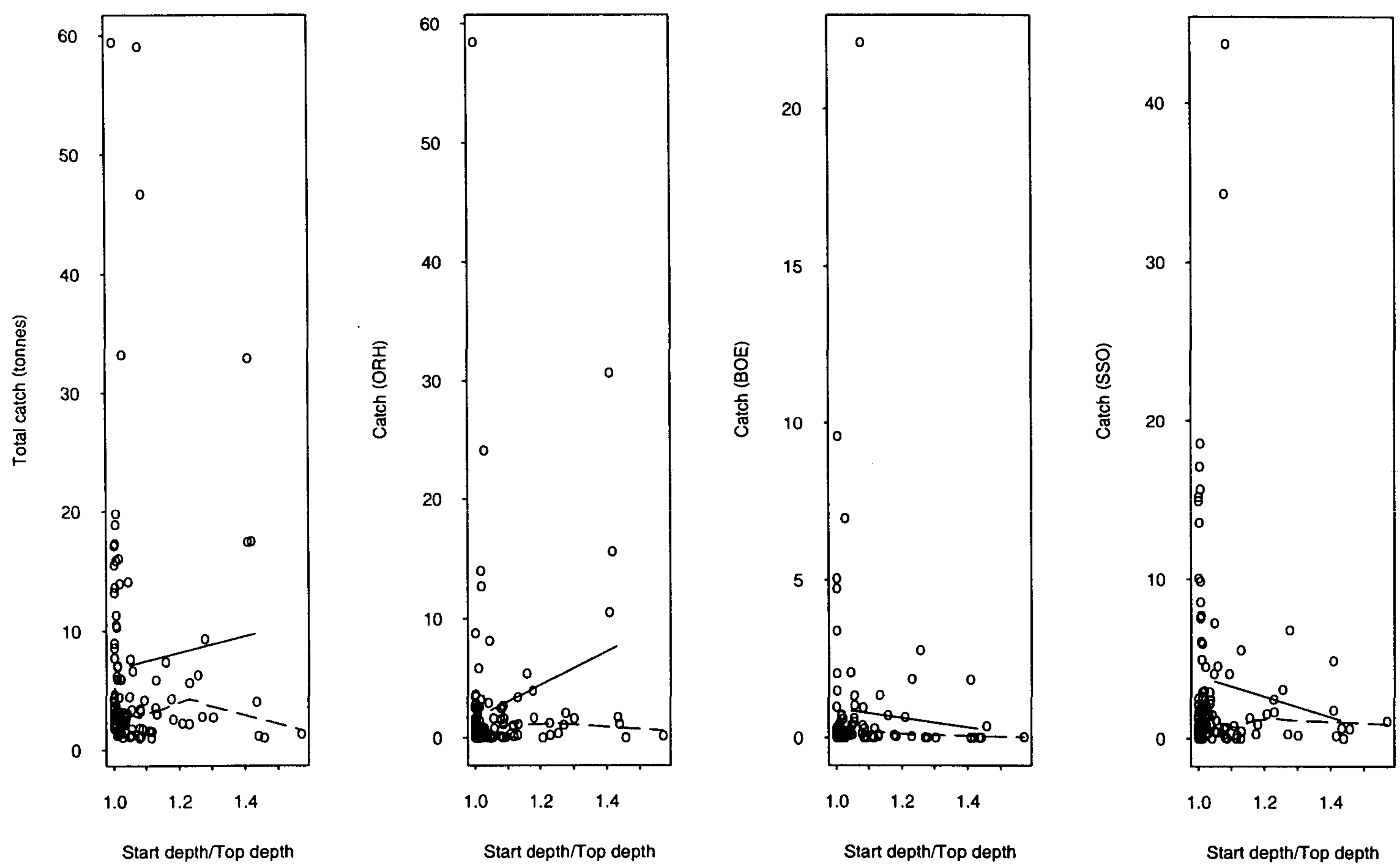

Figure 11: Scatterplot of catches vs start depth of trawl divided by hill depth. Two trend lines are shown (dashed line, lowess fit; solid line, 2-cell average)

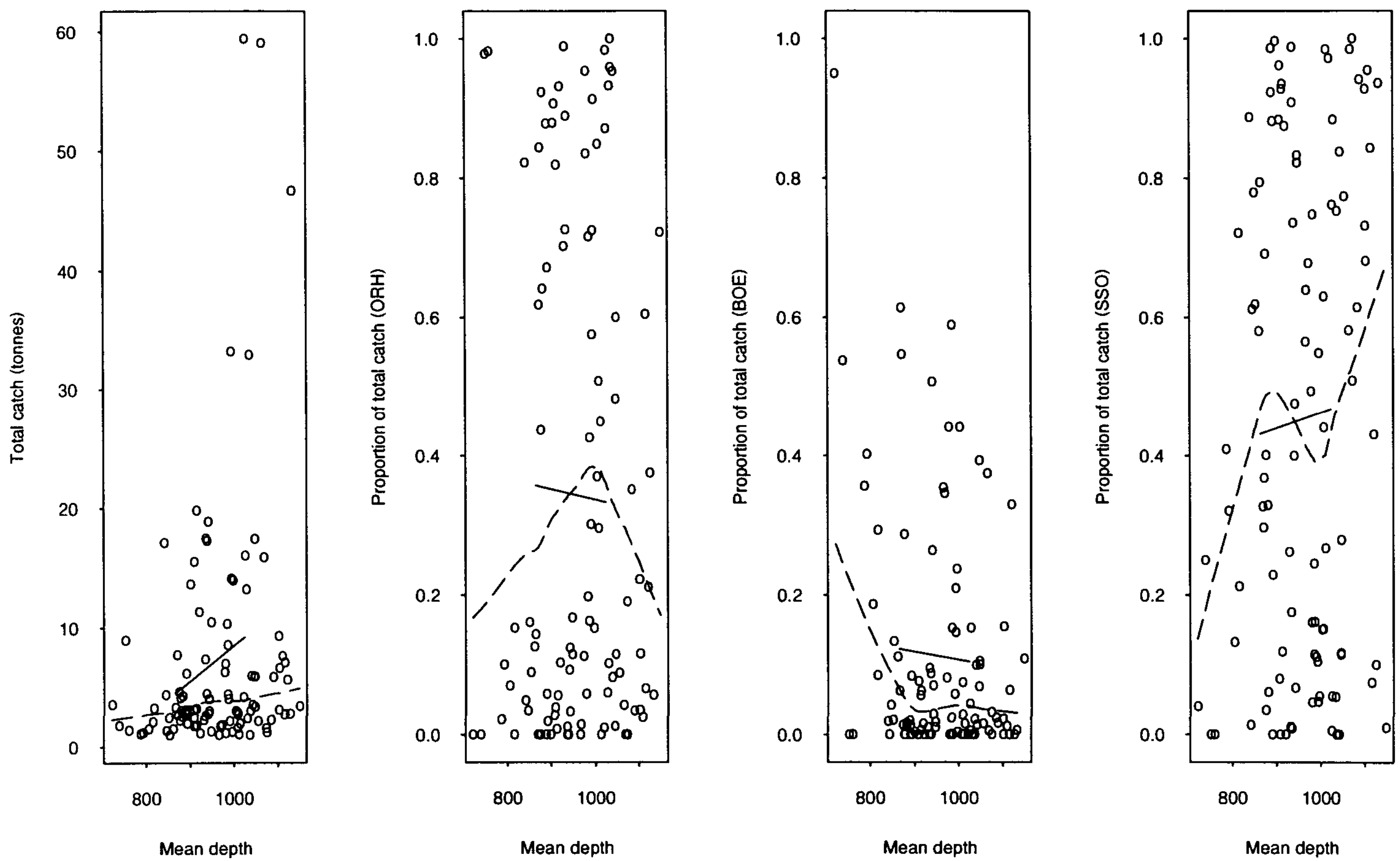

Figure 12: Scatterplot of species proportions vs mean depth of trawl. Two trend lines are shown (dashed line, lowess fit; solid line, 2-cell average)

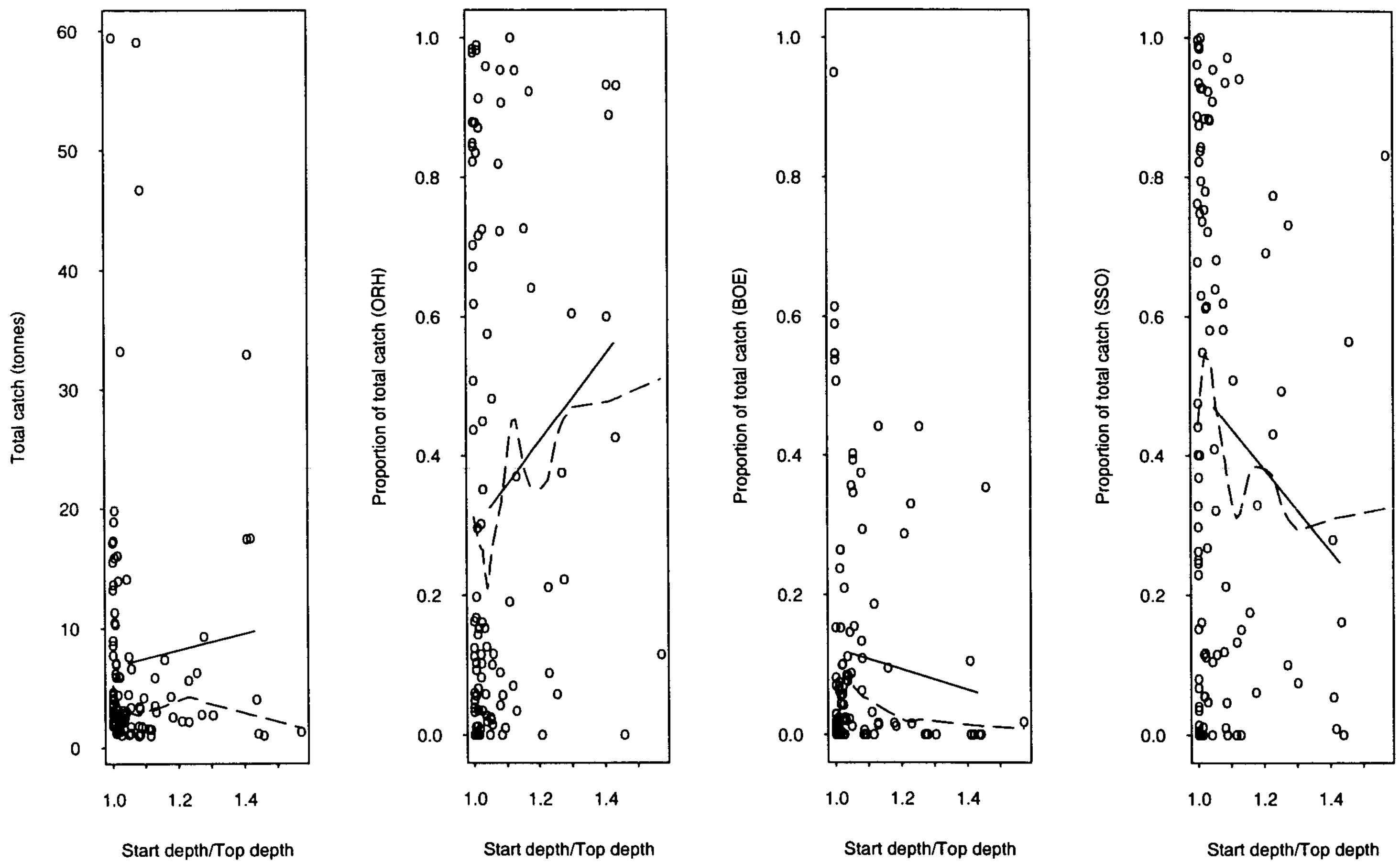

Figure 13: Scatterplot of species proportions vs start depth of trawl divided by hill depth. Two trend lines are shown (dashed line, lowess fit; solid line, 2-cell average)

Appendix 1: Formulae for measurements between an idealised beam and the bottom

Given the slope of the bottom (β), the equivalent beam angle (θ), and the range of the bottom from the transducer (R), we must determine four measurements: B, C, D, and E (*see* Figure 1). The cases where $\beta \le \theta/2$ and $\beta > \theta/2$ need to be considered separately (in the latter case, the idealised beam first hits the bottom at its extreme edge, independent of β).

The formulae are given below. Each can be derived, fairly straightforwardly, by using standard trigonometric rules and identities.

$$B = R\tan(\beta) \qquad 0 \le \beta \le \frac{\theta}{2}$$

$$R\frac{\sin(\theta/2)}{\cos(\beta)} \qquad \frac{\theta}{2} \le \beta < \frac{\pi}{2}$$

$$C = \frac{R}{\cos(\beta)}[1 - \cos(\beta)] \qquad 0 \le \beta \le \frac{\theta}{2}$$

$$\frac{R}{\cos(\beta)}[\cos(\beta - \frac{\theta}{2}) - \cos(\beta)] \qquad \frac{\theta}{2} \le \beta < \frac{\pi}{2}$$

$$D = R[1 - \cos(\frac{\theta}{2} + \beta)] \qquad 0 \le \beta \le \frac{\theta}{2}$$

$$R[\cos(\beta - \frac{\theta}{2}) - \cos(\frac{\theta}{2} + \beta)] \qquad \frac{\theta}{2} \le \beta < \frac{\pi}{2}$$

$$E = \frac{R}{\cos(\beta)}[1 - \cos(\frac{\theta}{2} + \beta)] \qquad 0 \le \beta \le \frac{\theta}{2}$$

$$\frac{R}{\cos(\beta)}[\cos(\beta - \frac{\theta}{2}) - \cos(\frac{\theta}{2} + \beta)] \qquad \frac{\theta}{2} \le \beta < \frac{\pi}{2}$$