

10-10-95
Cawthron Report No. 298

LIBRARY



CAWTHRON

**Current velocity measurements near
Te Pangu Bay, Tory Channel,
Queen Charlotte Sound**

Report for:

Regal Salmon

Picton

Author:

Cameron Hay

Cawthron

4 October, 1995

EXECUTIVE SUMMARY

Current measurements over six days spanning the largest tides in July, have shown that the changes (ie. the pattern) in both current speed and current direction was correlated closely with the state of the tide. There were eleven high tides over the monitoring period, and at both Te Pangu and Clay Point the S4 meters clearly showed that currents were strongest 1-2 hours before the time predicted for the start of the eastward (ie. ebb) flow in Tory Channel, which is approximately the time of highwater in Picton. Alternating with these velocity peaks were minor peaks that roughly coincided with the onset of the westward (flood) flow - usually up to one hour after the predicted time.

At Te Pangu, eleven periods when the tides were predominantly to the southeast (the troughs in Fig. 3) alternated with twelve periods when currents were mainly in the northwesterly quarter. At Clay point there was a similar pattern - eleven periods where the set was clearly to the east or northeast, and 12 periods when the flow direction was westerly or northwesterly.

At both sites the easterly directed currents were clearly the strongest. These occurred during the flood, with peak velocities commonly in the period 1-2 hr before the onset of the eastward flow (ie. approx high tide). Shortly after high tide, current velocities rapidly declined.

The average current speed at Te Pangu off the northwestern corner of the farm was about 20 cm. sec⁻¹ and the strongest currents at this site were 69 cm. sec⁻¹ (about 1.3 knots). Current speeds off the northeast corner of the farm, in shallower water, were significantly slower. At Clay Point, currents were obviously stronger than at Te Pangu - the average being 27 cm. sec⁻¹ and the strongest 93 cm. sec⁻¹ (almost 2 knots). The fact that the current meters were dragged deeper during peak flows could mean that the peak flows were slightly underestimated.

The periods of very little water movement (less than 5 cm. sec⁻¹) at Te Pangu and Clay Point amounted to less than 10% of the monitoring period.

The results suggest that on the flood tide the westward flowing water in Tory Channel forms eddies along the Channel margins which are directed backwards into Te Pangu Bay (an anti-clockwise eddy) and into the northern embayment near Clay Point (a clockwise eddy). This probably explains the reports from Te Pangu that current flow is sometimes the reverse of the direction of flow in the centre of Tory Channel.

1 INTRODUCTION

In late June 1995, Cawthron were asked by Mr Barry McClure of *Regal Salmon Ltd.* (Regal) to measure current velocities at two sites in Tory Channel: (1) adjacent to the existing Regal farm in Te Pangu Bay on the south side of the Channel, and (2) in the centre of an embayment directly opposite Te Pangu, on the north side of the Channel.

The existing salmon farm in the western embayment of Te Pangu Bay (Licence 484) has an area of 5.85 Ha with dimensions 325 x 180 m. The long side of the rectangular farm is orientated approximately east-west across the mouth of the western embayment of the Bay.

The embayment on the north side of the channel, at approx 41° 14.5'S; 174°14.6'E, is unnamed on NZ Chart 6153. Situated immediately west of Te Uira-karapa Pt and near colloquially named "Clay Point" the locality is a new salmon farm site for Regal. In this report the site is referred to as Clay Point.

Cawthron was asked to deploy current meters at these two localities for several days and at the time of the month in July when tides were greatest. Graphs and diagrams summarising the data were supplied to Regal on 19 Aug 1995. This final report concludes the contract.

Terminology and units: As is conventional when describing currents and tidal streams, the direction is that in which the water is generally moving; ie. a westerly current is one flowing **towards** the west (the reverse is conventional for wind direction). The tidal stream that runs with the rising tide is the *flood*, while that which runs with a falling tide is the *ebb*. HW and LW are high and low water respectively. Current velocities are expressed as centimetres per second (cm. sec⁻¹) or as knots. A knot is approximately 52 cm.sec⁻¹ or 1 nautical mile per hour.

2 TORY CHANNEL AND THE NZ TIDAL REGIME

In New Zealand the time of high tide occurs progressively later anticlockwise around the coast starting from the northwest in the Tasman Sea. So by the time the tidal wave has started up the east coast near North Cape it is soon to begin another circuit of the country down the west coast in that region. It takes about 12 hours (a tidal cycle) for the tidal wave to travel around the approximately 4,000 Km of coast at a velocity of about 300 km.hr⁻¹.

In the Cook Strait region this means that when it is low water at the western or Tasman approaches to Cook Strait, it is nearly high water on the Pacific side, and a tidal current flows into the Tasman Sea. Conversely when it is high tide on the Tasman side of the Strait, and low tide on the Pacific side, then the tidal current is into the Southwest Pacific. As the tidal wave circles New Zealand it induces a see-sawing effect (a standing wave) in the Strait, with water slopping backwards and forwards, and water levels rising and falling and tidal streams racing to and fro (Harris 1990, p.117). There are approximately two high and two low tides per day in the Strait. In fact the situation is rather more complicated than this, and the tidal regime of the Strait is a consequence of the superposition of two standing waves. The wave entering from the Tasman end reflects near Cape Campbell with the incident and the reflected waves forming one standing wave. The wave entering the Pacific end, that reflects where the Strait opens out at about Titahi Bay, generates incident and reflected waves that combine to form a second standing wave (Heath 1974). Further complications arise because of the highly variable bathymetry of the Strait (tidal waves move faster in deeper water) and the convoluted shape of the coastline. Tidal streams in an around Cook Strait are unpredictable, sometimes running in

one direction for 10 and, exceptionally, even 18 hours, followed by a very weak reverse flow (1995 Nautical Almanac, p.25)

In the Tory Channel area, the flood tide arrives first at West Head at the narrow Cook Strait entrance of Tory Channel, about 50 minutes before it reaches the much wider northern entrance of Queen Charlotte Sound between Capes Koamaru and Jackson. The tide floods through the Cook Strait entrance, at a speed of up to 5-7 knots and is directed westward, at 2-4 knots, along Tory Channel towards the Queen Charlotte Sound entrance of the Channel near Dieffenbach Point. Here, now well inside the Sound, the tidal stream divides with part of the flow going westward towards Picton and part of the flow northeastward towards Long Island - where it meets the tidal wave flowing in from the north. Superficially this northward part of the flow might appear to be an ebb flow out of the Sound, but as just described, it is a branch of the flood stream. A consequence of this regime is that the constricted flood-flow has to supply the very large volume of water needed to raise tidal levels over the broad expanse of the central and inner part of Queen Charlotte Sound - hence the fast rates of flow recorded in the Channel.

On the ebb tide, when the tide is high on the Tasman side of the Strait and low on the Pacific side, the stream in Tory Channel ebbs towards the east, flowing out into Cook Strait, and presumably, because of the time difference between the state of tide at West Head and at the northern entrance, a disproportionate amount of the water from the inner Sound ebbs out of Tory Channel before it starts to ebb out of the wider northern entrance.

On the coasts of New Zealand the change in direction of a stream seldom coincides with the time of high and low water on the adjacent shore (1995 Nautical Almanac, p. 25). Near Te Pangu in Tory Channel however, it appears that slack water; ie the interval between the cessation of the eastward (ebb) flow and the westward (flood) flow occurs at about the time of low and high water at Picton. The time difference for the start of the eastward and westward flows is often sometime between the half-hour period before and the half-hour period after high and low tide times (Table 2).

3 METHODS

Predicted tide times and tidal ranges for Picton over the period of greatest tides in July (17 July) are listed below (Table 1). Easting and westing times for tidal streams in Tory Channel were obtained from the NZ Nautical Almanac. Tidal heights were estimated from Chart NZ 6153 from Okukari Bay, which is just inside the Cook Strait entrance of Tory Channel.

According to local knowledge the times of high and low water at Picton occur about 15-20 minutes and sometimes 30 minutes earlier at Te Pangu than at Picton. In the absence of any tidal data from Te Pangu we have assumed this time difference to be approximately correct.

During the monitoring period the start of the flood and ebb tidal streams in Tory Channel approximately coincided with the times of high and low water at Picton (Table 2), and appeared to be most closely correlated when the tidal range was greatest (17 July). The differences were however, inconsistent. Before 16 July the times predicted for the start of the western stream and eastern streams were up to half an hour before (+ values) low water at Picton, while during the second half of the monitoring period, the predicted times for westward and eastward flows were up to 49 min *after* (- values) the time of low water at Picton.

Table 1: Predicted tidal times and heights at Picton 13-19 July 1995 (NZ Hydrographic Office, RNZN).

Date 1995	Time	Height (m)	Date	Time	Height (m)
13/7	0231	0.1	17 Jul	0006	1.5
	0946	1.3		0525	-0.1
	1456	0.1		1234	1.3
	2208	1.5		1757	0.0
14/7	0317	0.0	18 Jul	0041	1.4
	1034	1.4		0606	0.0
	1545	0.0		1307	1.2
	2250	1.6		1839	0.0
15/7	0402	0.0	19 Jul	0116	1.3
	1118	1.4		0648	0.0
	1631	0.0		1329	1.1
	2329	1.5		1923	0.1
16/7	0444	-0.1			
	1157	1.3			
	1715	0.0			

Table 2: Differences between times of low water and high water at Picton and the times of the westward (flood) and eastward (ebb) flows in Tory Channel. The + values are the time differences in minutes before Picton time; the - values are the differences after Picton time.

Date 1995	LW	Westward (Flood) flow		HW	Eastward (ebb) flow	
13/7	0231	0219	+12	0946	0913	+33
	1456	1442	+14	2208	2137	+31
14/7	0317	0303	+14	1034	1006	+28
	1545	1534	+11	2250	2225	+25
15/7	0402	0353	+09	1118	1100	+18
	1631	1628	+03	2329	2315	+14
16/7	0444	0444	+00			
	1715	1724	-09	1157	1151	+06
17/7	0525	0537	-12	0006	0002	+04
	1757	1820	-23	1234	1238	-04
18/7	0606	0632	-26	0041	0048	-07
	1839	1916	-37	1307	1322	-15
19/7	0648	0728	-40	0116	0133	-17
	1923	2012	-49	1339	1403	-24

On 13 July 1995 Cawthron installed one S4 "InterOcean" current meter at each locality. S4 meters emit an electromagnetic field and use the conductivity of seawater to measure water velocity and direction. They have no external moving parts such as propellers and vanes. In addition a *Sensordata* SD6000 current meter, with directional vane and propeller, was deployed at Te Pangu on the same date. The three current meters were left running until 19 July 1995, and were programmed to measure current speed and magnetic direction at 10 minute intervals which provided about 830 readings over the monitoring period. To convert from magnetic to true readings add 21 degrees.

Cawthron were asked to position the meters at a depth where current velocities were likely to be strongest. Accordingly, on 13 July at Clay Point current speed was measured at 3 m depth intervals to 21 m depth. These measurement, tabulated below (Table 3) suggested the current was probably strongest at about 6 m below the surface, and so this was the depth used for the longer term recording.

Table 3: Current meter speeds at 3 m depth intervals at Clay Point, 13 July 1995.

Depth (m)	Speed (cm. sec ⁻¹)	Time
0	13.8	10.47
3	3.4	10.40
6	18.4	10.33
9	15.8	10.26
12	13.0	10.19
15	12.6	10.09
18	1.6	10.02
21	2.4	09.54

The current meters were suspended at about 5.5 m ± 0.5 m below the surface from 40 litre, subsurface buoys, and each mooring was anchored by three 1.2 m long lengths of railway iron weighing approx 200 kg in total. This was intended to hold the mooring taught and vertical. However, when current speeds exceeded 1.5 knots the drag on the mooring temporarily pulled the meters down to 7-9 m depth.

The S4 meter at Te Pangu was deployed at 1404 h in 40 m of water, off the northwest corner of the cages and about half the distance between that corner and the outer line of buoys marking the mooring blocks. The SD6000 meter was moored at 1455 off the northeast corner of the cages, in 28.6 m of water, halfway between the cage corner and the outer line of mooring buoys.

At Clay Point, the meter was installed at 1220 h in the centre of the proposed salmon farm site, at 40 m depth, and at a position selected by Mr Paul Sowman of Regal. The global positioning satellite (gps) fix on this position was 41° 14.14'S; 174°14.61'E.

4. RESULTS

4.1 Te Pangu (S4 meter):

Velocity:

Off the northwest corner of the existing farm the average current speed from 832 readings was 19.8 cm sec^{-1} . The fastest speed of was 68.7 cm sec^{-1} (1.3 knots) recorded on 17 July at 1110h, 74 min before estimated HW. The minimum speed was 0.2 cm sec^{-1}

A summary of the frequency of readings over a range of current velocities follows (Fig. 1).: For 10.4% of the period measured, current speeds were slower than 5 cm sec^{-1} . For more than half of the monitoring period, current speeds at this site were slower than 20 cm sec^{-1} . Current speeds greater than 1 knot (52 cm. sec^{-1}) occurred for about 4-5% of the total time.

At Te Pangu highest and the lowest current velocities correlated closely with the tidal cycle (Fig. 2). A series of major peaks in tidal flow with velocities in the $45\text{-}65 \text{ cm. sec}^{-1}$ range happened 60-90 min **before** the estimated time of HW. At about the time of HW and shortly thereafter, tidal velocities rapidly declined to lowest speeds at about mid tide on the falling (ebb) tide. As the tide continued to fall, tidal velocity again increased to form minor peak flows of $20\text{-}30 \text{ cm. sec}^{-1}$ about 1 hr **after** LW. On the rising (flood) tide velocities declined from the $20\text{-}30 \text{ cm sec}^{-1}$ minor flow peaks until about the time of mid tide, whereupon current speeds increased sharply to attain the peak velocities of $45\text{-}65 \text{ cm sec}^{-1}$ before HW as described previously. So on the basis of these measurements it appears likely that the current will be strongest on the flood tide about 1 hr before HW and weakest at about mid tide, particularly on an ebb tide.

Direction:

Off the northwestern corner of Te Pangu farm the prevailing direction of the strongest current flow was to the southeast. By marking all current velocities faster than 45 cm. sec^{-1} in the tabulated raw data (which as described above is typically about 1-2hr before HW) we found that the direction of the current at each reading was invariably towards the SE between ESE (113° mag.) and SSE (156° mag). In Fig. 3 the southeasting is evident as the "valley floors" at about 135° mag. When current direction was plotted against speed (Fig. 4) the southeasterly direction of the strongest currents was obvious. It is also clearly evident in the current rose diagram (Fig. 5) which additionally shows that the southeasterly trend was the main direction in terms of the percentage of the total time

As Fig. 3 shows, the southeasting mainly prevails when the tide is flooding. On the ebb tide the current direction is much more variable, swinging from north, through south to east and back again, and creating the jagged pattern seen in Fig. 1 after high tide, which is consistent with eddying effects.

As mentioned above, the southeasting coincides with the strongest flows for about two hours before HW. After HW however, direction changes abruptly (counterclockwise), and the direction of the now much weakened flow is mainly towards the quadrant between north and west. This weaker trend to approximately the northwest is apparent in the current rose diagram (Fig. 5), and also in the progressive vector plot (Fig. 6), which clearly shows the net movement of water to the southeast (mainly during the latter part of the flood tide), and the weaker, tidally

driven, reverse flows towards the northwest mainly on the ebbing tide, and until at least an hour after the time of low water.

To summarise, at Te Pangu on the flooding tide the flow shortly after predicted low water is still weakly towards the northwest. Flows are weakest at about mid tide, but shortly thereafter the current strengthens and swings decidedly towards the southeast reaching peak flows about two hours before highwater. Shortly after highwater the current speed again weakens and flow direction becomes quite erratic on the ebbing tide - probably as a result of weak eddies

4.2 Te Pangu (SD6000 meter) - the northeast corner

Velocity:

Off the northeast corner of Te Pangu farm the average and maximum velocities recorded by the conventional SD6000 meter were 14.0 and 42.4 cm sec⁻¹ respectively. This suggests (assuming both the S4 and the SD6000 meters were reading accurately) that the current at the northeastern corner of the farm was about a quarter to one third weaker than at the northwest corner. The frequency of current speeds over a velocity range is depicted in Fig. 7. Velocities were less than 0.2 knot for about 38% of the time, and below 0.4 knot for about 75% of the time. Flow rates could change abruptly as on 16 July when the flow decreased from 33 cm sec⁻¹ (54° mag) at 0955 hr to 1.2 cm sec⁻¹ (359° mag) at 10.05hr. The peak flows of 30-40 cm. sec⁻¹, and were about 50% slower than the peak flows recorded by the S4 meter.

Unlike the data obtained from the S4 meter on the northwestern corner, there was a much less clear-cut relationship between current velocities and tide. There were however, eleven major flow peaks and 10 flow troughs consistent with the S4 data (Fig. 8).

Direction:

When current velocities were strongest (> 30 cm sec⁻¹) current direction was predominantly between NNE and E (37 out of 40 records) - the mean direction in this quadrant being 57° ± std. error 2.8° mag. This contrasts with the predominating southeasterly direction of the S4 meter in the northwest corner. It suggests that at periods of peak flow, the current sweeps into Te Pangu Bay past Papatea Point at the west entrance of the Bay, towards the southeast, and then swings to the left, and out of the Bay towards the northeast and the eastern margin of the Bay. During weakest flows (<5 cm sec⁻¹) current direction was relatively variable. During periods of very slow flow (1 cm sec⁻¹) it was often towards the north, but there was no obvious trend.

4.3 Clay Point

Velocity:

The current velocity at Clay Point, where the average and maximum velocities were 27.1 and 93.4 cm.sec⁻¹ respectively, was much stronger than at Te Pangu. The strongest currents at Clay point were 40-50% stronger than the strongest currents recorded at Te Pangu over the same period. Weak currents (eg. less than 10 cm. sec⁻¹) at Clay Point occurred for half the time that they occurred at Te Pangu - 18% compared with 32%. Current speeds of between 1 and nearly 2 knots were recorded for about 11% of the period measured at Te Pangu (Fig. 9). It is

possible that these measurements may underestimate the maximum current speed at Clay Point. During the periods of strongest flow, the current metres were dragged deeper to about 9-10 metres, and it is possible that the current flow above the meters was stronger during these periods. As at Te Pangu, there were pronounced major and minor peaks and troughs of current velocity that correlated closely with the tidal cycle. A brief description of the cycle is as follows. Major peak flow rates of 60-80(90) cm. sec⁻¹ were 1-2 hours before the estimated time of HW on the flooding tide. Shortly before HW the current abruptly weakened from 60-80 cm. sec⁻¹ to 10-20 cm. sec⁻¹. The current flow was consistently weakest at about mid tide on the ebbing tide. After mid tide, on the ebbing tide; ie when the tide was half out, the current flow increased again to attain minor peaks of 30-50 cm.sec⁻¹ about 1 hour after low tide.

During the flood tide, currents weakened from the minor peaks just described until about mid tide when the rate of flow was negligible (ca 10 cm. sec⁻¹). In the second half of the flooding tide, flow rates increased sharply to attain the major peak values described above, which were 1-2 hr before the estimated time of high water (Fig. 10).

Direction:

Plotting tidal direction against time (ie. the state of the tide) (Fig. 11), and current speed against direction (Fig. 12) showed a very strong ENE set, peaking at about 80° mag, and a weaker set towards WNW peaking at about 290° mag. These pronounced current directions are apparent as the troughs and the peaks in the graph of tidal stream direction in Fig.11. They are also obvious in the current rose diagram (Fig. 13) and in the progressive vector plot which shows a net water movement to the ENE interrupted by relatively short tidal reversals to WNW - thus giving a saw-tooth appearance to the plot (Fig. 14).

It would appear from these data that as the current weakens at about the time of HW, it is swinging slightly anti-clockwise from ENE towards the north. At, or close to slack water, the current is typically directed towards the sector between NW and NNE. Thus if Figs 10 and 11 are superimposed, the troughs of Fig. 11, which are the lowest velocities, approximately coincide with the "peaks" of Fig. 11 which represent the period when the current direction is between west and north. After slack water, the current strengthened to 40 - 60 cm.sec⁻¹, with the velocity peaking ½-1 hr after LW. During this time the direction of the current swings anti-clockwise briefly to the SW and then clockwise back again to the NW - perhaps an eddying effect. Then as the current velocity declines from these lesser peaks in velocity to the time of the next slack water period, the current direction continues its clockwise swing towards the north. This northerly trend continues with the flooding tide, until about 1-2 hr before HW, when once again it rapidly speeds up and sets firmly to the NE.

5 DISCUSSION

In mid channel of Tory Channel, the tide ebbs to the east, with the easting commencing at about the time of high water in Picton. One might therefore predict that during the ebb flow the current metres at both Te Pangu and at Clay Point would show an easterly set. In fact they did not. As mentioned, although all current meters showed a pronounced easterly set, this was consistently during the *flood*, particularly an hour or so before predicted high tide - almost the reverse to what might be predicted. And during the ebb, the flow had a weaker westerly or northwesterly set - again the reverse direction to what might be expected.

Without having other current metres in the bay and in the main channel, it is difficult to explain these apparently contradictory flows. A likely explanation is that the flow reversals are a result of eddies forming on the margins of Tory Channel. During the flood, as the water in Tory Channel moves westward, a counterclockwise eddy inside Te Pangu Bay on the south side, and a clockwise eddy in the Clay Point embayment to the north, would account for the current directions that were recorded on the meters.

At Te Pangu the fact that the main current direction off the northwest corner of the farm was to the southeast, and the main current direction of the meter off the northeastern corner was to the northeast, is consistent with a large anticlockwise eddy curving backwards into the bay during the flood. The fact that the velocity of the current appears to decrease as it sweeps into the bay might also explain why sediments tend to be deposited in the eastern embayment of Te Pangu and not in the western embayment. It would also appear to agree with the observations of some of the Regal Staff on the salmon farm who have noted that the surface flow in the main channel is often in the reverse direction to the drag on the salmon nets.

At Clay Point the northeasterly set is consistent with a clockwise, or right-handed eddy curving back into the embayment during the flood. Such an eddy may form the distinctive submarine ridge that lies at least part way across the entrance of the embayment parallel to the shore.

Presumably during the ebb, the eddy patterns in these embayments are reversed, but the current meters indicate that the velocities on the ebb are not as strong as during the flood. So when the ebbing flow in mid-channel is eastward, clockwise eddies on the southern shore would explain the northwesterly set at Te Pangu at that stage of the tide.

Finally it must also be remembered that these current meter measurements come from just one depth, 5-6 m below the surface. It seems most unlikely that the current pattern described above is consistent down through the water column. Scuba divers have observed that both the velocity and the direction of the current at Te Pangu changes with depth, and that sometimes the surface water is moving in the opposite direction to deeper layers (*pers. obs.*).

6 REFERENCES

- Harris, T.F.W. 1990. *Greater Cook Strait: Form and Flow*. DSIR Marine and Freshwater, Wellington. 212 p.
- Heath, R.A. 1974. The lunar and semi-diurnal tide in Cook Strait, New Zealand. *Deutsche Hydrographische Zeitschrift* 27: 214-224.

7 LIST OF FIGURES

- Figure 1:** Te Pangu (NW corner). Current speeds expressed as a percentage of the total monitoring period.
- Figure 2:** Te Pangu (NW corner). Variation in current speeds with time and tidal cycle. The diamonds indicate the time of the easting (ebb) and westing (flood) flows and also the height of the tide.
- Figure 3:** Te Pangu (NW corner). Variation in current direction with time and state of tide. The diamond symbols indicate time of easting (ebb) and westing (flood) flows, and also the height of the tide.
- Figure 4:** Te Pangu (NW corner). Current speed plotted against direction.
- Figure 5:** Te Pangu (NW corner). Current rose diagram showing the pronounced SE set of the strongest current.
- Figure 6:** Te Pangu (NW corner). Progressive current vector plot showing the southeasterly set and small tidal reversals.
- Figure 7:** Te Pangu (NE corner), SD6000 meter. Current speeds expressed as a percentage of the total monitoring period.
- Figure 8:** Te Pangu (NE corner), SD6000 meter. Variation in current speed with time (upper), and variation in current direction with time (lower).
- Figure 9:** Clay Point. Current speeds expressed as a percentage of the total monitoring period.
- Figure 10:** Clay Point. Variation in current speeds with time and tidal cycle. The diamonds indicate the onset time of the easting (ebb) and westing (flood) flows and also the height of the tide.
- Figure 11:** Clay Point. Variation in current direction with time and state of tide. The diamond symbols indicate time of easting (ebb) and westing (flood) flows, and also the height of the tide.
- Figure 12:** Clay Point. Current speed plotted against direction.
- Figure 13:** Clay Point. Current rose diagram showing the pronounced E to ENE set of the current.
- Figure 14:** Clay Point. Progressive current vector diagram showing the net water movement to the ENE and the brief tidal reversals to the NW.

Velocity frequency chart for Te Pangu
13/7/95 - 19/7/95

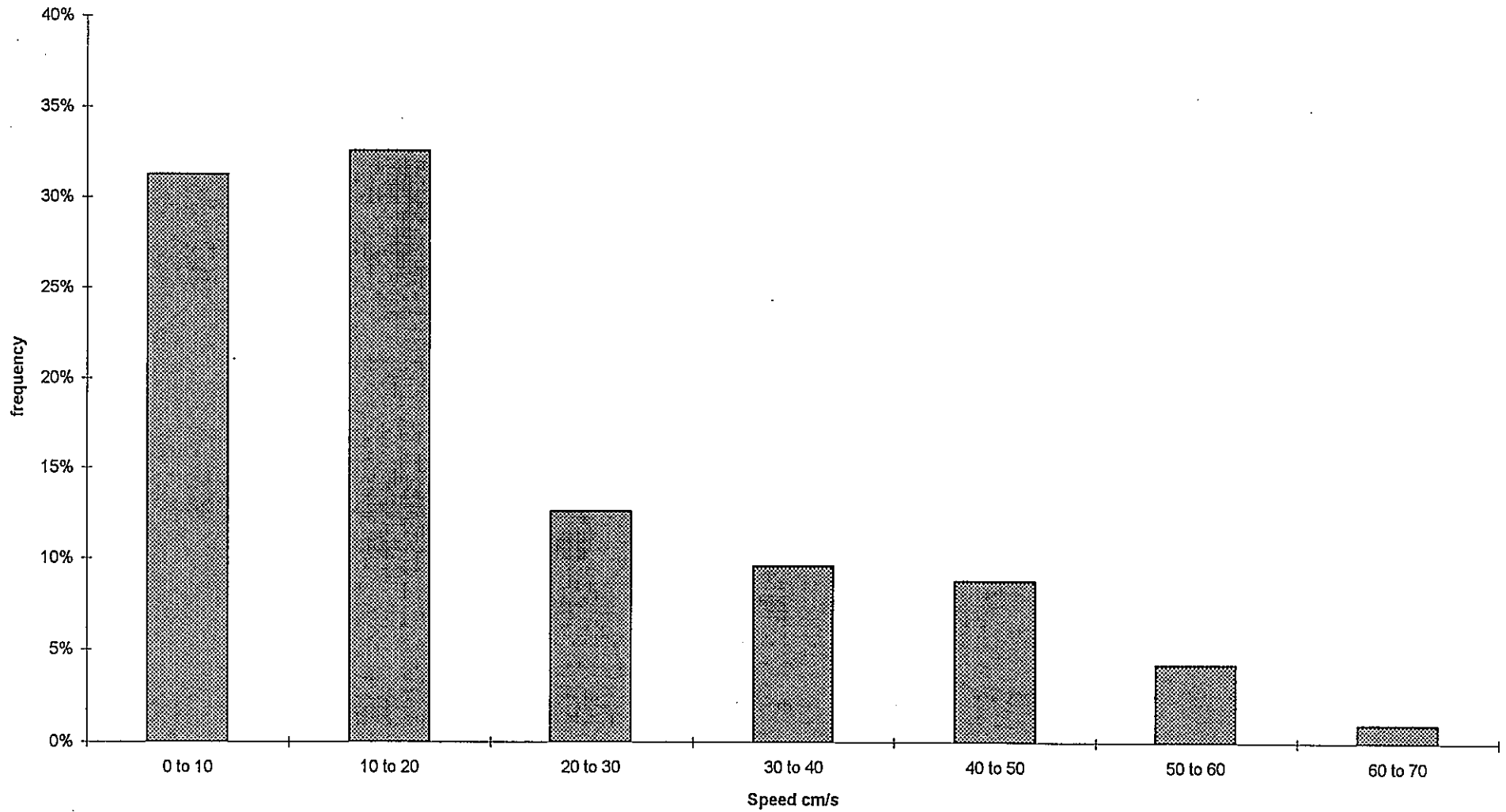


Figure 1: Te Pangu (NW corner). Current speeds expressed as a percentage of the total monitoring period.

Tidal currents at Te Pangu
13/7/95 - 19/7/95

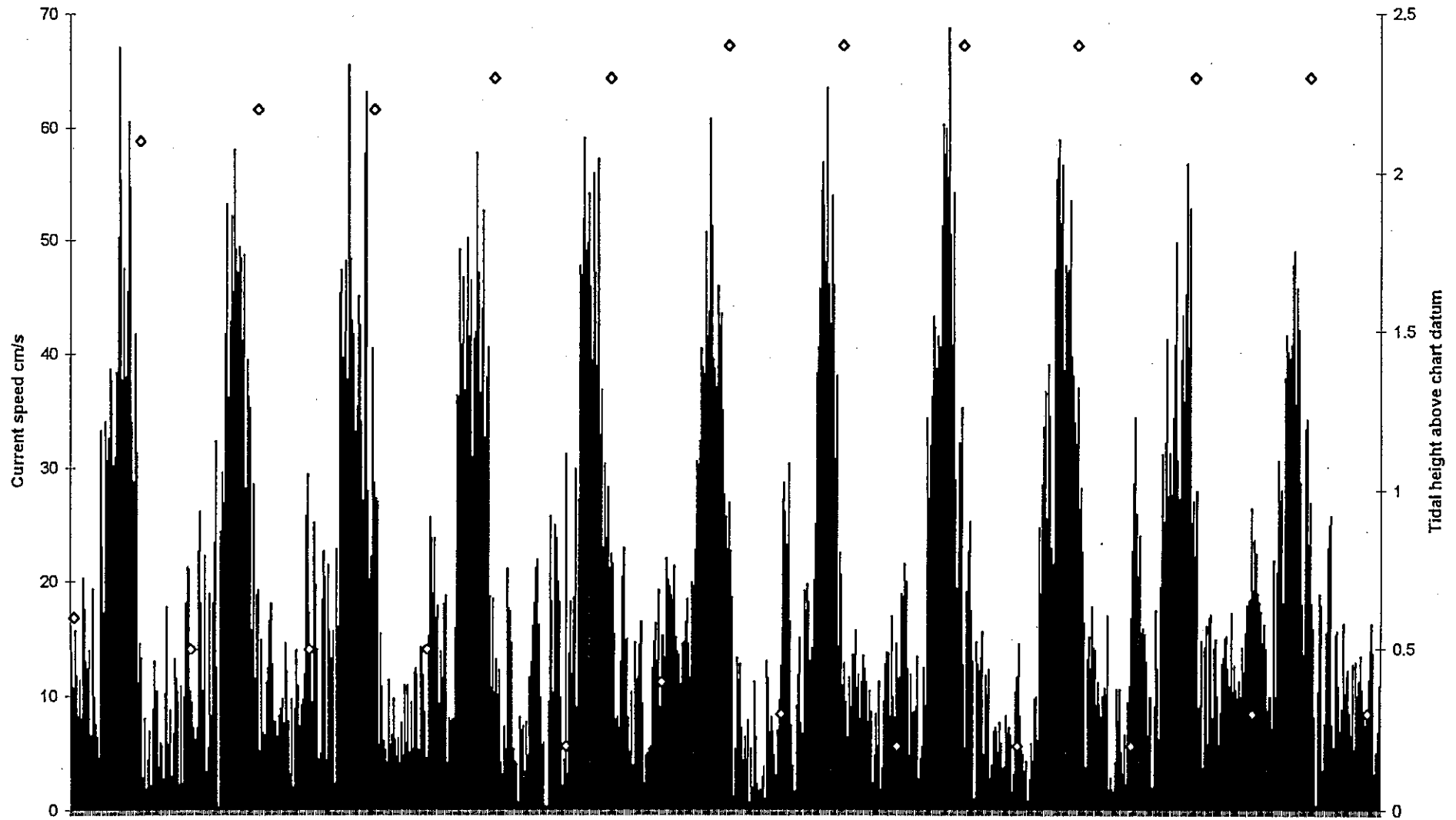


Figure 2: Te Pangu (NW corner). Variation in current speeds with time and tidal cycle. The diamonds indicate the time of the easting (ebb) and westing (flood) flows and also the height of the tide.

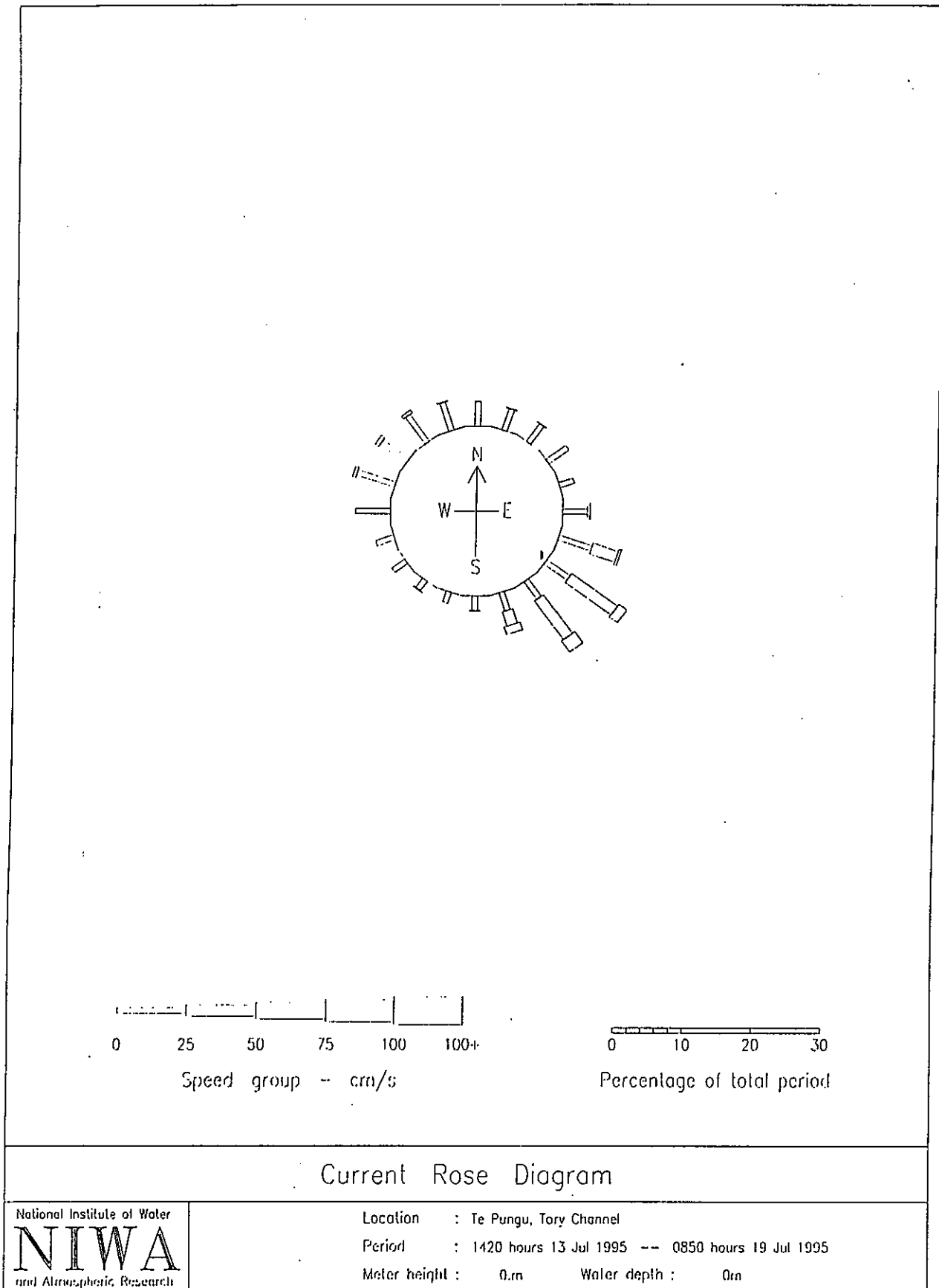


Figure 5: Te Pungu (NW corner). Current rose diagram showing the pronounced SE set of the strongest current.

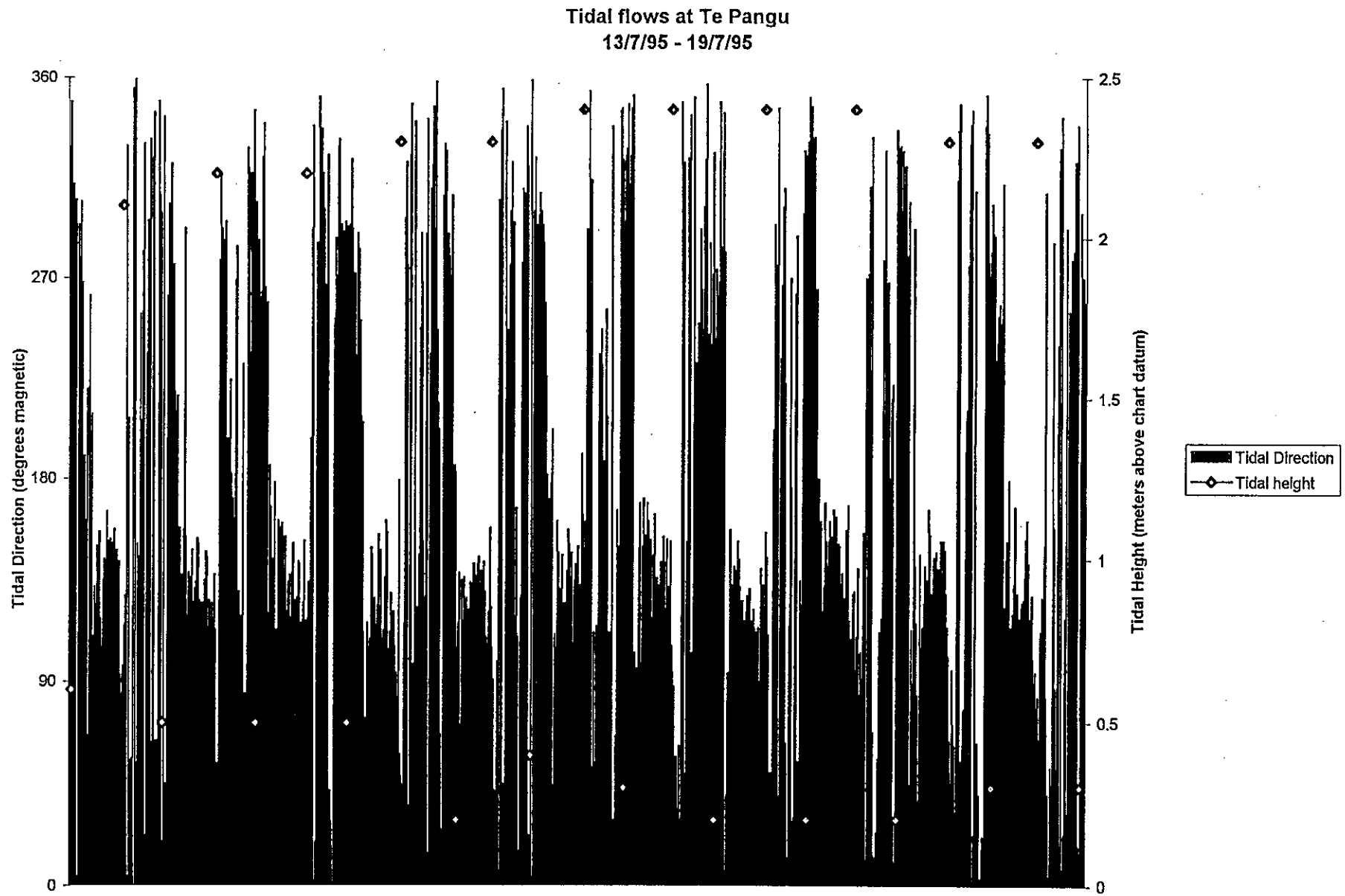


Figure 3: Te Pangu (NW corner). Variation in current direction with time and state of tide. The diamond symbols indicate time of easting (ebb) and westing (flood) flows, and also the height of the tide.

Correlation between current velocity & Direction
Te Pangu
13-7-95 to 19-7-95

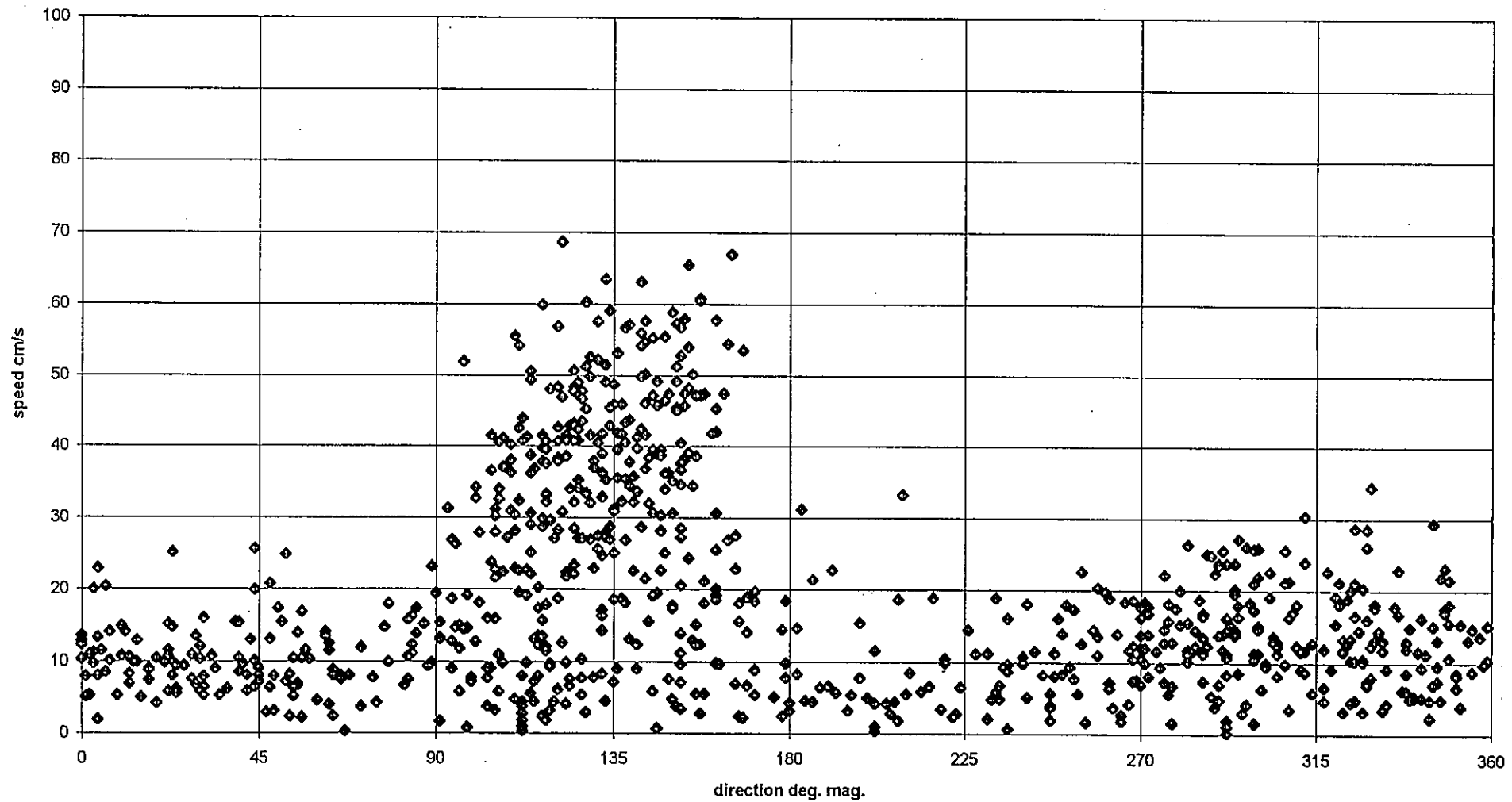


Figure 4: Te Pangu (NW corner). Current speed plotted against direction.

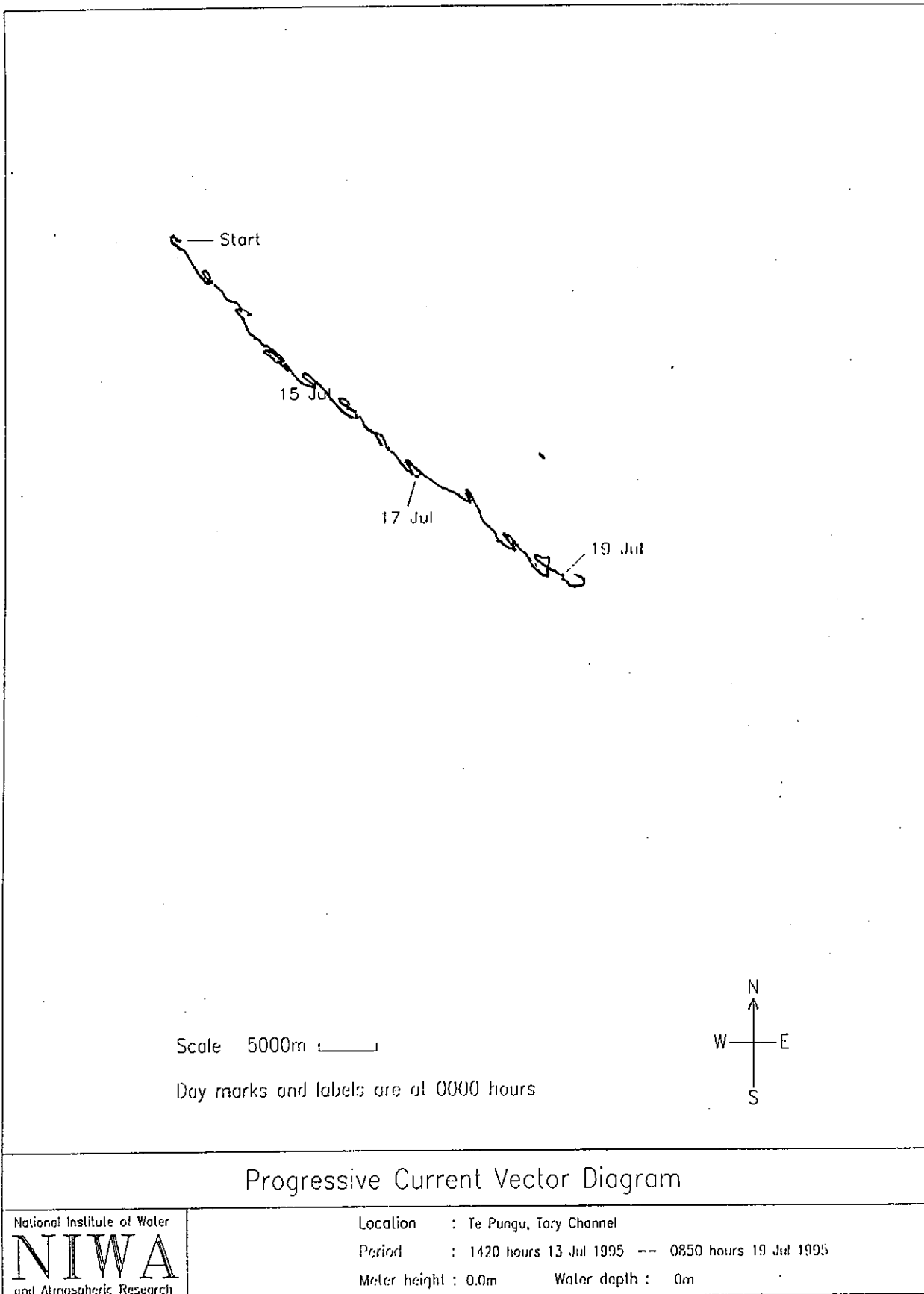


Figure 6: Te Pungu (NW corner). Progressive current vector plot showing the southeasterly set and small tidal reversals.

Velocity frequency chart for Te Pangu (SD6000 meter)
13/7/95 - 19/7/95

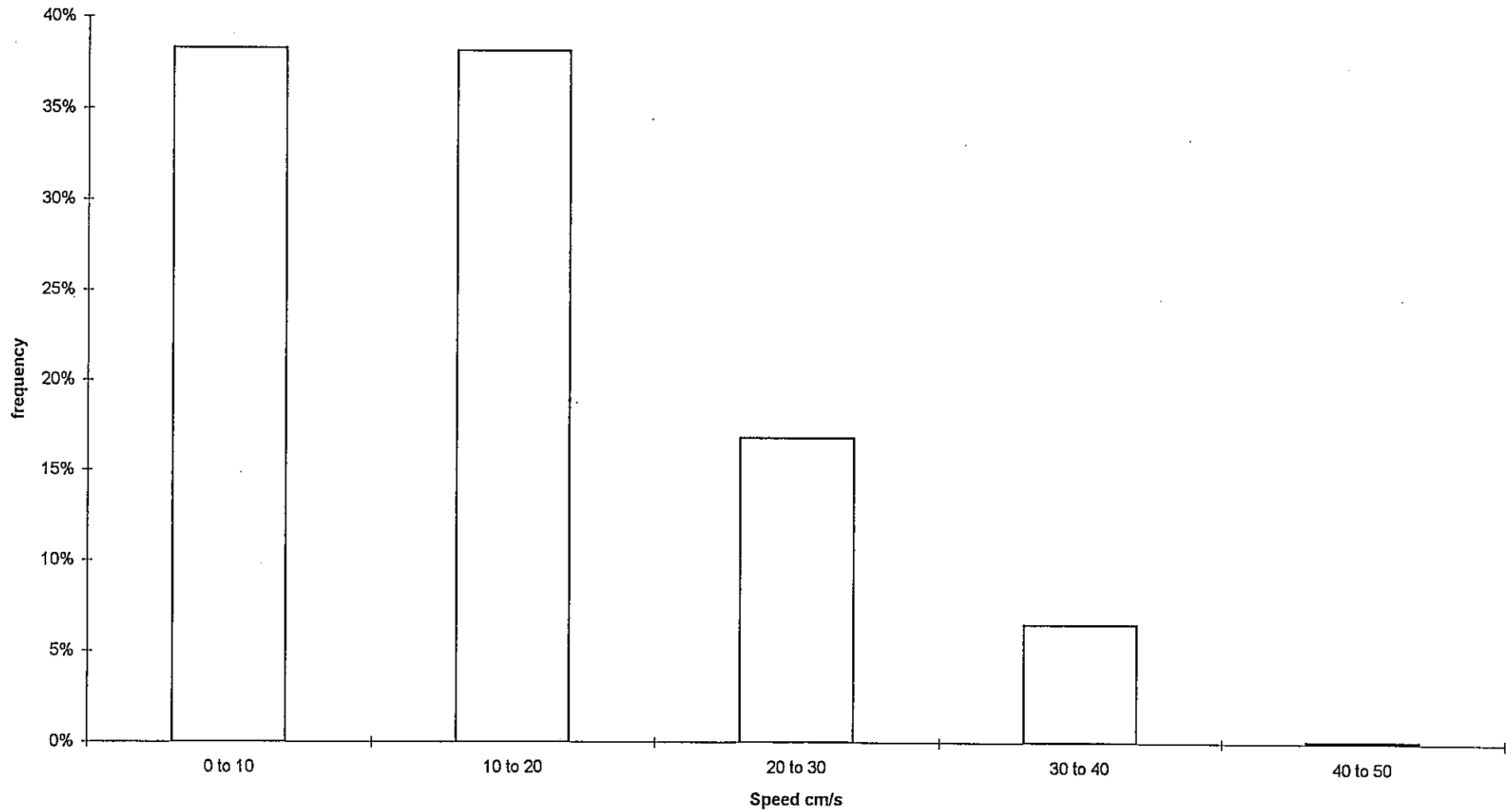


Figure 7: Te Pangu (NE corner), SD6000 meter. Current speeds expressed as a percentage of the total monitoring period.

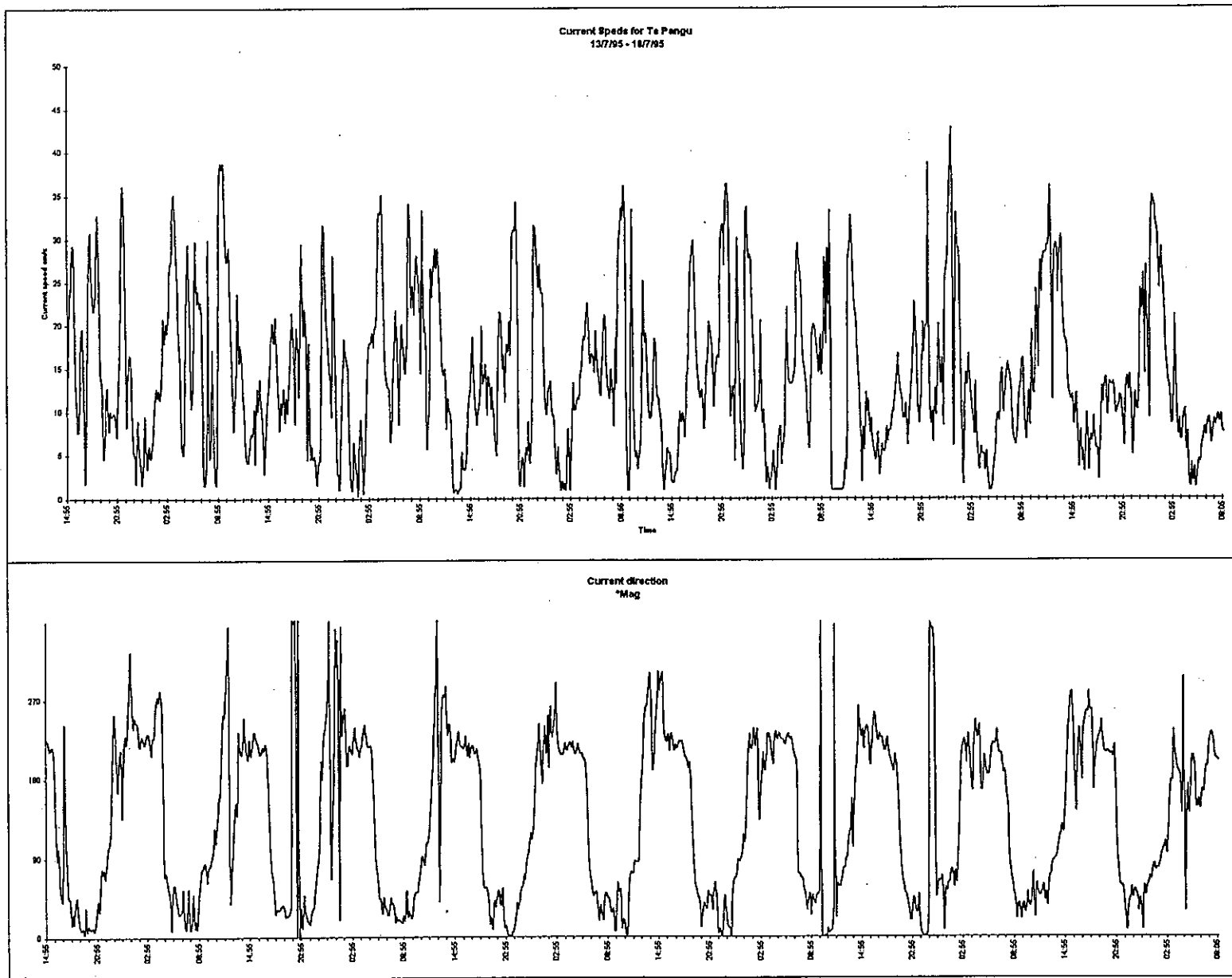


Figure 8: Te Pangu (NE corner), SD6000 meter. Variation in current speed with time (upper), and variation in current direction with time (lower).

Velocity frequency chart for Clay Pt.
13/7/95 - 19/7/95

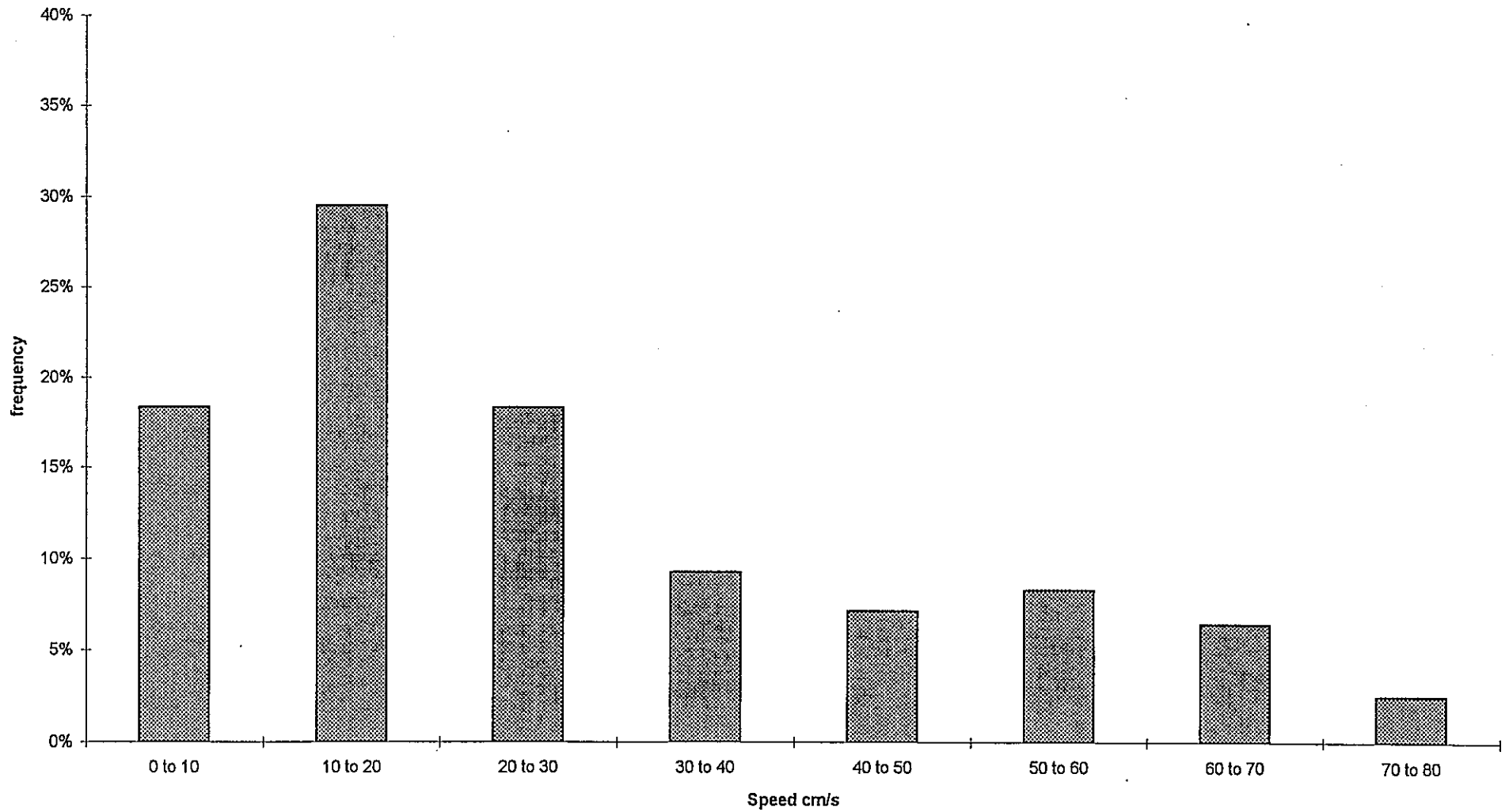


Figure 9: Clay Point. Current speeds expressed as a percentage of the total monitoring period.

Tidal currents at Clay Pt
13/7/95 - 19/7/95

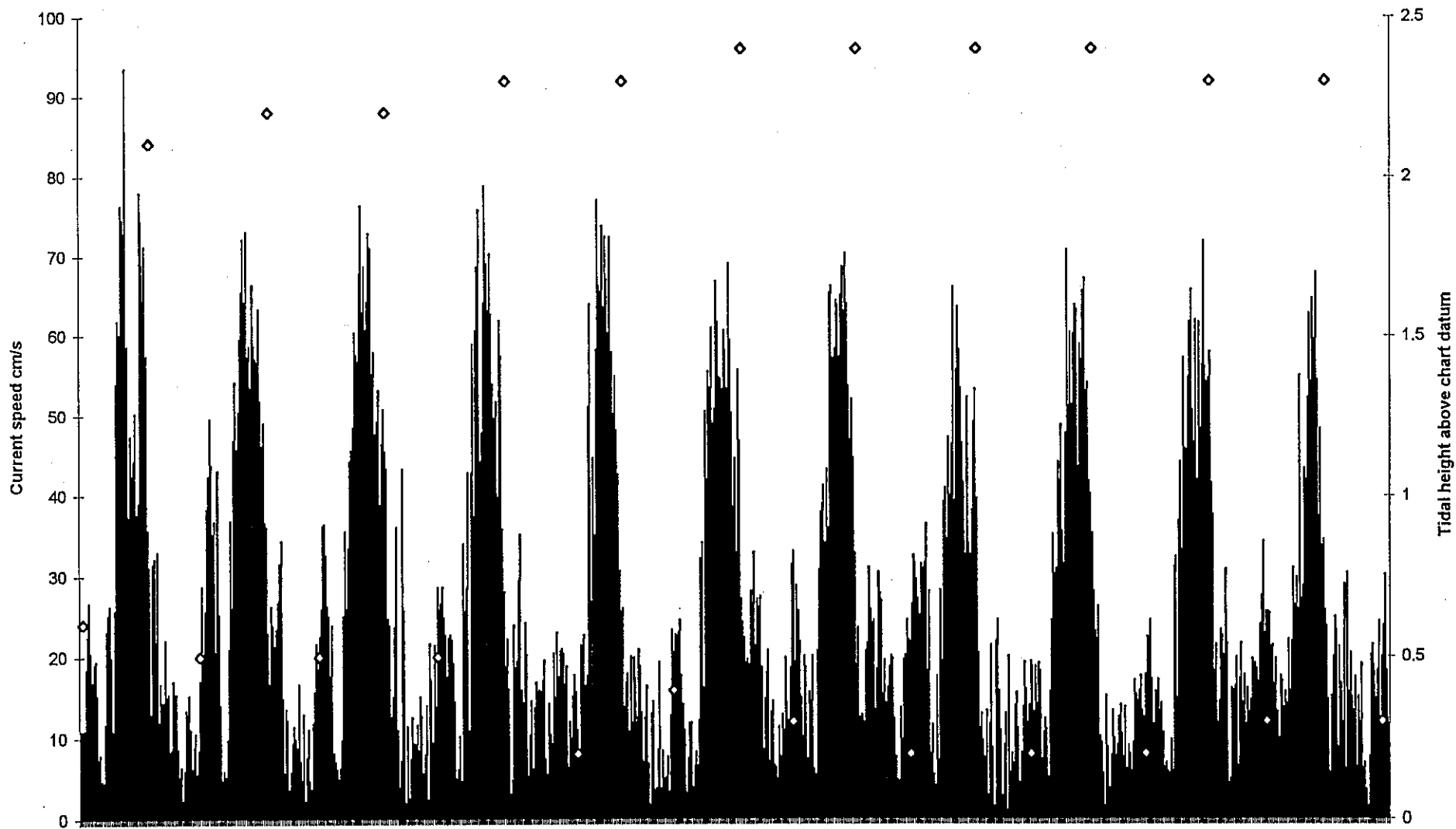


Figure 10: Clay Point. Variation in current speeds with time and tidal cycle. The diamonds indicate the time of the ebbing (ebb) and westing (flood) flows and also the height of the tide.

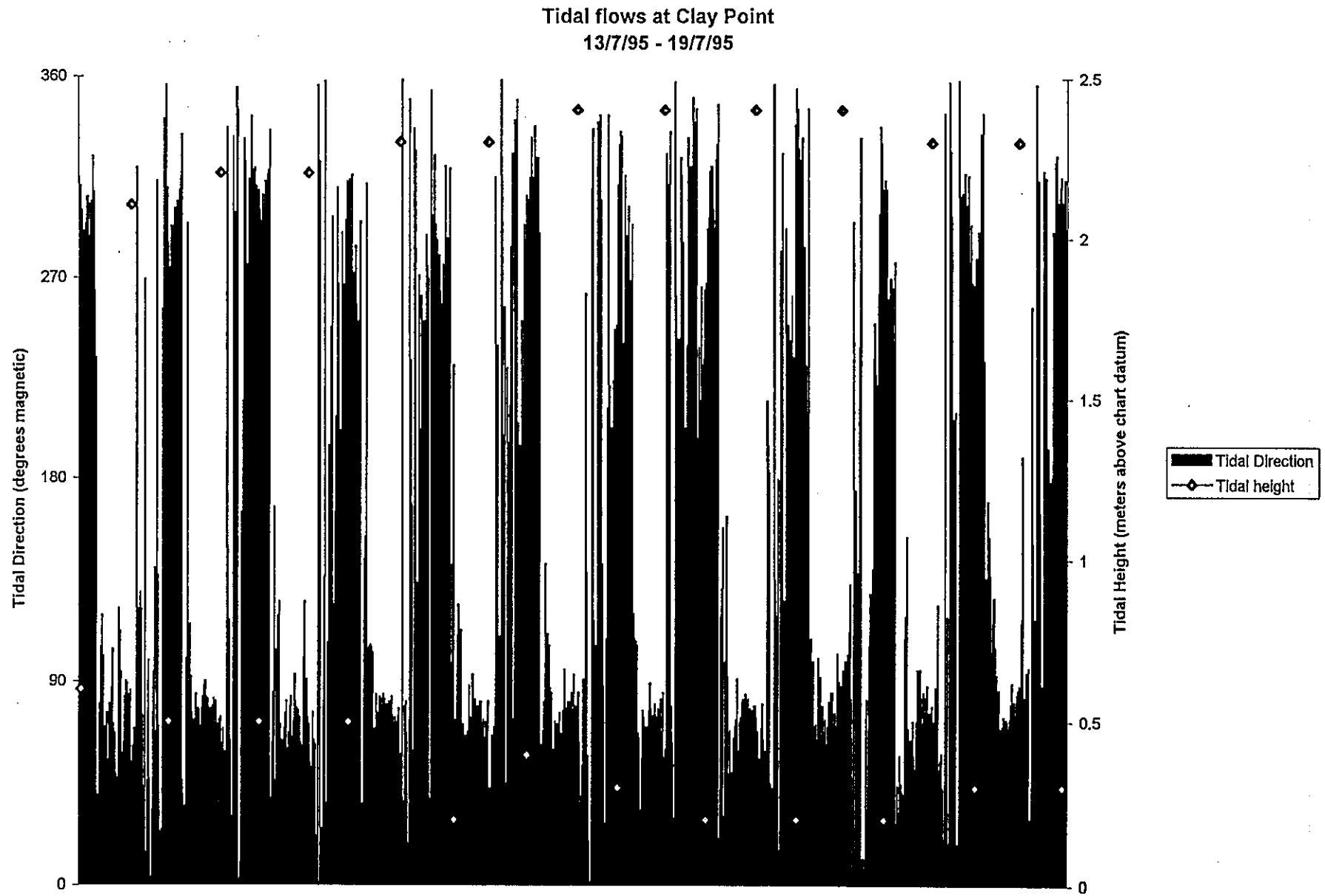


Figure 11: Clay Point. Variation in current direction with time and state of tide. The diamond symbols indicate time of ebbing (ebb) and westing (flood) flows, and also the height of the tide.

Correlation between current velocity & Direction
Clay Pt.
13-7-95 to 19-7-95

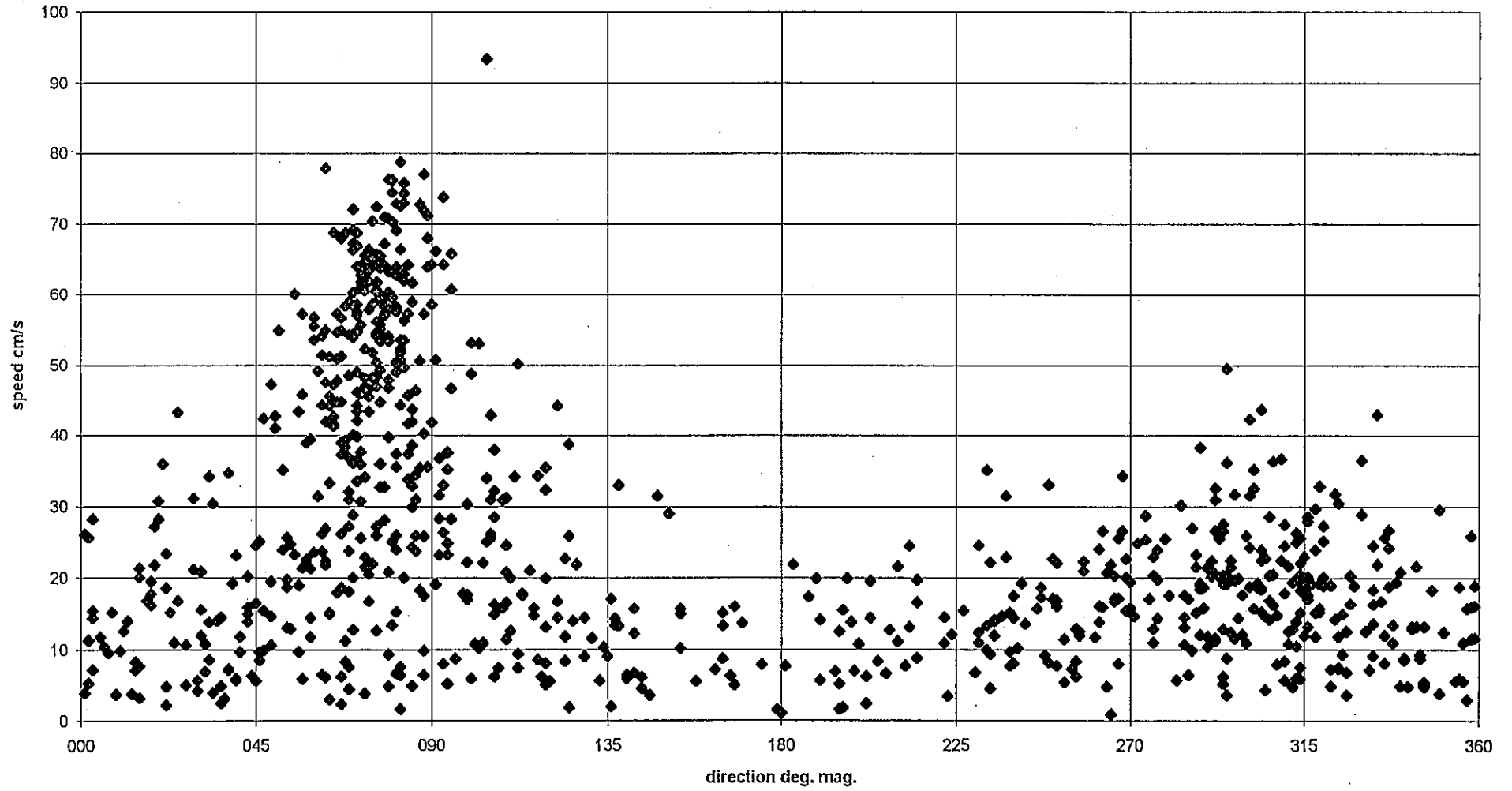


Figure 12: Clay Point. Current speed plotted against direction.

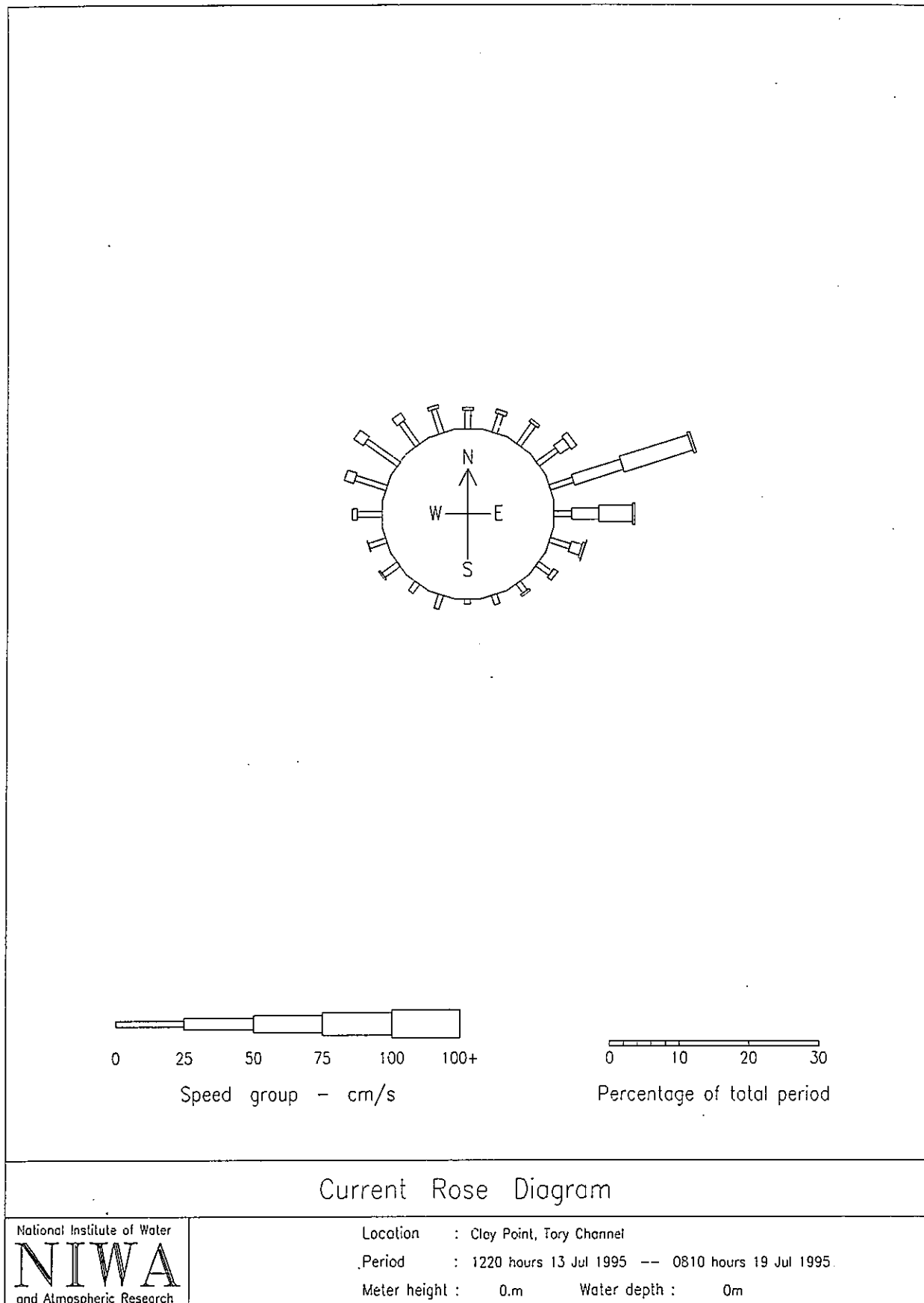


Figure 13: Clay Point. Current rose diagram showing the pronounced E to ENE set of the current.

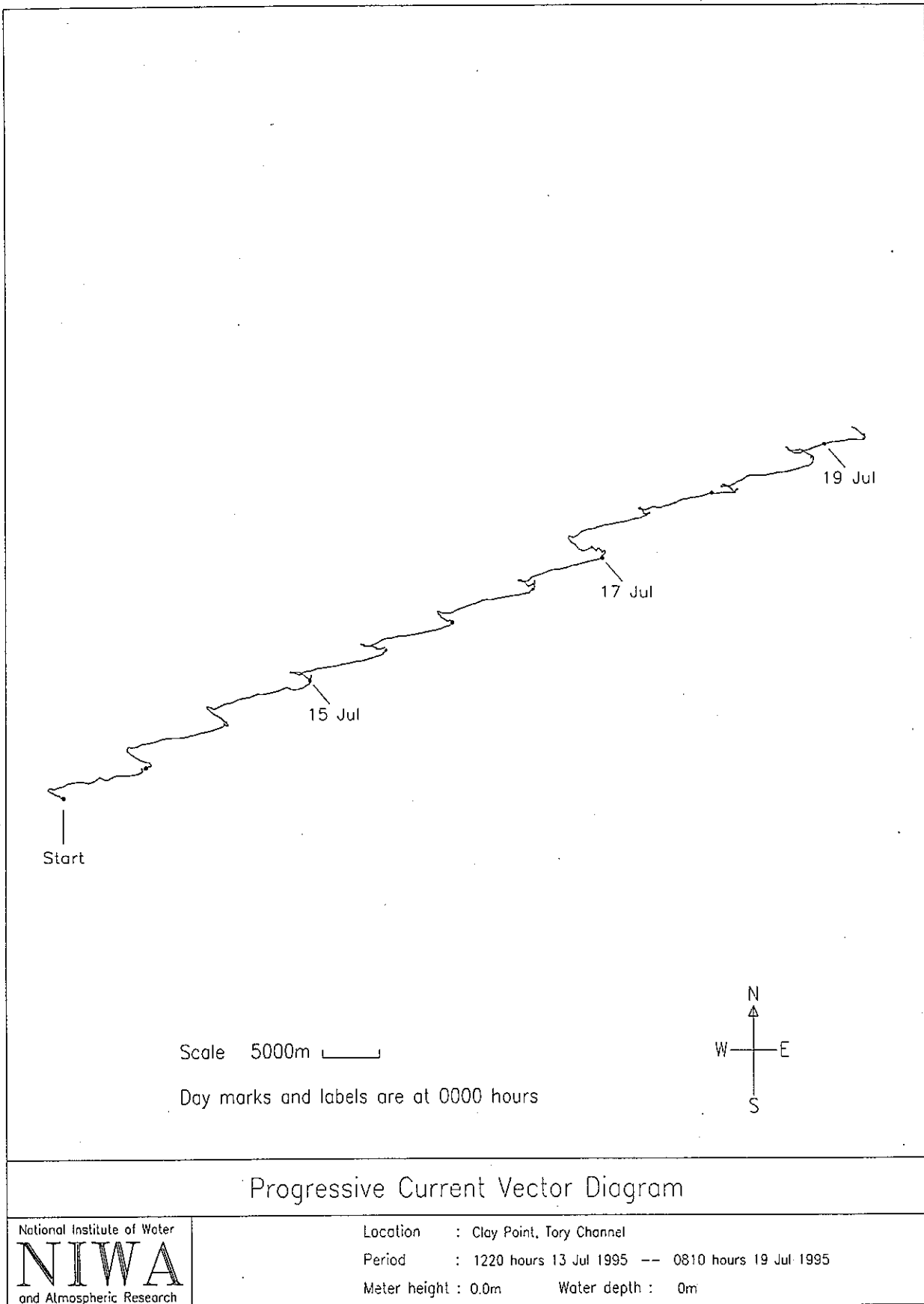


Figure 14: Clay Point. Progressive current vector diagram showing the net movement to the ENE and the brief tidal reversals to the NW.

1013 (substitution of)

Cawthron Report No. 353

LIBRARY



CAWTHRON

**Ecological effects of the Te Pangu Bay
salmon farm, Tory Channel**

Report for:

Regal Salmon Ltd

Author:

Barrie Forrest

Date:

October 1996

■ 98 HALIFAX ST EAST ■ PRIVATE BAG 2 NELSON NEW ZEALAND ■ TEL 0-3-548 2319 FAX 0-3-546 9464

Library

Cawthron Report No. 353

**Ecological effects of the Te Pangu Bay
salmon farm, Tory Channel**

Report for:

Regal Salmon Ltd

Author:

Barrie Forrest

Date:

October 1996

TABLE OF CONTENTS

1. INTRODUCTION.....	1
2. METHODS.....	1
2.1 Sites.....	1
2.2 Organic Enrichment.....	1
2.3 Ecological Effects.....	1
3. RESULTS AND DISCUSSION.....	3
3.1 Sediment Texture and Enrichment.....	3
3.2 Sediment-dwelling Macrofauna.....	5
3.3 Surface-dwelling Biota.....	8
3.4 Significance of Salmon Farm Effects.....	8
3.5 Recommendations for Further Investigation.....	9
3.6 Summary and Conclusions.....	9
4. REFERENCES CITED.....	10
Appendix 1: Counts of macrofaunal taxa in replicate core samples.....	11

Figures and Tables

Figure 1: Location of sampling sites and dive transect at the Te Pangu salmon farm.....	2
Figure 2: Sediment core photographs.....	4
Figure 3: Mean organic matter content of sediment samples.....	5
Figure 4: Mean number of macrofaunal taxa and mean density per core sample.....	6
Table 1: Taxa comprising 5% or more of total macrofaunal abundance.....	7
Table 2: Generalised model of the effects of organic enrichment.....	7

1. INTRODUCTION

Regal Salmon Ltd has asked Cawthron to carry out a survey of the ecological effects of their Te Pangu Bay salmon farm. Previous monitoring surveys carried out by Cawthron have concluded that seabed effects beneath the Te Pangu Bay cages are minimal (Gillespie and MacKenzie, 1990; Gillespie *et al.*, 1991; Gillespie, 1994). This contrasts with much of the published information on sea cage salmon farm effects which show that the faeces and uneaten food pellets which settle out beneath the cages often cause extreme organic enrichment of the seabed (Weston, 1986; Gowen and Bradbury, 1987; Findlay, 1995). The likely explanation for the low level effects observed at the Te Pangu Bay farm to date is that the high tidal current velocities around the farm (Hay, 1995) prevent the build-up of enriched sediments. This report describes the results of the latest monitoring survey carried out by Cawthron on 4 March 1996, approximately seven years after production began at the Te Pangu Bay site.

2. METHODS

2.1 Sites

Replicate sediment cores were collected from sites indicated in Figure 1. These sites were a subset of those sampled in the pre-farming baseline survey of Gillespie *et al.* (1989) and were located as follows:

- One site at 32m water depth directly beneath the salmon cages (referred to as site A2 by Gillespie *et al.*, 1989). Sampling was carried out beneath cages having a maximum salmon biomass.
- Sites at 25m and 50m from the east end of the cages (28-30m depth), corresponding to the direction of maximum water current velocity (Hay, 1995).
- A control site in adjacent Te Weu Weu Bay (27m depth).

2.2 Organic Enrichment

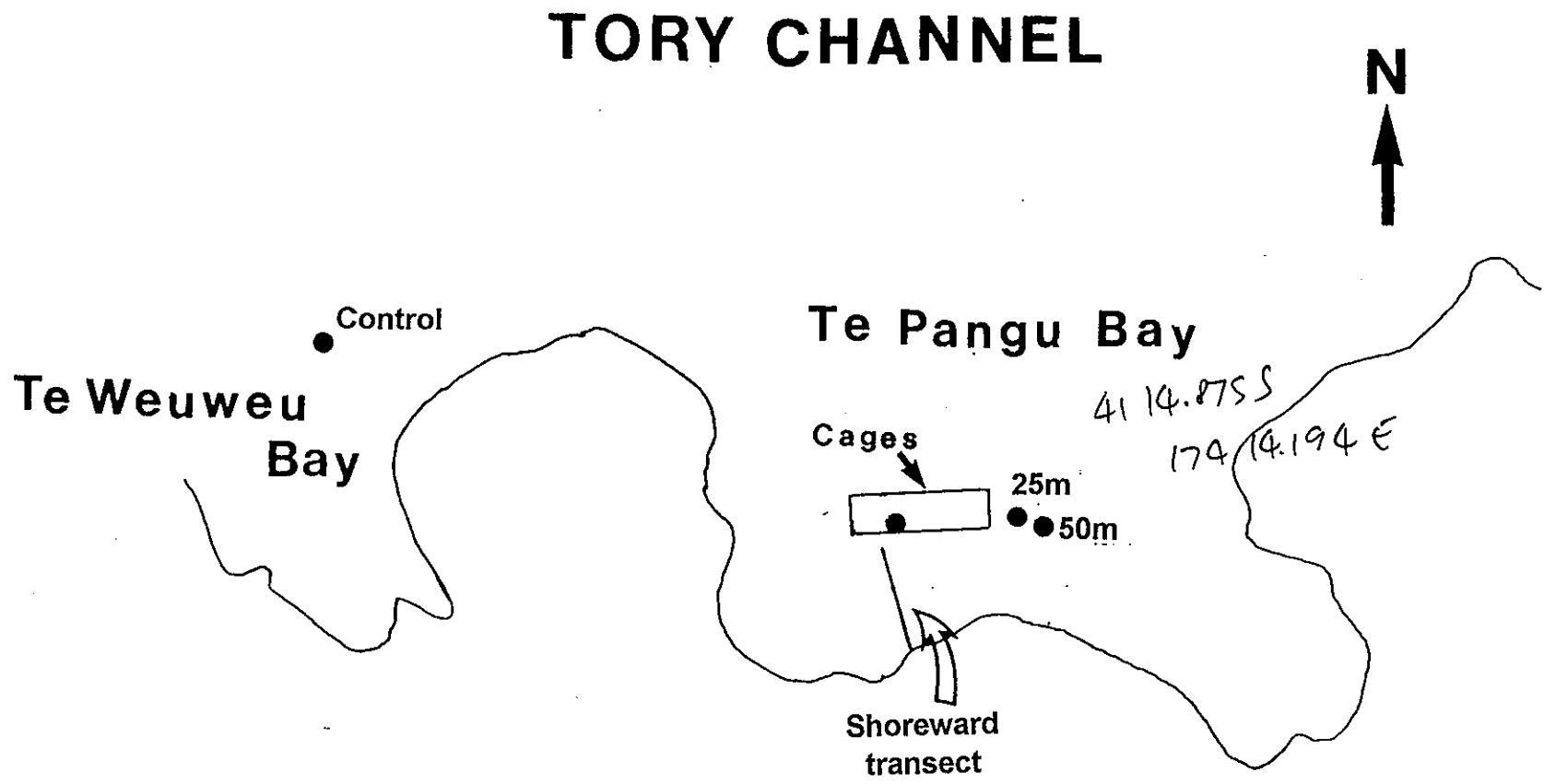
At each site, three sediment cores of 63mm diameter and approximately 100mm long were collected from the seafloor by divers. Cores were photographed to provide a comparative record of the level of organic enrichment. Unenriched sediments are typically grey/brown and odourless whereas enriched sediments are often grey/black and smell of hydrogen sulphide. The surface 50mm of sediment in each core was retained and analysed for percentage ash-free dry weight as a measure of organic content. These data were compared to those from the baseline survey (Gillespie *et al.*, 1989) and subsequent monitoring studies (Gillespie and MacKenzie, 1990; Gillespie, *et al.*, 1991).

2.3 Ecological Effects

The following habitat characteristics were noted by divers at each site, and along a transect 50m from the shoreward edge of the salmon farm (24m depth) to the shore (Figure 1):

- Sediment texture (*i.e.* estimate of amount of sand/mud/shell, sediment cohesiveness *etc.*)
- Plant and animal species living on the surface of the seabed.

Figure 1: Location of sampling sites (filled circles) and the shoreward dive transect at the Te Pangu Bay salmon farm.



Because of the constraints on dive time imposed by site depth, emphasis was placed on noting the conspicuous plant and animal assemblages rather than compiling an extensive list of biota.

At each sampling site, divers also collected five sediment cores of 130mm diameter (100mm deep). These cores were sieved through a 0.5mm mesh and the 'macrofauna' retained on the sieve were preserved for later identification and counting. The presence, absence and density of macrofauna in core samples provides a sensitive bio-indicator of ecological change. This technique was not used in previous surveys, since the purpose of these surveys was to describe any major ecological effects using changes in habitats and the densities of key surface-dwelling species as indicators. The inclusion of macrofaunal sampling in the 1996 survey aimed to provide an indicator of the more subtle changes which may occur *within* the seafloor sediments beneath the salmon farm, rather than at the sediment surface. An advantage of using macrofauna is that they can be easily sampled using standardised and repeatable methods to provide a quantitative 'baseline' against which any future survey results can be compared.

3. RESULTS AND DISCUSSION

3.1 Sediment Texture and Enrichment

The seafloor beneath the salmon farm was firm, and consisted of an estimated 70-80% fine sand and 20-30% shell grit and mud. There was no evidence of an accumulation of organic-rich particulates beneath the salmon cages. Nevertheless, a moderate level of enrichment was evident within seafloor sediments beneath the farm. This enrichment was also present at sites 25m and 50m from the east end of the cages, although slightly less than that directly beneath them. Sediments at farm and east transect sites were grey/black (Figure 2) and had a mild smell of hydrogen sulphide, whereas the control site consisted of golden brown relatively odourless sand. Organic matter levels were highest beneath the farm (4.8%) and lowest at the control site (2.6%) (Figure 3).

Compared with previous years, organic matter levels in the 1996 survey are higher, especially at the site beneath the cages and 50m east (Figure 3). Beneath the cages there has been a steady increase in the level of organic matter since farming commenced. It is difficult to say whether this is a real trend which reflects a build-up of organic material beneath the cages over the years, or whether it reflects sampling variation. Overall, organic levels beneath the cages are very low. Published data and our previous experience suggests shows that organic matter levels beneath salmon cages typically range from approximately 15-45%. Interestingly, in moving shoreward from the farm, sediments changed from firm sands to softer sandy muds, with no organic enrichment evident 50m shoreward of the cages. This highlights the strong tidal currents present in the vicinity of the farm which disperse farm wastes and fine sediments along a predominantly west-east axis, parallel to the shore.

Figure 2: Sediment cores from the Te Pangu Bay farm (top), 50m east (middle) and control (bottom). Note the black colour of the farm cores indicating organic enrichment.

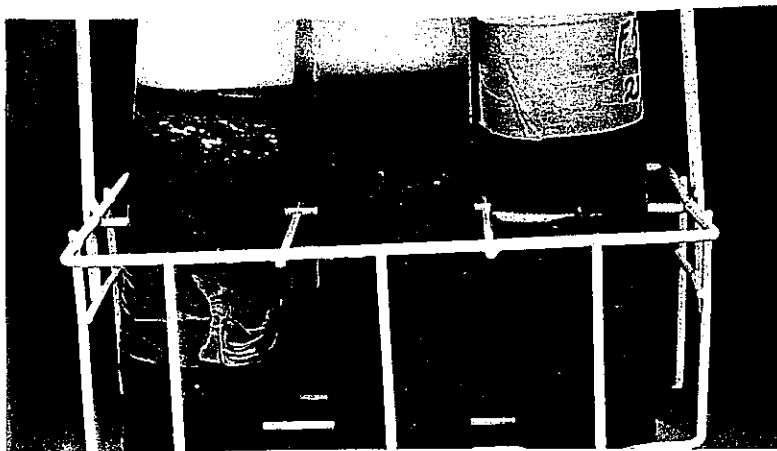
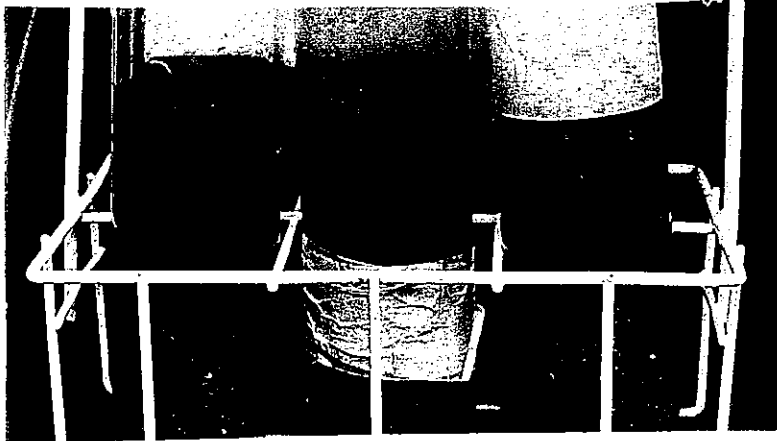
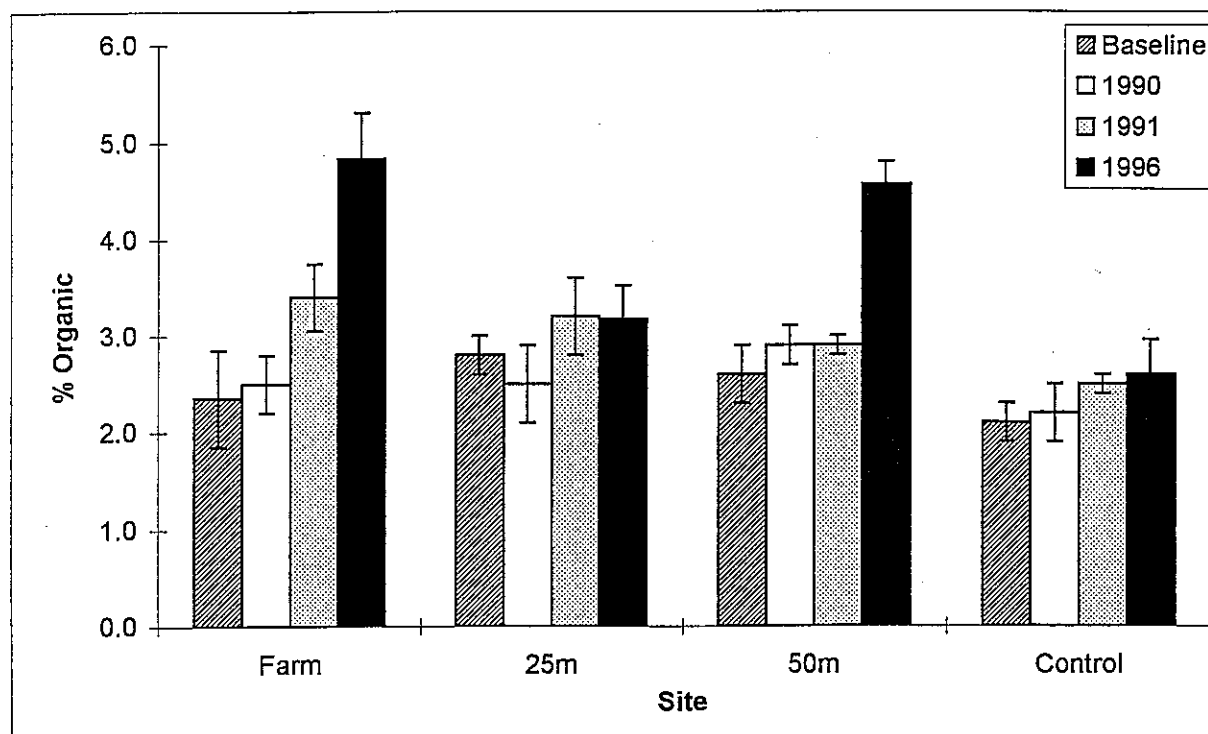


Figure 3: Mean organic matter content (\pm SE) of sediment samples.



3.2 Sediment-dwelling Macrofauna

Raw data on macrofaunal taxa¹ and densities within each sample are given in Appendix 1. Beneath the cages, and at sites 25m and 50m from the eastern edge, the number of macrofaunal taxa ranged from 3 to 12 (Appendix 1), and on average was approximately half that of the control site (Figure 4). The relatively diverse range of polychaete worms and bivalve molluscs present at the control site were absent from the farm and eastern transect sites. The mean abundance of macrofauna was at least ten-fold higher beneath farm and east transect sites than at the control. The significantly greater abundance at the sites affected by the farm was attributable to the presence of very high densities of nematode and capitellid worms, which together comprised 94-99% of the total macrofaunal abundance (Table 1). These taxa are regarded as 'opportunistic' species which are often numerically dominant in enriched sediments. At the control site on the other hand, no single taxon was numerically dominant, with 8 different taxa comprising 5% or more of total macrofaunal abundance (Table 1).

The macrofaunal patterns observed conform to the well established effects of organic enrichment detailed in a review by Pearson and Rosenberg (1978). Using the information from this review, a generalised model of the response of macrofauna to different levels of organic enrichment is summarised in Table 2. Using the criteria in Table 2, the seabed beneath the Te Pangu Bay farm and on eastern transect sites would be classed as 'moderately' enriched.

¹ Taxa (plural of taxon) refers either to a single species or several different species within a recognisable animal or plant group.

Figure 4: Mean number of macrofaunal taxa and mean density per core sample (\pm SE).

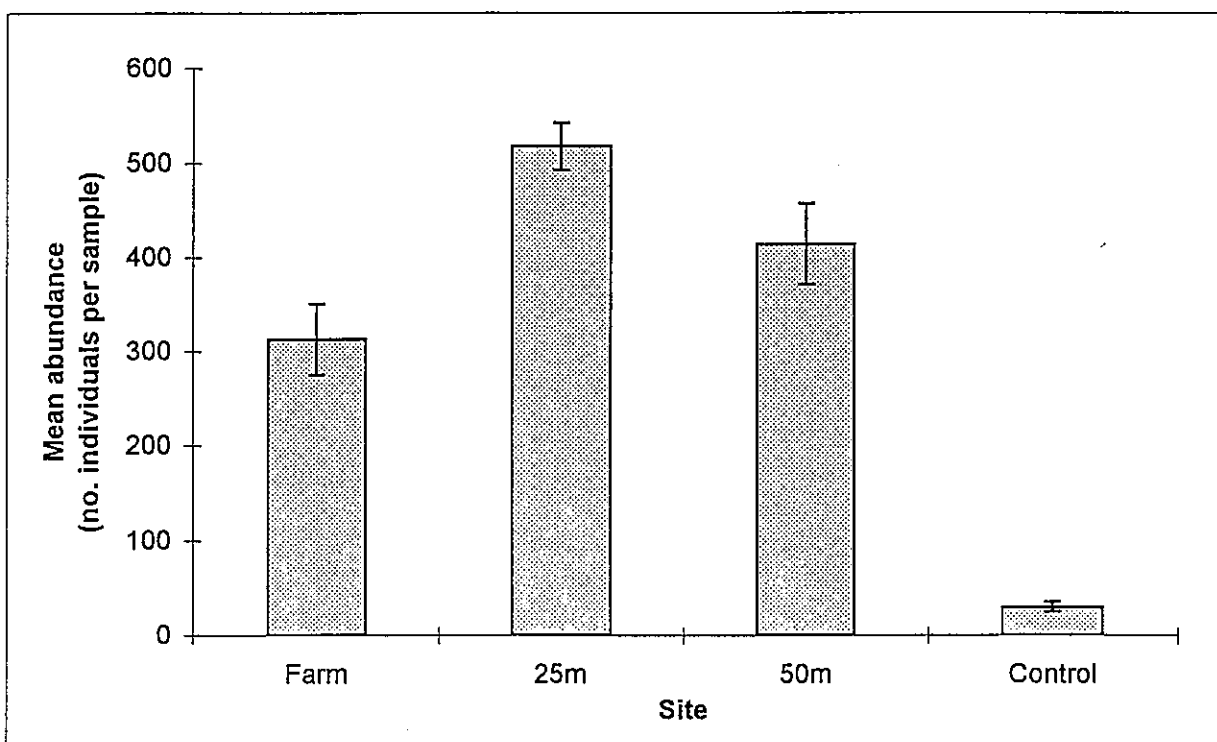
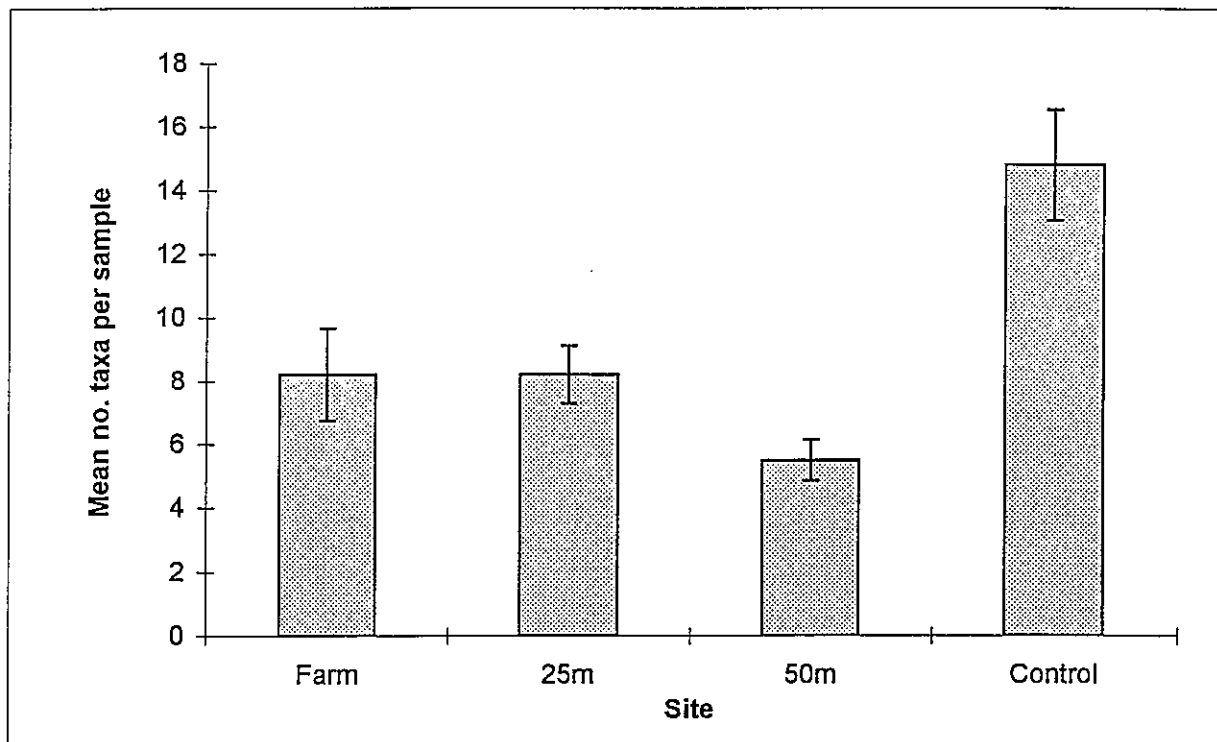


Table 1: Taxa comprising 5% or more of total macrofaunal abundance at any one site.

Site	Taxon	Percent contribution
Te Pangu Bay farm	Nematoda	46
	Capitellidae	48
	<i>Combined contribution</i>	<i>94</i>
25m east	Nematoda	39
	Capitellidae	59
	<i>Combined contribution</i>	<i>98</i>
50m east	Nematoda	50
	Capitellidae	49
	<i>Combined contribution</i>	<i>99</i>
Control	Capitellidae	20
	Cossuridae	7
	Glyceridae	5
	Paraonidae	15
	Cumacea	11
	Amphipoda	5
	Ostracoda	6
<i>Combined contribution</i>	<i>69</i>	

Table 2: Generalised model of the effects of organic enrichment (based on Pearson and Rosenburg, 1978)

Level of enrichment	Macrofaunal Response
Normal	Moderate species richness with a moderate abundance distributed evenly among species
Low	Transition zone: abundance and species richness may be higher than 'normal'
Moderate	Moderate-low species richness with a few 'opportunist' species occurring in high abundance
High	Low species richness consisting of one or a few opportunist species which reach very high abundance levels
Extreme	Anoxic, sulphide-rich conditions either devoid of macrofauna or having very few species in very low abundance

3.3 Surface-dwelling Biota

Farm and east transect sites

The farm and east transect sites had a similar surface-dwelling biota. Tufts of foliose red algae (< 1% cover overall) were noted. The dominant species were *Hymenena palmata* and *Pterocladia* spp. which are typical of low light conditions. The filter feeding anemone *Actinothoe albocincta* was common at all sites, but no other surface-dwelling biota were noted. The surface-dwelling biota appears reduced in comparison with that noted by Gillespie *et al.* (1989) during the baseline survey, suggesting that the farm has had some adverse effect. However, the effect is clearly not adverse to the point that all species are excluded, and it is encouraging that species such as *Actinothoe albocincta* which are regarded as being sensitive to excessive sedimentation are still common.

Shoreward transect

As noted in section 3.1, the enrichment evident 50m from the eastern boundary of the farm was not evident 50m shoreward. At 50-100m shoreward of the cages (approximately 20-24m water depth), common biota in addition to that described beneath the cages included snakestars (*Pectinura maculata*), cushion stars (*Patiriella regularis*), solitary ascidians (*Cnemidocarpa bicornuata*), and thecate hydroids (*e.g. Solanderia racemosa*), and a more diverse and dense assemblage of red algae was present.

During the baseline survey, Gillespie *et al.* (1989) found that, relative to the farm site, the biota along this shoreward transect were considerably more diverse and abundant. Hence the apparently impoverished biota now present beneath the cages is not only a reflection of a farm impact, but also indicates a natural ecological change as water depth increases. The surface-dwelling biota at the deeper control site were similarly impoverished.

3.4 Significance of Salmon Farm Effects

The results of this and previous surveys indicate that the strong shore-parallel tidal current at the Te Pangu Bay salmon farm minimises the overall magnitude of the farm effect, although the effect is discernible further from the farm edge than has been found in other studies. Previous Cawthron surveys indicate that the discernible effect of the Te Pangu Bay farm extends less than 100m from the east edge of the farm, but less in other directions. Other studies have shown that the zone of organic enrichment beneath salmon farms may be restricted to within 50m from the edge of cages (*e.g.* Weston, 1986; Edwards, 1988). In these situations, however, water currents are considerably weaker than at Te Pangu and the enrichment effect within this 50m zone is considerably more severe. In many cases, anoxic and sulphide-rich sediments develop beneath the cages in a matter of months after farming commences. These sediments can be inhospitable to macrofauna, and become covered with bacterial mats such as *Beggiatoa* spp. which are indicative of high sulphide levels at the sediment surface (Findlay *et al.*, 1995). While effects may be more localised than at Te Pangu, situations of extreme enrichment have a number of drawbacks:

- There is an increased likelihood that anoxic bottom waters will develop, and the release of toxic hydrogen sulphide will adversely affect the salmon stock.

- The seabed is likely to take months or even years to recover if farming is ceased. This is especially true for situations where macrofauna are completely destroyed, since macrofauna play a major role in sediment oxygenation and the processing of organic matter.

Hence while the Te Pangu farm may affect a relatively larger area of seabed, the seabed is only mildly enriched and still contains a relatively diverse and abundant macrofauna. Moreover, the effects which occur would be unlikely to persist for long if the farm was removed. From this perspective, the Te Pangu cages appear to be well sited to minimise environmental effects.

3.5 Recommendations for Further Investigation

There are two key areas which would be interesting to investigate further:

- The first is to establish where the transition between enriched and control conditions occurs off the eastern end of the farm. The main purpose of this would be to confirm that the extent of effects has not changed significantly since previous studies.
- The second is to gather further data on organic matter levels in the sediments. The main purpose of this would be to determine whether the increase in organic material beneath the cages over the years indicates a gradual increase in enrichment, which may have implications for farm management in the longer term.

3.6 Summary and Conclusions

- The deposition of organic-rich food and faeces beneath the Te Pangu salmon farm causes a moderate and localised enrichment of the seabed.
- At the time of the 1996 survey, the organic matter level beneath the farm site was about twice as high as at the control, and appears to have steadily increased since the farm was established. Overall, however, organic matter levels beneath the cages were relatively low compared with other farm locations.
- The number of macrofaunal taxa was reduced beneath the farm compared to a nearby control site. However, macrofaunal abundance was approximately ten fold greater beneath the farm, reflecting high densities of two worm species which thrive in the enriched sediments.
- Surface-dwelling biota appeared reduced in density and diversity compared with the 1989 baseline survey.
- A farm effect was discernible 50m east of the cages. Previous studies suggest that effects extend 50-100m off the east end of the farm, and less in shoreward and western directions.
- In a shoreward direction, no effect was discernible at 50m from the farm edge, highlighting the shore-parallel dispersion of farm waste caused by the strong west-east tidal current.
- Overall, the Te Pangu salmon farm appears to be well sited to minimise environmental effects.

4. REFERENCES CITED

- Edwards, J.M.R. 1988. The impact of sea cage salmon farming on the benthic environment of Big Glory Bay, Stewart Island. MSc Thesis, University of Otago, Dunedin, New Zealand.
- Findlay, R.H., L. Watling and L.M. Mayer. 1995. Environmental impact of salmon net-pen culture on marine benthic communities in Maine: a case study. *Estuaries* 18(1A): 145-179.
- Gillespie, P. 1994. Comment of the state of the seabed environment beneath salmon-rearing cages at Te Pangu Bay: observation made 24-25 August 1994. Cawthron Report No. 266, Cawthron Institute, Nelson. 4p.
- Gillespie, P. and L. MacKenzie. 1989. Site characterisation of proposed salmon farm licence area in Te Pangu Bay, Tory Channel. Cawthron Report No. 172, Cawthron Institute, Nelson. 8p. plus plates.
- Gillespie, P. and L. MacKenzie. 1990. Monitoring survey of Te Pangu Bay salmon rearing site, Tory Channel. Cawthron Report, Cawthron Institute, Nelson. 10p. plus plates.
- Gillespie, P., L. MacKenzie and R. Asher 1991. Monitoring survey of Te Pangu Bay salmon rearing site, Tory Channel. Cawthron Report, Cawthron Institute, Nelson. 7p. plus plates.
- Gowan, R.J. and N.B. Bradbury. 1987. The ecological impact of salmonid farming in coastal waters: a review. *Oceanography and Marine Biology Annual Review* 25: 563-575.
- Hay, C. 1995. Current velocity measurements near Te Pangu Bay, Tory Channel, Queen Charlotte Sound. Cawthron Report No. 298, Cawthron Institute, Nelson. 24p.
- Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Ann. Rev.* 16: 229-311.
- Weston, D.P. 1986. The environmental effects of floating mariculture in Puget Sound. Report for Washington Department of Ecology. Washington.

ACKNOWLEDGEMENTS

I am gratefully indebted to Sam Buchanan and Larry Oakley for assistance with field sampling, and to Paul Gillespie for his review of this report.

Appendix 1: Counts of macrofaunal taxa in replicate core samples.

SITE	Common Name	TP-F					TP-25					TP-50				TP-control					
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	1	2	3	4	5	
NEMATODA	(round worms)	61	135	177	181	164	237	256	153	212	158	208	284	189	148		1	2		2	
SIPUNCULA	(peanut worm)																		1	1	
PRIAPULIDA																1					
MOLLUSCA	(molluscs)																				
GASTROPODA	(snails)																				
<i>Amalda mucronata</i>																1					
<i>Buccinum lineum</i>									1												
<i>Dentalium sp</i>	tusk shell																1				
Unidentified sp.1										1										1	
PELECYPODA	(bivalves)																				
<i>Arthritica bifurca</i>		8							1	1			1								
<i>Atrina zelandica</i>	(horse mussel)																	1		1	
<i>Corbula zelandica</i>		1	2	6	1								1								
<i>Ennucula strangei</i>																	1				
<i>Leptomys reliaria</i>				1									2	2							
<i>Notocallista multistriata</i>																1	1			1	
<i>Nucula nitidula</i>																		1		1	
<i>Thracia spp.</i>																		1		1	
<i>Thyasira resupina neozelanica</i>																	1				
<i>Venericardia purpuata</i>																				1	
<i>Venerupis largillierti</i>									1												
Unidentified sp.1																			1	1	
POLYCHAETA	(bristle worms)																				
Capitellidae		101	177	214	162	104	317	302	274	276	354	255	197	207	144	1	12	5	4	8	
Cossuridae																		1	2	6	1
Dorvilleidae			2	1				2			1			7	1						
Flabelligeridae							1												1		
Glyceridae							1		1		1	1				1	3		2	2	
Lumbrineridae							1										1			1	
Nereidae	(rag worms)	9	3	5	3	6	3	6	4	1		1	1								
Paraonidae																	1	7	6	6	3
Phyllodoceidae	(paddle worms)	1	1	1														1			
Polynoidae	(scale worm)		1					1													
Spionidae		3	7	5	1		3	1	2	3	2	1	1	2		1	1			1	
Syllidae							1											1			
Terebellidae			3					1													
CRUSTACEA	(crustaceans)																				
Cumacea	(cumaceans)																2	4	5	5	
<i>Nebalia sp.</i>		3			1									1							
Amphipoda		3	1	2	1		1	2		1			1					2	3	2	1
Isopoda																				1	
Eurydicidae	(sea lice)							1													
Ostracod																	1	2	2	1	3
Decapoda																					
<i>Halicarcinus cookii</i>	(spider crab)		2																		
<i>Pagurus novaezelandiae</i>	(hermit crab)																		1		
Unidentified crab (larvae)																			1		
Shrimp							1													1	
Tanaid shrimp			3		1														1	1	1
Crustacean (unidentified sp.1)									1	1							1				
Ophiuroidea	(brittle star)																			1	1
Total no. macrofauna		190	337	412	351	274	566	572	435	498	517	466	485	409	295	12	45	31	28	33	
Total no. of taxa		9	12	9	8	3	10	9	6	10	6	5	6	7	4	11	21	13	13	16	
Mean no. macrofauna/core		313					518					414			30						
Mean no. taxa/core		8.2					8.2					5.5			15						

101013 (substation of)
Cawthron Report No. 306

LIBRARY



CAWTHRON

Effects of expanded salmon farm mooring zone, Te Pangu Bay, Tory Channel, Marlborough Sounds

Report for: Regal Salmon Limited

Author: Sean Handley

3 October 1995

INTRODUCTION

Regal Salmon have retained Cawthron to carry out an ecological site characterisation of the seabed of the proposed expanded mooring zones of an existing Salmon Farm in Te Pangu Bay, Tory Channel, Marlborough.

The original environmental site characterisation was carried out by Cawthron for Regal Salmon Limited, 25-26 October 1989 (Gillespie & MacKenzie 1989). Three subsequent monitoring surveys have been carried out by Cawthron in 1990 (Gillespie & MacKenzie 1990), 1991 (Gillespie, *etal.* 1991), and 1994 (Gillespie, *etal.* 1994).

The expanded mooring zone is proposed to allow better utilisation of the existing farm and meet mooring requirements. The scope of the ecological assessment described in this report is a qualitative characterisation of the seabed and evaluation of the potential effects of mooring structures in the area of the proposed expanded mooring zone around the existing farm.

METHODS

On the 18th of September 1995, a survey of the ecology of the seafloor in the vicinity of the proposed mooring zone was carried out. Methods included visual observations using SCUBA, dredging areas beyond safely diveable depths, and depth profiles with an echo sounder (Figure 1). Estimates of species abundances are given after species names as (R)= rare, (C)= common, and (A)= abundant. Emphasis was placed on identifying the presence of features of ecological significance.

RESULTS AND DISCUSSION

- Depth profile (transect)

A dive transect was carried out from the shore line to 20 metres depth within the south-eastern boundary of the proposed mooring zone (Figures 1 & 2). The near-shore zone comprised shallow sloping boulder habitat colonised by patches of large brown seaweed (*Macrocystis pyrifera* C, *Carpophyllum flexuosum* R) interspersed with patches of small coralline encrusted cobbles with abundant cats eyes (*Turbo smaragdus* A), snakestars (*Pectinura maculata* C), kina (*Evechinus chloroticus* C) and the fish tripplefin and spotties.

Below this reef community the substrate changed to fine white sand/shell inhabited by snakestars (*Pectinura maculata* C), cushion stars (*Patiriella regularis* R), sea lettuce (*Ulva* sp. C), spotties (*Notolabrus celidotus*) and blue cod (*Parapercis colias*). Fine grained white sand dominated below 10 metres of depth overlaid by a thin layer of brown diatom film. The seafloor then sloped away more rapidly to 24 metres where again clumps of sea lettuce (*Ulva* sp. R) were observed.

Between 26 to 29 metres the seafloor levelled out and the substrate changed to coarse shell/gravel habitat which had little mud indicating scouring by high currents. Fish were abundant including spotties, triplefin, and blue cod, and there were patches of kina (*Evechinus chloroticus* C), snakestars (*Pectinura maculata* C), horse mussel (*Atrina zelandica* <0.1/m²), sea cucumber (*Stichopus mollis* R), tunicates (C), sponges (0.1/m²) hermit crabs (A).

- Dredge sample

Samples of the seafloor biota were taken from the western boundary of the farm using a scallop dredge with a 1cm mesh netting (Figure 1). Organisms collected in the dredge included snakestars (*Pectinura maculata*), cushion stars (*Patiriella regularis*), nesting mussels (*Modiolarca impacta*), hermit crabs, sea squirts, and encrusting bryozoans which were typical of the animals found in the coarse shell/gravel habitat of the dive transect (above).

- Effects of salmon farm mooring structures.

The observations recorded in this survey were similar to those of the previous surveys with a noted increase in the proportion of shell material at the boundary of the farm and again a lack of scallops and kina. Gillespie *etal.* (1994) noted a localised decrease of previously common species including snake stars, cushion star, tunicates, bryozoans, sponges and hermit crabs within the boundary of the farm. These species were noted to be more common at the boundary of the farm supporting Gillespies observations of a localised impact on these species directly beneath the farm. Algal cover was again very low in the vicinity of the farm boundary but as Gillespie *etal.* (1994) noted this was again likely to be the result of a winter seasonal effect.

The area of the seabed to be impacted by the 29 mooring blocks proposed for the site will be approximately 174m² or 0.19% of the total salmon farm and mooring zone area. As the zones where the mooring blocks will be placed are subjected to high currents and the organisms inhabiting this environment are common in Tory Channel, it is expected that the impacts of these structures will produce minimal ecological effects. In fact, the mooring blocks will increase the habitat diversity of the local area, which is likely to increase species diversity.

REFERENCES

- Gillespie, P., & MacKenzie, L. 1989. Site characterisation of proposed salmon farm licence area in Te Pangu Bay, Tory Channel. *Cawthron report No.172. pp8.*
- Gillespie, P., & MacKenzie, L. 1990. Monitoring survey of Te Pangu Bay salmon rearing site, Tory Channel. *Cawthron report.*
- Gillespie, P., MacKenzie, L., & Asher, R. 1991. Monitoring survey of Te Pangu Bay salmon rearing site, Tory Channel. *Cawthron report.*
- Gillespie, P., Asher, R., Quaterman, A., & Oakley, L. 1994. Comment on the current state of the seabed environment beneath salmon-rearing cages at Te Pangu Bay: Observations made 24-25 August 1994. *Cawthron report No. 266. pp4.*

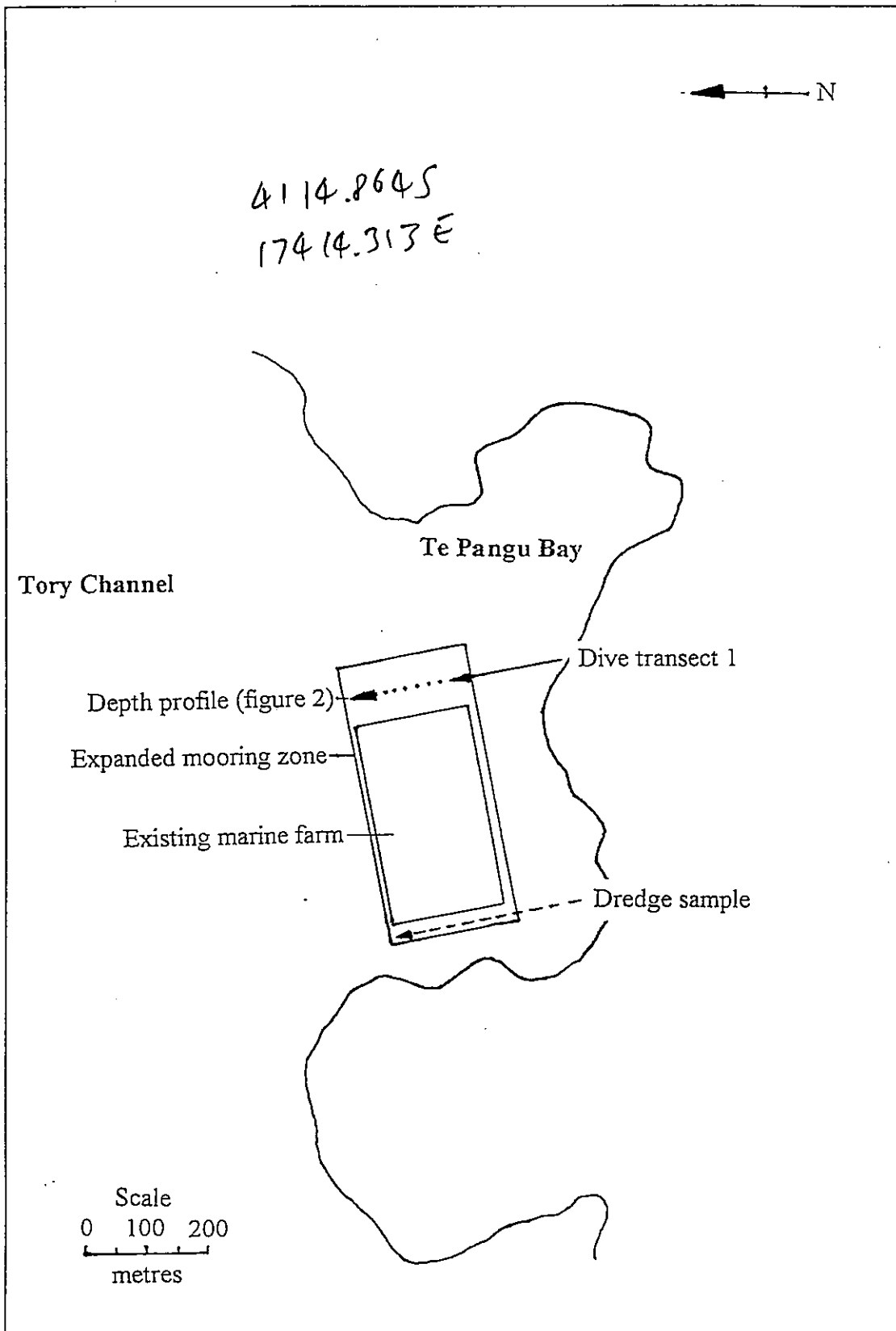
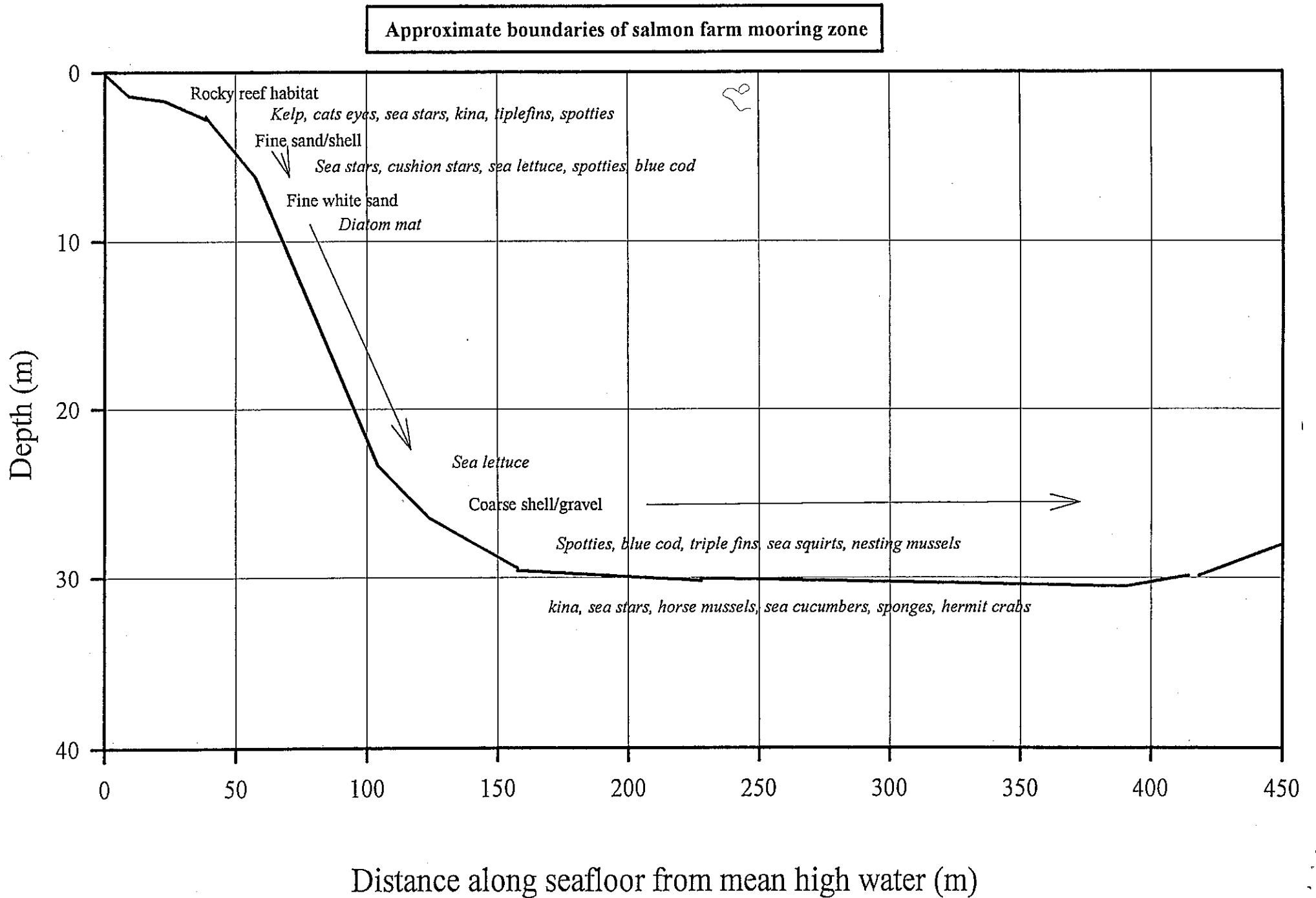


Figure 1 Proposed salmon farm mooring zone indicating dive transect, depth profile, and dredge sampling.

Figure 2. Subtidal profile indicating common substrata and species



- Gillespie, P.; MacKenzie, L. 1990: Monitoring survey of Te Pangu Bay salmon rearing site, Tory Channel. *Cawthron Report*, Cawthron Institute, Nelson. 10p plus plates.
- Gillespie, P.; MacKenzie, L.; Asher, R. 1991: Monitoring survey of Te Pangu Bay salmon rearing site, Tory Channel. *Cawthron Report*, Cawthron Institute, Nelson. 7p plus plates.
- Garnier, E. 1997: Bay of Fundy salmon aquaculture environmental management project: 1997 grower report. Prepared for Jail Island Salmon Ltd. 10p.
- Gowen, R.J.; Bradbury, N.B. 1987: The ecological impact of salmonid farming in coastal waters: a review. *Oceanography and Marine Biology Annual Review* 25: 563-575.
- Hay, C. 1995: Current velocity measurements near Te Pangu Bay, Tory Channel, Queen Charlotte Sound. *Cawthron Report No. 298*, Cawthron Institute, Nelson. 24p.
- Iwama, G.K. 1991: Interactions between aquaculture and the environment. *Critical Reviews in Environmental Control* 21: 177-216.
- Luczak, C., Janquin, M., Kupka, A. 1997: Simple standard procedure for the routine determination of organic matter in marine sediment. *Hydrobiologia* 345:87-94.
- Samuelsen, O.B.; Ervik, A.; Solheim, E. 1988: A qualitative and quantitative analysis of the sediment gas and diethylether extract of the sediment from salmon farms. *Aquaculture* 74: 277-285.

ACKNOWLEDGEMENTS

I am gratefully indebted to Stephen Brown (Cawthron) and staff from the Ruakaka salmon farm for their assistance with field work, and to Paul Barter (Cawthron) for providing Figure 1 and reviewing this report.

11010103 (substation)

Library



LIBRARY

Seabed Impacts of the Te Pangu Salmon Farm: Annual Monitoring Report 1998

Prepared for

The New Zealand King Salmon Company Ltd

by

Barrie Forrest

Cawthron Institute
98 Halifax Street East
Private Bag 2
NELSON
NEW ZEALAND

Phone: +64 3 548 2319

Fax: +64 3 546 9464

Email: info@environment.cawthron.org.nz

Information contained in this report may not be used without the prior consent of the client

1. INTRODUCTION

As part of their environmental monitoring strategy, New Zealand King Salmon (NZKS) contracted Cawthron to design a programme for annual monitoring of seabed impacts of their Marlborough Sounds salmon farms. Our recommendation to the Company was that they carry out a detailed survey of effects at least every five years, along the lines of the Cawthron surveys carried out at the Te Pangu and Ruakaka Bay farms in early 1996 (Forrest 1996a, 1996b). We suggested that, in the interim years, they should carry out a scaled-down and lower-cost survey using some key indicators of seabed enrichment.

The purpose of undertaking scaled-down annual surveys is to develop a long term record of salmon farm impacts which will not only fulfil regulatory monitoring requirements, but also provide essential information on the need for, or success of, changes in the Company's operational practices. In addition, the Company wished for farm managers and workers to be actively involved in the surveys so that they gained a better understanding and awareness of the effects of salmon farming.

This report describes an annual monitoring survey carried out on 29 September 1998 at the Te Pangu Bay salmon farm in Tory Channel, Queen Charlotte Sound. Field investigations at the Te Pangu farm were carried out in conjunction with surveys at nearby NZKS salmon farms at Ruakaka Bay and Otanerau Bay (Forrest 1998a, 1998b).

2. METHODS

The programme involved sampling and observations at three of the four seabed sites surveyed in March 1996 (Forrest 1996a) which were a subset of those sampled in a pre-farming baseline survey by Gillespie & MacKenzie (1989). These sites (ranging from 29-30m deep) are shown in Figure 1 and were as follows:

- Beneath the most heavily stocked cages at a site referred to as site A2 by Gillespie & MacKenzie (1989).
- 50m east of the cages in the direction of maximum water current velocity as measured by Hay (1995). The addition of new cages to the east end of the farm (not stocked with fish at the time of our survey) means that the 50m east site is now at the edge of the new cages, and will need to be relocated for future surveys.
- At a control site on the north side of Tory Channel, in an embayment between Deep Bay and Kawhia Bay. This was a change from the Te Weu Weu Bay control site previously sampled by Forrest (1996a), and was chosen because it was considered more representative of pre-farm conditions at Te Pangu.

Three sediment cores (63mm diameter, 100mm long) were collected from each site by divers. Cores from the control site and 50m site were collected by NZKS divers from the nearby Ruakaka salmon farm, and cores from beneath the cages were collected by Cawthron divers.

For each site, the three core samples were photographed and the surface 50mm was pooled into a single composite sample for analysis of % silt/clay (< 63µm) and % organic matter. These analyses provide a measure of the extent of sedimentation and organic loading from waste salmon food and faecal material. The % silt/clay was analysed by wet sieving without removal of carbonate material.

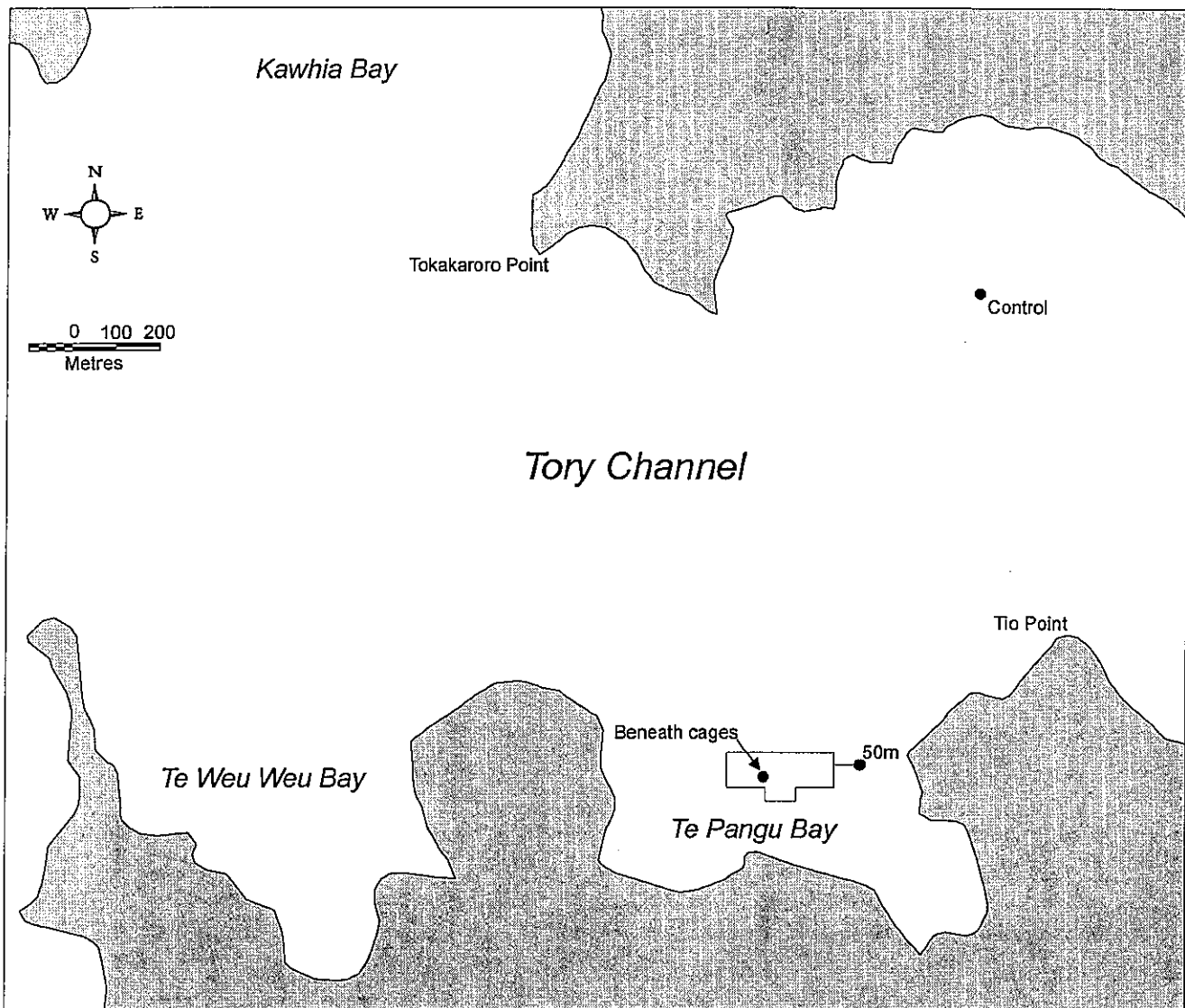


Figure 1 Map of the Te Pangu Bay area showing the location of the seabed survey sites.

The % organic matter was analysed by overnight oven drying at 105 °C and combustion at 550 °C for 2 hours, using a method modified from Luczak *et al.* (1996). From the content of core samples, and from diver observations, we assessed key indicators of seabed enrichment as follows:

- (i) The depth of the anaerobic “black zone”. Unenriched sediments are typically grey/brown whereas excessively enriched and anoxic sediments can be black. As the level of enrichment increases, and the sediment becomes increasingly anoxic, the black zone moves closer towards the sediment surface.
- (ii) The presence and coverage of mat-forming filamentous bacteria *Beggiatoa* spp. These bacteria metabolise sulphide but require oxygen to live. Their presence, therefore, provides an indication that the sediments are highly anaerobic and sulphide-rich at the sediment surface, but that the overlying water column is still oxygenated (Findlay *et al.* 1995).

- (iii) The extent of outgassing from the sediment. Strong outgassing is another symptom of excessive enrichment. The gas bubbles apparent at the sea surface are primarily methane, since this compound is relatively insoluble (Iwama 1991). Other products of excessive enrichment such as ammonia, sulphide, and carbon dioxide, tend to dissolve readily in seawater (Samuelsen *et al.* 1988).
- (iv) The presence and amount of salmon feed. Feed wastage is usually a major factor in causing excessive enrichment beneath salmon farm cages (Gowen & Bradbury 1987, Iwama 1991)
- (v) The presence of sulphide odours. Unenriched sediments are typically relatively odourless whereas excessively enriched and anoxic sediments have a strong "rotten egg" smell of hydrogen sulphide.

In addition to sediment sampling at the three sites, Cawthron divers collected underwater video footage and noted conspicuous or common seabed-dwelling species at the site beneath the cages. Survey data were compared to that from the baseline survey (Gillespie & MacKenzie 1989) and monitoring studies (Gillespie & MacKenzie 1990, Gillespie *et al.* 1991, Forrest 1996a).

3. RESULTS AND DISCUSSION

3.1 Description of Impacts

Results from the Te Pangu Bay salmon farm survey are summarised in Table 1. The sediments beneath the cages and at the 50m site were moderately enriched, with the black zone at or near the sediment-water interface (Plate 1), and smelled strongly of hydrogen sulphide. NZKS divers estimated a *Beggiatoa* cover of 5% at the 50m site, but no *Beggiatoa* was observed beneath the cages by Cawthron divers. Because of the constraints on dive time imposed by site depth, we were unable to verify the NZKS observations at the 50m site.

Despite the moderate enrichment evident beneath cages and 50m east, the sediment organic contents of 3.7% and 3.4% respectively were only slightly higher than at the control site (3.2%, Figure 2).

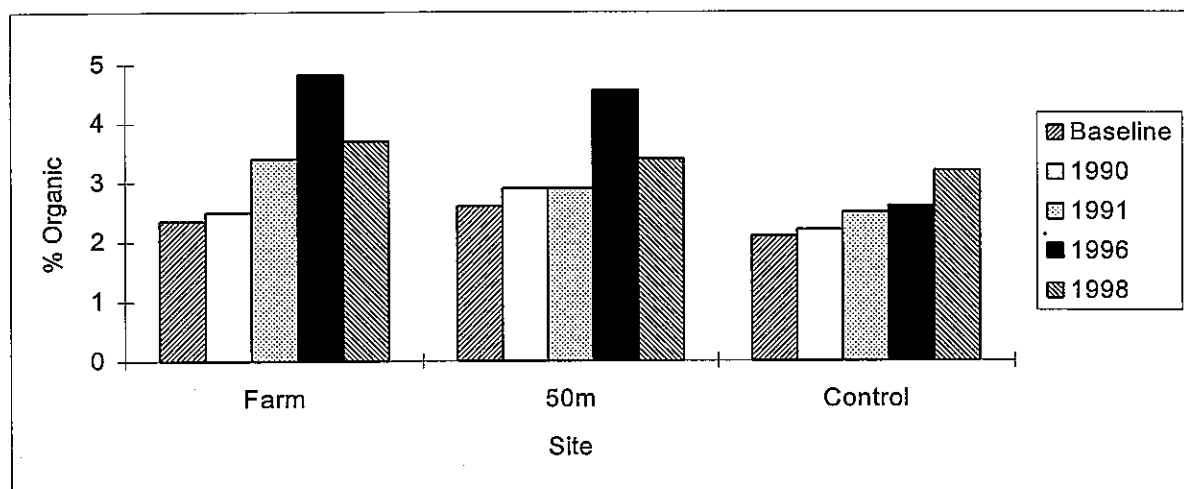


Figure 2 Organic content at farm and control sites in 1998 compared with previous years.

Table 1 Summary of sampling and results of the 1998 seabed monitoring survey at the Te Pangu salmon farm.

Site	Depth (m)	Sampling method	Sediment % silt/clay	Sediment % organic	Black zone depth (mm)	Beggiatoa (% cover)	Outgassing (Y/N)	Feed present	Odour	Conspicuous plants & animals
Cages	30	Diver cores (Cawthron)	16.3	3.7	0-5	0	No	No	Slight-moderate sulphide	A range of common coastal/harbour species (see list below*)
50m	29	Diver cores (NZKS)	23.6	3.4	10-20	5**	No	No**	Slight-moderate sulphide	Not determined**
Control	30	Diver cores (NZKS)	7.7 (high shell content)	3.2	40-60	0**	No	No**	Clean	Not determined**

* Species noted were anemones (*Actinohoe albocincta*), sea squirts (*Cnemidocarpa bicornuata*), starfish (*Patiriella regularis* & *Coscinasterias calamaria*), mussels (*Perna canaliculus* & *Modiolarca impacta*), sea cucumbers (*Stichopus mollis*), and foliose red algae (*Rhodomenia* sp., *Hymenena palmata*).

** Sites dived and observations made by NZKS divers.

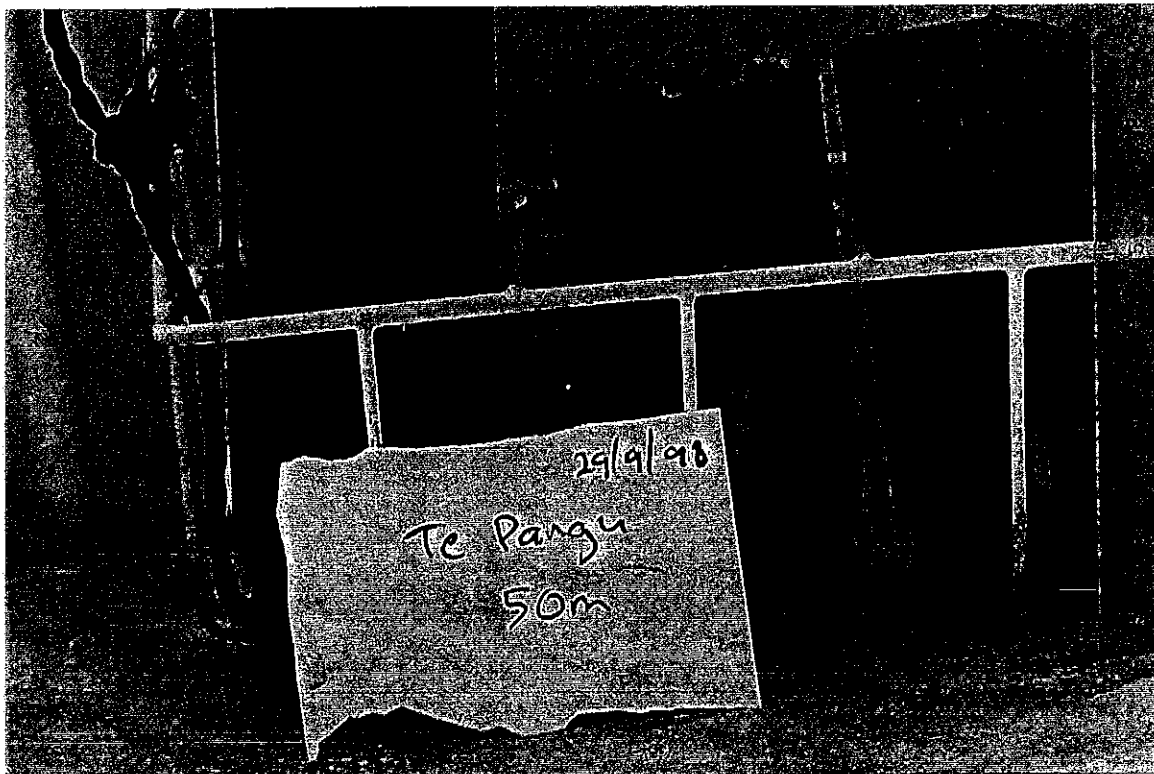
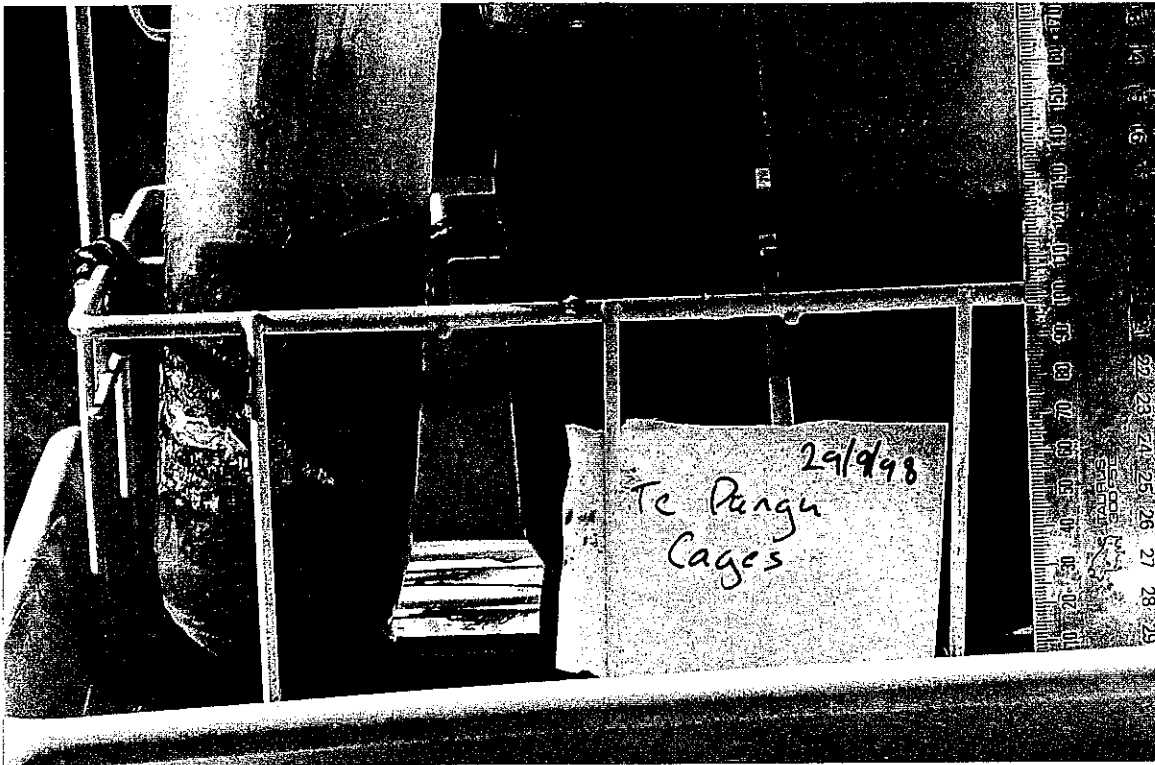


Plate 1 Sediment cores taken from beneath cages (top) and 50m east of the cages (bottom). The black colour of the cores, especially notable beneath the cages, indicates an excessive level of organic enrichment.

Overall, organic levels beneath the cages were very low. Published data and our previous experience shows that organic matter levels beneath salmon cages typically range from approximately 15-45% (*e.g.* Forrest 1996b, 1998a).

A variety of surface-dwelling macrofauna and seaweeds were present across the seafloor beneath the cages. These are noted in Table 1. The range of species found are common around much of the New Zealand coastline. The other sites were not dived by Cawthron hence a record of conspicuous species was not collected. Based on the 1996 survey, however, we would assume that the species assemblage present at the 50m site would be comparable to that beneath the cages. While we are unable to compare the cage site and 50m site to the control, the results of the 1996 survey (Forrest 1996a) and baseline survey (Gillespie & MacKenzie, 1989) suggest that the surface-dwelling biota at these two sites is impoverished relative to areas inshore of the farm (which are beyond the limit of farm impacts). Forrest (1996a) noted that this difference is likely to reflect a combination of both farm impact and natural spatial change.

The relatively low silt/clay component of the sediments at all sites, and the fact that the seabed at the 50m east site experiences a similar level of impact to that beneath the cages (Table 1), is evidence of the strong tidal currents in the area. These currents widely disperse farm wastes along the east-west axis of tidal flow, and prevent the concentration and build-up of wastes in areas immediately beneath the cages.

Previous Cawthron surveys indicate that the discernible effect of the Te Pangu Bay farm extends out to approximately 100m from the eastern edge of the cages. This contrasts with salmon farms in poorly flushed embayments (*e.g.* the NZKS salmon farm in Ruakaka Bay), where the seabed impact is more localised but considerably more severe than at Te Pangu. Hence while the Te Pangu farm may affect a relatively larger area of seabed, the seabed is only mildly enriched and still contains a reasonably diverse and abundant assemblage of plants and animal. Thus the cages appear to be well situated to minimise environmental effects.

3.2 Comparison With Previous Surveys at Te Pangu and Elsewhere

The moderate seabed impact at both the farm and 50m site was comparable to that recorded in the 1996 survey (Forrest 1996a). Up to and including 1996, there has been a steady (but small) increase in organic matter levels in sediments beneath the cages (Figure 2). Forrest (1996a) questioned whether this was a real trend indicative of a slow build-up of organic material, or whether it reflected sampling variation. The decrease in organic matter in the latest survey compared with 1996 suggests that sampling variation or perhaps seasonal changes explain the differences.

With respect to seasonal changes, Paul Sowman (NZKS) noted that the salmon eat more during spring (the timing of the 1998 survey) and food wastage, hence organic load to the seabed, is generally less than during summer (the timing of the 1996 survey). Regardless of the reason, the physical environment of the Te Pangu farm is clearly a dominating force which reduces the potential impacts of the Te Pangu farm to the extent that seasonal changes in impact are probably of little significance.

3.3 Comparative Ranking of Impacts

In Table 2, we have presented an index for gauging the severity of seabed impacts at NZKS salmon farms. This index was recently used to summarise the results of the Ruakaka farm survey (Forrest 1998a) and is intended to provide a simple "at a glance" measure of the relative severity of seabed impacts between sites and over time. For the completeness of this report, we have repeated below the explanation of the index given in Forrest (1998a).

The method uses a number of key indicators of seabed enrichment, and provides criteria by which the condition of each indicator can be gauged to indicate the severity of impact. For some of the indicators, these criteria are modified from those used in studies to rank the impacts of salmon farming in the Bay of Fundy (*e.g.* Garnier 1997). Other indices (*e.g.* the depth of the anoxic "black zone") are measures which are often used in organic enrichment studies.

Using these criteria, each indicator is classified as showing a low, medium, or high impact, and is assigned a score of 10, 20, or 30 points respectively. An average score for the site can then be calculated by dividing the total score by the number of indicators used. Thus average scores can theoretically range from a "low impact" score of 10 to a "high impact" score of 30.

We have used average rather than total scores to allow the inclusion or exclusion of different indicators as is necessary or desirable. For example, in 1996 we measured sediment-dwelling macrofauna in addition to the indicators described in this report, since we wanted to obtain a good understanding of the ecological impacts of seabed enrichment (Forrest 1996a). Hence sediment-dwelling macrofauna provide an additional indicator of impact which forms part of the overall average site score for the 1996 data set. The averaging method also gets around the problem of indicators which do not easily grade from low to high impact. In the case of Te Pangu, this only applies to outgassing, since this effect is only evident in highly enriched situations which have not been recorded from Te Pangu.

Note that this index is provisional and may need to be modified to suit other locations, or as we learn more about salmon farm impacts. The index values in Table 2 should therefore be regarded as a coarse measure of the severity of farm impacts. We have proposed this index more as a guide for NZKS rather than, for example, a method which would be suitable for regulatory compliance purposes. Bearing this in mind, the comparison in Table 2 shows the similarity in impact scores beneath cages and 50m east, and shows that the level of impact has remained similar between 1996 and 1998. In the scale from 10 (low impact) to 30 (high impact), both sites at both times fell in a narrow range of scores from 15-17.

Table 2 Ranking of impact based on measured or observed conditions beneath the Te Pangu salmon cages and at the 50m site.

Seabed impact indicator (measured or observed)	Seabed condition			Impact rank			
	High impact (score = 30)	Moderate impact (score = 20)	Low impact (score = 10)	Cages 1996	Cages 1998	50m 1996	50m 1998
% increase in organic matter compared with control site	> 90%	50-90%	< 50%	10	10	10	10
Depth of black zone compared with control site	At surface or > 90% shallower	50-90% shallower	< 50% shallower	30	30	30	20
Bacterial coverage of seabed	25-100%	Trace to < 25%	Absent	10	10	10	20
Gas bubbles	Freely released from sediment	NA	NA	NA	NA	NA	NA
Salmon feed (coverage of seabed)	> 10%	Trace to ≤ 10%	Absent	10	10	10	10
Conspicuous epibenthic species	Absent	Present but clearly impacted	Comparable to control/baseline	20	20	20	NA
Sediment-dwelling macro-fauna relative to control	Absent or reduced in density & richness	High dominance and/or reduced richness	Comparable to control/baseline	20	NA	20	NA
			Total score	100	80	100	60
			No. scoring categories	6	5	6	4
			Average score	17	16	17	15

4. SUMMARY AND RECOMMENDATIONS

The seabed effects of the Te Pangu salmon farm were assessed on 29 September 1998. The survey assessed "worst-case" effects by sampling beneath the most heavily stocked cages, and along an eastern transect in the direction of the strongest tidal current. Sites sampled were a subset of those investigated in a March 1996 survey, although the location of the control site was changed.

The deposition of organic-rich food and faeces from the farm has caused a moderate enrichment impact on the seabed beneath the cages and at the site 50m east. Nevertheless, a reasonably diverse assemblage of seaweeds and animals was present at these sites. The spatial pattern of impact, and the primarily sandy composition of the sediment beneath the cages, demonstrates the strong tidal currents in the area which widely disperse farm wastes along the east-west (shore-parallel) axis of tidal flow.

Seabed impacts at the time of the September 1998 survey were similar to that described in March 1996, despite the different timing of surveys with respect to season. The physical environment of the Te Pangu farm is clearly a dominating force which reduces potential farm impacts to the extent that seasonal changes in impact are probably of little significance.

A provisional scale of impact was developed for NZKS salmon farms using several key indicators of organic enrichment. On this scale, a minimum score of 10 points indicates a "low impact", an intermediate score of 20 points indicates a "moderate impact", and a maximum score of 30 points indicates a "high impact". Using this method, the sites beneath the Te Pangu cages and 50m east scored in a narrow range from 15-17 for the 1996 and 1998 surveys.

Because of a recent eastern extension of the salmon farm, the 50m east site is now at the edge of the new cages. For future monitoring purposes we would recommend selecting a new site 50m from the new cages but at a similar depth. Since Te Pangu Bay quickly shallows further east of the present 50m site, the new site would need to be located more towards the north eastern mooring block. In this location the site would be at a comparable depth and, according to salmon farm employees, would still be in the path of the tidal current which sweeps through the farm.

5. REFERENCES CITED

- Findlay, R.H.; Watling, L.; Mayer, L.M. 1995: Environmental impact of salmon net-pen culture on marine benthic communities in Maine: a case study. *Estuaries* 18: 145-179.
- Forrest, B. 1996a: Ecological effects of the Te Pangu Bay salmon farm, Tory Channel. *Cawthron Report No. 353*, Cawthron Institute, Nelson. 11p.
- Forrest, B. 1996b: Ecological effects of the Ruakaka Bay salmon farm, Queen Charlotte Sound. *Cawthron Report No. 352*, Cawthron Institute, Nelson. 13p.
- Forrest, B. 1998a: Seabed impacts of the Ruakaka Bay salmon farm: annual monitoring report 1988. *Cawthron Report No. 462*, Cawthron Institute, Nelson. 10p.
- Forrest, B. 1998b: Seabed impacts of the Otanerau Bay salmon farm, Queen Charlotte Sound. *Cawthron Report No. 464*, Cawthron Institute, Nelson (*in prep.*).
- Gillespie, P.; MacKenzie, L. 1989: Site characterisation of proposed salmon farm licence area in Te Pangu Bay, Tory Channel. *Cawthron Report No. 172*, Cawthron Institute, Nelson. 8p plus plates.