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A STUDY OF THE BEHAVIOUR OF THE SAND CRAB *PORTUNUS PELAGICUS* USING ULTRASONIC TAGS.

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Final report to the F.I.R.C on the project:

"A study of the behaviour of the sand crab Portunus pelagicus using ultrasonic tags".

Previous report 10/83.
Authors N.A.Gribble and M.J.Thorne

Summary.

The objectives of the project, as stated in the original application were :

i). To develop ultrasonic tags suitable for tracking and monitoring behaviour of sand crabs.

ii). To develop simple methods of tracking tagged , free-ranging crabs in Moreton Bay.

iii). To obtain positional and behavioural information over 24 hour periods.

Results.

1. Equipment, Tracking methods and Software development.

The tracking system (or package) developed, consists of three components:

i). An ultrasonic tag suitable for tracking medium sized crabs.

ii). A small portable hydrophone and sonic receiver which matches the tag and can be carried in small boats. A method of tracking tags from a dinghy, using a single hydrophone of this type, has also been perfected.

iii). A computer program for the calculating and plotting the position of both the boat and the crab. Two versions have been written; one is suitable for any small micro computer, the other is designed to run on a DEC PDP 10.

2. Biological data.

This system has been field tested in Pumicestone Passage, Moreton Bay Queensland. Twenty-four hour data on the movements and activity of the sand crab, Portunus pelagicus, have been collected on 8 individuals. The main points derived from the data are:

i). The crabs remained in a localised area which is defined as a temporary foraging area (TFA). For the 8 crabs tracked the average TFA was .1 Km2 but with a large variation between crabs.

ii). Rate of movement ranged from an average of 45.6 m/hr to 223.5 m/hr with instaneous rates of over 1410 m/hr recorded.

iii). Activity occured in short duration bursts and was linked to excursions from deep water onto the shallower sandflat and sandbar. These are interpreted as foraging excursions.

iv). Activity was influenced both by time of day (available light) and tide but not greatly by current.

v). Orientation of movement was at 90 degrees to the deep water gutter in the short term (foraging) and parallel to the shore over the longer term.

Introduction

Over the past few years the traditional pot fishery for sand crabs in Moreton Bay has become much less important than the trawl-based fishery. Formerly, sand crabs were more or less incidental catches for the prawning industry but the increased value of crabs and depressed prawn catches are making crabs a target species for trawlers. While it is unlikely that pot fisheries would endanger stocks, trawling can catch large numbers of crabs; this is shown by the vastly increased catches in recent years.

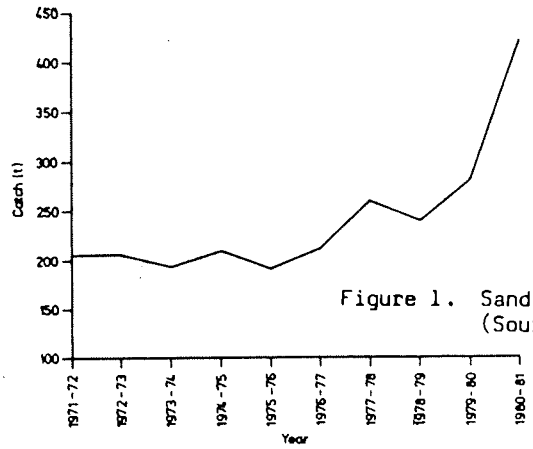


Figure 1. Sand crab landings for years 1971-72 to 1980-81.
(Source : Australian Bureau of Statistics)

It is obviously important to obtain more information on the biology of the sand crab in view of this increased fishing pressure. The Queensland Fisheries Service received a F.I.R.T.A grant in 1984 to carry out a study of the sand crab fishery in Moreton Bay and to study the large scale movements of the crabs by means of passive tagging (mark and recapture).

The present study has been running since June 1981 and aimed to develop an "active" tagging system in which the tags produce a signal which is continuously tracked. Using these tags detailed information has been gathered on daily movements, distance travelled, speed of movement, area of foraging, activity patterns, activity and direction of movements related to time of day, tides and bottom profile. This detailed information on daily activity and movement of individual sand crabs, combined with the data from the proposed larger scale Q.F.S study, can produce a comprehensive picture of the behaviour of sand crabs in Moreton Bay.

Sand crabs present a challenge in the design of an active tracking system. The crab is a portunid, hence a swimming crab, yet spends a great deal of its time buried in the sand. Thus the tag must be sufficiently robust to withstand abrasion encountered when the crab buries, and powerful enough to signal through a few centimeters of sand. It must also be light and streamlined to minimise interference while the crab is swimming. The later constraint is similar to that imposed on the design of tags for tracking birds. With flying birds (or swimming crabs) the maximum allowable weight of a tag has been determined as no more than 5% of an animals body weight.

The major types of tracking tags developed for aquatic animals are radio, electromagnetic, and ultrasonic. Radio tags will not operate efficiently in sea water therefore the tag must be either electromagnetic or ultrasonic.

Electromagnetic tags propagate a signal that will easily penetrate overlying sand, however they are of short range and they require bulky transmitter coils. An ultrasonic tag can be designed to be small and light weight with extended range. An inherent drawback however is that its signal will be severly attenuated by obstructions. The last factor can be offset by increasing the power output of the signal or by contriving a tag that is not fully buried when the crab buries.

Therefore an ultrasonic tag gives the best compromise for tracking sand crabs or indeed for any burying, as opposed to burrowing, marine crustacean.

The complementary elements in an ultrasonic tracking system are the hydrophone/sonic receiver matched to the tags output, the protocol used for location of the tag, and data reduction/analysis methods. To simplify field logistics it was decided to develop a tracking protocol that required only one hydrophone/receiver hence only the one operator and boat. Computer programs were written to reduce the lists of compass bearing, recorded while tracking, to crab positions relative to the study site and to analyse changes in crab position for activity patterns.

SECTION 1

Equipment, Tracking methods and Software developement

1. Equipment

(i) The ultrasonic tag.

Four prototype tags have been designed, constructed and tested during the course of this project. The design criteria for the tracking tag were:

A. The range should be a minimum of 200 meters with 400 meters as the maximum range to be aimed for.

B. The tags should have a life expectancy of at least 24 hours with 48 to 72 hours being preferable.

C. The frequency of the ultrasonic signal should be such that it could not be confused with either man made or natural noise. The frequency also had to be high enough so that the tagged crab was unaffected by the signal.

D. The weight of the tag had to be kept to below 5% of the body weight of a small adult crab.

E. The shape of the tag had to conform to the dorsal carapace of a crab and to present the minimum frontal surface area (ie. to produce the least drag.) Essentially the tag had to be kept flat and wide rather than cylindrical as with fish tags.

F. The tag had to be locatable even when the crab was buried.

(i.a) Prototype tag Mark I.

This tag was based on a circuit published by Young et al(1) . It used discrete components, was constructed with point to point wiring, and was powered by two mercury cells. When field tested it was found to have a range of less than 4 meters.

It was decided to abandon this circuit after consultation with Dr. Yarbury of the Telemetry unit, Physics Department, Sydney University. Although apparently simple, tags of this type require expert construction and tuning.

(i.b) Prototype tag Mark II.

The ICM 556, a dual timer integrated circuit, was used as the control element of tag Mk.II. This chip is relatively small, will run off 3 volt batteries, consumes only 180 micro amps and yet contains most of the functions required in an ultrasonic tag circuit. Construction was again by point to point wiring but problems with component overheating during soldering became apparent. The circuit was potted in polyester resin with the battery potted separately in neutral silastic. A single three volt Lithium calculator battery was used to power the tag. Four Mk II tags were constructed; one using standard sized components as a test bed; three using miniature components for bench and tank testing, with the last tag also used in field tests .

A short article describing this tag and the Mk III version was published in the Underwater Biotelemetry Newsletter and is included in appendix 1 of this report. Full details of bench, tank, and field tests are included in appendix 2.

(i.c) Prototype Tag Mark III.

This prototype is the same circuit as the Mk II tag, but with a more powerful output section. The range of this tag was greater than the earlier version but the consequent increase in power consumption limited its operational life . A compromise between range and power limitations was necessary.

Two Mk III tags were built, one as a test bed and the other used in tank and field tests. A extra tag was constructed using this circuit but with a Darlington pair output transistor configuration. This tag was a variant of the Mark III rather than a separate type. It suffered the same drawbacks as the Mk III.

(i.d) Prototype Tag Mark IV.

This was the final field version of the ultrasonic tracking tag. To overcome the problem of component failure during point to point soldering, a printed circuit board was designed and fabricated using flexible circuit board. Minor design changes to the circuit to improve frequency stability were also made, however the basic circuit was the same as that in the Mk II tag.

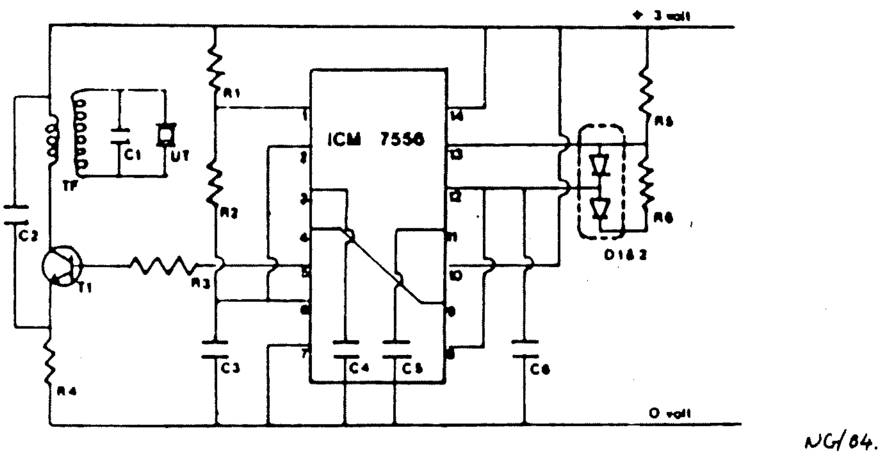


Figure 2. Circuit diagram of ultrasonic tag Mark IV.

All resistors were Phillips 1/10 watt (miniature), unless otherwise stated. Vitramon chip capacitors, Phillips miniature Tantalum capacitors, and a ceramic RF tuning capacitor were used where the compromise between component size and value dictated.

Parts list.
See text for description of output transformer.

R1	1.2 k	C1	*- 300 pf (select on test)
R2.R5	82 k	C2	6.8 uf Tantalum
R3.R4	150	C3	15 pf
R6	2 M . 1/4 watt	C4.C5	10 nf
		C6	4.8 uf Tantalum

Transistor	Philips BCF 32
Diode pair	Philips BAV 99
I.C.	Intercil ICM 7556, dual low power Timer
Transformer	See Text and Table 1
U.T.	Vernitron PZT-5 2-2020-5, 200 khz.

FIG. CONSTRUCTION DETAILS FOR THE MARK IV ULTRASONIC TAG

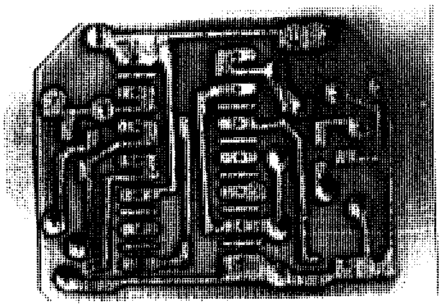


FIG. 3a

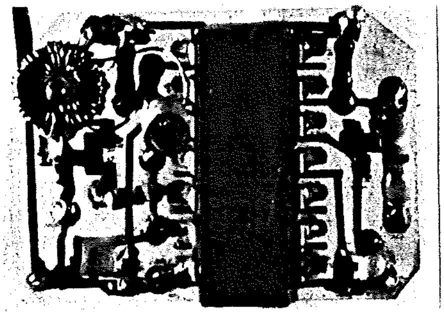


FIG. 3b

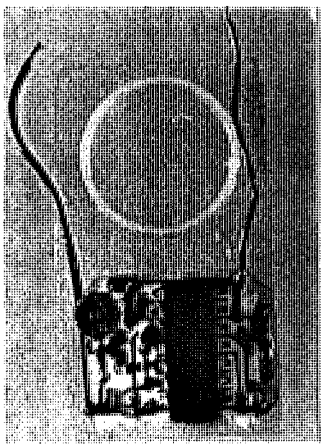


FIG. 3c

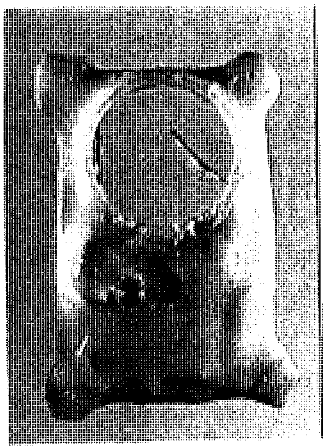


FIG. 3d

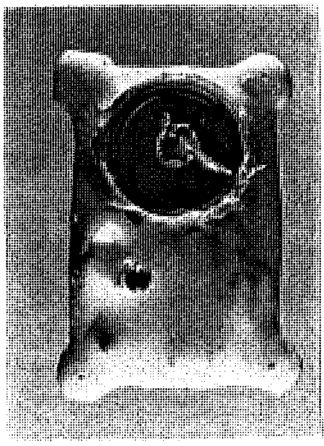


FIG. 3e

(i.e) Production Tags.

Ten Mk IV tags were built and used for tracking sand crabs off Toorbul in Pumicestone Passage. The tags are 47mm by 31mm and 5mm thick. The ultrasonic transducer projected a further 5mm from the top surface of the tag, (see fig 2). The weight in air was 9 grams, including battery, however the weight in water was 2 grams or less. This was because positive buoyancy, in the form of micro-spheres, had been added to the expoxy potting compound. Appendix 2., contains details of potting compounds and test results obtained.

Construction details are best followed from figures 3a-e. Photograph 3a shows the printed circuit used in the production tag. The components were soldered to the copper side of the board. Photographs 3b to 3e show respectively; the completed circuit board with components; the circuit potted and positioned on the fibre-glass reinforcing sheet, prior to final potting in epoxy; the potted tag with the battery cavity cleared; the finished tag with battery potted in.

The toroid output transformer was wound on a Amidon FT-23-72 miniature ferrite core. The primary winding consisted of six turns of 32# enamelled wire. The secondary winding was 23 turns of 36# enamelled wire. Tuning was carried out just prior to potting with capacitor C6 selected on test.

The ultrasonic transducer was soldered to the short secondary winding leads then a core of high density rubber foam was inserted. This foam allowed the piezoelectric cylinder to vibrate when potted in epoxy, which improved its acoustic efficiency. It was then potted in clear epoxy separately from the rest of the tag.

(ii). The hydrophone/ultrasonic receiver.

Two versions of ultrasonic receivers were built for the project. Fig 4 and 5 show the circuit diagrams for these receivers. The first was based on a simple direct conversion receiver taken from the A.R.R.L Handbook(2). The coils for this circuit were salvaged from IF stage of a small medium wave radio reciever. It was found that these adjustable pot core inductors could be retuned from 455 khz to around 200 khz using the full travel of the center slug and a small value capacitor in parallel. The second circuit used the National Semiconductors LM 1812, ultrasonic transceiver chip. The circuit was taken from NS Linear Applications Handbook(3) with the transmitter side left unconnected. A 50 mH inductor was used in the tuning circuit and the R/C ratio was calculated using the formulae in the handbook.

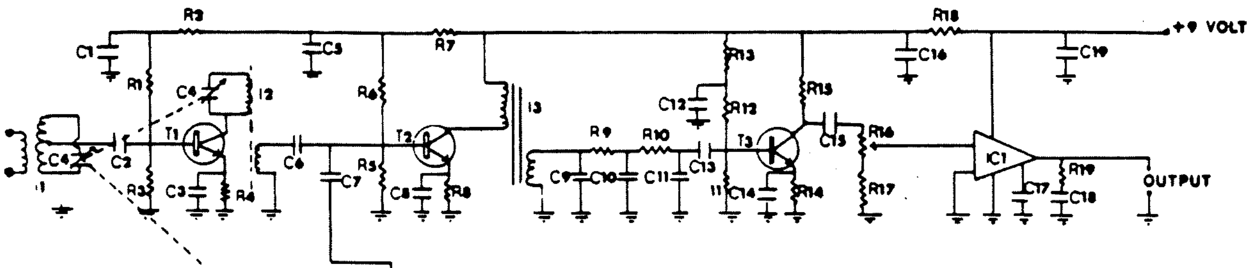
A number of configurations were tried in the construction of the hydrophones however two types proved most useful:

1. A directional hydrophone constructed from a conventional depth sounder transducer that was mounted pointing horizontally on a steerable bracket.

2. An omnidirectional hydrophone built specifically for the project. This used a Channel Industries C11 ultrasonic transducer with a 150-200 khz tuned preamplifier. The preamp was a simple Fet device with appropriatly tuned coil filters.

Fig 6 shows the hydrophones and the gear used for collecting field data.

FIG.4a RECEIVER (SIMPLE DIRECT CONVERSION)



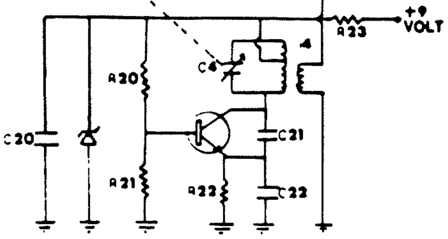


FIG.4b PREAMPLIFIER

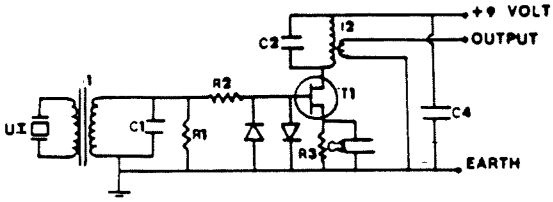


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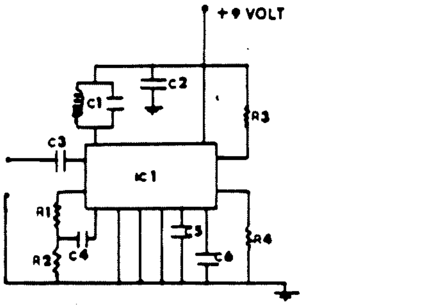
FIG.5 RECEIVER (BASED ON THE LM 1812)



List of components (Fig 4a)

Capacitors		Resistors	
C1,C5,C16	100mfd	R1,R6,R20	47K
C19,C20	300 "	R2	100
C1,C6,C7, C13	.001 "	R3,R5,R11	15K
C3,C10,C11	.03 "	R22,R4,R8, R9,R14	1K
C8,C17	10 "	R7,R18,R23	220
C9	.02 "	R12	68K
C14	25 "	R13	2.2K
C15	2 "	R15	6.8K
C18	.05 "	R17,R16*	10K
C21	270pf	R19	10
C22	680pf	R21	12K

Semiconductors

T1	2N 3819
T2	BC 317
T3	BC 549A
T4	BC 317
IC1	LM 386
ZD	6.8 volt Zener

Coils
See Text.

List of Components (Fig 4b)

Capacitors		Resistors	
C1	1000pf	R1	40K
C2	330pf	R2	1K
C3	.01pf		
C4	10mfd		

Semiconductors

T1	2N 3819
D1,D2	1N 914

Coils
See Text

List of Components (Fig 5)

Capacitors

C1	
C2	500mfd
C3	.001 "
C4	.001 "
C5	.002 "
C6	.2 "

Resistors

R1	4.99k
R2	10k
R3	10K
R4	1K

Semiconductors

IC1 1812

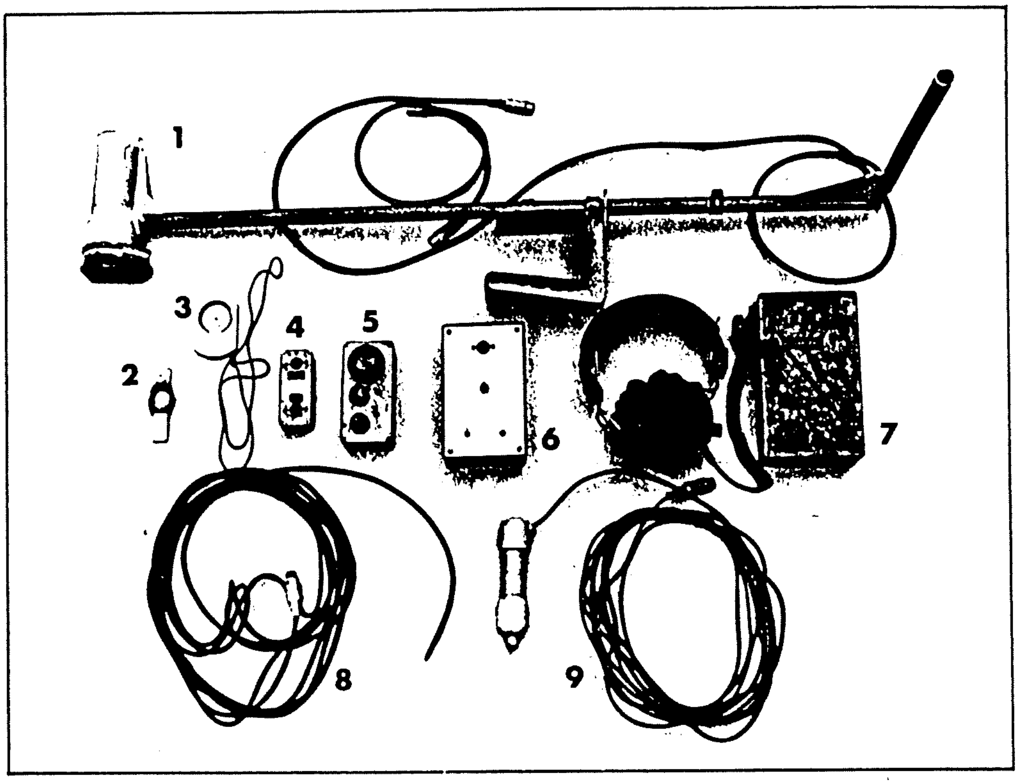


Fig. 6 Tracking Field Gear.

1. Hydrophone with small boat mounting bracket.
2. Wrist Watch.
3. Hand bearing compass.
4. Hydrophone Preamplifier.
5. Small sonic receiver (based on the LM 1812).
6. Ultrasonic beacon signal generator.
7. Sonic receiver (direct conversion).
8. Ultrasonic beacon transducer and 5 metre of cable.
9. Omnidirectional hydrophone with trolling cable.

2. Method of Tracking.

The most accurate method of locating an ultrasonic tag is by using an array of hydrophones which are permanently attached. to the sea bed. Time of signal arrival can be used to calculate the position precisely. The next most accurate method is by using two boats and hydrophones which take simultaneous bearings of the tag and then use triangulation to obtain the position.

It is also possible to obtain an estimate of position using only one boat and hydrophone. This method is a compromise between simplicity and accuracy and was used in the present study.

The assumptions made when using a one hydrophone method of tracking are:

i). That the absolute range of the tag is known. In the case of this study 400 meters was the greatest distance that the tag signal could be received.

ii). That the tagged animal is going to move over relatively large distances. The resolution of this tracking method is a 20 by 15 meter elipse.

iii). That the tagged animal is not going to move faster than it is possible to track, given that frequent stops are required to take position fixs of the boat.

iv). That the signal from the tag is relatively constant, allowing its strength and frequency to be calibrated for distance.

The protocol when tracking was to anchor the boat at a position where the signal was clearly received. Compass bearings were taken of at least three prominent landmarks, then the hydrophone was used to take the bearing of the tagged animal relative to the boat. A record of signal strength was taken, relative to a predetermined calibration scale. A record was also made of the arc through which the hydrophone could be rotated while receiving the signal, the maximum declination/inclination angle of the hydrophone, and of the signal frequency. This sighting/recording procedure was repeated at regular intervals until the signal became too weak, then the boat was moved and anchored at a position where the signal was clearly received again.

In this study it was found that 200 meters from the crab was the optimum position for tracking. If the crab stayed within a 300 meter diameter circle of the boat then no change in position was needed, however if it moved beyond this the signal became too faint for reliable tracking and the boat had to be repositioned.

Fig.7 shows the effect of distance and hydrophone angle on the accuracy of bearings.

Fig.8 shows the confidence limits for a given estimation of range.

The hydrophone can be calibrated for distance by placing an ultrasonic beacon at known distances and noting signal strength, hydrophone arc, and hydrophone declination. For a tag this has to be modified slightly for frequency changes. As the tag battery is depleted the frequency shifts downwards and its signal strength lessens, so the distance calibration must be adjusted accordingly.

FIG.7a THE EFFECT OF DISTANCE ON THE ERROR INVOLVED IN RANGE ESTIMATION due to HYDROPHONE ANGLE AND HYDROPHONE ARC. (See footnote of Fig. 8)

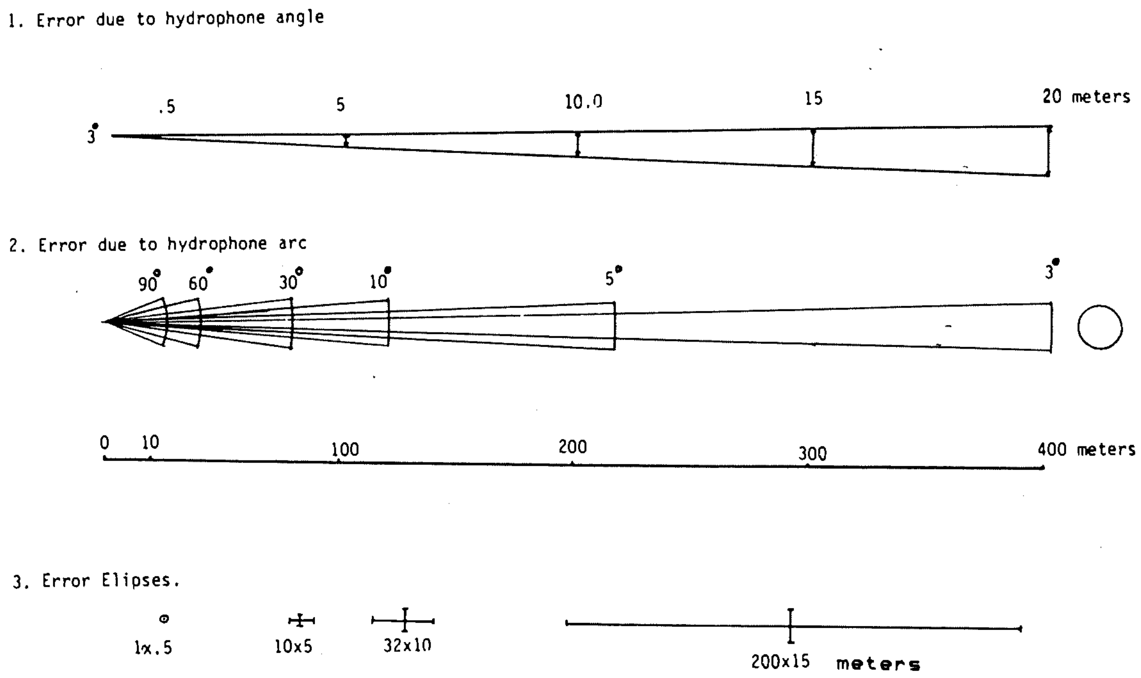


FIG.7b HYDROPHONE ARC/DISTANCE CALIBRATION CURVE.

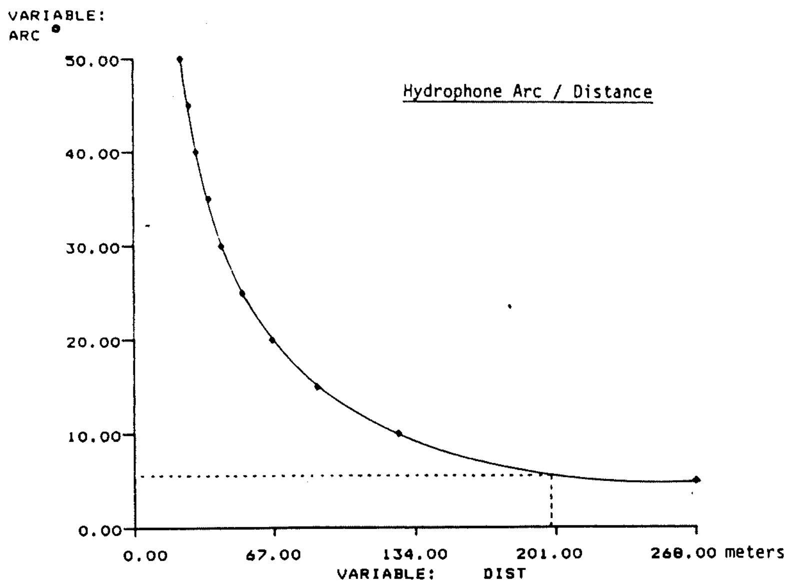
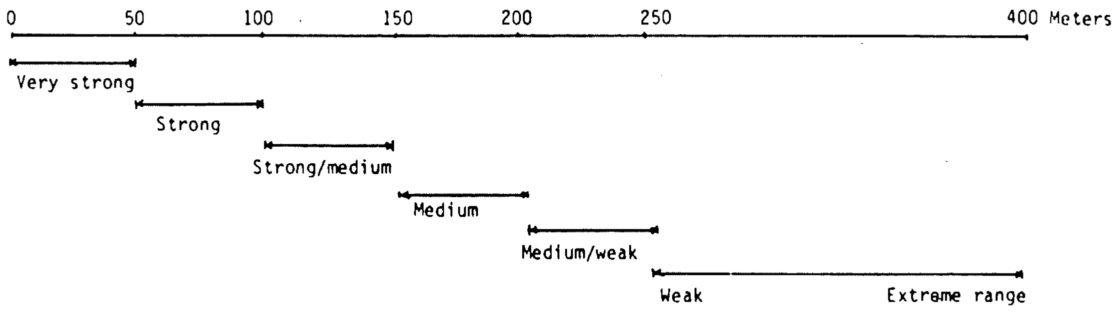


FIG.8 SIGNAL STRENGTH AS A FUNCTION OF DISTANCE



Footnote.

Fig.7a (1) shows the error in range estimation due to hydrophone angle. It was found that a bearing to a known signal source could be taken with an accuracy of ± 1.5 degrees. It is considered unlikely that better accuracy could be expected from a hand bearing compass in a 3 meter punt. The effect of ± 1.5 degrees on an estimation is that at 300 meters the crab could be up to 7.5 meters either side of the bearing position.

Fig.7a (2), the error due to hydrophone Arc refers to the arc through which the hydrophone can be turned while receiving a signal. Near signals can be received over a wide arc while distant signals have a narrow arc of reception. The error involved is due to the diminishing change in arc as distance increases. This can be seen from the calibration curve in Fig.7b.

Fig.7a (3). Error elipses combine the errors from (1) and (2) and show the maximum possible area that could contain a crab for a given hydrophone bearing and arc.

Fig.7b Self-explanatory.

Fig.8 Signal strength as a function of distance. Sound traveling through water obeys the inverse square law of propagation. Signal strengh becomes logarithmicaly weaker with increasing distance. This phenomenon is compensated for by the human ear which has a logarithmic reponse. That practical result is that for up to 300 meters the trained ear can make good estimates of distance based on signal strengh. Fig.8 shows the maximum limits (most conservative estimate) to distance estimates derived from field trials with a fixed signal source.

By combining signal strength information with hydrophone arc (both horizontal and vertical) an estimate of signal distance (range) can be made which has an average error elipse of 20 by 15 meters up to the maximum distance of 300 meters. In the position plots this elipse is aproximated by an oval for plotting convenience.

A number of factors can complicate the straightforward use of this calculated distance calibration.

i). Time of day can affect the transmission of ultrasound through water. Early morning is traditionally the best time for tracking. Temperature effects and layering caused by the sun can cut down the received signal strength later in the day.

ii). The presence of air bubbles, turbulence or weed in the water will drastically reduce signal strength.

iii). If the tagged animal buries in sand or mud both reduced signal and fluctuating frequency will result.

iv). The salinity, or rather layers of different salinity water, can cause reduction of signal and sometimes multiple path reflections of the signal.

v). The surface, and sometimes the bottom, can cause reflections slightly out of phase with the principal signal. This is most pronounced when there is heavy wave action.

In practice an experienced operator can make the range estimation in the field, balanced by the prevailing conditions. Given the worst case, with heavy sea conditions at mid-day added to salinity layering due to rain and possibly turbulence or excessive weed being present, the position of the tagged animal can still be estimated; it has to be within the area bounded by the maximum distance the tag signal can received and between the confidence limits of the bearing from the boat to the crab. That is, within 400 meters of the boat and somewhere within the triangular area described by the left and right limits of the hydrophone angle.

Two variations on the one hydrophone method are:

(a). To set up two buoys and to move continually between them, taking a hydrophone bearing at each and triangulating to get the tag position. The drawback is that the bearings are not simultaneous hence if the tagged animal moves between observations then the triangulated position is incorrect.

(b). To move the boat over the top of the tagged animal from at least two directions. The position is located when the signal is strongest. The drawback is the disturbance caused to the animal by the boat.

3. The Data Reduction and Analysis Programs.

A suite of programs called Crabtrack has been written to plot the relative positions of the boat and tagged animal, and to perform preliminary analysis of activity.

The suite consists of 5 programs:

1. Crabtrack:Create . This formats field data into an input data file interactively. It is not absolutely necessary to use this program, as an experienced operator can produce data files using a line editor, however it can simplify formatting for novices.

2. Crabtrack:Edit. This program simplifies editing of input data files but can be bypassed by experienced operators.

3. Crabtrack:Map . Output files from Crabtrack Map contain sequentially, positions of the boat, the crab, the distance moved by the boat, the distance moved by the crab, and the elapsed time between observations. These files are suitable for immediate use with most plotters.

4. Crabtrack:Act . " Crabtrack Act" uses output files from "Crabtrack Map" to generate files containing coordinates for an expanded view of the animals path and its relative activity over the sampling period. These files are used to plot path and activity.

5. Crabtrack:Decide. This is a decision support program for calculating the crab range from intermediate results from "Crabtrack Map". The options within Decide are:

A. The field records of signal strength, angle of hydrophone, declination of hydrophone, and signal frequency can be used to calculate a range by reference to a calibration table.

B. An estimated position and range can be calculated by triangulation and compared with the recorded range from field data.

Plots of both estimated and recorded range can be made for visual comparison. The input data file can then be edited to include amended data from either or both of these support routines. Appendix 4 contains the program listings and instructions for use for all five programs.

SECTION 2

Biological Data

The results of the tagging program are presented in three ways for each tagged crab :

(i) A map of the crab movements relative to the Pumicestone Passage study site.

(ii) A map of the path of the crab showing direction of movement relative to sea bottom profile.

(iii) A graph of relative activity versus elapsed time, time of day, and state of tide.

Study Site Description.

Pumicestone Passage was chosen as a suitable area for tracking for the following reasons:

(a). Sand crabs can be caught in large numbers in the main passage and on the sand flats.

(b). The Queensland Co-ordinator Generals Department published a report in 1982 ,"PUMICESTONE PASSAGE Water Quality and Land Use Study", in which the Water Quality Council of Queensland presented the results of a two year study covering the hydrodynamics of the passage as well as the full range of physico-chemical parameters.

(c). The Queensland Department of Mapping and Surveying have available aerial photographs of the Passage taken in 1978, 1981 and August 1983. Detailed local maps were made of the study site using these combined with grid depth soundings.

(d). The passage is relatively narrow with easily distinguished landmarks. This allowed accurate position fixing both day and night.

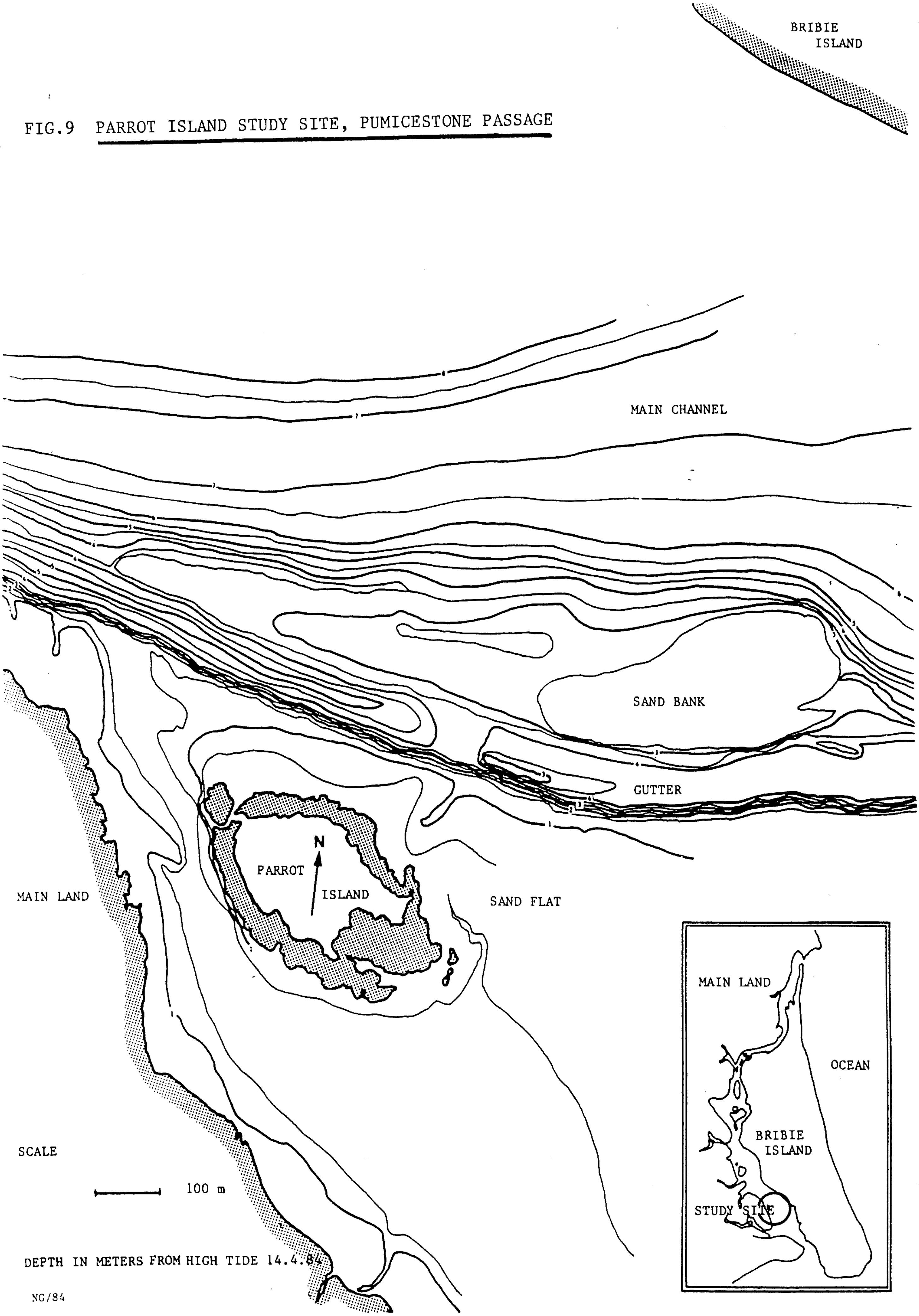
General description of Study Area.

Pumicestone Passage is a narrow estuarine body of water aproximately thirty-seven kilometers in length which separates Bribie Island from the Mainland. The Passage is normally open to the Pacific Ocean at its northern entrance where there is a shallow and unstable sand-bar. At the southern end, the channel enters Moreton Bay through a wide and unobstructed opening which is spanned by the Bribie Island bridge.

The Passage varies in width from aproximately three kilometers at Tripcony Bight down to thirty meters at the narrows near Roys, (the Skids). Depth varies from shallow, particularly in the central and southern reaches where narrow channels (navigable by smallcraft only), separate intertidal mud/sand flats and numerous small islands. Towards the northern end, the Passage has an average width of five hundred meters and near Caloundra the water is deeper and the navigable channels are wider. In the extreme south, beyond Toorbul, the Passage widens to an average of one kilometer and the channel deepens to be readily navigable.

The Passage may in fact be considered as comprising two estuaries joined by a constricted connection in the area of the Skids.

FIG.9 PARROT ISLAND STUDY SITE, PUMICESTONE PASSAGE



From historical records it would appear that there has been a continuing deposition of silt from land runoff. Harbours and Marine charts of the area warn of a constantly shifing main channel and sand banks.

There are seven principal creeks which enter the Passage from the mainland and two smaller creeks entering from Bribie Island. Storm runoff into the passage is mainly from these creeks and leads to a rapid, short duration drop in salinity.

Flanking the Passage along much of its length are mangrove areas, the most extensive being in the areas adjacent to the four southern mainland creeks.

The uses of the Passage include active recreation (boating, fishing, swimming, and water-skiing), commercial fishing (including crabbing), shellfish culture, nursery area for marine life, and drainage of stormwater runoff from urban and rural areas. A fish Habitat Reserve is located between the Skids and just south of Tripcony Bight. The entire Passage or the major sections of it have been proposed as a national park and the proposition is being considered at present by the State Govenment.

Study site.

The site off Parrot Island was chosen based on anecdotal advice from local fishermen and from inspection of the series of stereo pair aerial photographs. Crabs could be reliabily caught from the area and the photographs showed that the sand formations were stable over at least five years. This last point is important in a Passage noted for its constantly shifting main channel and shoal areas.

Fig. 9 shows the contour map of the Parrot Island site with an insert of its position relative to Pumicestone Passage. The essential features of the site are a gently sloping sand flat which is uncovered at low tide. The flat ends at a sharp drop-off down to a gutter which runs parallel to the island. The seaward border of the gutter is a low sand bar with the main channel further out.

The Water Quality Council of Queensland report(4) states that, for this area of the Passage;

(a). Average salinities are about equal to those found in the open ocean, reflecting the relatively minor influence of the freshwater inflows and the major influence of a nett tidally-induced northerly water flow.

(b). Temperature depends on local depth and distance from the ocean mouth. However the study site does not reach the +30 C that is reported for the central reaches during summer.

(c). Dissolved oxygen at the surface and at a point five hundred millimeters from the bottom are similar and are approximately 90% maximum saturation possible at a given temperature, pressure, and salinity. There does not appear to be any stratification.

(d). The turbidity is high throughout the year.

The site is a well defined, stable area with known abiotic parameters and has a constant population of crabs.

Trip Reports and Tagging Results.

The raw field data, consisting of consecutive series of compass bearings and elapsed times, were reduced to crab positions by the computer program "CRABTRACK" and plotted. A summary of the field notes for each trip is presented as the preamble to the individual crab tracking results .

The map of crab movement, plotted for each crab, is on the same scale as the Fig 9. (or the scale is indicated) and the position of a crab is shown as a 20 by 15 meter probability oval. Depth isobars are at 50 cm intervals.

The plots of crab activity show the tidal cycle as the upper broken line, the solid line represents the rate of crab movement in meters per minute relative to elapsed time, and lower scale gives the real time. Periods of continuous tracking are indicated by the solid line below the elapsed time scale. The tidal cycle plot represents the 1.5 hours either side of high and low tide as a straight line and is the aproximation of "slack water".

The plots of crab path are on various scales depending on the magnification, however all probability ovals are 20 meters across the long axis and each plot can be scaled relative to its oval.

Tag 1.(Trip 1)
Date 21/12/82
Site Off Moreton Island

This trip was the first field trial of the production tag, Mk.IV, attached to a crab rather than to a diver. The site off Moreton Island was chosen as it had been used previously and its characteristics were known. (See Appendix 2 for field trial data.)

A crab was caught by suicide net early in the morning, the tag was attached and the crab was returned to the same area within thirty minutes. Tracking was carried out over the next four hours and again twenty-four hours later. The tag signal was easily located on the second morning but the frequency was apparently oscillating slowly. The tag was in the same general area having moved less than 100 meters. The signal was triangulated and a diver recovered the tag which was found rolling slowly across the sea bottom with no crab in sight. When inspected the soft wire ties used to attach the tag to the crab had been untied. It was considered that human intervention was a distinct possibility, as this area is heavily crabbed. The soft wire ties were replaced on later tags by 40lbs breaking strain stainless steel trace wire.

No map was plotted for this crab.

Tag 3. (Trip 2)
Date 7/2/83
Site Toorbul, Pumicestone Passage

A male crab, 157 mm carapace width, was captured at 2.30 pm by suicide net. It was released with a tag attached at 3.00 pm, into the same area that it had been captured.

Tracking was continued until the crab had passed beyond the extremes of the study site. (See map 2.)

The crab moved 50 meters initially then was stationary for over 1 hour 50 minutes. After this the crab moved at right angles to the shore, over the shallow sand flats and into the deeper channel. It then moved parallel to shore following the channel at a speed of 4.16 meters per minute. The signal was lost at 7.00 pm and tracking was discontinued till 4.30 am next morning.

No signal could be located within the study area despite an 8 hour grid search extending over 5 km in either direction. The average speed necessary to clear the study area was 3.54 meters per minute. This is assuming that the crab travelled along the line of the last bearing and that the first pass of the grid search reached the 5.5 km limit by 8.30 am.

There are four possible explanations for not locating an ultrasonic signal under these circumstances;

A. The crab/tag had moved outside the search area.

B. The tag may have malfunctioned.

C. The crab/tag could have taken by crab pot during the night and so was not in the search area. This is unlikely as the search was started before any of the local amateur fishermen were crabbing.

D. Within the study area there are shallows that are inaccessible, even to shallow draft dinghies, and it is possible that the crab/tag could have hidden there.These shallows are dry at low tide, which on the 7/2/83 was at 12.03pm, just at the end of the search. On a falling tide large crabs could be expected to move back into deeper water and therefore back into the search area. As a final check the channels near the shallows were scanned before calling off the search at 12.30 pm.

The crab/tag was recovered 51 days later in a crab pot off the Toorbul boat ramp, which is the general area that the crab was originally caught. The tag was re-batteried and tested. It was found to be functional and transmitted perfectly. The old battery was tested and found to be completely exhausted. There was no evidence of water penetration or physical damage beyond abrasion. Therefore the tag did not malfunction.

Information supporting the hypothesis that the crab moved outside the search area comes from a passive tagging program run in conjunction with this study. A streamer tag was attached to a large male crab which was recovered 3 days later, 12 km away. To cover the distance in this time requires a minimum average speed of 2.74 m/min, with a maximum of 4.19 m/min possible. This speed range agrees with the sustained speed of the crab observed in the present study.

FIG. 10a ACTIVITY (RATE OF MOVEMENT) OF CRAB 3

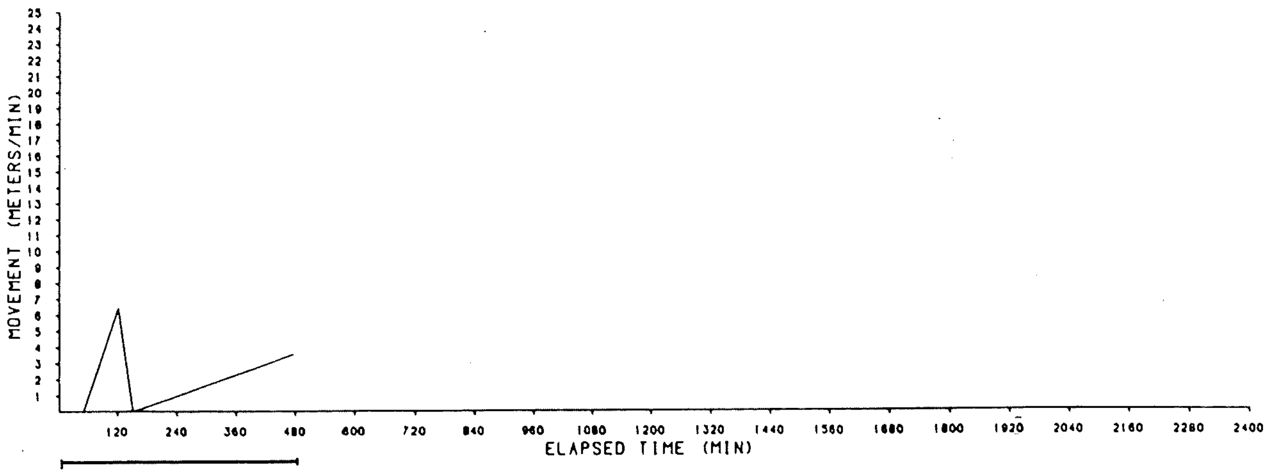
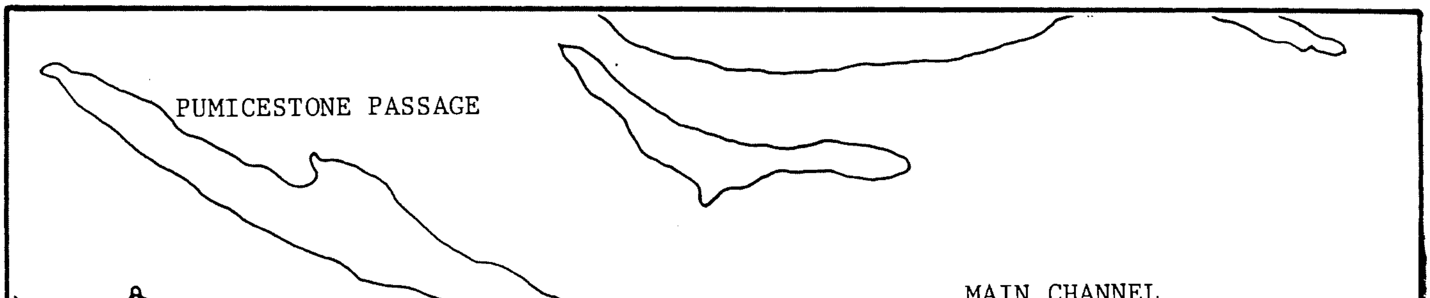


FIG. 10b PATH OF CRAB 3



Tag 4. (Trip 3)
Date 15/2/83
Site Toorbul

A male sand crab, 150 mm carapace width, was captured at 4.30 am by suicide net, off the point of Parrot Island. (See map 3) Tag 4 was attached and the crab was held in a shallow water cage until just before release at 10.50 am. The tag was operating perfectly and the crab did not appear distressed.

Release was effected at precisely the point of capture and the tag signal was monitored continuously for the next 30 mins, then at 30 min intervals. The crab remained stationary for 2 hours approximately then moved 50 meters and became stationary once more. The signal was triangulated and a crab pot marker buoy was found to be close to the position of the crab.

The crab pot was hauled in and the crab/tag was inside. It had begun foraging within two hours of release and feeding within four hours. The crab/tag was transported back to the University of Queensland and observed in an aquarium for the next 112 days. The tag operated for the first 72 hours at full strength and then at reduced signal levels until 96 hours approximately.

The crab fed normally, showing no distress for the entire time of observation. The crab was found to be capable of burying and even of mating with the tag in place. When the tag was removed after the 112 days it was rebatteried and functioned normally.

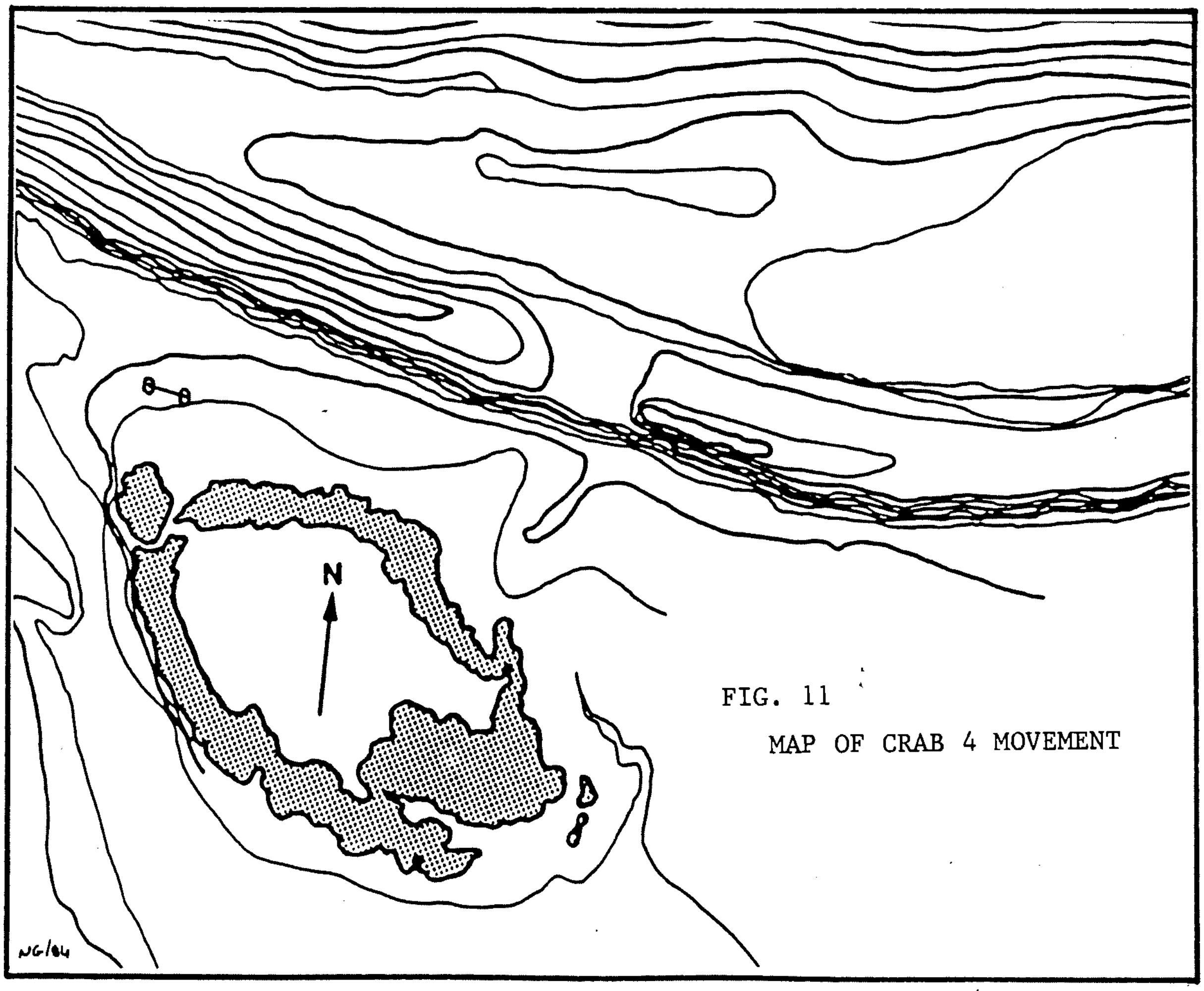


FIG. 11
MAP OF CRAB 4 MOVEMENT

FIG. 12a ACTIVITY OF CRAB 4

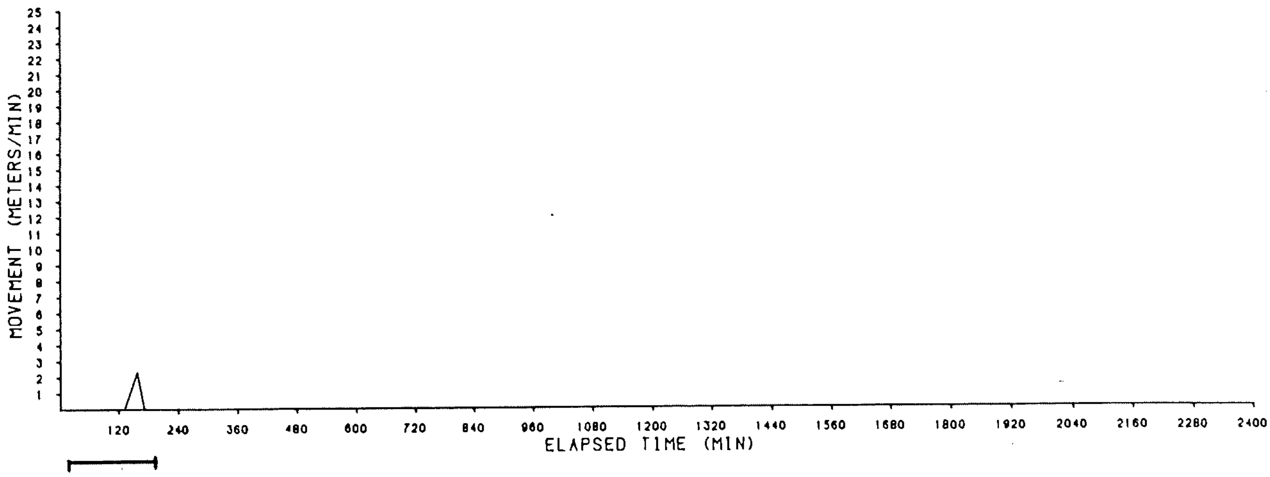
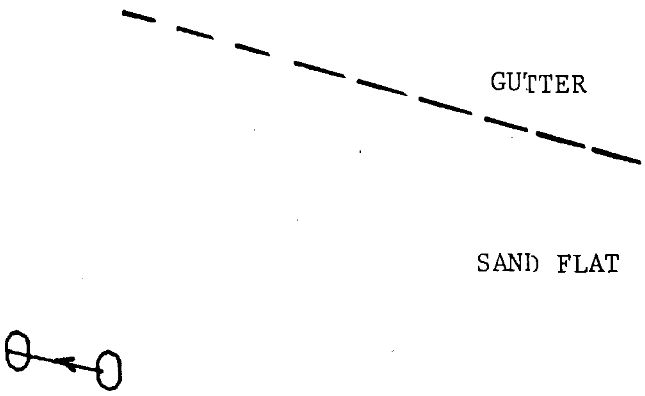


FIG. 12b PATH OF CRAB 4



Tag 5.(Trip 8)
Date 13/4/83
Site Toorbul, Pumicestone Passage

A male sand crab, 165 mm carapace width, Sacculina infested, was captured by crab pot at 8.45 am. Tag 5 was attached and the crab was returned by 9.00 am. Contact with the tag was maintained for the next 33 hours with two periods of continuous tracking, 11.5 hours on the first day and 12 hours on the second. Position fixes for the boat and crab were taken every 15 min when continuously tracking, where possible.

The crab remained in a small area and was relatively inactive.

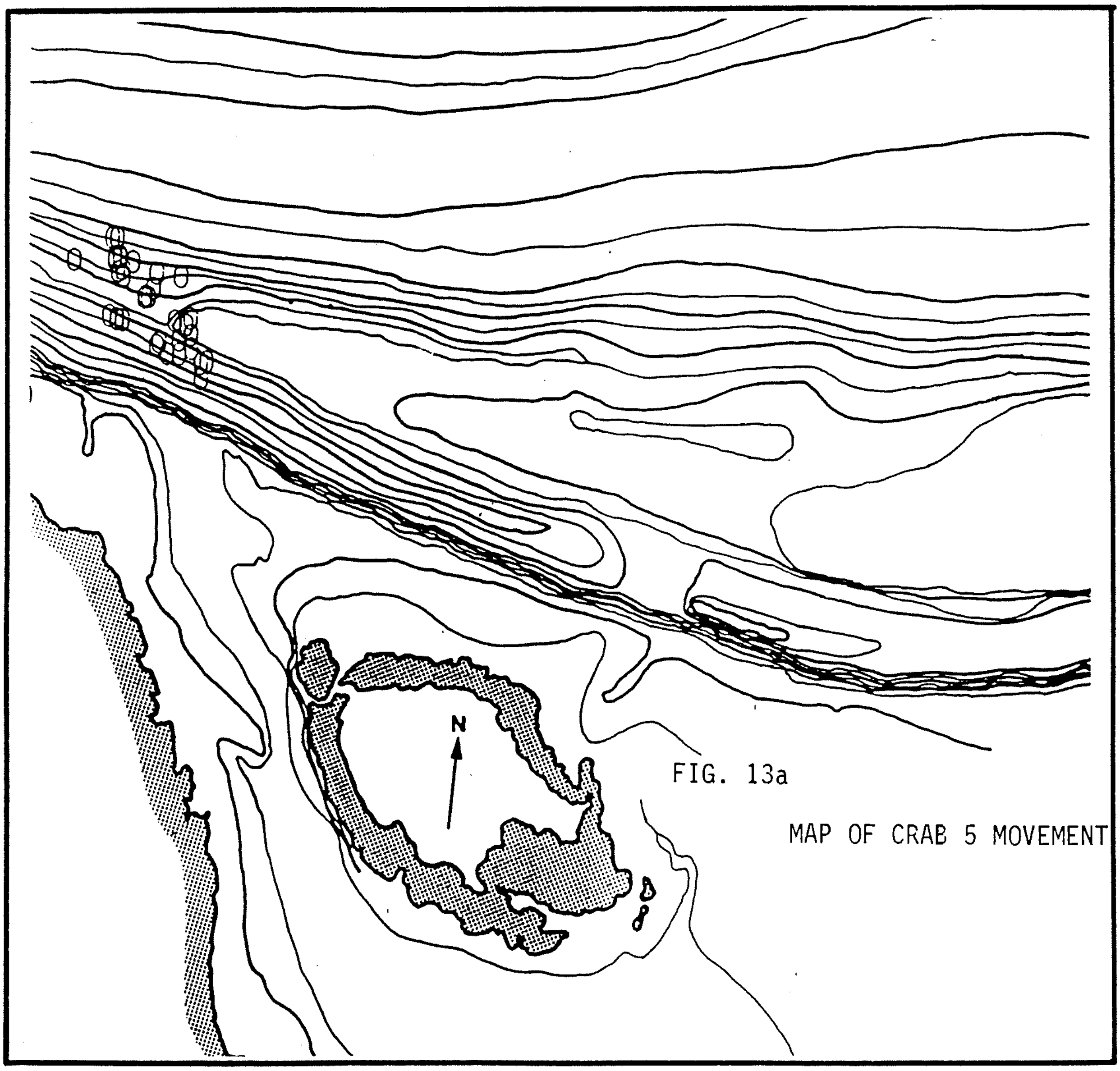
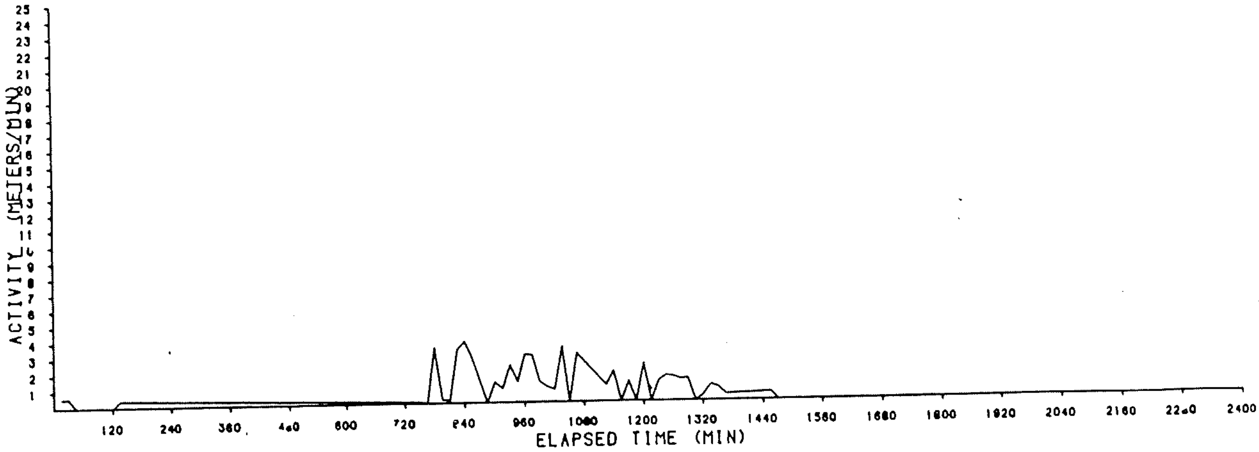


FIG. 13a

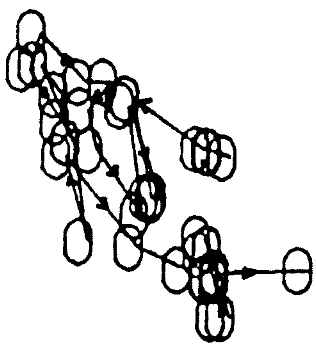
MAP OF CRAB 5 MOVEMENT

FIG. 13b ACTIVITY OF CRAB 5



NOTE. Crab 5 was not included in the analysis of movement or activity as it was parasitised by Sacculina and the crabs behaviour may have been affected.

FIG. 13c PATH OF CRAB 5.



Tag 6. (Trip 9)
Date 3.6.83
Site Toorbul, Pumicestone Passage

A male sand crab, 171 mm carapace width was captured at 7.30 AM , off the point of Parrot Island. The crab was transported to the temporary field laboratory opposite the Toorbul boat ramp, a 15 min journey each way. The tag was attached and the crab was kept in a bucket of aerated sea water for 90 minutes prior to release. The crab appeared to be healthy and the ultrasonic signal was strong and steady. The crab/tag was released at the point of capture, at 9.33 AM.

The tag signal failed aproximately 15 miniutes after release. The reason for this failure is unknown, however a likely cause can be related to the behaviour of crabs observed in aquarium tanks. When handled then returned to the tank , crabs remained stationary on the sand surface in fixed "threat" positions for a short time then buried rapidly into the sand. If this was the behaviour of the field crab then the tag would have been subject to abrasion within 15 mimiutes of release.

At this point in the project the tag batteries were being connected just prior to release. This was done to ensure the maximum operational life of the tag, but a side effect was that the Silastic battery sealant was not completely cured at the time of release. It is possible that abrasion of this soft sealant could have allowed in sea water and so shorted out the battery.

To guard against this possibility, all subsequent tags had the upper battery lead connected and the battery sealed in place 24 hours prior to a field trip. The lower battery lead was left clear and was connected just before the tag was attached to the crab. The underside of the battery case is protected by the dorsal carapace of the crab and is not subject to abrasion. When attaching the tag to the crab, silastic was used to seal the under side of the battery case and to glue the tag to the carapace.

No map was plotted for this crab.

Tag 7. (Trip 11)
Date 15.10.83
Site Toorbul, Pumicestone Passage

A male sand crab, 164 mm carapace width was caught, tagged and released at the point of capture by 9.35 AM. Contact was maintained for the next 34.5 hours with continuous tracking for 15 hours on the first day and 13 hours on the second.

To restrict the search area the boat was positioned to the seaward of the crab at all times; i.e. the crab had to be between the boat and Parrot Is. This shortened the time taken to locate the tag signal and allowed greater accuracy in determining its position.

Over the two days of tracking the crab kept to the strip of water running parallel to Parrot Island , moving slowly North-East along the bank. There were short periods when the signal frequency would become unstable. These occurred just before longer periods of constant frequency with little apparent change in crab position; it was assumed that the crab had buried when the signal behaved in this way. The corrollary was noted also; just before the crab position began to alter, after a long stationary period , a similar short period of unstable frequency occurred.

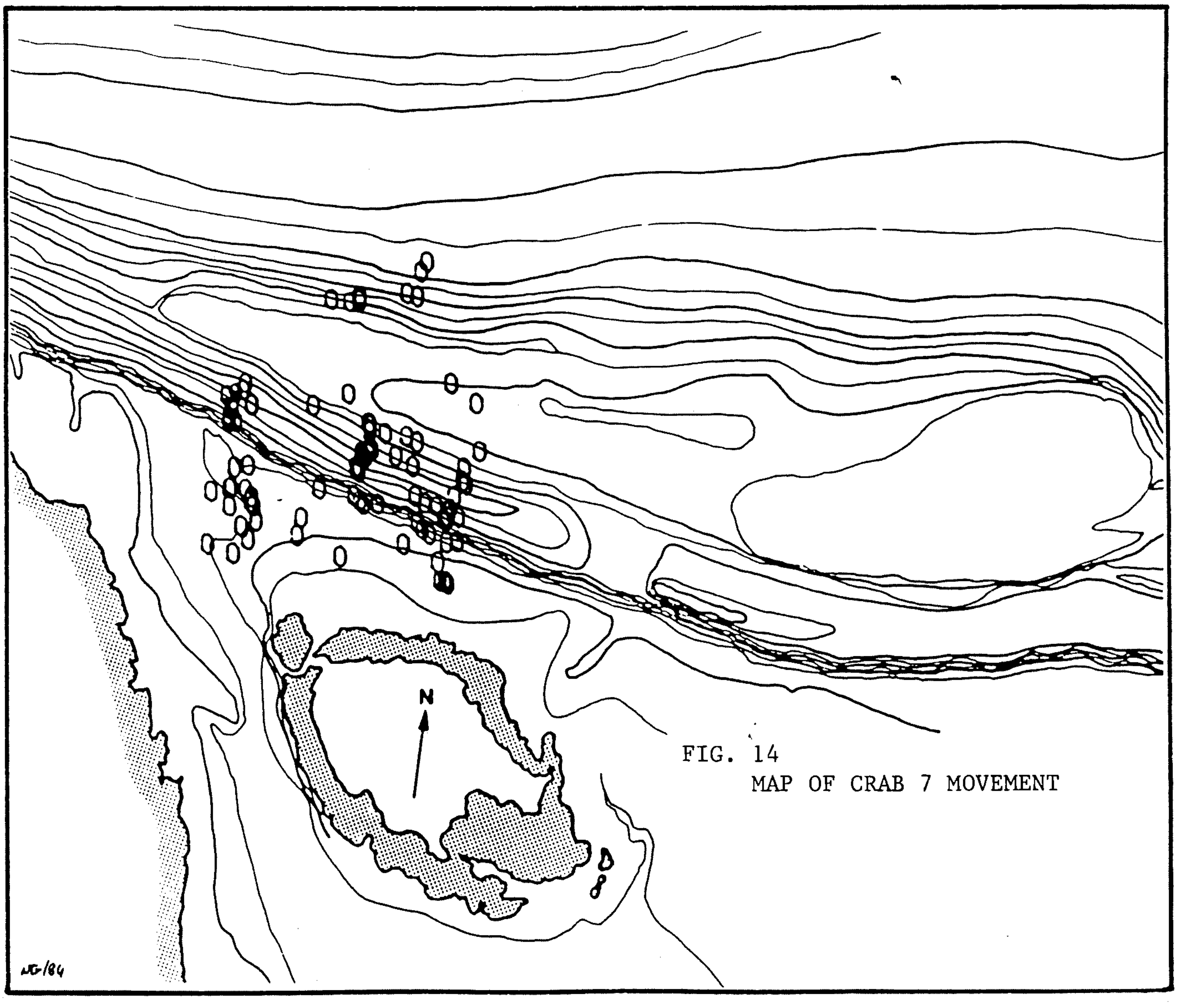


FIG. 14
MAP OF CRAB 7 MOVEMENT

FIG. 15a ACTIVITY OF CRAB 7

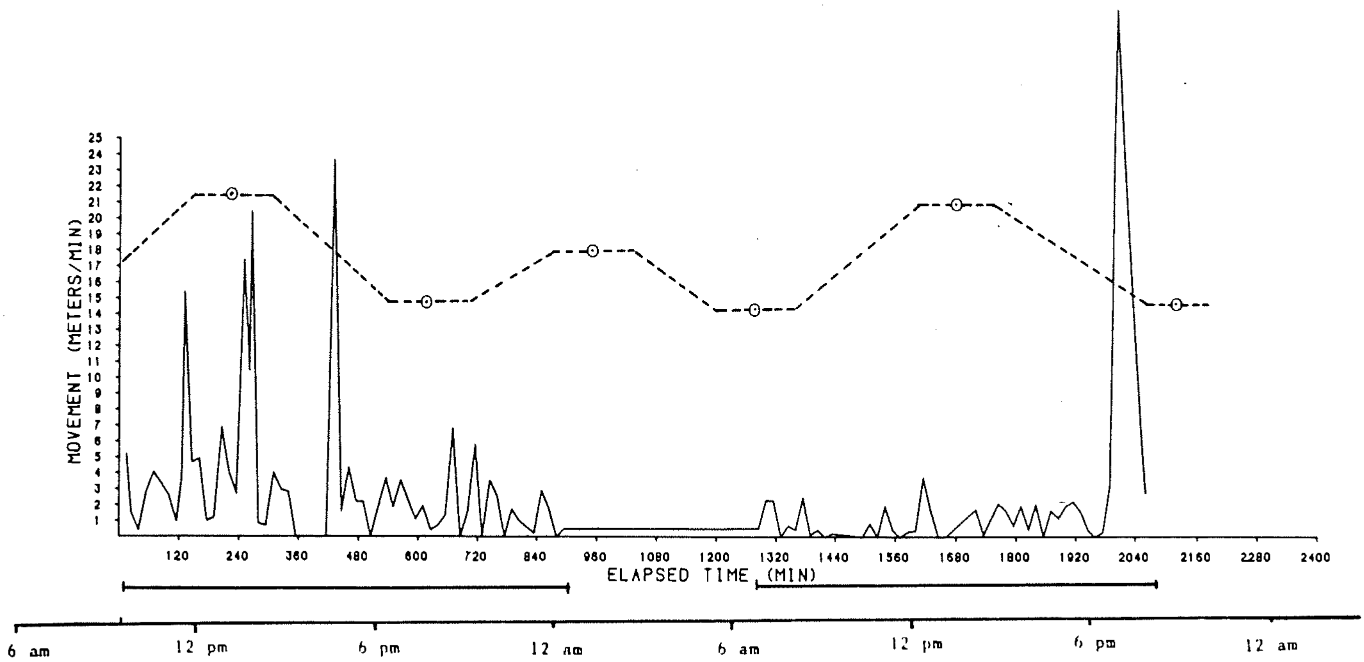
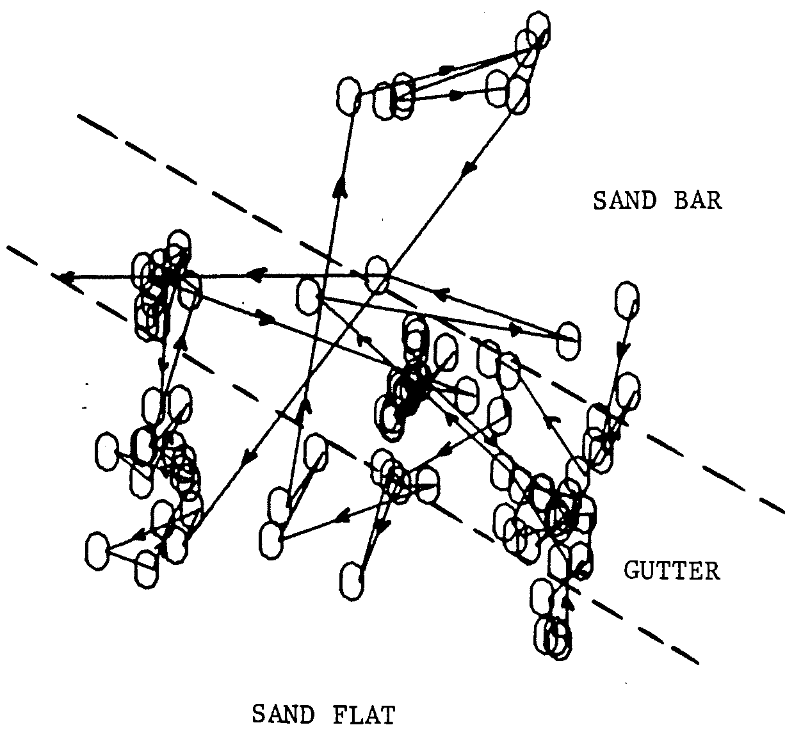


FIG. 15b PATH OF CRAB 7



Tag 8. (trip 12)
Date 9.11.83
Site Toorbul, Pumicestone Passage

A female sand crab, 140 mm carapace width was caught at 7.15 AM, released with tag attached at the point of capture by 8.40 AM. Contact was maintained for 30.25 hours with 14.25 hours continuous tracking on the first day and 9 hours on the second. The sea conditions were rough (sea state 4) with the wind constant from the South-East. The boat was held almost stationary in the wind with little effect from the tide, however wave action combined with wind pressure caused the anchors to drag on occasion.

The compass bearings and consequent crab position estimations were not as accurate on this trip due to the sometimes extreme boat movement. The positions are still within the 20 meter probability elipse (see methods section) but the rate of movement and activity pattern should be considered as estimates only.

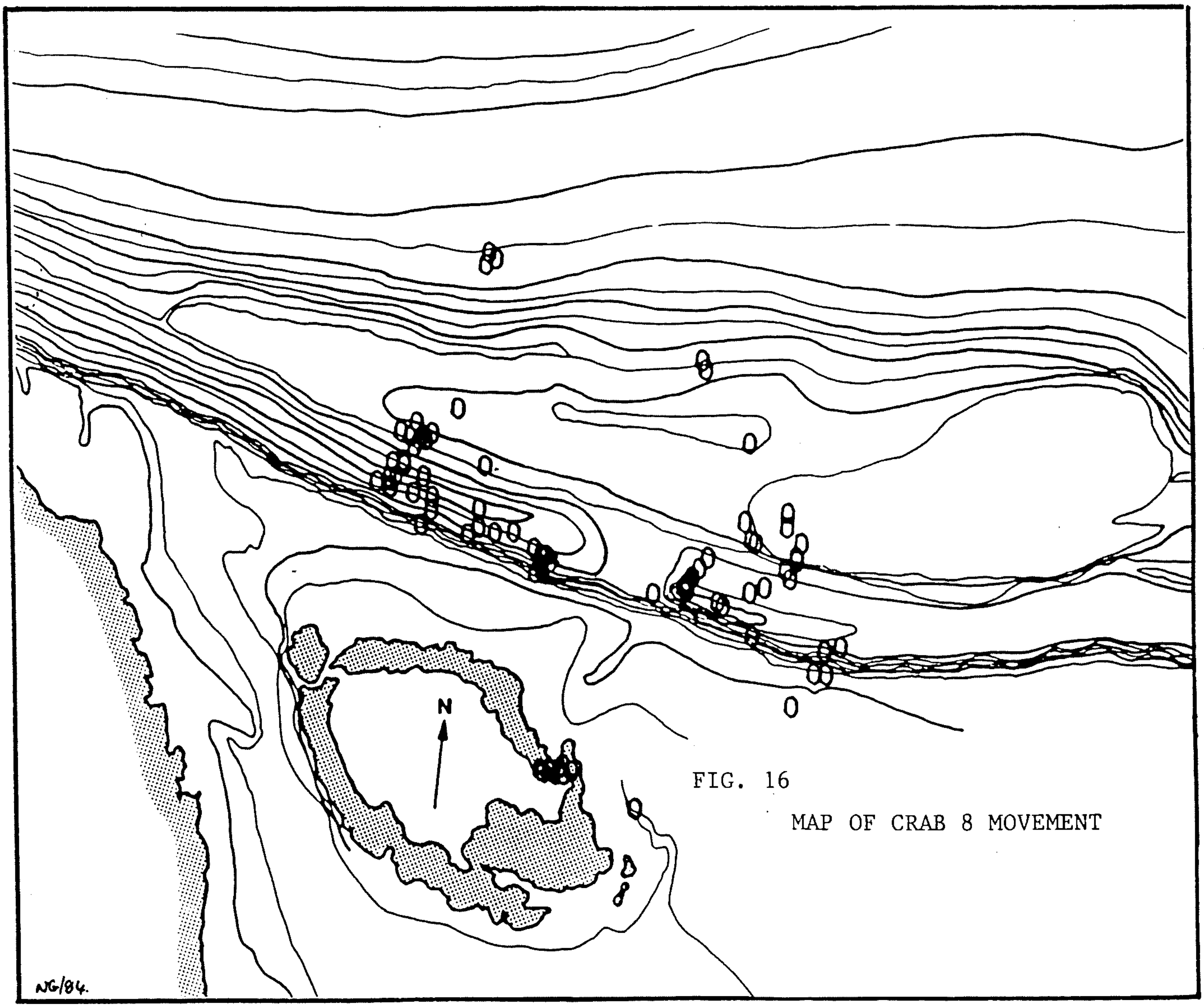


FIG. 16

MAP OF CRAB 8 MOVEMENT

FIG. 17a ACTIVITY OF CRAB 8

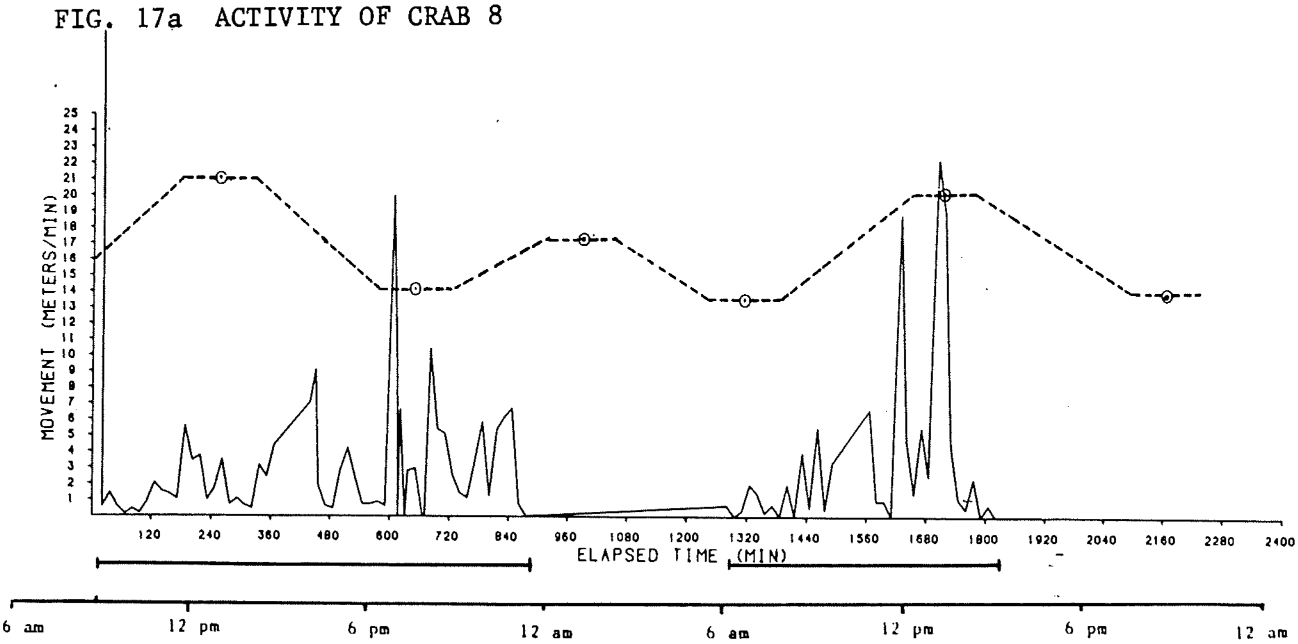
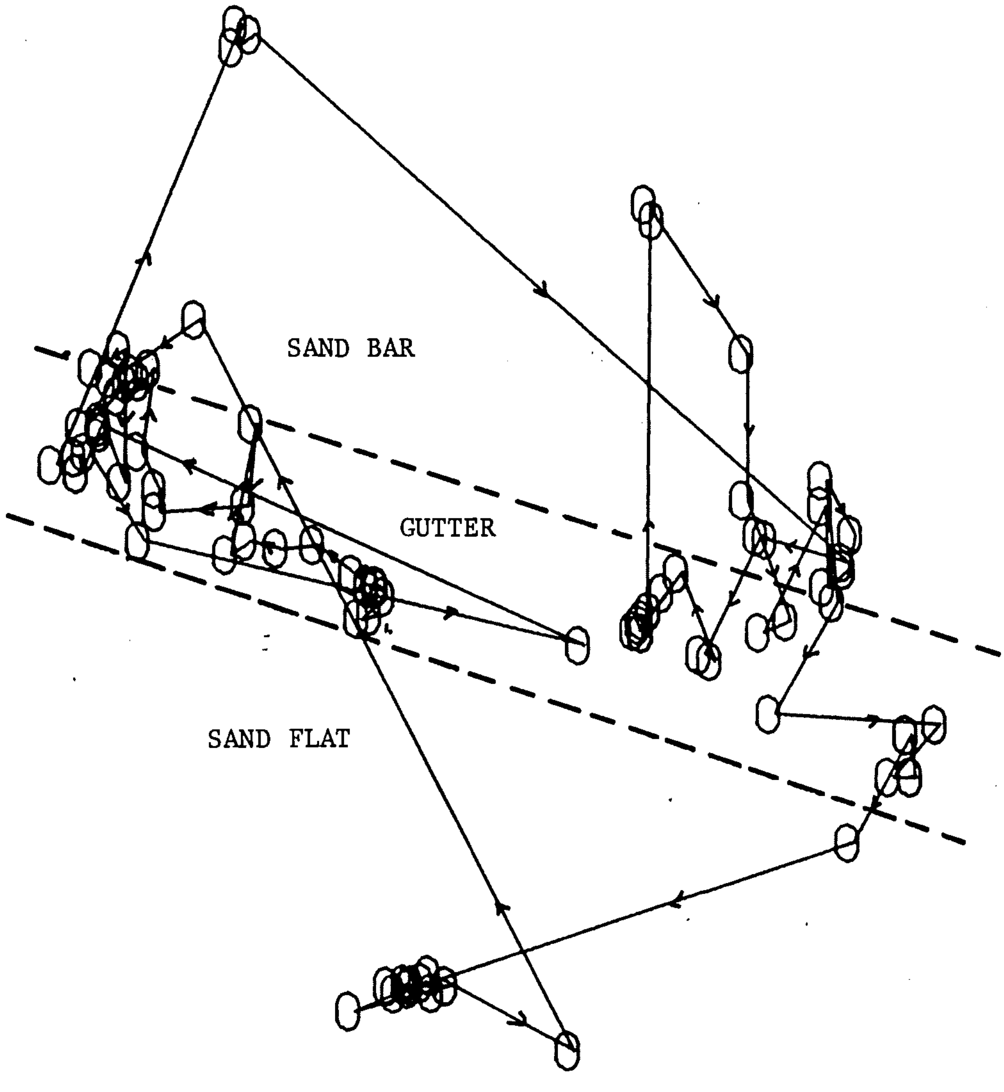


FIG. 17b PATH OF CRAB 8



Tag 9.(Trip 14)
Date 6.12.83
Site Toorbul, Pumicestone Passage

Tag 9 was the third tag in series II of Mk IV tag production (see appendix 2). In order to increase the effective operational life of these tags, the hydrophone receiver was retuned so that the initial tag frequency was at the top of the receiver tuning dial. The frequency drop over time, which had been experienced with previous tags in this series, could be anticipated and the tag tracked even when it produced lower frequencies at the end of its battery life. Previously these were "off the dial" of the hydrophone receiver so tracking had to be aborted.

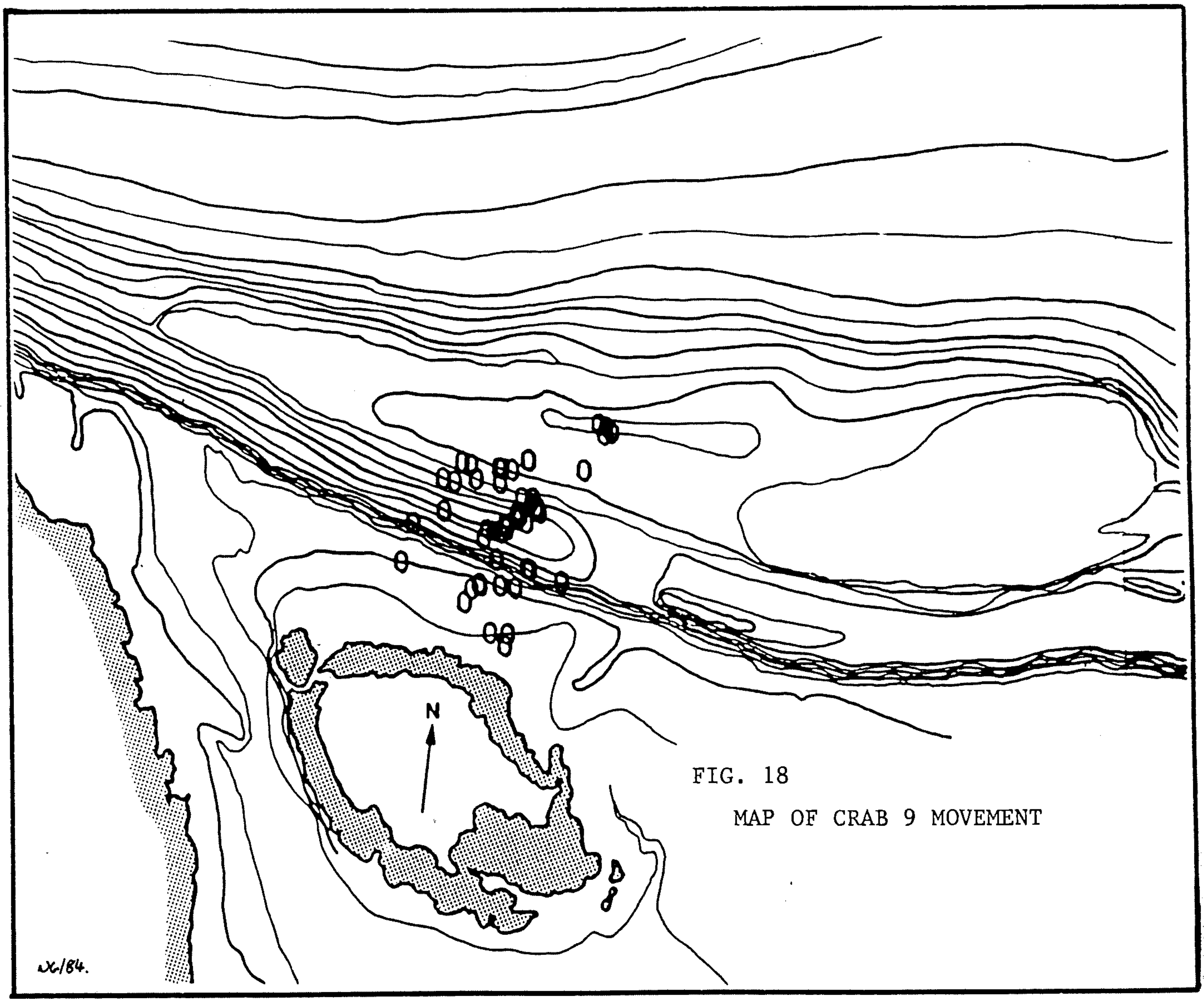


FIG. 18

MAP OF CRAB 9 MOVEMENT

FIG. 19b DETAIL OF CRAB 9 ACTIVITY

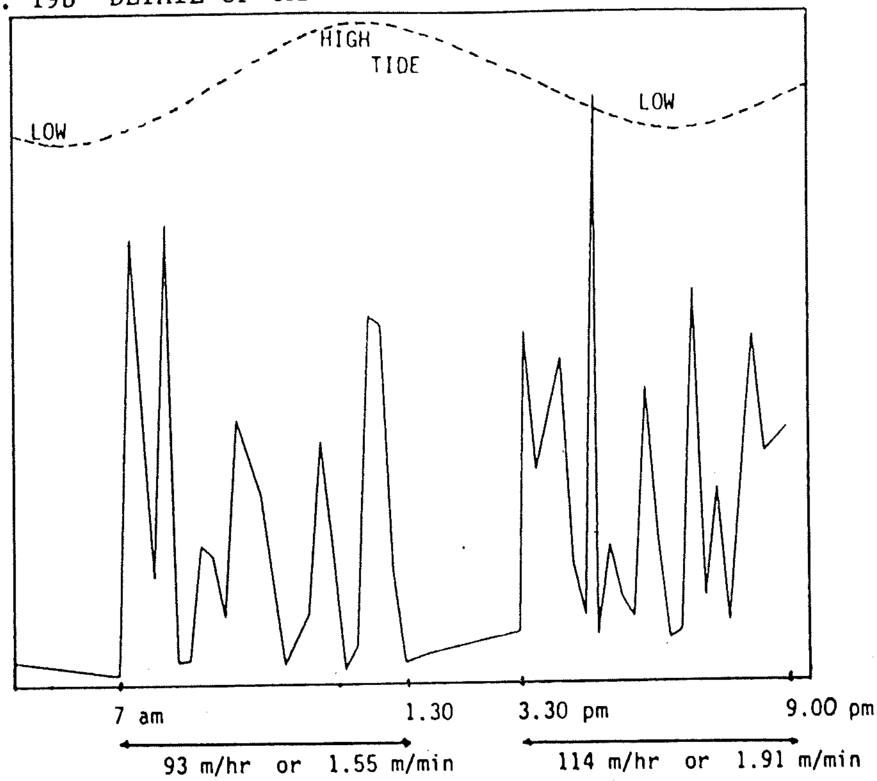


FIG. 19a ACTIVITY OF CRAB 9.

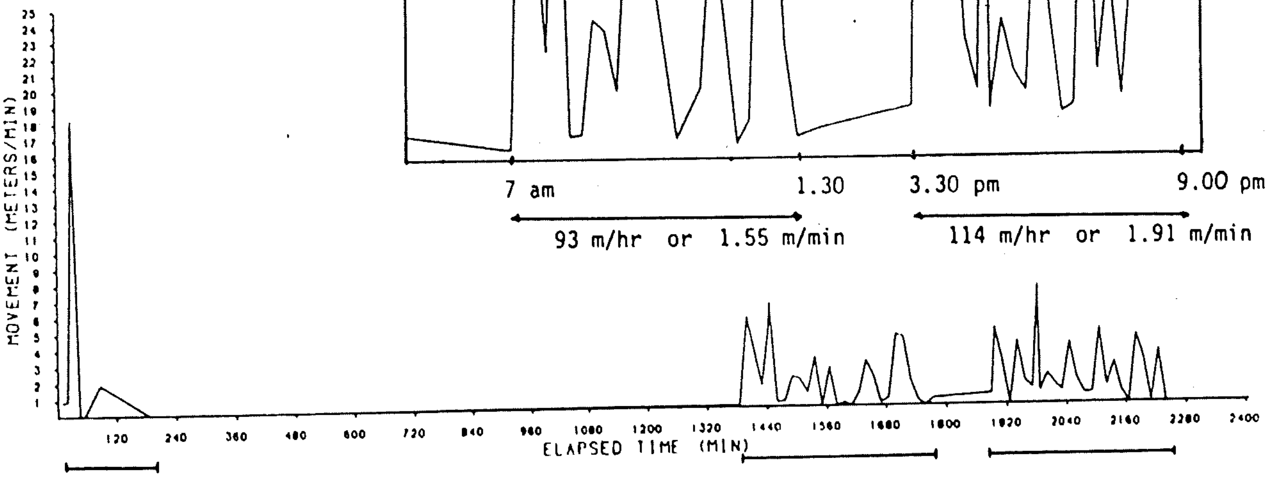
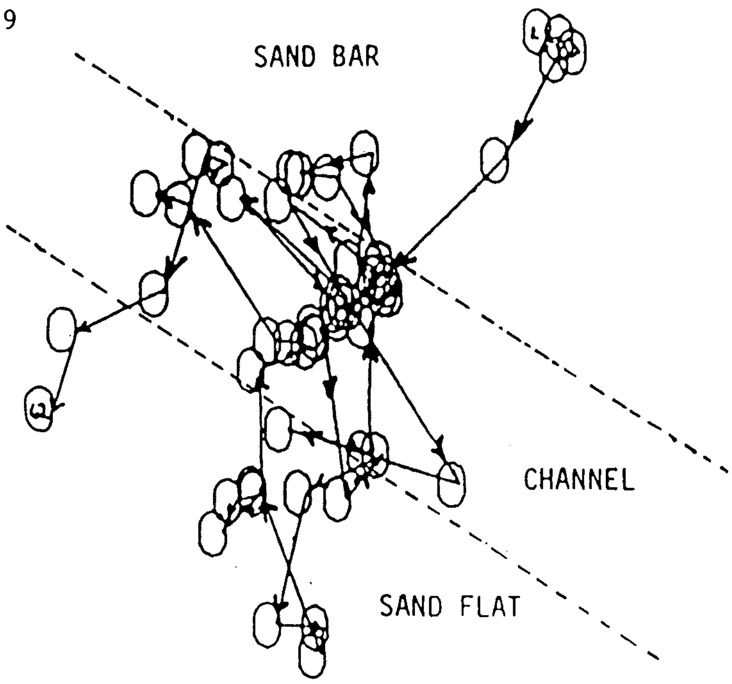


FIG. 19c PATH OF CRAB 9



Tag 10.(Trip 17)
Date 28.2.84
Site Toorbul, Pumicestone Passage

Tag 10 and Tag 11 were attached to male sand crabs, 170 mm and 145 mm carapace width respectively. The frequency of tag 10 was set slightly higher than tag 11 to aid in identification. Both tagged crabs were released at 10.00 am at the point of their capture (aproximately) and were simultaneously tracked for the next two days.

Tag 10 was continuously tracked for 14 hours on the first day and for 1 hour on the second. On the morning of the second day the crab was moving out of the study site and contact was lost. The crab was recaptured and the tag retured on the 4.3.84 by an amateur crabber.

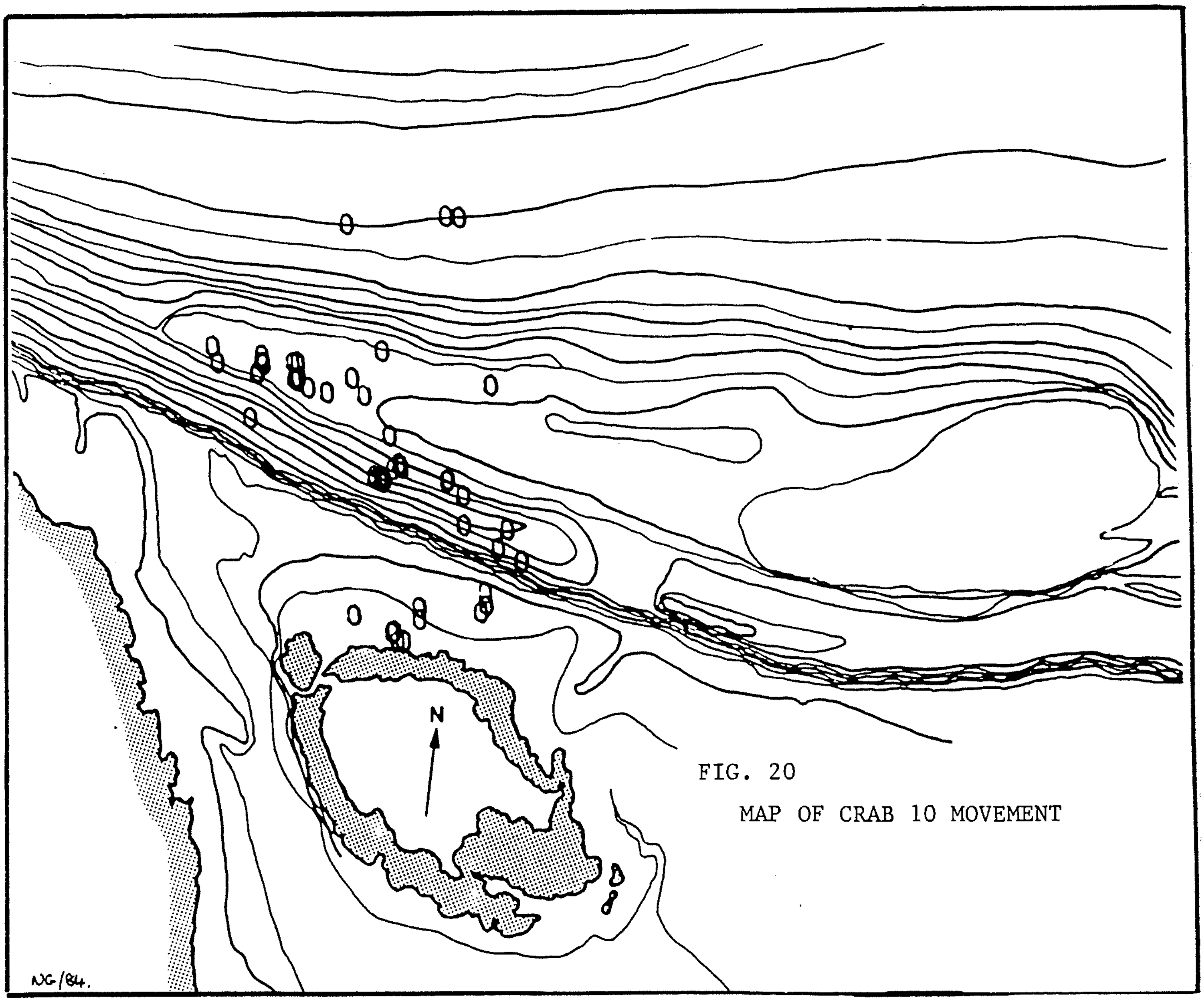


FIG. 20

MAP OF CRAB 10 MOVEMENT

FIG 21a ACTIVITY OF CRAB 10

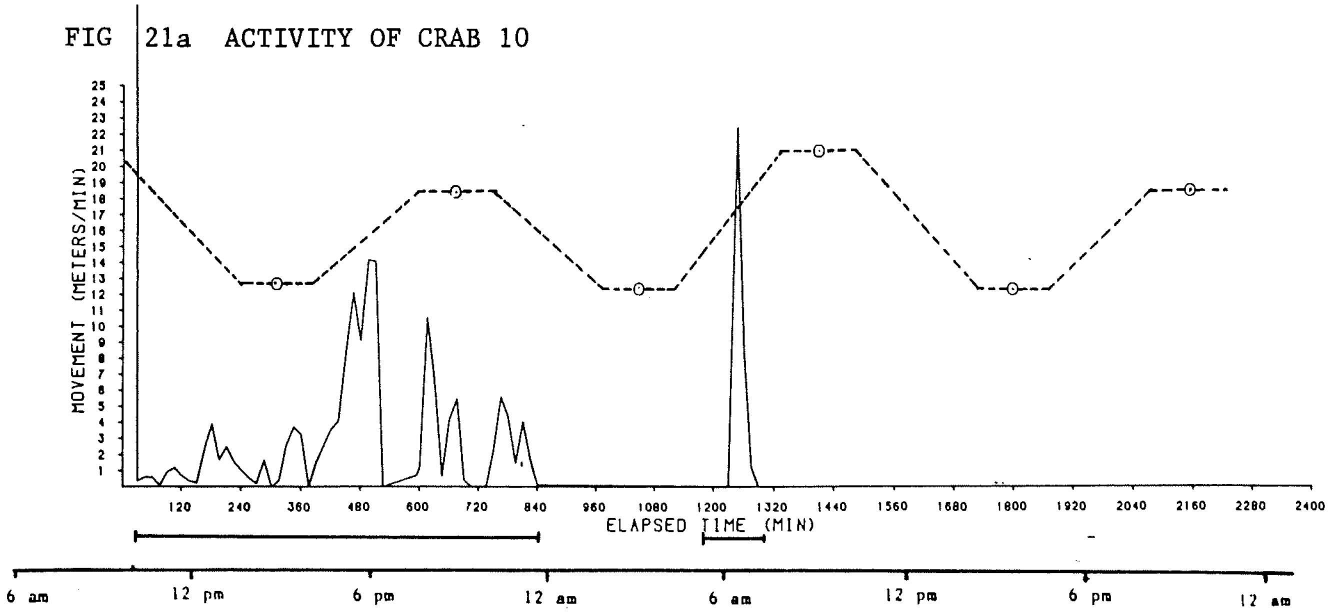
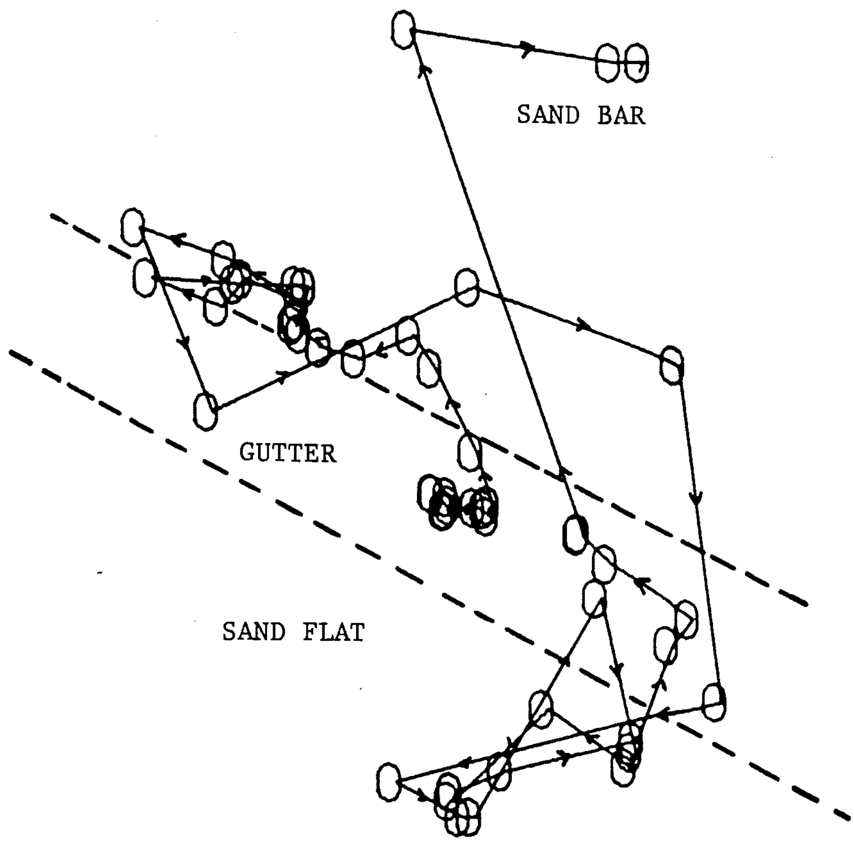


FIG. 21b PATH OF CRAB 10



Tag 11. (Trip 17)
Date 28.2.84
Site Toorbul, Pumicestone Passage

Tag 11 was attached to a male sand crab (145 mm carapace width) and released similtaneously with tag 10. (See preceeding report)

Contact was maintained for a total of 30 hours with two sessions of continuous tracking; 15 hours on the first day and 9.5 hours on the second. The tracking had to be aborted at 4 pm on the 29.2.84 due to heavy rain. The electronic gear became too wet to be reliable.

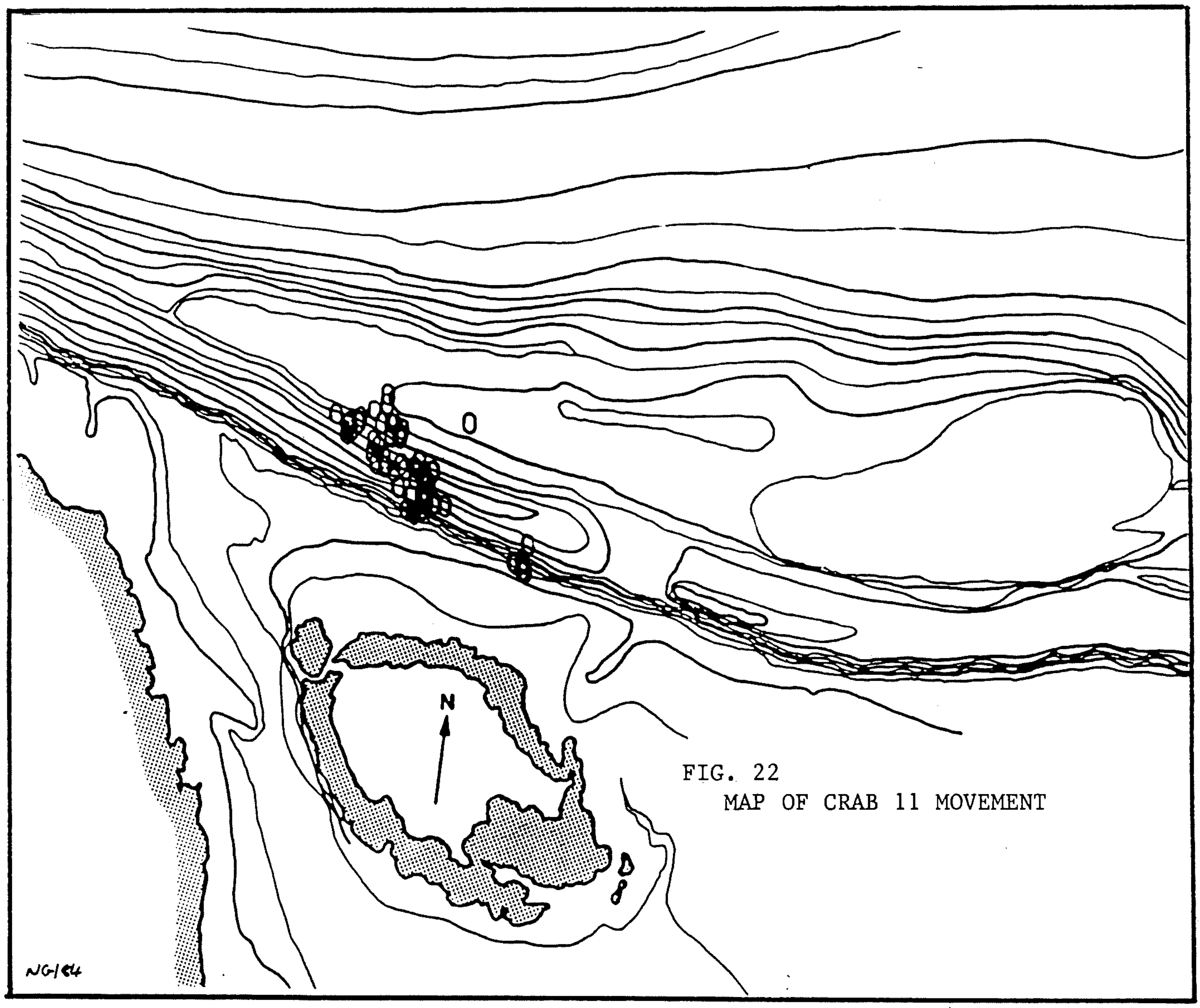


FIG. 22
MAP OF CRAB 11 MOVEMENT

FIG. 23a ACTIVITY OF CRAB 11

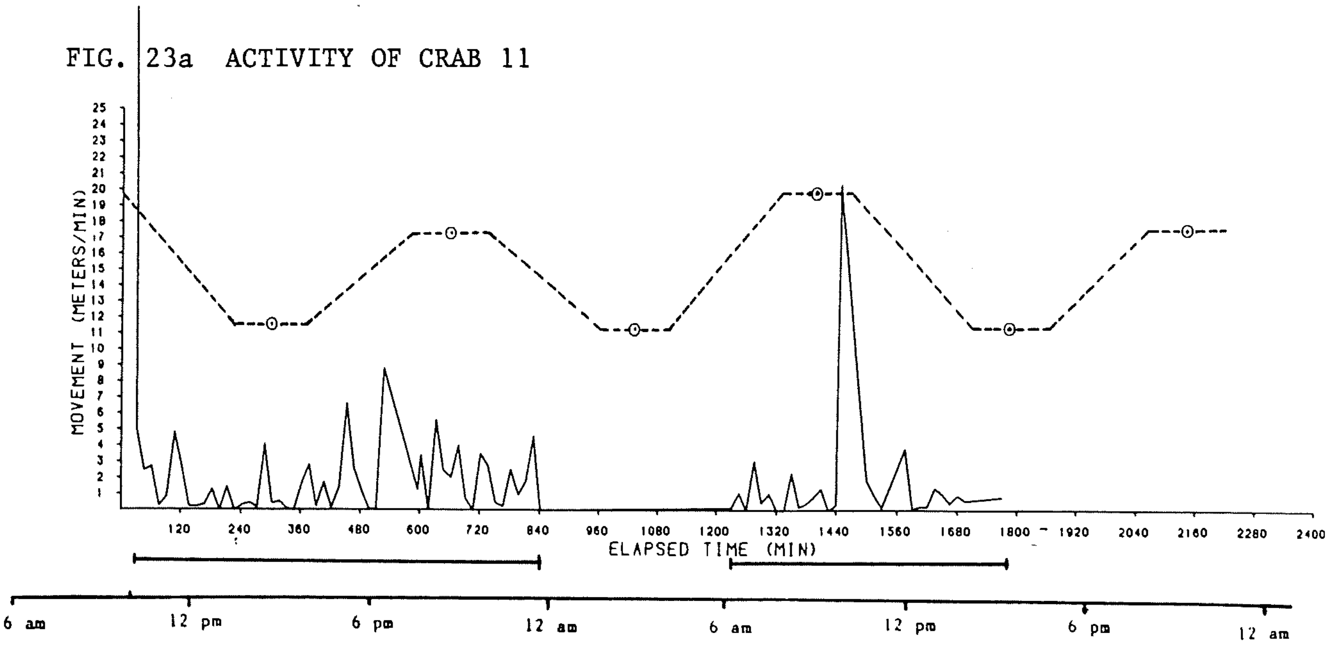
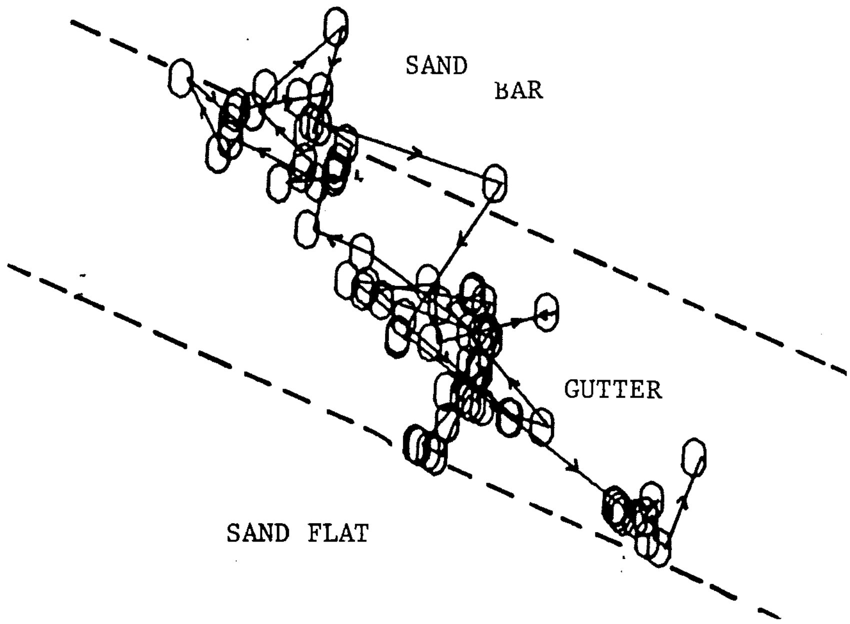


FIG. 23b PATH OF CRAB 11



Tags 10 + 11 (combined interaction)
Date 28.2.84
Site Toorbul, Pumicestone Passage

Two tagged male crabs were released simultaneously (see previous two tracking reports) to determine if:

(i) separate foraging areas would be set up or

(ii) the crabs would overlap their foraging areas.

The crabs were caught in the first and second dilly of a six baited dilly chain laid on a 28.8 meter transect running parallel to the seaward edge of the gutter off the point of Parrot Is. The chain was set by 6 pm on the 27.2.84 and taken in at 6 am on the 28.2.84. The data gained from Tag 4 suggests that the bait would attract crabs from at least 50 meters away. Data from Tags 5 to 9 show that for the 24-48 hour periods studied the crabs remain in a localised area aproximately 200 by 100 meters. There can be considerable movement within this area and there is a general shift in the area along the shore, towards the north-west. Therefore it is possible that the two crabs came from adjacent areas and the bait attracted one into the area of the other, or that the two foraging areas overlapped.

The crabs were released together at a point mid way between the sites of their capture. They remained in the close proximity for the first 90 minites then moved off into separate regions. Crab 10 moved towards the bridge end of the gutter while crab 11 stayed close to the point off Parrot Island.

Over the next 21 hours both crabs remained in the gutter parallel to Parrot Is. During the afternoon and evening Crab 10 moved along the gutter into the southern Bridge end. During the night it moved back along the gutter on the inner edge of the sand bank; by midnight the crab was past the dinghy heading north-west. Next morning the crab was located on the seaward side of the sand bank , having crossed over it during the night, and was tracked heading south-east till it passed beyond the range of the hydrophone.

Crab 11 stayed in the vicinity of Parrot Island point through the day, evening and most of the night but began moving along the gutter into the southern end after this had been vacated by crab 10. Next day there was a small movement back along the gutter towards the point.

The striking aspect of the tracking was the lack of overlap in the areas occupied by the crabs when both were in the Passage. The closest they came was just before midnight when crab 10 moved along the sandbar edge of the gutter while crab 11 was on the landward edge.

Analysis

The first stage analysis of the tracking data is in the form of the position maps , crab path and the activity timecourse plots. A summary of this data is in table 1. Crab 5 was infested with Sacculina and for the purposes of this investigation can be of no commercial interest, therefore no analysis was performed beyond mapping its movment.

The second stage analysis used the position maps, plots of path, and activity plots to calculate the area occupied by the crabs, their usage of the study site and their preferred direction of travel.

The "temporary foraging area" for the all crabs except Crab 5 was determined using the convex polygon method of home range estimation, including all observed positions. The method applied in this way gives an over-estimation of the area utilised by each crab (compared with other methods, see reference 5), however it can be plotted simply and the area quickly determined with a planimeter.

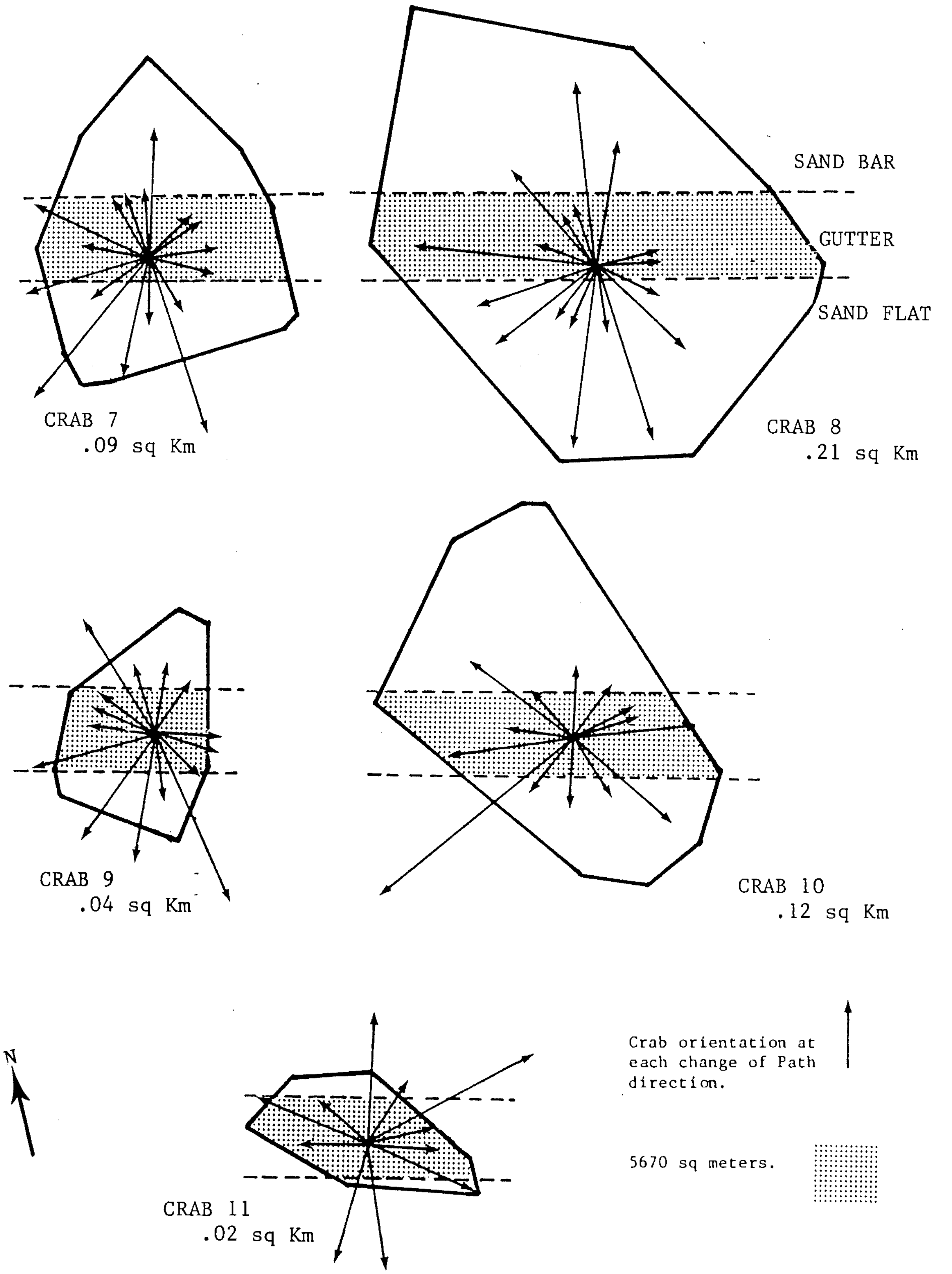
TABLE 1 SUMMARY OF TRACKING DATA

TAG No.	CRAB SEX	CRAB WIDTH	DIST. (M)	DURATION (HOURS)	RATE(M/HR) AV.	RATE(M/HR) MAX.	AREA (M2)
3	M	157	1603.45	7.91	202.7	390	-
4	M	150	58.37	3.83	15.3	150	-
5	M*	165	-	33.00	-	-	12,403.72
7	M	164	6131.59	34.83	176.0	1410	87,038.64
8	F	140	7029.00	31.83	220.8	1320	210,367.01
9	M	150	1700.65	37.33	45.6	1110	37,423.78
10	M	170	4805.81	21.50	223.5	1362	116,524.04
11	M	145	4058.00	29.50	137.6	1230	25,799.73

* Male sand crab with Saculina (parasite) externa visible.

Correlation between activity, time of day (available light) and state of the tide was determined by eye from simultaneous plots of the three variables. Preferred direction of movement (orientation) was determined using the plots of crab path and a combination of the activity timecourse plots with the field notes. Each time the crab changed direction, the bearing (angle) of its new line of movement was recorded and plotted as part of a circular distribution. If the probability oval for the new position overlapped the previous one then the angle was ignored as unreliable. Fig 24 presents the plots of the crab orientation together with the areas utilised by each crab in relation to the gutter off Parrot Island. Fig 25a & b present circular histograms of the combined orientation for all the crabs. Table 2 gives a summary of the areas used by each crab during the tracking periods.

FIG. 24 TEMPORARY FORAGING AREAS (T.F.A.) and
ORIENTATION OF CRAB MOVEMENT. (Normalised to the Gutter off Parrot Is.)



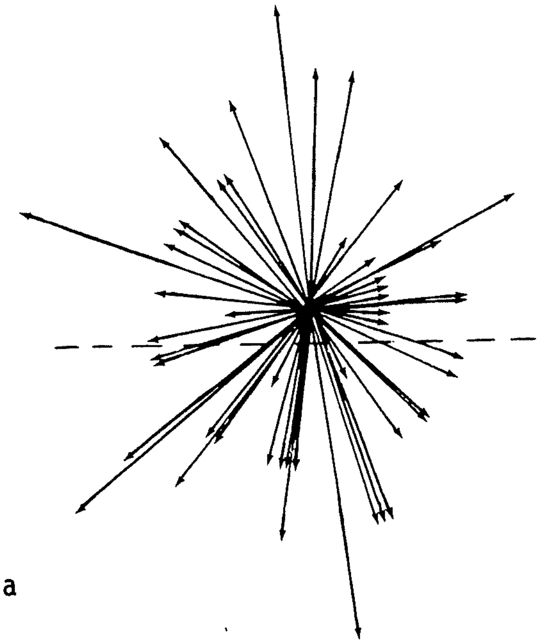


FIG 25a

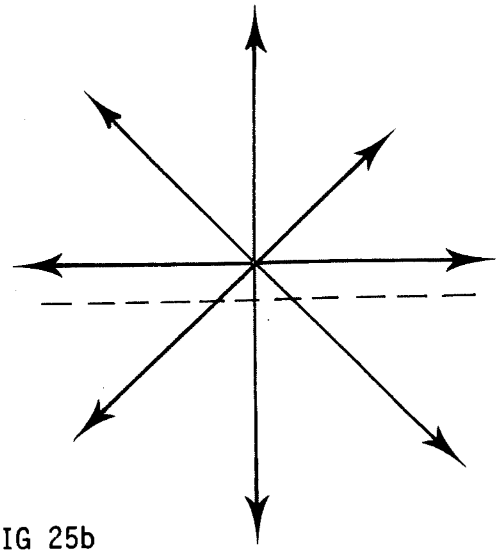


FIG 25b

TABLE 2 SUMMARY OF AREA USEAGE WITHIN THE STUDY SITE.
(Number of times a crab was recorded within a particular area of the study site.)

CRAB	SANDFLAT		GUTTER		SANDBAR	
	No.	%	No.	%	No.	%
7	24	28.9	47	56.6	12	14.5
8	19	23.5	51	63.0	11	13.6
9	12	27.3	23	52.3	9	20.5
10*	10	19.6	21	41.2	20	39.2
11	5	7.1	60	85.7	5	7.1
Total	70	21.3	202	61.4	57	17.3

<u>Note for FIG.24.</u>

(i) The plots of orientation and area have been normalised relative to landward edge of the gutter.

(ii) The arrows represent the direction of movement of the crab and the single choice of a direction is shown as one cm ; where the crab chose to move in the same direction more than once the arrows are shown as the summed length.

<u>Note for FIG.25a&b.</u>

(i) In fig 25a the arrow length is calibrated as for fig 24.

(ii) In fig 25b the arrow length sigifies the sum of the choices of movement in a given direction within a 45 degree sector, each mm of the arrow represents one choice of that direction.

Discussion

The ultrasonic tracking system designed and developed for this project consists of an ultrasonic tag, a hydrophone and ultrasonic receiver, a tracking protocol, and computer programs for field data manipulation. The tag has a signal frequency of 200 Khz, a range of 300-400 meters, and an operational life of 36-48 hours in the field. It has been designed to give minimal interference with the animal and yet give reliable signal levels during all activities. The ultrasonic transducer of the tag is mounted on a short vertical stalk so that the crab can be located even when buried in the sand. A matching hydrophone and ultrasonic receiver has been developed, as has a technique of tracking crabs using only one hydrophone and one boat. This method simplifies logistics yet gives position information with 20 meter resolution. The final component of the tracking system is a suite of computer programs which is compatable with most mini computers and performs the data reduction and preliminary analysis. Output is in a form suitable for immediate plotting as maps or graphs.

The tracking system was used to track sand crabs (Portunus pelagicus) in Pumicestone Passage, Moreton Bay Queensland. The results of this study have been analysed under four categories:

(i) Area occupied by an individual crab.
(ii) Rate of Crab movement.
(iii) Crab activity.
(iv) Crab orientation.

(i) Area occupied by an individual crab.

The area was calculated for each crab from its "Map of Crab Movement". Fig 24 summarises this data while Table 2 gives a breakdown of the usage of sections within an area occupied by an individual crab.

One of the primary aims of the field work was to determine if a crab remains in a definable area or territory. From the 8 crabs observed in this study, 2 left the vicinity of their capture and subsequent release within 24 hours. Crab 3 moved directly offshore after release, buried for approximately 2 hours then moved out of the study site. It was recaptured from the general area of its original capture 51 days later. Crab 10 was tracked for 22 hours, staying within a localized area of the study site, it then crossed over the sand bar and travelled out of the study site along the main channel. This crab was recaptured 4 days later, 1km from the point of release. Crab 4 was recovered from a crab pot, 4 hours after release and 50 meters from the point of return. Little can be deduced concerning territoriality from the behaviour Crab 4, except that the crab was not "escaping" but foraging.

The other 5 crabs occupied localized areas which ranged in size from 25,800 sq meters (.02 sq Km) to 210,367 sq meters (.21 sq Km) for at least 24 hours. The plots of Crab Path show that all of the crabs had a similar pattern of movement; a series of abrupt changes of direction and retracing of tracks. The crabs moved repeatedly from the gutter onto either the sand bar or sand flat then back into the gutter. Of the total number of times that a crab was located (ie. a position fix was recorded), 61.4% of the times were in the gutter, 21.3% were on the sand flat, and 17.3% were on the sand bar. Each crab appeared to have a small area or succession of small areas in the gutter that it would return to most often. Crab 9 has a series of overlapping position fixes located in a deep hole midway along the gutter. All its excursions onto the sand bar or sand flat radiate out from this position. The same pattern can be seen in the path of Crab 7 and Crab 11 where there is two, possibly three, concentrations of position fixes located within the deep gutter. Crab 8 and Crab 10 show a more diffuse pattern of position fixes however there are concentrations at a number of points along the gutter. Crab 8 in particular seems to have preferred the deep holes in both the southern and northern ends of the gutter. Crab 10 left the study site after 22 hours hence its pattern will be confounded. It can be seen from Fig 24 that the gutter divides the area occupied by each crab into two almost equal parts. The sandflat and sandbar were visited almost equally by each crab with the more active crabs ranging over larger areas of both.

The picture built up by this data is one where the crab has a preferred location within the deep water section of the study site and forays up onto the shallower, tidal areas. The crab can change this prefered location, have multiple locations or can move completely away. The pattern of movement while in the shallow sections was typically: a rapid movement from the gutter to a partictictular site, then a series of small apparently random position changes over a limited area, followed by a rapid movement back to the gutter.This pattern can be reasonably interpreted as foraging. The classical definitions of territory or home range cannot be applied to this situation as the patterns are based on 24 hour data. For this reason the area occupied by the crab is best termed the "Temporary Foraging Area", comprising of the central deep water "base" site or sites together with the adjacent "shallow water foraging sites".

(ii) Rate of crab movement.

The maximum rate of movement was determined by dividing the distance between successive position fixes by the time taken by the crab to travel between them. The average rate of movement was calculated from the total distance travelled during the tracking period, divided by the elapsed time. Table 1 summarises this data and the individual activity plots show its variability over time. The variability is of interest because it appears there are two levels in the rate of movement. The activity plot of each crab has a number of short periods of high rates of movement with relavitly slower rates being the norm. The peak rate of 1410 meters per hour was recorded for crab 7, however the average rate for this crab was only 176 meters per hour. The group average for the 8 crabs was 146 meters per hour.

Crab 3 was tracked for 2 hours as it moved steadily out of the study area at the sustained rate of 4.16 meters per minute (249.6 meters per hour). If this rate represents the normal continuous rate for crab movement then the norm of the activity plots represent an intermittent series of limited distance movements, at approximately the normal rate. The short periods of high rates of movement were 5 to 6 times the normal rate. They represent either fast longer distance movements or very fast movements over a short distances followed by a stationary period which have been averaged out by the elapsed time between observations.

(iii) Crab activity.

The activity plots have the rate expressed in meters per minute and the approximate time between observations is 15 minutes. Assuming that an active crab is a moving crab and conversely that a an inactive crab is stationary, then the changing rate of movement is a good indication of relative activity, (activities such as feeding, courting or fighting , which do not involve large position changes, will be underestimated in such a scheme).

Peaks of activity ("fast movements") were associated with high tide for all crabs with the one exception, during low tide for crab 8. The sand flat was exposed at low tide, effectively excluding the crabs. As the tide rose, the flat became available for foraging therefore explaining the peaks in activity at this time. The peaks in activity that occurred on the falling tide can be explained by the reverse phenomenon, the crabs were being excluded. When the path of crab 8 was compared with its activity plot it was apparent that the crab was moving in the gutter at low tide and moving on the sand flat at high tide. There appears to be a similar pattern in the background "slow" movements. For Crabs 10 and 11, the observations made during the first tidal cycle show a general increase in the rate of movement associated with the rising tide. This trend can be seen in the observations made during the third tidal cycle for Crab 8 and the first cycle for Crab 7.

The direction of the current in the gutter was parallel to the edge of the sand flat and reversed each tidal cycle. There were 3 hour periods of slack water at high and low tide. The activity peaks (fast movement) occurred irrespective of the presence of the current or the direction of the current. Crab 8 exhibited a peak during the low slack water, a peak during the rising tide with the current flowing into the passage, and another peak at slack high water. The other crabs have their peaks distributed from the rising tide with the current flowing in, through the slack high water, to the falling tide with the current flowing out.

The effect of the time of day on activity is difficult to assess because of the overiding tidal effect. Laboratory experiments show that there is a strong correlation between activity peaks with both dusk and dawn. Furthermore there is a general increase in activity at night. In the field, the periods of continuous tracking typically started early in the morning and continued for approximately 16 hours till after midnight. This protocol allows the comparision of the hours before dusk with the hours immediately after it. "Dusk" in the field is defined as the time of the afternoon when the angle of the suns rays is so low that light does not penetrate to sea bottom. At the study site this time preceded sundown by an average 2 hours. Crabs 10 and 11 showed a significant increase in activity from 4.30 pm in the afternoon of the first day, however this period coincided with the rising tide. Crab 7 had a short duration peak at 4.30 pm but the activity following was significantly less than the activity prior to dusk. In this case dusk coincided with a low tide. Conversely Crab 8 exhibited an increase of activity from 5 pm on the first day, also during a low tide. Crab 9 had a relatively even pattern of activity with only minor peaks associated with the tidal flooding and draining of the sand flat.

At this study site, tide appears to affect crab behaviour to a greater extent than does time of day. If dusk coincided with high tide, the effects on activity were summed; the crabs became relatively more active with a greater number of "fast" movements. If dusk coincided with low tide then the positive effect of time of day was either reduced or cancelled by the tidal effect. A possible complicating factor that has not been considered is cloud cover (amount of available light), nor has the effect of height of tide (depth of water) been considered. Futhermore the high turbidity in Pumicestone Passage results in a decreased range of light intensities compared with those in the laboratory.

(iv) Crab orientation.

The angle of the new line of travel was recorded each time a crab changed direction during a tracking period. Fig 24 presents the circular histogram of these angles normalised to the edge of the gutter and superimposed on the convex polygon describing the area occupied by the crab. Fig 25a gives the circular histogram of the combined angles chosen by all the crabs. Fig 25b shows the angles of Fig 25a, summed for 45 degree sectors.

Based simply on the angles chosen, the crabs appear to have traveled in a almost random fashion. Fig 25b shows that as a group, the crabs could travel in any direction but had a preference for the sectors facing towards the sand flat. The least chosen sector was towards the southern end of the sand bar. The sectors parallel to the gutter, facing both north and south , were chosen equally often. Caution should be exercised in interpreting this data as all changes of direction are included irrespective of the distance travelled along the new line. The plots of crab path document two broad categories of movements; long to medium distance movements of greater than 50 meters, and short distance or foraging movements. The movement criteria that define these categories are flexible and should be modified for the behaviour of individual crabs, however the general pattern is consistent. If the direction of the long movements is taken separately from the foraging movements then the trends shown in Fig 25b are reinforced. There was a strong preference for travel in the direction of the sand flat and in both directions parallel to the gutter. The comparatively weak preference for the sectors facing towards the sand bar may reflect the fact that crabs were found less often in this area. A more subtle reason is that the crabs may have taken a direct path onto the sand flat but a more circuitous one as they travelled back to the gutter. The result would be a strong preference in the direction of the flat but a more diffuse preference for its complement.

The "base" sites located in the gutter represent the loci of crab movement. On the crab path plots these loci appear to progress slowly along gutter during the period of the tracking. Crab 11 appeared to shift its "base" southwards in three steps during 30 hours of observation. Crab 8 had at least two loci, possibly three, which shifted first northwards, then back to the south end of the gutter. Crab 7 appeared to shift northwards in two or three steps over a 35 hour period. These shifts represent very slow movements, if compared with the rate of the "fast" movements or to foraging movements. The orientation of these long term changes in position was parrallel to the gutter with an apparent preference to the north.

(v) Miscellaneous.

Rare events are difficult to analyse for two main reasons: (a) statistical analysis can not accommodate very low numbers, (b) the difficulty in deciding the significance of such an event to the normal behaviour of the animal being studied.

Of the 56 crabs caught during this study only one was infected with Sacculina. The area foraged by this crab (crab 5) was smaller than that of any other crab tracked (Table 1) and the plot of its activity (fig 13b) shows a pattern similar to non-parasitised crabs but without their bursts of rapid movement. Both these observations are linked and can be explained if the parasitised crab was limited in its mode of locomotion. Given the size of the Sacculina "externa" it is possible that this structure interferes with the parasitised crab's ability to swim. The lack of the ability to swim could limit both the speed of movement and the area that could be foraged.

In the same "rare event" category is the similtaneous tracking of crabs 10 and 11. Two male crabs were released at the same place and time, to see if they would set up overlapping foraging areas. After release they moved to separate sections of the study site and remained separated for the duration of tracking. This result supports the concept that an individual crab sets up a temporary foraging area (T.F.A) and suggests that such an area is exclusive. As these crabs were originally caught in the same chain of "dillies" however, the presence of food must over-ride the need to stay within the individual area.

Both these cases are rare events, interesting but difficult to interpret.

Conclusions.

There was considerable variability in the behaviour of the sand crabs tracked for twenty-four hours in this study. The area occupied by each crab was variable, as was rate of movement, pattern of activity and orientation. A composite, "typical crab" is by necessity a simplification and can give only the general trends in behaviour.

The typical crab maintains a limited territory for at least 24 hours which can be defined as a "temporary foraging area" (TFA). The "base" or focus point for foraging excursions within the TFA is in deep water, while the foraging sites are in adjacent shallow water. There are three rates and types of movement. The "fast", directed movements over medium to long distances ; the slower, shorter, randomly directed movements associated with foraging; and the combination of these two that gives the very slow movement associated with the relocation of the "base" site. The crab appears to stay mainly within the deep water gutter, sweeping the the sand flat and sand bar either side in a series of quick foraging trips. A trip consists of a "fast" movement to an area of the shallows then a series of foraging movements, followed by another "fast" movement to a different area of the shallows or back to the gutter. The "fast" movements tend to be oriented either at 90 degrees to the gutter, when involved in short term foraging, or parallel to the gutter when involved in the longer term shifting of the deep water "base".

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(1) Young A.H. et el. New developments in Ultrasonic Fish Tracking. 1976 Proceedings of the Royal Society of Engineers. (b) Vol. 75,3.

(2) The Radio Amateurs Handbook, 1981. Published by the American Radio Relay League.

(3) National Semiconductors Linear Applications Handbook.

(4) Pumicestone Passage Water Quality and Land Use Study. Report of the Inter-departmental Committee. April 1982. Vol.2 "Water Quality and Circulation in the Passage contributed by the Water Quality Council Council of Queensland."

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Mr W L Fletcher	(Electronics W/S, Zoology Dept., University of Queensland)

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Mr P Gofton	(Diver/Museum Curator, Zoology Dept., University of Queensland)

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APPENDIX 1.

A SMALL ULTRASONIC TAG BASED ON THE ICM 7556

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The ICM 7556 integrated circuit is being used as the major component of a prototype telemetry tag to be attached to a large swimming crab, (Portunus pelagicus). This dual timer chip, the C-MOS equivalent to two of the ubiquitous 555 timers, has recently become available from Intercil. According to the data sheets the device has a maximum oscillation frequency of 500 khz and can operate from a two volt supply. It contains two timers, operating independently and consuming only 160 uA combined.

The appeal of using the 7556 is the potential for accurate frequency generation and reliable mark/space setting, available in one package, requiring the minimum of external parts, and without having to resort to crystal locking. Of almost equal importance is the vast array of 555 circuits that have been published. These range from temperature alarms to multi-plexing circuits and represent an impressive source of "applications" ideas.

Construction:

The tag is flat in order to conform to the dorsal carapace of the crab. Low profile Lithium "calculator" type batteries are used because of their physical compatibility, their ability to supply three volts and the almost constant voltage supplied for the life of the battery.

Point to point wiring, using 32g enamelled wire, allowed the best component packing density. Two types of toroid cores were tried in the output transformer, (see Table 1). The AMIDON cored transformer was self resonant at the chosen frequency of 200 khz but a compromise in the transformer turns ratio was necessary. Effectively the output voltage was limited to approximately 20 volts, peak to peak. The dual PHILIPS cores allowed higher transformer output voltages but they are bulkier, weigh more and require an extra capacitor to tune them.

Table 1 Output transformer Specifications:

Make	Type	No. Cores	Sec. Turns	Pri. Turns	Output (p.p)
AMIDON	FT-23-72	1	36 of 36g	10 of 32g	18 volts
PHILIPS	4322-020 -97160	2	200 of 36g -two layer	16 of 32g	40 volts

A prototype tag was built for each type of transformer. The AMIDON core tag was given a shorter pulse duration and a longer interval between pulses than the PHILIPS core tag by changing the timing resistors R5 to 33 k and R6 to 3.9 M. Similar, one transistor "C" class output amplifiers were used in both tags. Each tag was potted in DOW CORNING 1-2577 silicone conformal coating. Batteries were attached by using ACME 3021 conductive epoxy.

Table 2 Parts list:

R1	1.2 k	C1	*- 300 pf (select on test)
R2.R5	82 k	C2	6.8 uf Tantalum
R3.R4	150	C3	15 pf
R6	2 M . 1/4 watt	C4.C5	10 nf
		C6	4.8 uf Tantalum

Transistor	Philips BCF 32
Diode pair	Philips BAV 99
I.C.	Intercil ICM 7556, dual low power Timer
Transformer	See Text and Table 1
U.T.	Vernitron PZT-5 2-2020-5, 200 khz.

Fig.1 Circuit Diagram of the tag.

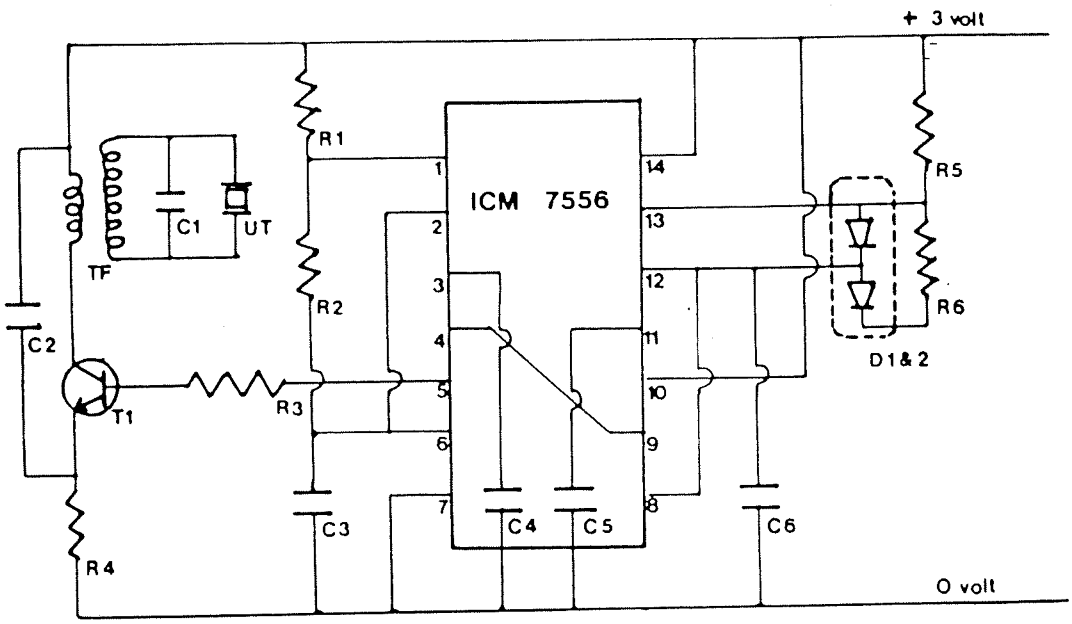
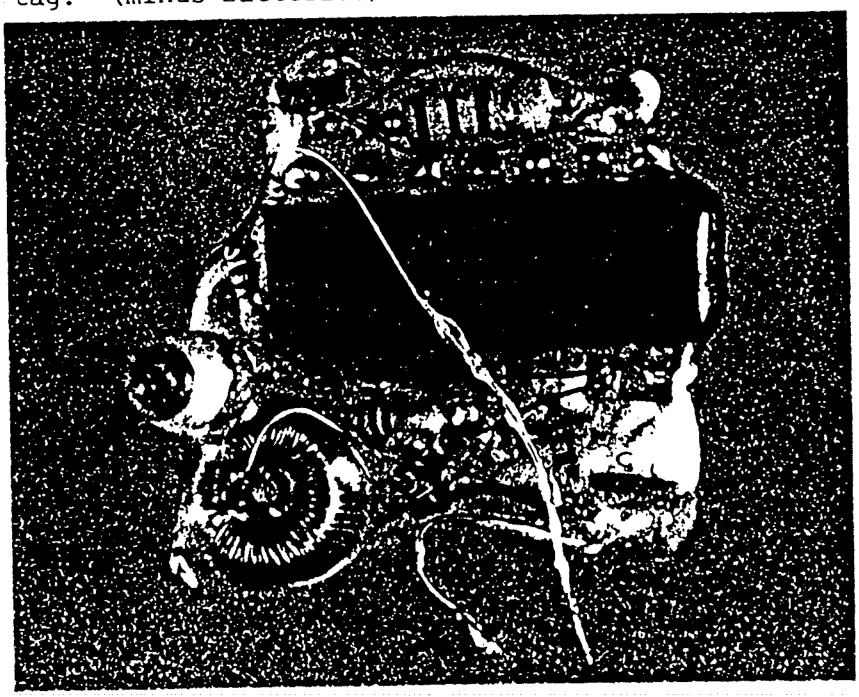


Fig.2 Potted tag. (minus batteries)



Performance:

On test the 7556 was found to have a quiescent current of between 116 uA and 95 uA. This was determined by disconnecting the output stage of the tag and monitoring the battery voltage with only the timing circuits operating. A 50 mah Lithium battery (CR 2016) dropped from 3.25 v to 2.9 v in 432 hrs and to 1.8 v in 528 hrs.

The prototype tag using the PHILIPS cores produced an output pulse 35 ms long with an interval of 900 ms between pulses. Its frequency was 200 khz with a 40 volt, peak to peak potential across the ultrasonic transducer. The tag gave a useable ultrasonic signal for 8 hrs from a 50 mAh battery and a clear signal could be received at 100 meters in a turbid tidal river.

The AMIDON core tag produced an output pulse 15 ms long at an interval of 1200 ms. Its frequency was 200 khz with an 18 v potential across the ultrasonic transducer. A usable signal was obtained for]4 hrs from a 50 mAh battery, although the signal was fainter at 100 meters than from the PHILIPS core tag, under the same conditions as above.

The receiver used in both trials is based on the simple Direct Conversion radio-receiver described in the ARRL Radio Amateur's Handbook. The hydrophone is made from two PZT-5 2-2020-5 transducers. These are fixed at the focus of a 5 cm wide parabolic reflector and a broadband FET pre-amplifier is mounted directly behind the reflector. Two core sheilded cable connects the hydrophone assembly to the receiver.

Problems and Prospects:

Converting the performance figures into current consumption shows that the PHILIPS core tag used 6.25 mA per hour and gave a strong signal at 100 m, while the AMIDON core tag used 3.6 mA but gave a weaker signal over the same distance. Thus a compromise between power consumption and detection range is necessary. Larger capacity batteries are a partial answer to this problem, (the operational tag will be fitted with 170 mAh, CR 2032 Lithium batteries), howerver a more efficient output stage would increase the range as well as lower the power consumption.

The second problem concerns frequency variation. Although the 7556 data sheets suggest that frequency is independent of supply voltage, it was found that there was a marked variation for a period just after the battery was connected and again when the battery was nearing exhaustion. A gentle downward drift in frequency was noted between these two events. This phenomenon corresponds with the expected voltage drop of a lithium battery over its life-span. The drift during the "plateau" period was small and predictable but would have to be taken into account in any bio-telemetry tag.

Initially the operational tag will be used to track the day and night movements of the crab, Portunus pelagicus. Ultimately it is hoped to use the 7556 as the transmitter stage of a heartrate bio-telemetry tag.

Acknowledgments:

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APPENDIX 2.

Results of Ultrasonic Tag Testing programme.

Summary of Ultrasonic Tag Prototypes.

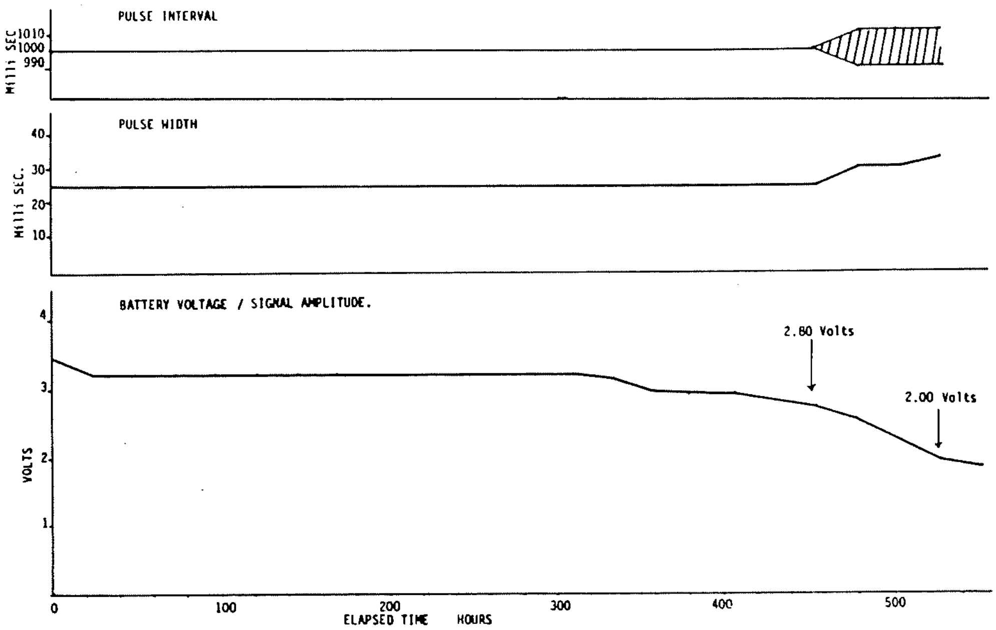
Model	No.	Description	Comment
Mark I	1	Simple one transistor circuit, potted in in polyester resin	Range when Tank tested was less than 2 meters. Developement abandoned.
Mark II	1	Test bed circuit (non-miniaturised)	Used for initial bench tests.
	2	Laboratory prototype (miniaturised)	Bench tests and component evaluation
	* 3	Laboratory prototype (miniaturised and potted)	Bench tests, potting compounds assessment, and initial Tank tests.
	4	Field prototype	Used for Tank tests and Field testing
Mark III	1	Laboratory prototype	Bench tests.
	2	Field Prototype	Tank and field trials.
Mark III (+)		Laboratory prototype (potted)	Bench and Tank testing.
Mark IV	Series I		
	1	Field prototype	Preliminary 24hr Tracking off Moreton Is.
	2	Field prototype	Malfunctioned after potting, cause unknown.
	3	Tracking tag	Tracking for 3 hrs in the field (Toorbul).
	4	Tracking tag	3.5 hrs tracking and 84 hours Tank trial.
	5	Tracking tag	33 hrs tracking.
	6	Tracking tag	Failed after 15 mins in field, faulty battery seal? (see tag report)
Mark IV	Series II		
	7	Tracking tag	34 hours tracking.
	8	Tracking tag	30 hours tracking.
	9	Tracking tag	37 hours tracking.
	10	Tracking tag	22.5 hours tracking.
	11	Tracking tag	30 hours tracking.

* Mark II No.3, during the tank trial the ultrasonic transducer was damaged by the burying activity of the crab. This led to a design change in the layout of the tag, moving the transducer forward and increasing its protective coating.

Bench Tests.

(1). Timing Circuit.

The timing circuit utilises the ICM 7556 dual timer chip and is common to the Mark II, Mark III, Mark III(+), and Mark IV tags. The test procedure was to disconnect the output transistor, transformer and Ultrasonic transducer then to directly monitor the output of the timing circuit on an osciloscope. The measurements recorded were; Pulse Width (PW) in milliseconds, Pulse Interval (PI) in milliseconds, Signal Amplitude (SA) in volts. The frequency stability was was not recorded as this changed dramaticaly when the output stages were connected and could be best monitored in later trials.



The composite graph 1, shows that after 312 hours the signal amplitude began to decline, however the pulse width and pulse interval remained constant till 456 hours. In the period from 456 hours to 528 hours the pulse width lengthened 32% and the pulse interval became varible . After 528 hours both PI and PW became erratic.

The battery specifications infer that 1.8 volts represents the fully discharged state. Hence if the circuit was swinging from 0 to postive rail voltage then the battery was discharged by 528 hours. In terms of current drawn from a 50 milli-Amp/hour battery this represents 50 mA in 528 hours or 95 uA per hour. If the point at which the signal became unreliable (i.e. PI and PW started to vary) is taken as the discharged stage then the current drawn is 50 mA in 456 hours or 110 uA per hour.

Therefore for constant signal parameters the critical minimun battery voltage is 2.80 volts and the quiescent current consumption for the timing circuit up till this voltage is 110 uA.

(2). Mark II Tag

The Mark II tag circuit and the Mark IV tag circuit are essentially the same. The major difference is that the Mark IV uses a flexible printed circuit board while the Mark II uses the chip and wire technique. The latter is somewhat similar to a three dimensional" birds nest".

The test procedure for the unpotted laboratory prototypes was to monitor the pulse width (PW), pulse interval (PI), signal amplitude (SA), and ultrasonic frequency stability (FREQ). The signal amplitude was measured as the voltage change across a resistor in the emitter leg of the output transistor. The value of the resistor in this voltage divider was decided empiricaly by the compromise between a useable deflection on the osciloscope and minimum effect on the normal circuit operation.

Frequency of the ultrasonic signal was measured in air by the hydrophone/sonic receiver that had been developed for the project. The receiver has arbitrary frequency settings (1 to 100 on a linear dial), however this was calibrated against a signal generator and the recorded settings converted to kHz.

All the prototypes were powered by CR2016 50mAh Lithium batteries. The ultimate power source for field tags was to be the larger CR2032 170mAh battery, however to control costs the smaller battery was used in laboratory tests. It is important to use a battery rather than conventional laboratory power supply because in simple tags, those that do not have voltage regulation circuitry, the internal resistance of the battery is one of the factors that determine the final output frequency. In this case the CR2016 specifications are very close to the CR2032 and it was assumed that the operational life of the 170mAh battery would be approximately three times that of the 50mAh one.

Trial 1. Mark II Tag Prototype

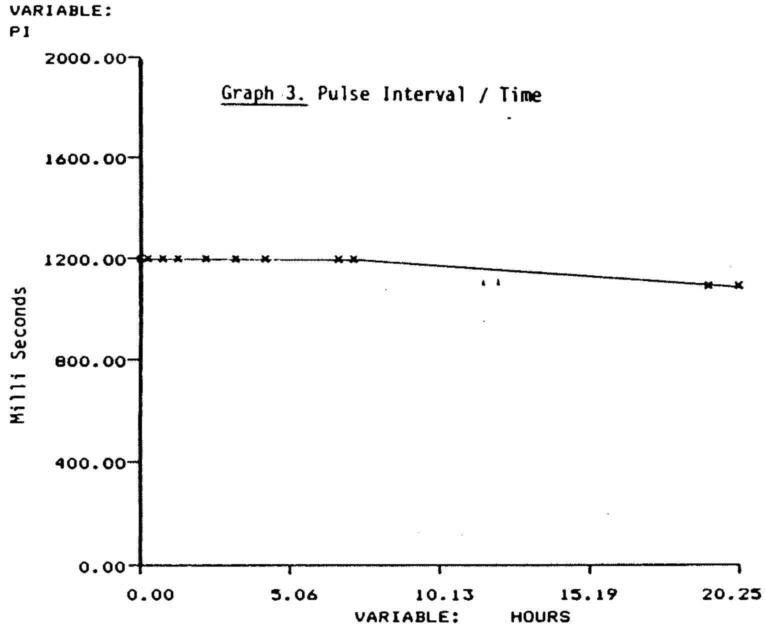
The lithium battery in this test had been used previously for some preliminary recordings. It had been "broken in" but not used excessively.

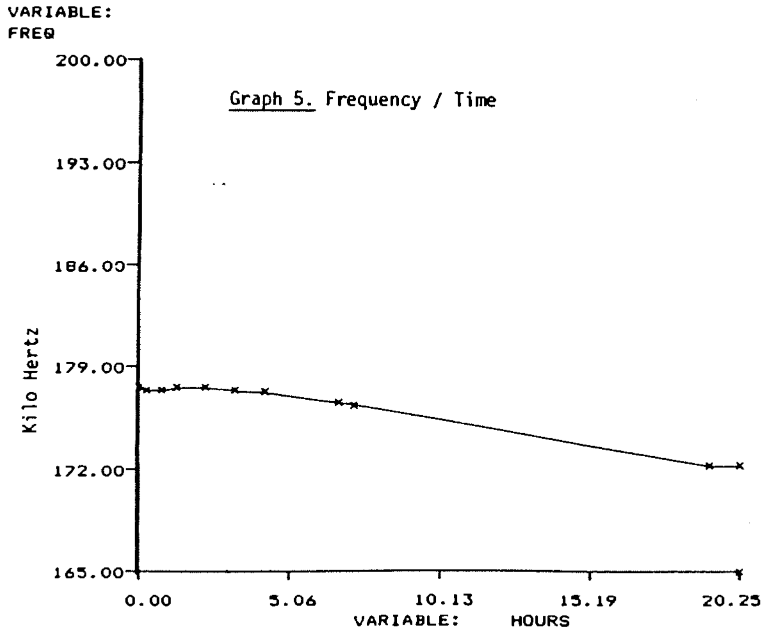
Graphs 2 to 5 show that PW, PI, SA, and FREQ are stable for the first 10 hours but decline after this time. The frequency shows a slight increase initially then a steady drop.

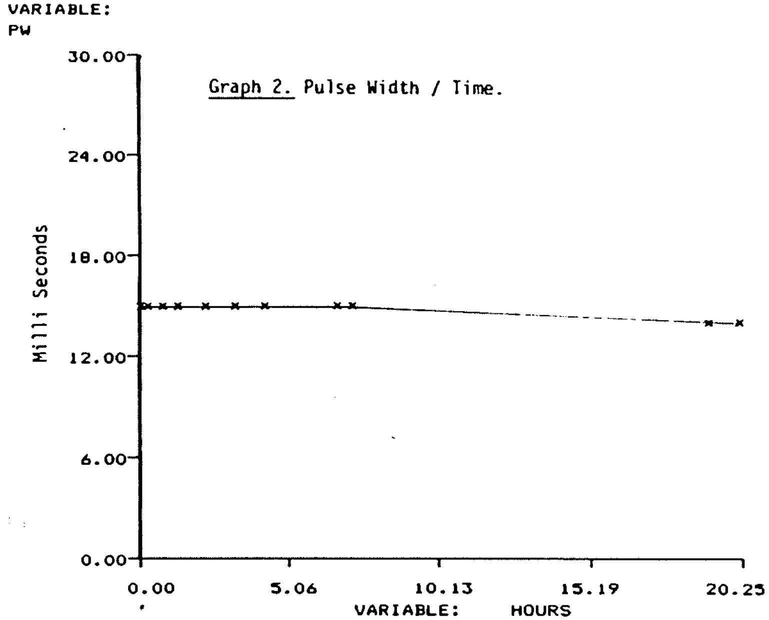
Trial 2. Mark II Tag Prototype

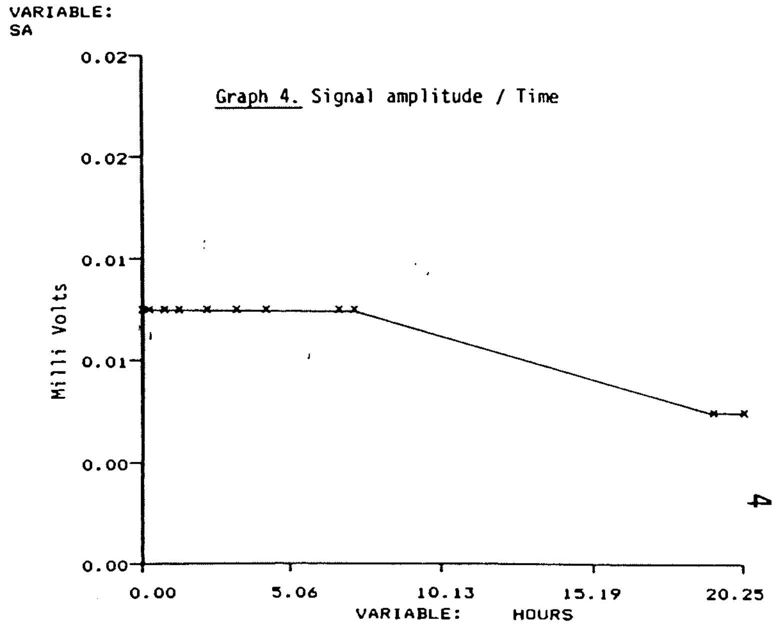
A completely fresh CR2016 battery was used in this test. The aim was to determine when the signal first became unstable and the test was run till one signal parameter showed a dramatic change.

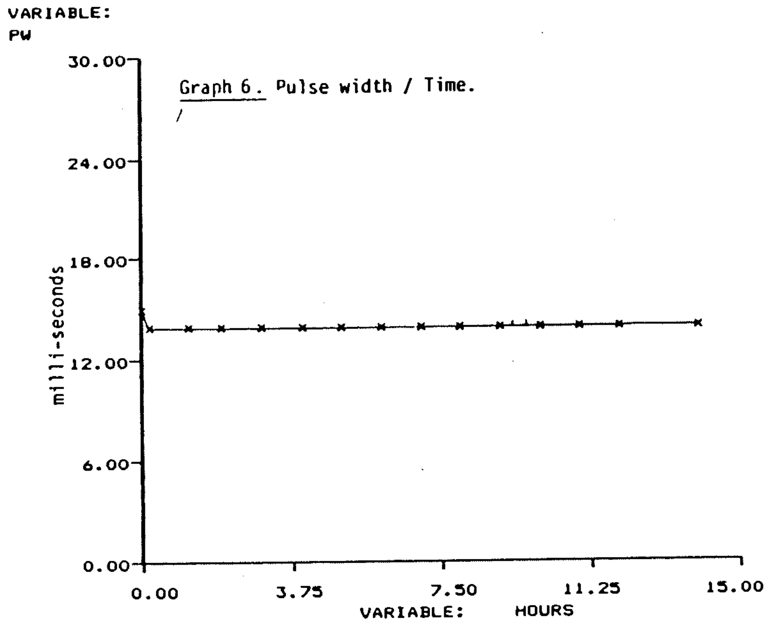
Graphs 6 to 9 show that the signal amplitude and frequency change appreciably after 12 to 15 hours while PW and PI remain constant. The frequency starts high, drops 4% quickly, shows minor instability for the first 3 hours, then remains constant for the next 9 hours followed by a sharp 3% decline. This curve matches the theorectical discharge curve of a lithium battery. Therefore the Tag powered by the larger CR2032 battery should produce a reliable signal for at least 36 hours possibly 45 hours. This is within the design criteria for the 24 hour Tag.


VARIABLE:
PI
Graph 3. Pulse Interval / Time
Milli Seconds
2000.00
1600.00
1200.00
800.00
400.00
0.00
0.00
5.06
10.13
15.19
20.25
VARIABLE: HOURS

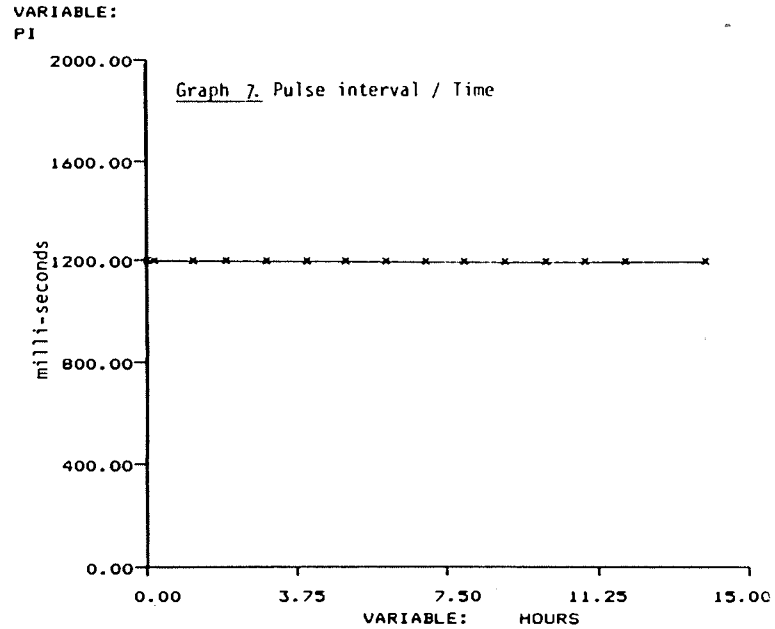

VARIABLE:
FREQ
Graph 5. Frequency / Time
Kilo Hertz
200.00
193.00
186.00
179.00
172.00
165.00
0.00
5.06
10.13
15.19
20.25
VARIABLE: HOURS


VARIABLE:
PW
Graph 2. Pulse Width / Time.
Milli Seconds
30.00
24.00
18.00
12.00
6.00
0.00
0.00
5.06
10.13
15.19
20.25
VARIABLE: HOURS

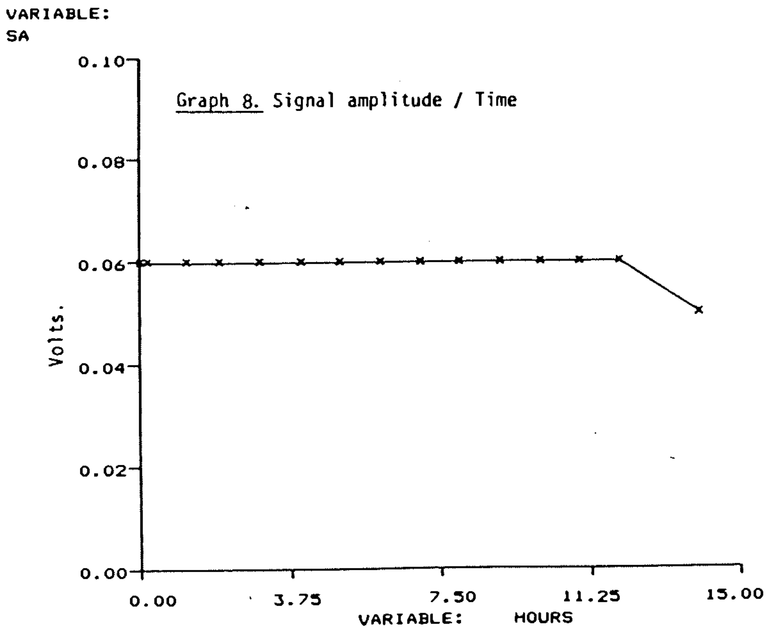

VARIABLE:
SA
Graph 4. Signal amplitude / Time
Milli Volts
0.02
0.02
0.01
0.01
0.00
0.00
0.00
5.06
10.13
15.19
20.25
VARIABLE: HOURS



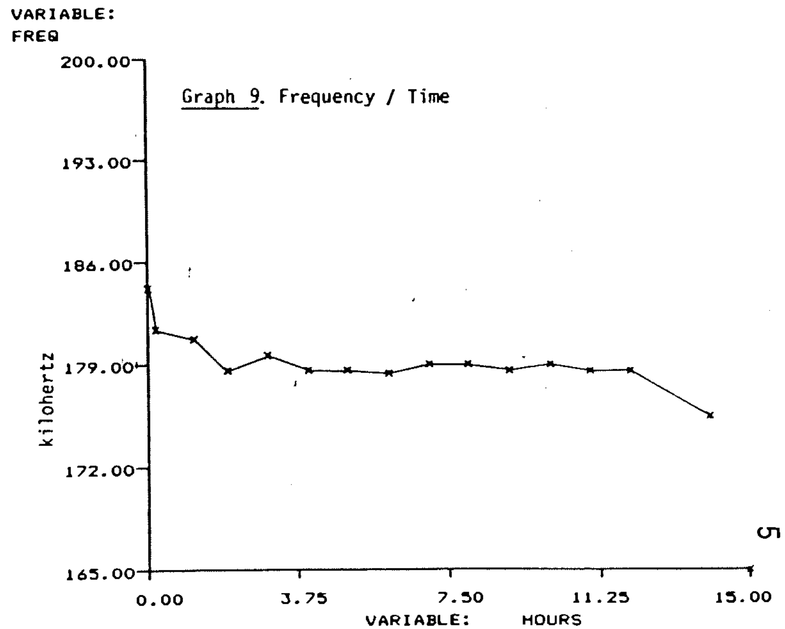
Graph 6. Pulse width / Time.



Graph 7. Pulse interval / Time



Graph 8. Signal amplitude / Time



Graph 9. Frequency / Time

(3) Mark III Tag

This circuit uses two Philips 4322-020-97160 miniature toroid transformer cores in the output transformer to boost signal power. A number of trials were run on this prototype using 50mAh batteries and one using a 170mAh battery. All showed similar cut off after about 10 hours.

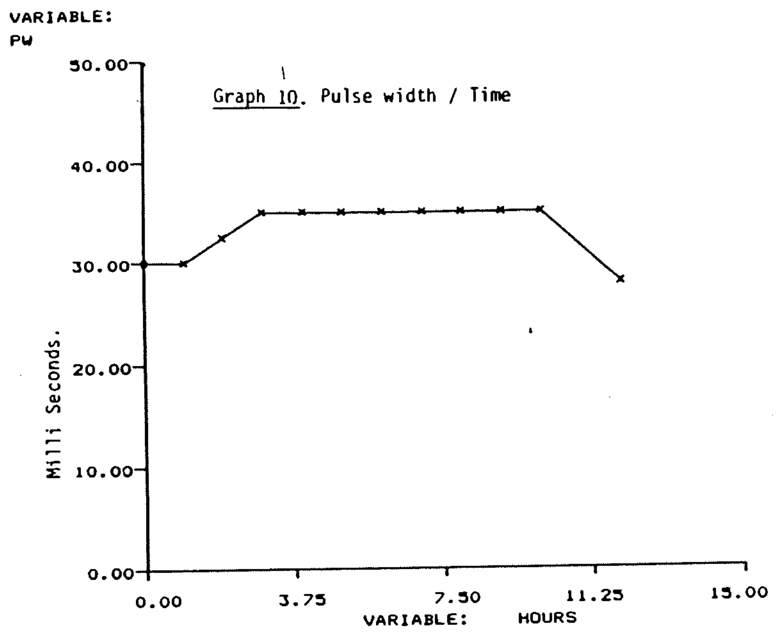
Trial 3 Mark III laboratory Prototype

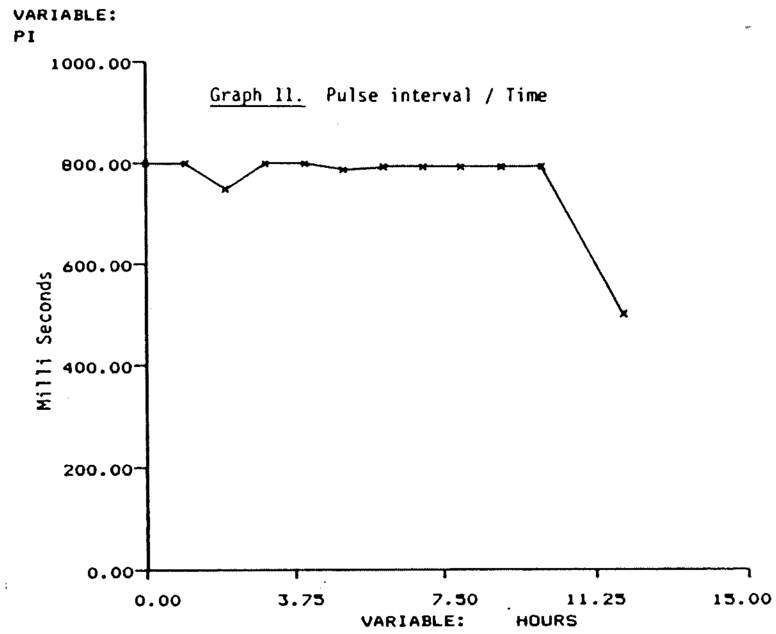
A new CR2032 battery was used. Graphs 10 to 13 show that PW, PI, SA, and FREQ decline dramaticaly after 10 hours has elapsed. The ultrasonic signal stopped completely.

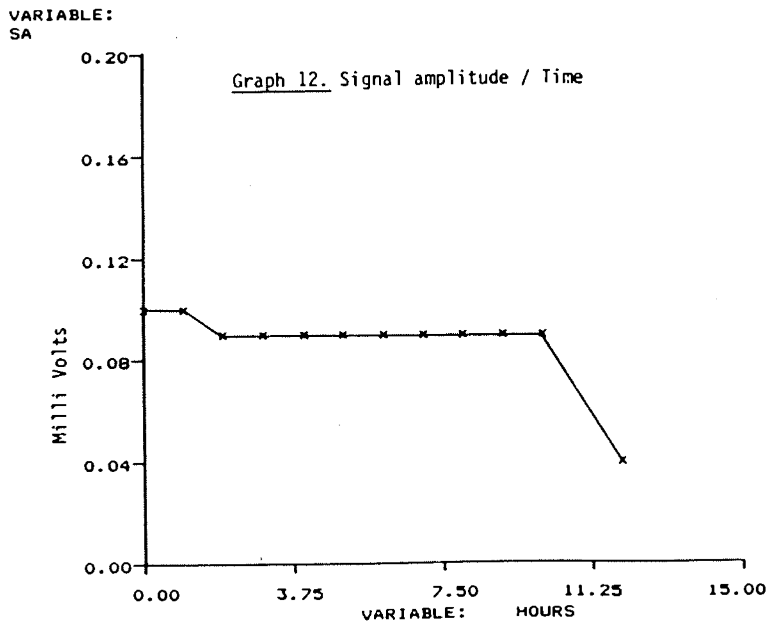
When the stoppage occurs it is sudden; the pulse interval decreases to 500 mS, the pulse width shortens to less than 30 mS, and the signal amplitude drops to 50% of its previous value. Similar phenomena were recorded with the CR2016 batteries.

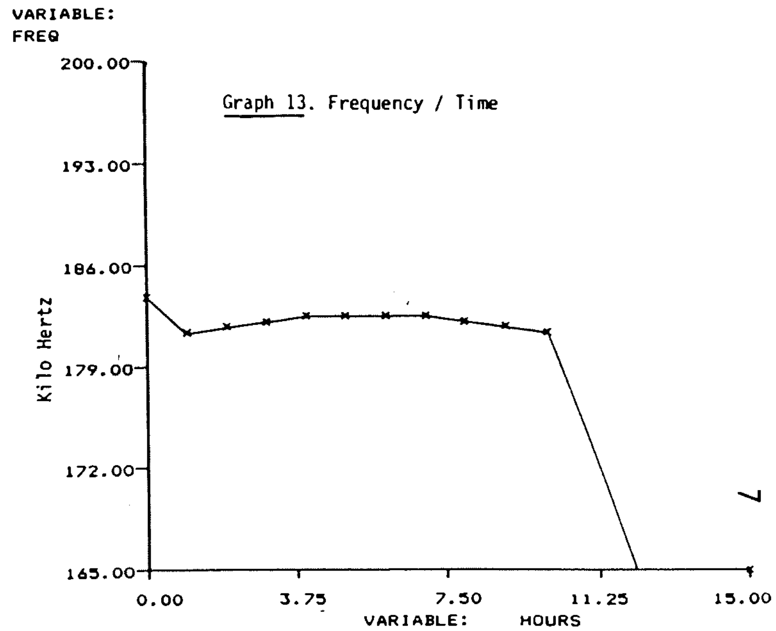
A possible explanation is that the circuit exceeds the maximum pulse current that can be drawn from these batteries. This could cause premature breakdown of the battery.

This Tag has an effective operational life of 10 hours independent of the capacity of the battery used, hence does not meet design criteria.


VARIABLE:
PW
Graph 10. Pulse width / Time
Milli Seconds.
50.00
40.00
30.00
20.00
10.00
0.00
0.00
3.75
7.50
11.25
15.00
VARIABLE: HOURS


VARIABLE:
PI
Graph 11. Pulse interval / Time
Milli Seconds
1000.00
800.00
600.00
400.00
200.00
0.00
0.00
3.75
7.50
11.25
15.00
VARIABLE: HOURS


VARIABLE:
SA
Graph 12. Signal amplitude / Time
Milli Volts
0.20
0.16
0.12
0.08
0.04
0.00
0.00
3.75
7.50
11.25
15.00
VARIABLE: HOURS


VARIABLE:
FREQ
Graph 13. Frequency / Time
Kilo Hertz
200.00
193.00
186.00
179.00
172.00
165.00
0.00
3.75
7.50
11.25
15.00
VARIABLE: HOURS

7

Tank Tests

A 3 meter diameter by .7 meter circular plastic lined pool was used for the tank tests. Tag Trials 1 and 2 were performed in fresh water but the tank was filled with sea water for the tests of the Mark IV production tags.

One drawback of a shallow circular test tank is that it tends to acousticaly concentrate the signal so that signal strengh measurements are inaccurate. A comparison between field trials and tank trials showed that although a tag could be recieved for in excess of 72 hours in the tank, in the field the signal was lost after a maximum of 48 hours and on average after 36 hours.

(1). Ultrasonic Tag Performance.

Trial 1. Mark II Field Prototype

A new 170 mAh CR2032 was connected and the initial frequency recorded in air. A attempt was made to quantify the signal strength by recording the volume settings on the receiver, however the multipath signal reflections made such arbitrary measurements unreliable. Graphs 14 and 15 show frequency stability and "volume" signal strength, repectively. Where the frequency drops below 165 kHz on the graph, it has actually dropped below the bandwidth of the receiver. Put simply, it has passed beyond the range of the tuning dial on the sonic receiver. The harmonics of the signal can still be heard as a click, but no frequency measurement can be made.

The signal was within the bandwidth of the receiver for 36 hours having dropped 6% in frequency. It should be noted that this drop represents 30% of the receiver bandwidth. The most interesting aspect of the graph is that the signal reappears after 50 hours at a slighly higher frequency than initially. A signal could be measured until 92 hours when it stopped. The battery when removed registered 1.8 volts which is its fully discharged state.

The prototype survived immersion and continued to transmit reliably for 36 hours at least. This is just within the design criteria.

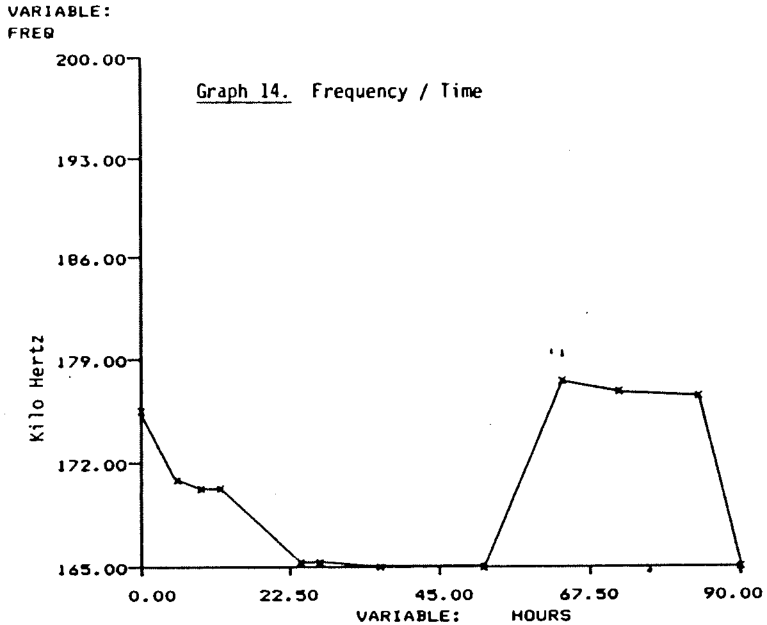
Trial 2 Mark III(+)

This prototype trial is typical of the results recorded for both the Mark III and Mark III(+) Tags. The circuit utilised a PHILIPS toroid core output transformer and a Darlington pair output transistor configuration. Graph 16 is selfexplanatory, the tag died after less than ten hours.

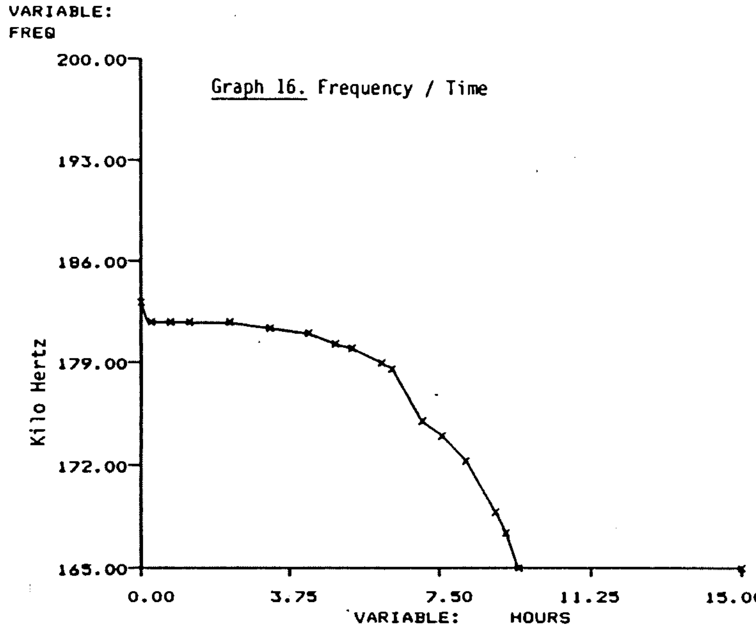
Trial 3 Mark IV

Tag number 3, series 1, was attached to a crab in the field and released. The crab was recaptured after four hours and returned to the laboratory where the tag was monitored for the next two days.

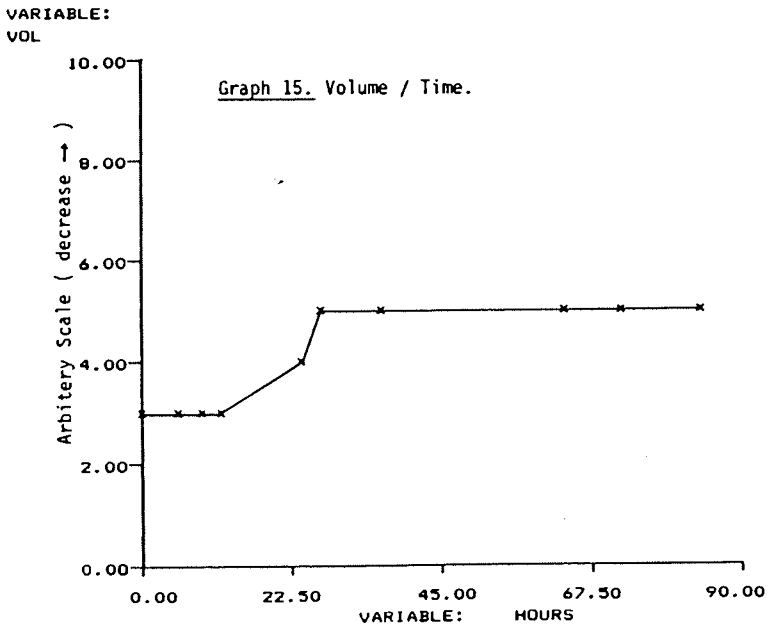
Graph 17 shows the tag frequency stability with time. The initial frequency setting in the field was 175 kHz which is mid receiver range. There was a drop of 15% in frequency over the first 48 hours with the signal moveing off the receiver dial. As in the Trial 1 the signal harmonics could still be heard as a click after 72 hours.



Graph 14. Frequency / Time



Graph 16. Frequency / Time



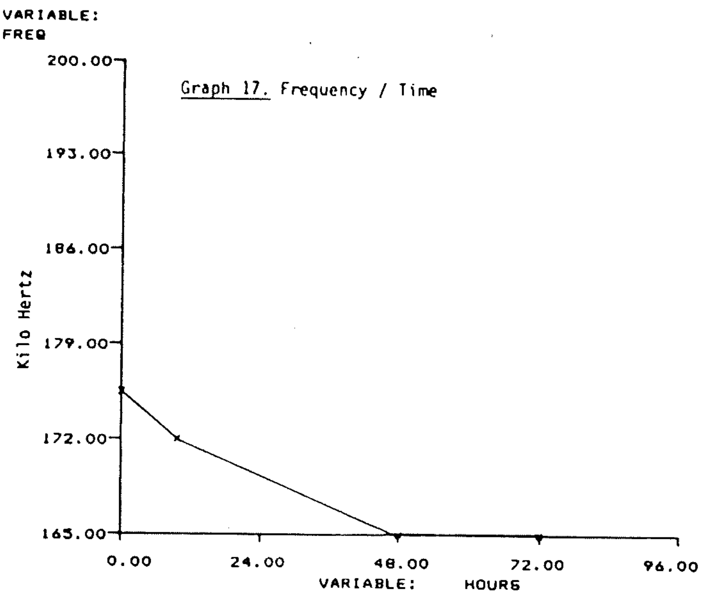
Graph 15. Volume / Time.

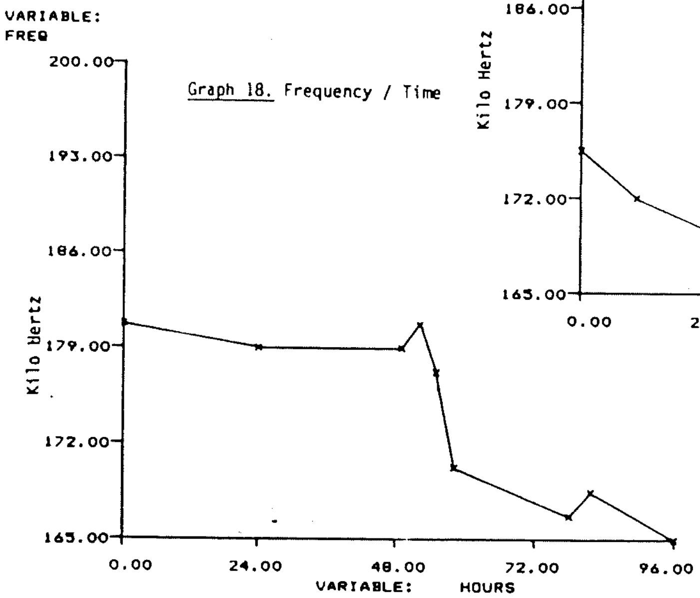
Note. The Mark IV, No 3, tag was left attached to the crab for 112 days, then removed and the batteries replaced. The tag functioned normally.

Trial 4 Mark IV

Tag number 8, series II was tank tested prior to being used in the field. The sonic receiver was tuned to match the bandwidth of the tag and therefore give the maximun possible time that the tag could be tracked. The frequency drop that had been observed in previous tests was allowed for by tuning the reciever such that the initial tag frequency was at the top of its range.

Graph 18 shows the frequency stability of the tag prior to the retuning of the receiver.





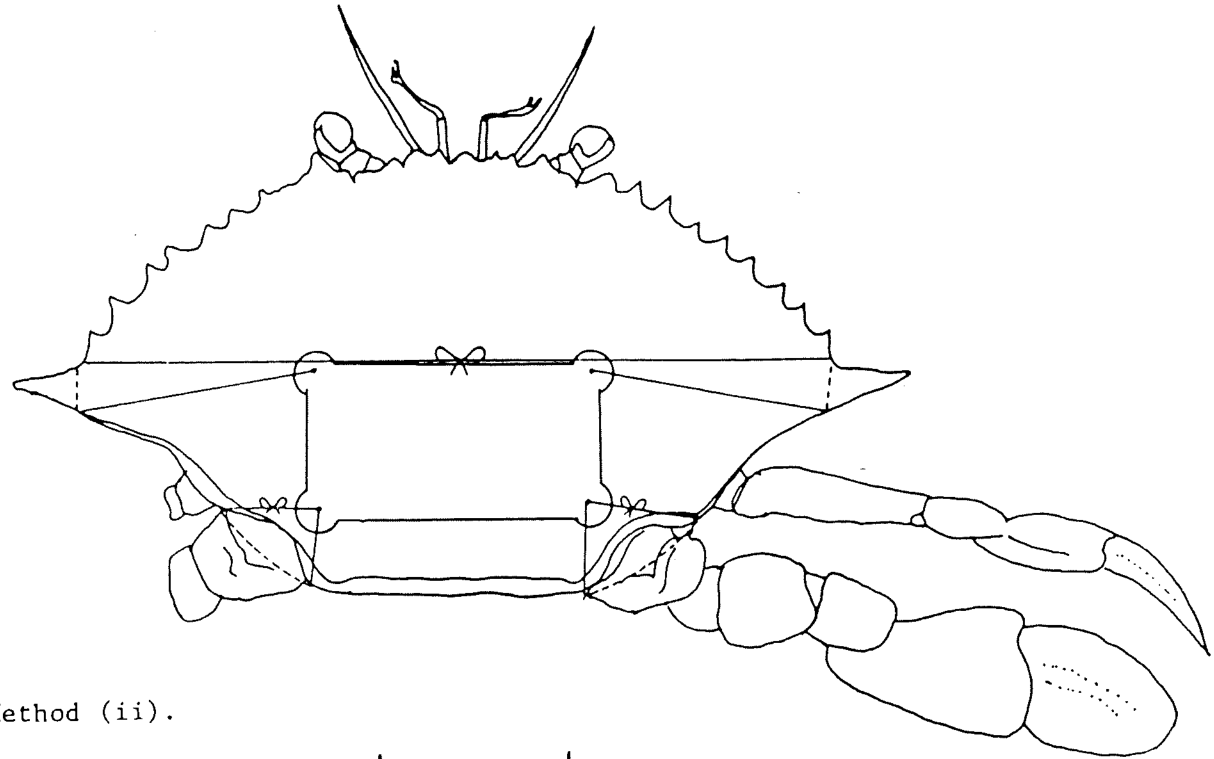
(2). Tag Attachment.

Two methods of attachment were tested:

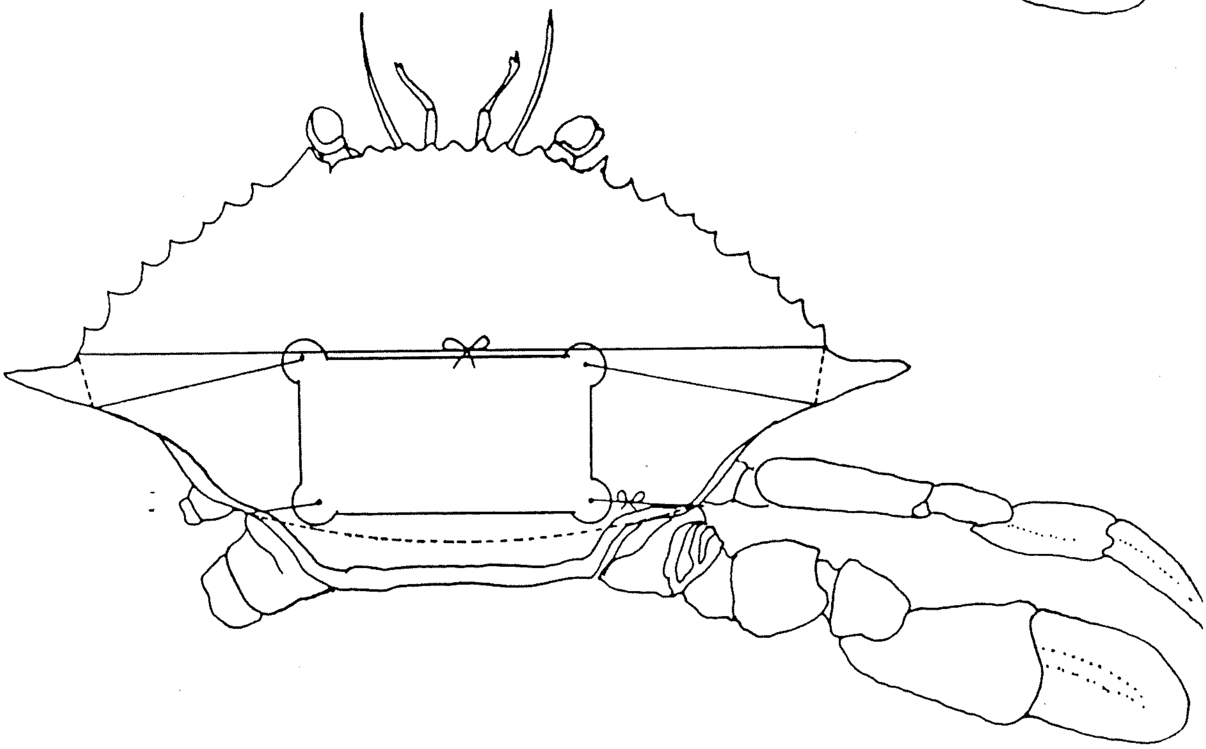
(i). See dia A. Wire loops were passed around both lateral spines and tied mid-line. A second pair of posterior loops were were passed around each swimming leg. The tag was also glued to the carapace with DOW CORNING 738 RTV non-corrosive adhesive/sealant.

(ii). See dia B. Wire loops were passed around both lateral spines and tied mid-line. A single loop of wire was passed underneath the posterior thorax, over the abdominal flap , between the third walking leg and the swimming leg on each side of the crab. The tag was glued to the carapace with RTV 738.

Dia. A Method (i)



Dia. B Method (ii).



Neither method appeared to injure or cause dramatic changes in the behaviour of crabs over 48 hours. Method (ii) was found to be much easier and quicker and therefore was considered less likely to involve "handling" shock for the crab. It was also considered to be more suitable in field conditions where the crab was to be returned to the water as soon as possible after capture.

(3). Long term effect of Tag attachment on Crabs

Attachment method (ii), was used in all the long term trials.

Trial 1 Dummy Tag

A solid polyester resin plug the same dimensions as the proposed tag was glued and wired to the carapace of a 150 mm adult male sand crab. The plug weighed 27 grams in air and no positive buoyancy had been added to the resin.

Table 1

Time	Date	Observation
3pm	17.9.82	Tag attached and crab returned to aquaria. The crab buried in the sand immediately.
3pm	18.9.82	After approximately 24 hours the crab emerged and began feeding. It was wary of the observer for a further 24 hours and spent some time rubbing the tag against the wall of the aquaria. The tag remained in position and no signs of lesions or trauma could be seen on the crab.
3pm	18.10.82	Tag still attached in the same position. The crab is feeding and burying normally.
3pm	16.12.82	Tag removed and crab examined for damage. No visible trauma apart from slight chafe where the wire loop passed between the third walking leg and the swimming leg.

The dummy tag had been attached for 3 months with no apparent harm to the crab. The behaviour was altered for the first 24 hours but a similar modification could be induced by simply handling the crab. Crabs had been observed previously rubbing their dorsal carapace against hard objects in the aquaria presumably to clean off algae. The tagged crab appeared to spend a greater than normal amount of time engaged in this activity.

Trial 2 Mark II Prototype

A prototype Mark II tag with battery, weighing 12.9 grams in air, was glued and wired to the dorsal carapace of an adult male sand crab with a carapace width of 150 mm.

Table 2

Time	Date	Observation
3pm	18.9.82	Crab buried immediately after being returned to the aquaria. The behaviour was altered for the next 24 hours.
3pm	20.9.82	Feeding normally.
12pm	22.9.82	Tag removed, no apparent physical damage to the crab.

The trial was terminated because the tag had become damaged. The ultrasonic transducer had been ground off by the burying action of the crab. The transducer was positioned towards the rear of the tag. This edge received the most abrasion from the sand when the crab was backing into substrate.

Subsequent prototypes had the ultrasonic transducer positioned towards the front of the tag and had a thicker protective coating of epoxy resin. The battery was sealed in DOW corning 738 RTV adhesive sealant and remained dry.

Trial 3 Mark IV Prototype

A Mark IV tag (number 3, series 1) was attached to a 150 mm carapace, male sand crab in the field. The crab was recaptured after 3.5 hours, brought back to the universty and placed into the aquaria without disturbing the tag.

Table 3

Time	Date	Observation
10.30am	15.2.83	Tag attached and crab released off Parrot Island, Pumicestone Passage.
8.00pm	15.2.83	Crab/Tag placed in aquaria. The crab remained stationary on the surface for 2 hours prior to burying.
10.30am	17.2.83	Tag still in position no apparent distress to crab. Feeding and burying.
10.30am	18.2.83	No apparent distress.
10.30am	19.2.83	No apparent distress.
10.30am	2.3.83	Pre-moult female was placed into aquaria with male and mating took place at moult. Tag remained in place.
10.30am	8.5.83	Tag removed from live crab.

Trial 3 continued.

Some chafeing was noticed where the attachment wires passed in front of the swimming legs. Small lesions were forming. When the battery was replaced the tag functioned normaly.

The tag had been on the crab for 112 days with minimal alteration to the behaviour and little physical damage.

(4). Hydrophone and Sonic receiver performance.

(i)The test procedure for the evaluation of hydrophones was to use a 200 kHz ultrasonic beacon as the standard signal source. The sonic receiver was then tuned and the volume was set at a standard setting. The receiver output was displayed on an osciloscope and the amplitude of the signal compared.

Table 4

Hydrophone type	Signal Amp.
Depth sounder hydrophone, 200 kHz resonant 4.5 cm dia., flat piezo-ceramic disc, transducer. Tuned pre-amplifier immediately behind disc.	1.8 volt
Two Vernitron PZT-5 2-2020-5, 200 kHz piezo-ceramic tranducers in a linear array at the focus of a 6 cm parabolic reflector. Pre-amp mounted behind array.	.4 volt

The difference in the form of decibels is

Db = 20 log 10 .4/1.8

= -13.06 Db difference

(ii) The test procedure for calibration of the receiver was to inject a signal from a laboratory signal generator and correlate the known frequency against the arbitrary scale of the tuning dial. The units of the dial was linear, from 1 to 100.

Table 5

Dial scale	Frequency (kHz)
1	200.20
100	165.00
Retuned lower to match Mark IV tags.	
1	186.69
100	156.68

The bandwidth of the receiver is 30-35 kHz depending on the centre frequency. A drop off in signal strength was noted between 10 and 1, as well as between 95 and 100. The dial was linear across the scale.

Field Trials

Field trials were carried out at four sites:

(i). Brisbane River Site.

Three pontoons set approximately 100 meters apart parallel to the river bank beside the University of Queensland. The river is still tidal at this point; the water is fresh to slightly saline, with large quantities of suspended silt and the depth varies from 1 to 3 meters with the tide.

The river test site was a convenient place to carry out short preliminary field trials on equipment in the development stage, however no long term observations of tag performance could be made because of security problems.

(ii). Moreton Island Site. No 1.

An area known localy as "the Wrecks" is an artificial reef constructed out of obsolete dredges. It lies parallel to Moreton Island, approximately 400 meters offshore, and forms the seaward edge of a protected channel 1000 meters long. The channel has an undulating sandy bottom, with patches of weed. The depth slopes from the beach out to a maximun of 12 meters. The underwater visibility is extremely good in calm weather.

Field trials on all tag prototypes were performed in the channel. These were primarily comparative range and signal strength evaluations with some investigations into the effect of substrate on signal propogation.

(iii). Moreton Island Site. No 2.

This site was at the northern end of "the Wrecks" on its seaward side, in a deep channel. The effect of depth on the tags was investigated here.

(iv). Pumicestone Passage, off Toorbul.

This is the same area as the crab tracking experiments were performed. (See chapter # for study site description.)

Final testing of production tags and the calibration of the hydrophone/sonic receiver was carried out at this site.

(1). Preliminary Trials

All field prototypes were tested at the Brisbane River site for range, and signal parameters prior to sea trials.

Range trials consisted of immersing an operating tag 50 cms below the surface at pontoon 1 and checking signal strength at pontoon 2, then at pontoon 3. Only the prototypes that could be received stronly at pontoon 3, approximately 200 meters, were used in sea trials.

(2). Sea Trial 1

(i) Three prototypes were tested in one session at the Moreton Island Test sites on 22.11.82. The sea state was 2 to 3, and underwater visibility was good.

Table 5.

Prototype	Battery	Frequency kHz air	Frequency kHz water	Max. Range meters
Mark II	50 mAh	177.6	172	200-250
Mark III	170 mAh	178.7	175.5	250-300
Mark IV	170 mAh	177.6	174.5	200-250

The tags were attached to a diver then tracked over a random pattern at site 1, with intermittent checks on the position accuracy when the diver surfaced. The diver kept as close to the bottom as possible and swam patterns which included both the shallow and deeper sections of the channel. A signal could be reliably received for all tags over all the patterns except when the distance was beyond the maximum range given in the table. The absolute maximum range for the Mark IV tag was 400 meters but the signal was too faint to be reliable.

To mimic the effect of the crab burying, the diver buried the Mark II tag under 6 cms of sand at a distance of 50 meters and at a depth of 5 meters. The signal was attenuated and there was a downwards shift in frequency but it could still be received clearly.

(ii) To test the effect of depth on the output of the tag a Mark IV tag was taken to the sea bottom at site 2. The divers depth gauge recorded 95 ft; the signal was strong but the frequency had again shifted downwards.

(iii) All tags were returned to the laboratory and the signal was monitored over the next 2 days .

Table 6

Tag	Operational life	Comment
Mark II	24 hours	50 mAh battery. If a 170 mAh battery had been used 72 hours could have been obtained.
Mark III	less than 24 hrs	The tag was failing even before the end of the sea trial.
Mark IV	72 hours	The operational life of the tag was not significantly altered by immersion or by the depth test.

Note. The tag potting technique and battery seal kept all the tags sucessfully water tight under field conditions. (see appendix 3)

(3) Sea Trial 2

Moreton Island Site 1 was used for the first test of a tag prototype attached to a crab.

A Mark IV prototype tag , the same tag as used in Sea Trial 1 , was connected to a 170 mAh battery and sealed at 6.30 am on the 20.12.82. At 9.30 am a male sand crab, carapace width 150 mm, was caught by suicide net at site 1. The tag was attached with soft tie wire and silastic as per attachment method (ii), and the crab was returned to the water by 10 am.

The crab/tag was continuously tracked up to 2 pm . The signal was clear and strong with a frequency of 172 kHz. Tracking was discontinued until next day.

At 8.30 am on the 21.12.82, the tag signal was triangulated to the same general area that it had been last located. The signal was clear and strong, although slowly oscillating in amplitude. The frequency was 165 kHz. Continuous tracking over the next hour showed little apparent movement of the tag so an exact position was triangulated. Divers started an underwater grid search at 9.30 am. The tag was located and retrieved by 10.00 am.

The tag had become separated from the crab and was rolling slowly across the bottom with the current, which explained the slow oscillations in amplitude. The soft wire ties were undone on the right-hand side. They had not been cut.

This area off Moreton Island is regularly fished by amateur crabbers. It is a strong possibility that the crab had been caught in the early hours of the morning, the tag removed and then thrown back.

Table 7

Time in Water	Frequency kHz
0	172
4 hours	170.6
22.5 hours	165
24 hours	165

The tag had been connected for 27.5 hours and had been in the sea for 24 hours by the end of the trial. The tag signal frequency had dropped 5%, however it had also gone off the receiver scale so this figure is unreliable.

APPENDIX 3.

APPENDIX 3

(i) Method of Potting Production Tags

Step 1. Dip and agitate populated circuit board in 100% alcohol. Blow off excess fluid with compressed air.

Step 2. Dip and agitate circuit in acetone. Blow dry with compressed air and allow to dry overnight.

Step 3. Dip and thoughly coat circuit board and components in DOW CORNING 1-2577 conformal coating. Do not coat the ultrasonic transducer. Hang the coated cicuit up by the battery lead and allow excess coating to drip off. Allow to cure for 24 hours.

Step 4. (see diagram 1a & b).
Mount circuit board and battery case on the fibre glass reinforcing strip and place on lubricated aluminium mould. Position the ultrasonic transducer towards the middle and front of the tag. The transducer should be 5 mm higher than the rest of the components. Drip the epoxy resin / Q-cell mixture onto the components and allow the thick mixture to find its own level. Make sure all cavities are filled. This process may need to be repeated until all components except the ultrasonic transducer are covered. Allow to dry for 24 hours and remove from mould.

Step 5. Cut away fibre glass reinforcing strip from the underside of the battery case. Trim excess potting compound and shape tag with a small file.

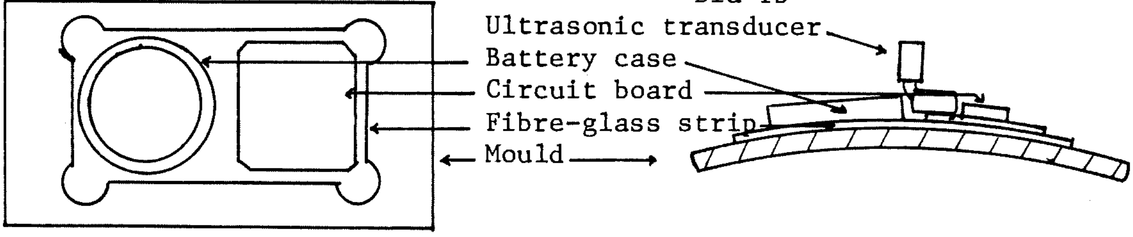
Step 6. Insert foam rubber core into ultrasonic transducer cylinder. Dip transducer into epoxy resin and allow to cure. This step may need to be repeated till the transducer is evenly coated.

Step 7. Dip complete tag into epoxy resin as a final coating. Hang tag up by the battery leads to allow the excess resin to drip off. Allow tag to cure for a minimum of 24 hours.

Step 8. Drill a small hole in each of the four attachment tabs.

Step 9. Solder tag battery leads to a CR2032 battery (with tabs previously glued on with ACME 3021 conductive epoxy).
Pot the battery into the battery case with DOW CORNING RTV 738, taking care to fill all voids. Completely cover the battery and leads. Smooth off the upper surface of the glue to conform to the shape of the tag.

Dia. 1a



(ii). Types of Potting compounds used.

1. Polyester Resin. CRYSTAL CAST ,QUEENSLAND HANDICRAFTS.
This was used for potting the first prototypes, Mark I and Mark II. It is a clear casting resin which is heavy and has a tendency to abrade quickly.

2. Epoxy Resin. ARALDITE
Epoxy Resin is theoreticaly harder than polyester and more resistant to abrasion. The tag has to survive repeated burying actions of the sand crab hence abraision resistance is important.

3. Micro-spheres. Q-CELLS , QUEENSLAND HANDICRAFTS.
Micro-spheres or micro-balloons are hollow air filled balls which, when added to a resin,produce positive bouyancy. A mixture of Q-CELLS and ARALDITE was used to both pot the tag and to provide floatation. The proportions of the mixture was simply as much Q-CELLS as could be added to a quantity of resin and still pour the resultant over the tag components.

4. Conformal coating. DOW CORNING 1-2577 Silicone Conformal.
This is the initial waterproof coating that is applied to the circuitry. It was found that both polyester and epoxy resin altered the tuning of the output transformer, whereas the conformal coating had no such effect.

5. Conformal coating. DOW CORNING 3140 RTV
Similar electrical properties to 1-2577 but is a two pot mix and hence more time consuming to use.

6. Battery seal. DOW CORNING 738 RTV
This a non-corrosive adhesive/sealant silicone rubber, that cures at room temperature and underwater.

7. Battery attachment. ACME 3021 conductive epoxy, RS COMPONENTS, SYDNEY.
Heat on any type of battery degrades operational life dramaticaly. The silver loaded epoxy allows attachment of tabs to the battery case without soldering or spot welding.

APPENDIX 4.

Appendix 4.

Computer programs.

1. Crabtrack:Map

A DEC 10 campatible program for calculating the position of a boat, given three bearings, and the position of an ultrasonic tag given one bearing and the range in meters.

Input data is contained in a sequential access file. The first entry is the number of observations or position "fixes" in the file; subsequent entries, read across rows, are bearing No.1, bearing No.2, bearing No.3, tag bearing, tag range (distance from the boat to tag), and elapsed time in minutes. No missing values are allowed for bearings 1,2,3 but missing values for tag bearings can be input as 999.At run time the program asks for the output data file code number and for the name of the input file. The code number is a single or double digit identifier for the output files.

Output data is contained in five sequential access files named; BOAT(X).DAT, CRAB(X).DAT, DIST(X).DAT, ESTP(X).DAT, ESTR(X).DAT, where (X) is the output data file code number.

BOAT(X).DAT and CRAB(X).DAT contain the x and y co-ordinates for the position of the boat and for the ultrasonic tag (or crab). These files are two column lists with the x co-ordinates in the first column. This file format is designed to be compatible with almost all types of plotters. The program variable "C2" is a scaling factor that adjusts for the scale of the plotted points to the chart or map that they are plotted on. It is neccessary to calculate this factor and insert "C2" in line 900 before running the program. Line 1450 has the x,y coordinates for the landmarks; these must be inserted in a clockwise direction. All distances are calculated in mm within the program.

DIST(X).DAT contains the elapsed time followed by the distance the tag has moved since the last observation. The distance is in mm and must be scaled up appropriately.

ESTP(X).DAT contains the x and y co-ordiates for the tag which have been calculated by triangulation, given that the movement of the boat between two observations has been greater than ten meters. If the distance moved is less than ten meters then this method of estimation is inaccurate. It can also be misleading if the tagged animal has moved between observations; triangulating from bearings taken in this case will give an apparent position which will differ considerably from previous and subsequent positions. The main use for this data is to check the position of the tagged animal when it is known to be stationary. It is an independent check against the subjective estimation of the range which is used to calculate the tag position in the main program.

ESTR(X).DAT contains the obsevation number and the estimated range from the boat to the tag, calculated from the positions in ESTP(X).DAT. Again it should be used as a check, with due regard for its limitations.

Note. DIST(X).DAT, is generated for use with the activity profile program, CRABTRACK:ACT.

Program algorithm.

The main program calculates the position of the boat by deriving the equation to the line passing through a known point x,y (a suitable landmark) with a slope of tan O , where O is the complement of the bearing from the boat to the landmark. The general form of the equation is Y=Y1+tanO(X-X1). Equations are derived for each bearing, then these are solved in similtaneous pairs by the substitution method. The result is three pairs of x,y co-ordinates which represent the classic "cocked hat" estimate of position. The centre of this probability triangle is calculated and this is taken as the position of the boat.

The position of the tagged animal is calculated relative to the boat position by the equations X=R*COS(W) and Y=R*SIN(W) where R is the range or distance from the boat to the tag, and W is the bearing. The X,Y co-ordinates are then added to the x,y co-ordinates of the boat position to give the position of the tag relative to the landmarks.

The Euclidian distance between consecutive positions of both the boat and those of the tagged animal are calculated by the equation D=square root((X-X1)^2+(Y-Y1)^2).

The "estimated" position of the tag is calculated when the distance moved by the boat, between consecutive observations, is greater than ten meters. The two bearings are then far enough apart to allow triangulation of the tag position. Equations to the line for each bearing are derived in the same way as for the boat position. Distance between boat and crab is calculated as the Euclidian distance between the two points.

The program contains three test loops:

i). Within the main program, if the distance moved by the tag is exactly the same as the distance moved by the boat, then the position of the tag is left unchanged and the distance moved is zero. This removes the artefact of small boat movements appearing as simultaneous movements of the tagged animal.

ii). If the bearing from the boat to the tag is greater than 360 then the tag position is not calculated. This allows for missing values in the data to be input as 999.

iii). " Estimation" of tag position and range is not calculated if the boat has moved less than ten meters between consecutive observations, or if consecutive bearings from the boat to the crab are equal. In neither case is triangulation reliable.

2. CRABTRACK:CREATE and CRABTRACK:EDIT.

These are complementary programs that will format and edit the input data file for CRABTRACK:MAP. They contain instructions for use and are self explanatory.

3. CRABTRACK:ACT.

There are two options within this program:

i). PATH.,which produces the co-ordinates for an enlarged plot of the sequential position fixs of the tagged animal.

ii). ACTIVITY TIMECOURSE., which calculates the rate of travel for the tagged animal since the preceeding position fix.

PATH is simply co-ordinate translation which is specific to the chart or map being used. ACTIVITY TIMECOURSE is based on the assumption that a moving animal is an active animal while a stationary one is inactive. Given this assumption then the rate of movement is a measure of activity. Rate of travel is calculated by dividing the euclidian distance between two consecutive observed positions, by the time elapsed between the two observations.

Intput files are CRAB(X).DAT for PATH and DIST(X).DAT for ACTIVITY TIMECOURRSE.

Output files are again plotter compatible x,y sequential arrays. PATH(X).DAT contains the enlarged plot co-ordinates while CRTC(X).DAT contains the elapsed time since the begining of the observations and the rate of travel in meters per minute.

4. CRABTRACK:DECIDE.

This is a decision support program to help with the estimation of tag range from field records of hydrophone arc, hydrophone declination, received signal strength, and signal frequency. A secondary routine is available which allows the comparison with the range estimated by CRABTRACK:MAP

The basis of the decision is the comparision of the feild records with a calibration of the hydrophone for known distances, subject to an adjustment for loss of signal strength due to battery depletion. The frequency shift has been found to be an accurate indicator of battery condition.

It should be stressed that this is a support program only and cannot substitute for the decisions of an experienced observer. Section 2 of the Report should be read in conjunction with this explanation for a full understanding of the problem.

(The source code for "Crabtrack:Decide" may be obtained from the authors on request.)

CREATE 10:03 15-FEB-84

```
10 PRINT "CRABTRACK:CREATE"
20 PRINT "THIS PROGRAM CREATES THE DATA FILE FOR CRABTRACK"
30 PRINT
40 PRINT "HELP= 1"
50 PRINT "CONT= 0"
60 INPUT H
70 IF H=0 THEN 140
80 PRINT" THE FILE CREATED IS A SEQUENTIAL ARRAY."
90 PRINT" TYPE THE THREE POSITION BEARINGS OF THE BOAT FIRST,"
100 PRINT" THEN THE CRAB BEARING, CRAB RANGE, AND LASTLY ELAPSED TIME."
110 PRINT" MISSING VALUES ARE NOT ALLOWED FOR THE BOAT BEARINGS"
120 PRINT" BUT MISSING CRAB BEARINGS CAN BE INPUT AS 999."
130 PRINT
140 PRINT "TYPE FILE NAME"
150 INPUT F$
160 FILE #1,F$
170 PRINT "NUMBER OF RECORDS= ";
180 INPUT N1
190 SCRATCH #1
200 PRINT #1,N1
210 FOR I=1 TO N1
220 PRINT
230 PRINT"RECORD ";I
240 PRINT"B1";
250 INPUT B1
260 PRINT"B2";
270 INPUT B2
280 PRINT"B3";
290 INPUT B3
300 PRINT"CRAB B4";
310 INPUT B4
320 PRINT"RANGE";
330 INPUT R1
340 PRINT"E.T";
350 INPUT T1
360 PRINT #1,B1;",";B2;",";B3;",";B4;",";R1;",";T1
370 NEXT I
380 PRINT
390 PRINT"DATA FILE IS ";F$
400 PRINT"NUMBER OF RECORDS=";I
410 END

READY
```

EDIT 10:05 15-FEB-84

```
10 PRINT "CRABTRACK:EDIT"
20 PRINT "THIS PROGRAM EDITS A DATA FILE FOR CRABTRACK"
30 PRINT
40 PRINT
50 PRINT "TYPE FILE TO BE EDITED"
60 INPUT F$
70 FILE #1,F$
80 PRINT "TYPE NEW FILE NAME"
90 INPUT F1$
100 FILE #2,F1$
110 SCRATCH #2
120 INPUT #1,N1
130 PRINT N1;"RECORDS IN ";F$
140 PRINT" TYPE LINE NUMBER TO START EDITING"
150 INPUT N4
160 PRINT" NEW NUMBER OF RECORDS"
170 INPUT N3
180 N1=N3
190 PRINT #2,N1
200 FOR I=1TO N1
210 INPUT #1,B1,B2,B3,B4,R1,T1
220 IF I<N4 THEN 510
230 PRINT B1;B2;B3;B4;R1;T1
240 PRINT "NO CHANGE=0, CHANGE=1, FINISH=2"
250 INPUT N2
260 IF N2=0 THEN 420
270 IF N2=2 THEN 440
280PRINT "RETYPE LINE"
290 PRINT
300 PRINT"B1";
310 INPUT B1
320 PRINT"B2";
330INPUT B2
340 PRINT"B3";
350 INPUT B3
360 PRINT"B4";
370 INPUT B4
380 PRINT"R1";
390 INPUT R1
400 PRINT"T1";
410 INPUT T1
420 PRINT #2,B1;",";B2;",";B3;",";B4;",";R1;",";T1
430 GOTO 510
440 PRINT #2,B1;",";B2;",";B3;",";B4;",";R1;",";T1
450 FOR X= 1 TO (N1-I)
460 PRINT X
470 INPUT #1,B1,B2,B3,B4,R1,T1
480 PRINT #2,B1;",";B2;",";B3;",";B4;",";R1;",";T1
490 NEXT X
500 GOTO 520
510 NEXT I
520 END

READY
```

PROG24 09:56 15-FEB-84

```
10 PRINT "CRABTRACK:MAP"
20 PRINT "THIS PROGRAM CALCULATES THE POSITION OF A BOAT"
30 PRINT "GIVEN THREE BEARINGS. (TAKEN AS 360 DEG. EAST OF"
40 PRINT "NORTH).. IT ALSO CALCULATES THE POSITION OF A"
50 PRINT "ULTRASONIC TAG., GIVEN ONE BEARING AND THE "
60 PRINT "RANGE IN METERS."
70PRINT
80 PRINT "TYPE OUTPUT DATA FILE CODE NUMER"
90 INPUTF1$
100 F2$="BOAT"+F1$+".DAT"
110 F3$="CRAB"+F1$+".DAT"
120 F4$="DIST"+F1$+".DAT"
130 F5$="ESTP"+F1$+".DAT"
140 F6$="ESTR"+F1$+".DAT"
150 FILE #1,F2$
160 FILE #2,F3$
170 FILE #3,F4$
180 FILE #4,F5$
190 FILE #5,F6$
200 SCRATCH #1,#2,#3,#4,#5
210 PRINT" TYPE INPUT DATA FILE"
220 INPUT F$
230 FILE #6,F$
240
250 PRINT
260 PRINT" PRINTOUT = 1, NO PRINTOUT =0"
270 INPUT C3
280 READ X1,Y1,X2,Y2,X3,Y3
290 INPUT #6,Z
300 FOR M=1TO Z
310 FOR N=1TO3
320 INPUT #6,B(N)
330 IF B(N) >270 THEN 380
340 IF B(N) >180 THEN 400
350 IF B(N) >90  THEN 420
360 B(N)=90-B(N)
370 GOTO 430
380 B(N)=-(B(N)-270)
390 GOTO 430
400 B(N)=270-B(N)
410 GOTO 430
420 B(N)=-(B(N)-90)
430 NEXT N
440
450 M1=TAN(B(1)*3.14286/180)
460 M2=TAN(B(2)*3.14286/180)
470 M3=TAN(B(3)*3.14286/180)
480 X4=(Y2-Y1+(M1*X1)-(M2*X2))/(M1-M2)
490 X5 =(Y3-Y1+(M1*X1)-(M3*X3))/(M1-M3)
500 X6=(Y2-Y3+(M3*X3)-(M2*X2))/(M3-M2)
510 Y4=Y1+(M1*(X4-X1))
520 Y5=Y1+(M1*(X5-X1))
530 Y6=Y1+(M1*(X6-X1))
540 X7=(X4+X5+X6)/3
550 Y7=(Y4+Y5+Y6)/3

READY
```

```
560
570 IF M=1 THEN 590
580 D2=SQR((I3-X7)^2+(I4-Y7)^2)
590 I3=X7
600 I4=Y7
610
620 INPUT #6,W,R
630 W1=W
640 IF W>360 THEN 1180
650 IF W>270 THEN 700
660 IF W>180 THEN 720
670 IF W>90  THEN 740
680 W=90-W
690 GOTO 750
700 W=-(W-270)
710 GOTO 750
720 W=270-W
730 GOTO 750
740 W=-(W-90)
750 M4=TAN(W*3.14286/180)
760 IFM4=M5 THEN 870
770 IF D2>1 THEN 790
780 GOTO 870
790 I5=(Y7-I8+(M5*I7)-(M4*X7))/(M5-M4)
800 I6=I8+(M5*(I5-I7))
810 M5=M4
820 I7=X7
830 I8=Y7
840
850 IF M=1 THEN 870
860 D3=SQR((X7-I5)^2+(Y7-I6)^2)
870 M5=M4
880 I7=X7
890 I8=Y7
900 C2=.086
910 R=R*C2
920 W1=(W1*3.14159)/180
930 X8=R*COS(W1)
940 Y8=R*SIN(W1)
950 X9=X7+X8
960 Y9=Y7+Y8
970
980 IF M=1 THEN 1050
990 D1=SQR((I1-X9)^2+(I2-Y9)^2)
1000 IF D1=D2 THEN 1020
1010 GOTO1050
1020 D1=0
1030 X9=I1
1040 Y9=I2
1050 I1=X9
1060 I2=Y9
1070
1080 IF I5=0 THEN1120
1090 Z1=I5
1100 Z2=I6

READY
```

PROG24 10:10 15-FEB-84

```
1110 Z3=D3
1120 PRINT #4,I5,I6
1130 PRINT #5,M,D3
1140 I5=0
1150 I6=0
1160 D3=0
1170 GOTO 1250
1180 X9=0
1190 Y9=0
1200 I5=0
1210 I6=0
1220 D3=0
1230 D1=0
1240
1250 PRINT #1,X7,Y7
1260 PRINT #2,X9,Y9
1270 INPUT #6,T1
1280 PRINT #3,T1,D1
1290 IF C3=1 THEN 1310
1300 GOTO 1420
1310 PRINT " POSITION FIX No."M
1320 PRINT " POSITION OF BOAT"," POSITION OF CRAB"
1330 PRINT " X="X7;" Y="Y7,"       ","X="X9;"Y="Y9
1340 PRINT "            DISTANCE MOVED",(D1*10),"METERS"
1350 PRINT "            BOAT MOVED",(D2*10),"METERS"
1360 PRINT "ESTIMATE OF CRAB POSITION",Z1,Z2
1370 PRINT "ESTIMATE OF CRAB RANGE   ",Z3/C2,"METERS"
1380 Z1=0
1390 Z2=0
1400 Z3=0
1410 PRINT
1420 NEXT M
1430 PRINT "FINISHED PROCESSING DATA"
1440 PRINT "OUTPUT FILES ARE :",F2$,F3$,F4$,F5$,F6$
1450 DATA 73,122,23,146.5,17.7,206.2
1460 END

READY
```

CRACT 10:12 15-FEB-84

```
10 PRINT"CRABTRACK:ACT"
20 PRINT"THIS PROGRAM PLOTS THE PATH OF A TAGGED ANIMAL"
30 PRINT "AND ITS ACTIVITY TIMECOURSE"
40 PRINT
50 PRINT "TYPE INPUT DATA FILE"
60 INPUT F$
70 PRINT " NUMBER OF POINTS"
80 INPUT N
90 PRINT"TYPE OUTPUT CODE NUMBER"
100 INPUT F1$
110
120 PRINT "DO YOU WANT ACTIVITY TIME COURSE YES=1, NO=0"
130 INPUT N1
140 IF N1=0 THEN 370
150
160 F4$="CRTC"+F1$+".DAT"
170 FILE #4,F4$
180 SCRATCH #4
190 PRINT"TYPE INPUT FILE NAME"
200 INPUT F3$
210 FILE #3,F3$
220 PRINT"TYPE SCALING FACTOR C"
230 INPUT C
240
250 DIM T(100)
260 DIM R(100)
270 FOR I=1 TO N
280 INPUT #3,T1,D1
290 S1=S1+T1
300 IF T1=0 THEN 330
310 A1=(D1/C)/T1
320 PRINT #4,S1,A1
330 NEXT I
340
350 PRINT"  OUTPUT ACTIVITY FILE IS:",F4$
360
370 F2$="PATH"+F1$+".DAT"
380 FILE #2,F2$
390 SCRATCH #2
400 FILE #1,F$
410 FOR I=1 TO N
420 INPUT #1,X1,Y1
430 IF X1=0 THEN 470
440 X2=X1-80
450 Y2=Y1-80
460 PRINT #2,X2,Y2
470 NEXT I
480
490 PRINT"OUTPUT CRAB PATH FILE IS:",F2$
500
510 END

READY
```

```
TYPE TRIP14.DAT
63
241 , 275 , 308 , 83 , 5 , 0
241 , 275 , 308 , 318 , 10 , 0
242 , 276 , 308 , 4 , 10 , 10
241 , 276 , 308 , 13 , 10 , 10
242 , 275 , 308 , 242 , 50 , 6
241 , 276 , 309 , 240 , 100 , 4
243 , 276 , 308 , 999 , 0 , 15
241 , 276 , 309 , 999 , 0 , 10
235 , 274 , 309 , 230 , 100 , 31
235 , 274 , 309 , 999 , 0 , 99
234 , 274 , 309 , 274 , 200 , 1200
228 , 273 , 309 , 260 , 200 , 15
230 , 273 , 309 , 268 , 200 , 30
229 , 273 , 309 , 269 , 150 , 12
229 , 273 , 308 , 267 , 150 , 3
228 , 273 , 308 , 269 , 150 , 15
229 , 273 , 308 , 268 , 150 , 15
228 , 272 , 309 , 267 , 150 , 15
227 , 272 , 308 , 269 , 150 , 15
226 , 273 , 308 , 266 , 150 , 15
227 , 273 , 308 , 266 , 100 , 15
227 , 273 , 308 , 266 , 100 , 15
226 , 273 , 309 , 258 , 100 , 15
226 , 273 , 309 , 258 , 100 , 15
226 , 273 , 309 , 260 , 100 , 15
226 , 272 , 309 , 260 , 100 , 15
226 , 273 , 309 , 267 , 100 , 15
226 , 273 , 308 , 271 , 150 , 15
227 , 273 , 309 , 269 , 150 , 15
227 , 273 , 309 , 270 , 150 , 15
227 , 272 , 309 , 268 , 150 , 15
226 , 273 , 310 , 251 , 100 , 15
226 , 273 , 309 , 270 , 150 , 15
227 , 274 , 310 , 269 , 150 , 15
226 , 274 , 310 , 270 , 150 , 15
227 , 273 , 309 , 270 , 150 , 15
227 , 273 , 310 , 270 , 150 , 15
229 , 275 , 311 , 274 , 200 , 114
228 , 276 , 310 , 275 , 200 , 6
228 , 275 , 311 , 270 , 200 , 15
229 , 275 , 311 , 270 , 200 , 15
230 , 276 , 311 , 265 , 250 , 15
230 , 275 , 311 , 270 , 250 , 15
230 , 275 , 312 , 273 , 250 , 15
223 , 274 , 312 , 273 , 200 , 11
224 , 275 , 312 , 272 , 200 , 4
225 , 275 , 313 , 270 , 200 , 15
225 , 275 , 312 , 268 , 200 , 15
224 , 275 , 312 , 272 , 200 , 15
225 , 275 , 310 , 262 , 175 , 15
225 , 275 , 311 , 275 , 150 , 15
224 , 274 , 311 , 274 , 150 , 15
224 , 275 , 311 , 270 , 150 , 15
224 , 275 , 311 , 248 , 100 , 15
224 , 274 , 311 , 240 , 100 , 15
223 , 275 , 310 , 252 , 100 , 15
223 , 275 , 310 , 246 , 100 , 15
221 , 274 , 312 , 246 , 100 , 15
219 , 274 , 311 , 258 , 150 , 15
219 , 274 , 311 , 247 , 175 , 15
219 , 274 , 311 , 247 , 175 , 15
219 , 274 , 312 , 250 , 200 , 15
219 , 274 , 312 , 999 , 0 , 15
```

```
TYPE CRAB14.DAT
103.73          139.44
104.316         138.437
105.027         138.641
104.486         139.19
102.216         134.819
97.5703         130.563
0               0
0               0
93.5305         133.668
0               0
99.8087         123.458
93.0409         125.808
96.239          124.825
96.2031         129.48
97.2287         130.779
97.2673         131.168
97.4536         130.769
95.2571         129.778
96.7057         131.431
95.7984         132.031
96.4909         135.9
96.4909         135.9
93.4667         135.092
93.4667         135.092
93.7613         135.035
93.7613         135.035
94.8046         134.916
96.9234         132.001
95.4115         130.224
95.6367         130.222
95.0715         130.122
91.0609         134.026
95.2547         130.604
94.1198         129.019
93.9906         129.383
93.9906         129.383
94.2326         128.912
94.932          122.875
96.5176         124.703
93.3897         123.17
93.3897         123.17
92.3041         118.362
94.0828         118.201
93.7857         117.036
91.1953         123.383
91.3265         123.178
89.7027         121.513
90.4317         122.854
91.3265         123.178
91.7336         127.938
93.5301         128.567
92.8344         128.751
92.0906         128.882
88.869          133.808
87.6345         134.172
90.5267         135.48
89.6863         135.803
89.6863         135.803
87.6865         130.846
84.488          129.611
84.488          129.611
83.2071         125.721
0               0
```

TYPE BOAT14.DAT

103.677	139.013
103.677	139.013
104.169	138.581
103.648	138.997
104.235	138.616
101.87	138.011
104.711	138.165
101.87	138.011
99.0585	140.256
99.0585	140.256
98.609	140.616
96.0277	142.747
96.8393	142.015
96.4283	142.378
97.9039	143.661
97.4925	144.066
97.9039	143.661
95.9323	142.661
96.9309	144.33
96.6983	144.899
97.0909	144.479
97.0909	144.479
95.2547	143.504
95.2547	143.504
95.2547	143.504
95.1211	143.375
95.2547	143.504
96.6983	144.899
95.6367	143.122
95.6367	143.122
95.5218	143.015
93.8609	142.158
95.2547	143.504
94.345	141.917
93.9907	142.283
95.6367	143.122
94.2327	141.812
93.7322	140.033
95.0186	141.837
93.3898	140.37
93.7322	140.033
94.178	139.781
94.0829	139.701
92.6605	138.507
90.2952	140.559
90.7263	140.368
89.7027	138.713
91.032	140.043
90.7263	140.368
93.8282	142.841
92.4058	141.418
91.9345	141.62
92.0907	141.782
92.0907	141.782
91.9345	141.62
93.1842	143.659
93.1842	143.659
89.6826	141.205
90.3686	143.464
90.3686	143.464
90.3686	143.464
89.0899	141.884
89.0899	141.884

TYPE DIST14.DAT

0	0
0	1.16134
10	0.738922
10	0.771005
6	4.92538
4	6.30028
15	0
10	0
31	5.09521
99	0
1200	11.986
15	7.16422
30	3.34557
12	4.65442
3	1.65518
15	0.39119
15	0.440464
15	2.40961
15	2.19803
15	1.08741
15	3.93031
15	0
15	3.13015
15	0
15	0.300182
15	0
15	1.05003
15	3.6036
15	2.33352
15	0.225144
15	0.573855
15	5.5967
15	5.41251
15	1.95017
15	0.386699
15	0
15	0.529732
114	6.07752
6	2.42004
15	3.48333
15	0
15	4.92856
15	1.78603
15	1.20199
11	6.85494
4	0.242737
15	2.32582
15	1.52602
15	0.951811
15	4.77676
15	1.90357
15	0.719707
15	0.755084
15	5.88612
15	1.28709
15	3.17417
15	0.900178
15	0
15	5.34493
15	3.42877
15	0
15	4.09489
15	0

TYPE ESTP14.DAT

0	0
0	0
0	0
0	0
0	0
87.5749	129.753
84.287	127.854
0	0
88.1119	141.35
90.6559	141.799
0	0
61.9362	141.775
0	0
0	0
149.192	145.453
143.161	145.137
0	0
0	0
0	0
101.182	144.765
0	0
0	0
0	0
0	0
115.574	144.57
147.064	144.02
0	0
0	0
96.4421	143.047
97.7708	143.504
185.278	143.504
0	0
0	0
0	0
68.301	141.812
202.859	132.399
111.785	140.37
0	0
0	0
0	0
69.884	139.701
0	0
0	0
138.091	138.713
52.9572	138.713
0	0
79.1201	140.773
87.0435	141.887
0	0
0	0
0	0
0	0
98.4003	145.355
0	0
0	0
98.7629	145.249
0	0
0	0
71.9559	135.645

TYPE ESTR14.DAT

1	0
2	0
3	0
4	0
5	0
6	16.5089
9	19.2873
11	0
12	8.03798
13	6.1872
14	0
15	36.0171
16	0
17	0
18	53.3324
19	46.2368
20	0
21	0
22	0
23	6.06016
24	0
25	0
26	0
27	0
28	18.8789
29	51.4348
30	0
31	0
32	2.73015
33	2.51605
34	90.9474
35	0
36	0
37	0
38	25.4934
39	108.253
40	18.3953
41	0
42	0
43	0
44	22.8079
45	0
46	0
47	48.3879
48	38.0981
49	0
50	14.8527
51	5.38285
52	0
53	0
54	0
55	0
56	5.48473
57	0
58	0
59	8.58198
60	0
61	0
62	18.2345

```
TYPE CRTC14.DAT
10              0.859212
20              0.896517
26              9.54531
30              18.3148
45              0
55              0
86              1.91118
185             0
1385            0.116143
1400            5.55366
1430            1.29673
1442            4.5101
1445            6.41543
1460            0.303248
1475            0.341445
1490            1.86791
1505            1.7039
1520            0.842953
1535            3.04675
1550            0
1565            2.42647
1580            0
1595            0.232699
1610            0
1625            0.813977
1640            2.79349
1655            1.80893
1670            0.17453
1685            0.444849
1700            4.33853
1715            4.19574
1730            1.51176
1745            0.299767
1760            0
1775            0.410645
1889            0.619902
1895            4.69
1910            2.70026
1925            0
1940            3.82059
1955            1.38452
1970            0.931775
1981            7.24624
1985            0.705631
2000            1.80296
2015            1.18296
2030            0.737838
2045            3.70291
2060            1.47564
2075            0.557912
2090            0.585336
2105            4.56288
2120            0.997744
2135            2.4606
2150            0.697812
2165            0
2180            4.14336
2195            2.65796
2210            0
2225            3.17433
2240            0
```