AN LHPR SYSTEM FOR ADULT ANTARCTIC KRILL (*EUPHAUSIA SUPERBA*)

D. G. BONE

British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 OET, UK

ABSTRACT. A large Longhurst–Hardy plankton recorder (L-LHPR) designed specifically for catching Antarctic krill (*Euphausia superba*) together with its method of operation and catch sorting is described. The system is switched on/off while being towed using an IOS acoustic net monitor. The net monitor also provides environmental data. The problem of coping with the wide range of krill densities encountered is discussed together with problems of net avoidance by krill generally and in relation to this net in particular. Results are given that indicate that the efficiency of the L-LHPR, in terms of catching ability at least, is as good as the IOS RMT system. The validity of density estimates derived from these nets is discussed.

INTRODUCTION

In 1977, while the Offshore Biological Programme (OBP) of the British Antarctic Survey was being organized, it was decided to develop a Longhurst–Hardy Plankton Recorder (LHPR) system (Longhurst and others, 1966) for the small scale sampling of krill. This would be an alternative to the IOS Rectangular Midwater Trawl (RMT) system (Baker and others, 1973) that we were also planning to acquire.

In the first field season of OBP a prototype LHPR was tested without much success, largely due to the late arrival of components which prevented testing before the system was shipped. From the experience gained in this first season both the net and the recorder box were redesigned and the system generally made more comprehensive. In order to gain the advantage of telemetered environmental information and command facilities the system was also linked to a net monitor of the RMT system.

When examining the feasibility of a LHPR system large enough to cope effectively with adult krill it soon became apparent that compromises would be necessary but those compromises were not expected to be detrimental to the end result because the principal interest was in one species which was much larger than the bulk of zooplankton organisms.

It was also apparent that if the published estimates of krill density, which ranged from 1 to 40000/m^3 (summarized in Everson, 1977) were realistic, no one piece of sampling gear of this type could give an accurate measure of density in all swarms. This is because where krill are more widely dispersed, any piece of gear having a catching aperture large enough to take a representative sample would rapidly become choked when it entered a dense swarm. With little reliable data available on likely catch rates it was hoped that the sampler design chosen would be efficient in low to moderate densities and accept that it could become choked if a very dense swarm was encountered. At the same time efforts were made to eliminate or minimize the biases which have been reported in LHPR systems (Haury, 1973; Haury and others, 1976).

This sampler, described below, has come to be known as the L-LHPR (for large Longhurst–Hardy plankton recorder) which distinguishes it from a smaller 'Benthos' Type 315 system which we use. The L-LHPR is as large as could be accommodated on RRS *John Biscoe*.

Description

The frame mounted system shown in Fig. 1 comprises entrance cone, net and recorder box.

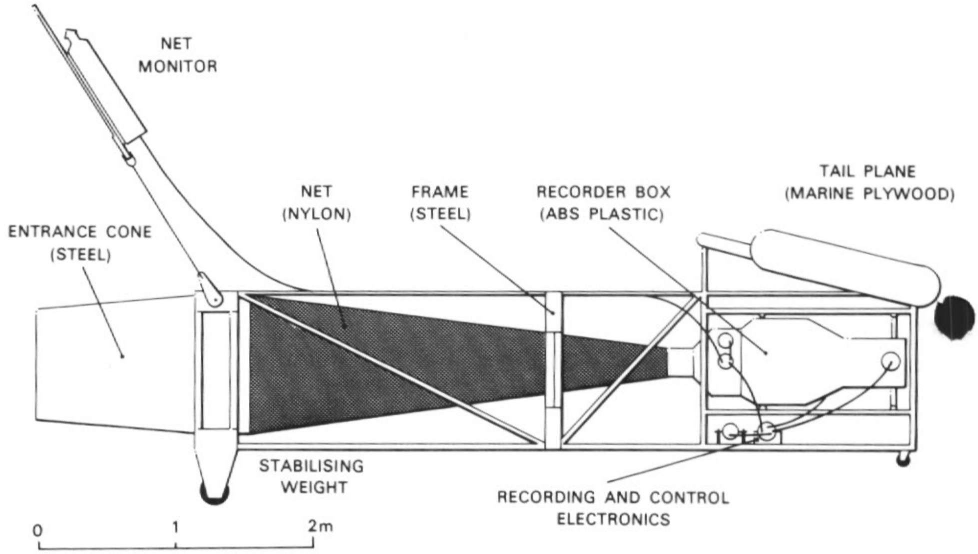

Fig. 1. Lateral view of the complete L-LHPR (large Longhurst–Hardy plankton recorder) system.

The frame

This is constructed mainly from rectangular section steel tube with all joints welded. For ease of transport it has been built in two pieces which join at the centre by means of fish plates. The overall dimensions of the frame are length 6.4 m, height 1.85 m and width 1.25 m without the tail plane (see below). The frame was zinc-sprayed after construction.

Tail plane

The tail plane which is inclined at an angle of approx. 13° was constructed from 18 mm marine plywood and has a chord length of 1.22 m and a span of 1.8 m. Vertical end plates of 12 mm marine ply were fitted to each 'wing tip', these are 0.3 m high and run for the full chord length; they are attached with the greater portion of their area below the plane of the 'wing'.

These end plates perform two functions, they provide lateral stability and prevent loss of lift from water spillage over the ends of the tail plane.

Towing bridles

The two towing bridles are attached to the forward upper end of the frame as shown in Fig. 1. The upper ends of the bridle shackle directly to the RMT net monitor cross.

Weights

Vertical stability and diving force are both provided by 136 kg of cast iron rings mounted beneath the frame at the forward end. No diving plane has yet been used on the frame. Heavy-duty swivelling castors were fitted at the rear of the frame to ease movement about the deck, this is further helped by allowing the cast-iron weights to act as rollers. Wooden runners were fitted beneath the frame to ease launch and recovery over the lip of the stern ramp.

Entrance cone

The entrance cone, to which the net is attached, has a mouth diameter of 0.81 m (0.5 m² cross-sectional area), which expands to 1.0 m diam. over a distance of 1.15 m (angle of expansion 5°). The conical section is followed by a parallel section 0.4 m in length. The conical section was constructed from 16-gauge mild steel plate and the parallel section from 10-gauge. The cone is reinforced internally with four longitudinal bars of solid mild steel and externally with longitudinal tubes and two circumferential bars. The leading edge is reinforced with a welded strip of steel and a similar strip is welded at the trailing edge to prevent the net slipping off.

The net

This is attached directly to the entrance cone, has a filtering section 3 m long with a 10 cm nylon fabric collar at the mouth and a 15 cm sleeve of similar material at the cod-end. It is circular in section at the mouth (1.0 m diam.) and reduces to a rectangle of 24.5 × 20 cm at the cod end.

The filtering material is 14 GGN nylon mesh which has an aperture size of 1550 μm, a porosity of 63% and a total filtering area of 6.124 m² giving a total open area of 3.858 m². The angle of convergence of the net is about 8° and it has no transverse seams.

The net mouth is attached to the entrance cone by stainless steel worm drive clips with a band of foam rubber sandwiched between. The cod-end sleeve fits over the entrance tunnel of the recorder box and is held on by four ABS plastic plates each of which has three pins which pass through eyelets in the sleeve and locate in the entrance tunnel wall. Foam rubber pads are placed between the plates and the sleeve. The whole is secured by two bands each constructed of four stainless-steel worm-drive clips arranged so that each side of the rectangle may be tightened. Because the net is held rigidly in the frame any side strain applied to the net, which may occur during launch and recovery, will stress the collars. In order to prevent the net tearing out the net material has been sandwiched by the collar material into which it is deeply set. The 'sandwich' is sewn through at least three times.

Recorder box

The recorder box is constructed mainly from 9 mm thick ABS (acrylonitrile–butadiene–styrene) plastic. PVC block was used in the opening/closing mechanism because ABS could not be obtained in sufficient thickness. Clear Perspex sheet, 12 mm thick, was used for the removable side of the box (lid). Nylon and Delrin were used for bearings and gear wheels respectively.

ABS was used in preference to PVC for the main structure of the box as it retains

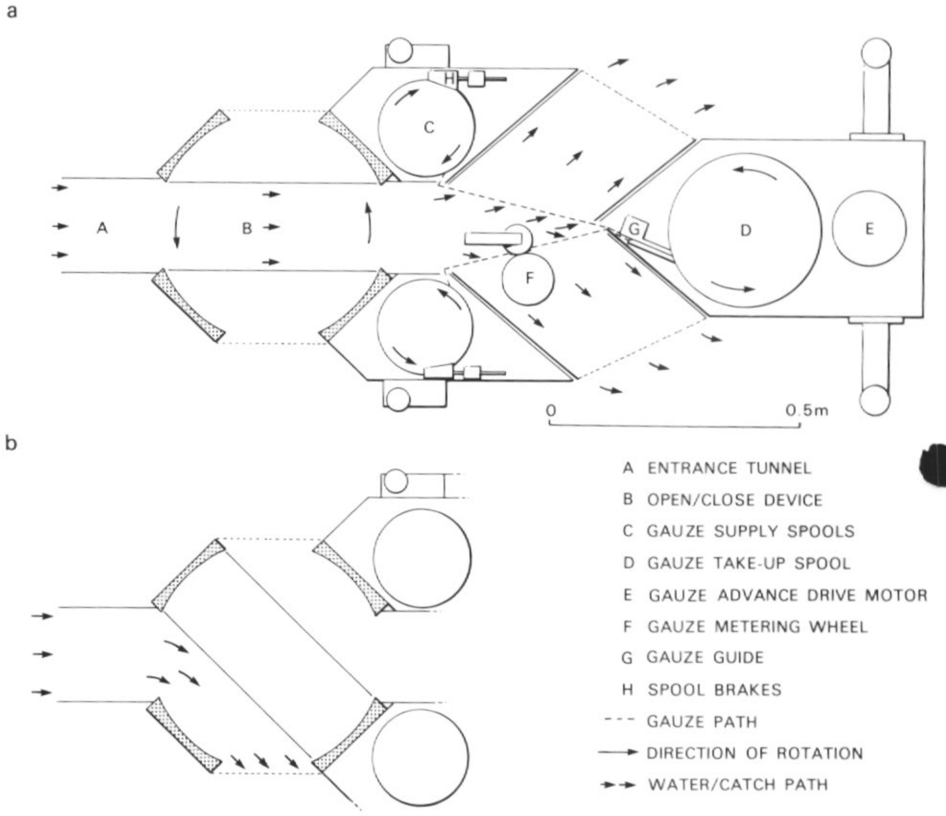

Fig. 2. Lateral view of the L-LHPR recorder box showing (a) the main features and the flow of water when the recorder box is in the open/on state, (b) detail of the opening/closing mechanism to show the flow of water when the recorder box is in the closed/off state.

its impact strength at low temperatures. Like PVC it can be solvent-welded with ease; nevertheless all joints were screwed as well as glued to give additional strength.

The main features of the recorder box are shown in Fig. 2. The entrance tunnel is rectangular with internal dimensions of 22 × 17 cm. These dimensions are maintained until the gauze filtering area is reached. Both filtering areas (gauze patches) are 22.7 cm wide but their lengths differ, the upper being 29 cm long and the lower 31 cm. This arrangement was adopted to make a cleaner exit for the gauzes and to give better sealing of the exit slot. The slot is sealed with a brush of nylon bristles which is common practice with LHPR's. This slot is approx. 2 cm wide to cope with large quantities of krill, salps and the large ctenophores likely to be encountered in Antarctic waters. The water exhaust tunnels have parallel sides so that there is no reduction in cross-sectional area. Each gauze is supported by 11 stainless steel rods which run longitudinally across the opening.

The gauze advance is driven by a stepper motor (for electrical details see below) acting through $\frac{3}{8}''$ pitch × $\frac{1}{2}''$ (9.5 × 12.7 mm) wide timing belt drive which gives a 3:1 reduction ratio. The motor is housed in an oil-filled cylindrical aluminium housing one end of which is closed by a Perspex piston which automatically compensates for changes in pressure. Gauze metering is achieved in the usual way with a measuring wheel activating a magnetic switch.

The gauze spools have cores of ABS pressure piping and flanges of Perspex. The

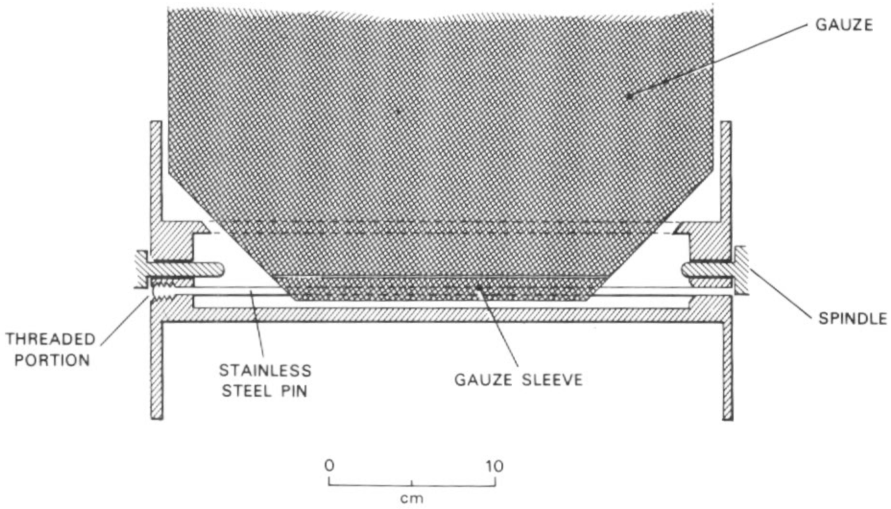

Fig. 3. Plan view of a gauze supply spool to show method of attaching gauze to spool.

capacity of the take up spool is greater than that needed for the clean gauzes to allow for a thick layer of catch. The gauzes are 33 cm wide and 26 m long, the mesh being the same as that used in the net. The edges and the ends of the strips were ultrasonically welded to prevent fraying.

Trials with a prototype of the present recorder box revealed that if a gauze was not fixed accurately at right angles to the axis of the spool then it did not wind on evenly or neatly. Also fixing gauzes on with adhesive tape under cold wet conditions was very difficult. To overcome these problems the gauzes were manufactured with a tongue, the end of which was turned back and welded to form a sleeve. Slots were cut in the spool cores and removable stainless steel pins fitted. To attach the gauzes the tongue is passed through the slot and the pin is then inserted through the sleeve to lock it in place (see Fig. 3). This has proved very satisfactory and easy to operate. If the gauzes run out before the system is switched off the motor stalls but is undamaged.

Spool brakes

Another point learnt from the prototype recorder box was that water passing through the exhaust tunnels did so with sufficient force to drive the gauze through into the take up chamber. To prevent this brakes have been fitted that act on the supply spools. These take the form of spring-loaded wooden-faced Perspex wedges acting on one flange of the supply spool. The amount of tension that has to be set on the springs has to be found by experiment and varies with the speed at which the net is towed. For towing at 4 kn the friction that has to be set on the brakes is almost enough to stall the gauze advance motor when the system is run dry.

Leather-faced wedges were tried but these proved to be difficult to set at the right tension as the edges of the spool flanges 'bedded' into the wet leather.

Gauze guide

Dry trials with the prototype revealed that if a bulky catch of krill was taken there would be a possibility of some working its way out of the length of gauze sandwich between the exit slot and the take up spool.

The guide employs 2 pairs of sprung Perspex plattens which grip the edges of the gauze sandwich outside the filtering area. The guide swivels and automatically aligns itself between the exit slot and the circumference of the roll of gauze sandwich, swivelling out as the roll diameter increases.

Open/close device

The recorder box is also fitted with an opening/closing device which consists of a section of the entrance tunnel which rotates within a cylindrical housing having inlet and outlet ports.

When in the recorder-box-closed position (= cod end open), Fig. 2b, catch reaching the cod end is flushed straight out into the open sea. A rotation of 45° connects the net direct to the recorder box and activates it. If sampling is to be terminated a further rotation of 135° returns the device to the closed/off state but primed ready for another 'open' command.

The device is driven by a 12 V DC motor (Moore-Reed type 30 PMP rated at 140 gm cm torque at 5600 r.p.m.) driving an 18 tooth spur gear (0.9″ PCD; 22.8 mm) through a 300:1 reduction gear-box. The spur gear drives a 235 tooth (11.75″ PCD; 298.4 mm) disk gear (Delrin) screwed to the top of the rotating channel, this gives an overall reduction ratio of 3916:1. The channel rotates on a central stainless steel spindle, one end of which drives the switching unit.

The open/close drive unit and the switching unit are both in oil-filled housings similar in principle to that described for the gauze advance stepper motor. The described method of driving the open/close channel replaces an earlier version which

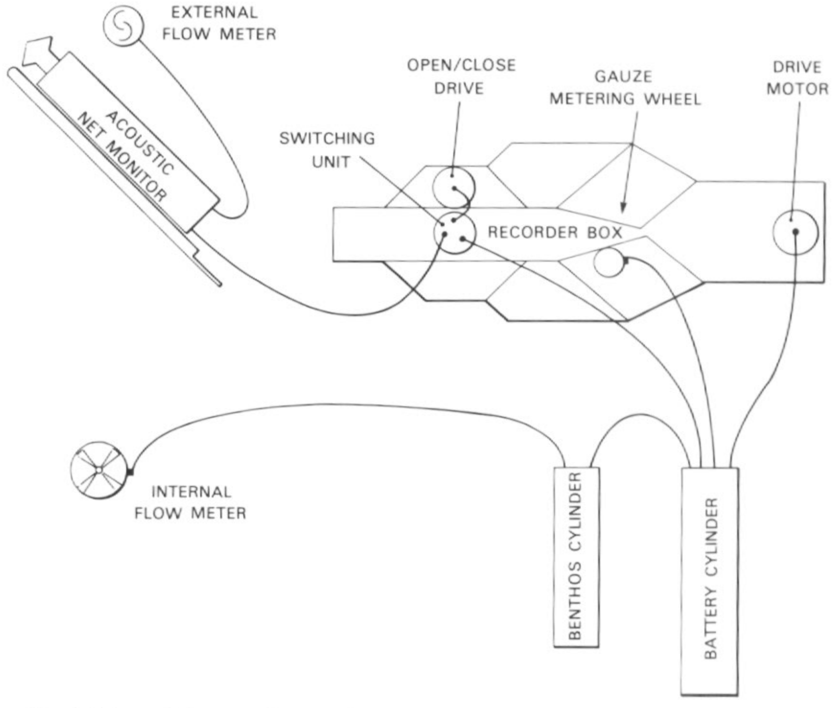

Fig. 4. Schematic layout of connections between electronic components of the system.

employed a 625:1 gear-box driving the centre spindle directly. In use this suffered damage in spite of shock-absorbing connectors between the channel and the spindle.

The recorder box is fitted with small wheels on the front end which allow it to be run into the frame from behind. After the net has been attached and tensioned the box is fixed rigidly in position using four adjustable-length stainless steel struts.

The orientation of the box within the frame is such that the gauze patches are horizontal in the manner suggested by Haury and others (1976).

Two flow meters monitor the sampler (see Fig. 4). The first is positioned inside the parallel section of the entrance cone. This is linked to the Benthos recorder-control cylinder (see below) where data are recorded on a chart roll. The second flow meter is mounted on the net monitor cross, data from this are transmitted to the ship via the acoustic link.

Electronics

The acoustic net monitor developed by the Institute of Oceanographic Sciences for use with their RMT net system (Clarke, 1969; Baker and others, 1973) is used to monitor and control the L-LHPR. A Benthos type 315 recorder/control unit is used to record temperature, depth, flow and gauze advance. The motor logic of this unit is also used to control the heavy duty driver circuit required for the gauze advance

Table I

Operation	*Equipment*	*Equipment activity*
Launching and paying out	Net monitor	*Transmit* depth, temp. and flow (1) *Indicates* 'net closed'
	Open/close device	In venting position
	Benthos cylinder	Off
	Recorder box	Not operating
On receipt of 'open' command	Net monitor	Changeover switch (1) operates closing circuit to O/C drive (power from battery cylinder)
	Open/close device	Rotates
O/C device reaches recorder box 'open' position	Switching unit	Changeover switch (2) operates cutting off power to O/C drive Microswitch to Benthos closes Microswitch to net monitor closes
	Net monitor	Indicates 'net open' state
	Benthos cylinder	*On, records* depth temp., gauze advance, flow (2). Logic circuit controls gauze advance
	Recorder box	Operating
Receipt of 'close' command	Net monitor	Changeover switch (1) operates closed circuit to O/C device (power from battery cylinder)
	Open/close device	Rotates
	Switching unit	Microswitch to Benthos opens Microswitch to net monitor opens
	Benthos cylinder	Off
	Recorder box	Stops operating
	Net monitor	Indicates net closed
O/C device reaches 'venting' position	Switching unit	Changeover switch (2) opens
	Net monitor	Continues to transmit temp., depth and flow (1)

motor. The net monitor and Benthos systems are interfaced through the switching unit of the opening/closing device and a battery cylinder which also contains the heavy-duty driver board. The schematic layout is shown in Fig. 4.

The acoustic net monitor is carried on the net monitor cross as for use with the RMT (see Fig. 1) and the LHPR towing bridles attached to the cross in place of the RMT towing bridles. The monitor is connected to the switching unit on the recorder box by a 7 m long 5-core cable. The monitor 'sees' the switching unit in exactly the same way as it 'sees' the RMT net release gear. On receipt of an 'open' command the monitor closes the contacts providing power (from the battery cylinder) to the drive motor of the opening/closing device which then runs until the rotating channel has lined up to open the recorder box. When the recorder box is fully open a single pole double throw microswitch operates cutting off power to the drive motor. Simultaneously another microswitch completes a circuit through the net monitor which causes it to indicate the net-open state. A third switches on the Benthos cylinder to begin normal operation of the L-LHPR. These operations are summarized in Table I. On receipt of a close command the monitor restores power to the open/clo[illegible] drive motor which runs until the controlling microswitch operates again. This rotati[illegible] also opens the circuits to the Benthos cylinder and the net state indicator.

The stepper motor used for the gauze advance drive (SLO-SYN type M111 FD310) requires more current and a slower stepping rate than that used in the Benthos type 315 recorder box so the normal motor drive board has been replaced by a specially designed heavy-duty board which is housed with its power supply in the battery cylinder. The battery consists of 16 × 10 Ah nickel-cadmium rechargeable cells (total nominal voltage 19.2 V). Although rated for 10 V the motor is run directly from this voltage, during development the motor withstood this overating during extensive trials without the benefit of oil immersion, low-temperature environment and very short running period which it has in use. The only time that the motor would be stressed in use would be if it stalled early in a haul.

During inter-advance periods no holding torque current is applied to the motor but the windings are all shorted together to increase resistance to rotation. There is no evidence that the take up spool unwinds between advances.

Methods

The sampler is deployed over the stern of RRS *John Biscoe* utilizing the luffing gantry and main trawl winch. A drogue (60 × 60 cm) attached to the rear of the frame by 18–20 m of rope steadies the frame during launch and recovery. A trip line [illegible] employed to aid recovery of this drogue.

Launching is achieved by lifting on the trawl wire and gantry until the combination of the weight of the frame and pull of the drogue swing the frame out over the lip of the stern ramp. The gantry is then luffed fully out before the sampler is lowered away.

Recovery is the reverse of the above procedure, but to bring the frame sufficiently far forward to allow the gates to be closed, rope, from a drum end, is led to the front of the sampler to pull it the last 1.5 m. The L-LHPR is shown stowed on deck in Fig. 5.

Whenever possible launching and recovery are carried out with the ship heading into the wind, or swell, whichever is likely to be the major cause of rolling.

The gauze strips used in the recorder are too expensive to allow a pair to be used for each haul, with subsequent preservation and storage for examination at a later date. For this reason only three sets are carried and the gauzes are sorted and analysed

Fig. 5. The L-LHPR stowed on the after deck of RRS *John Biscoe*.

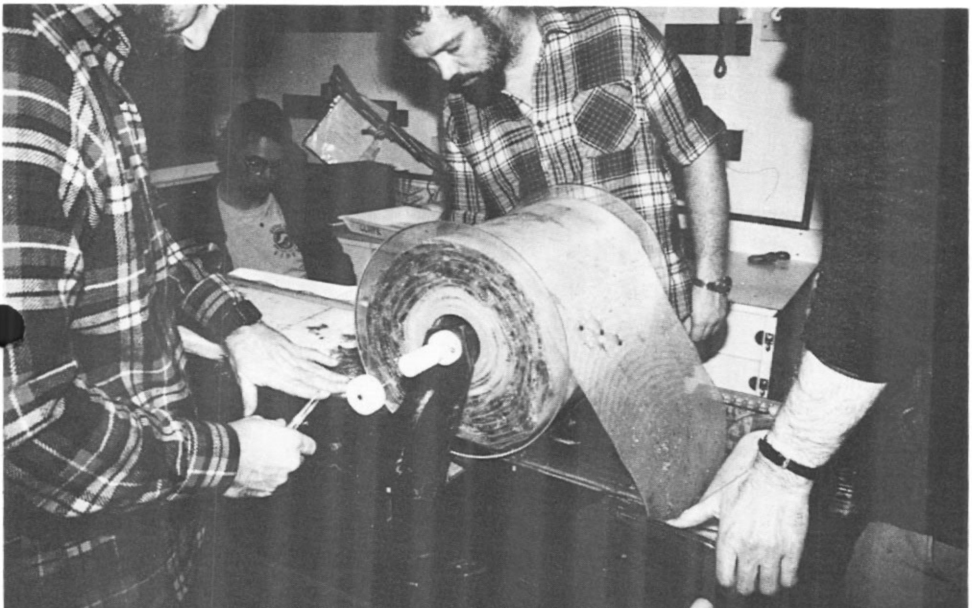

Fig. 6. The sorting table in use. The large gauze take-up spool is mounted in the centre. The top gauze is led over the take-up spool and rewound at the supply spool seen at the right. The lower gauze leads across the sorting table and is rewound onto a supply spool on the left side.

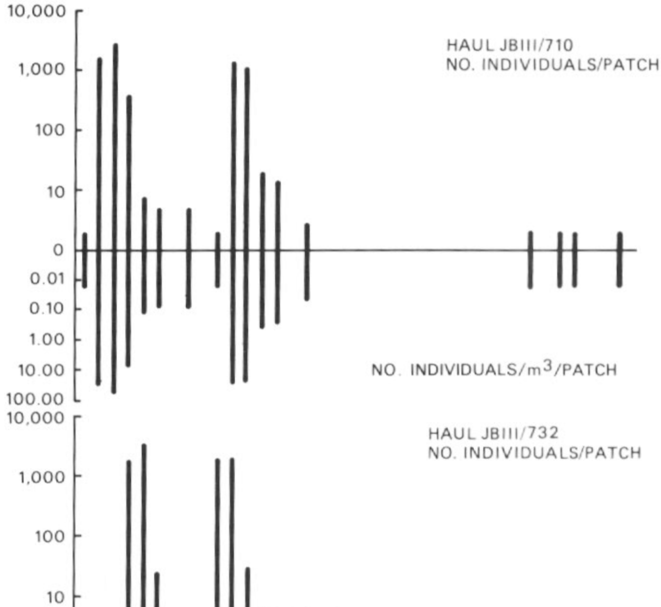

Fig. 7. The number and density of krill caught on successive patches of gauze during two hauls with the L-LHPR.

immediately after each haul. After analysis the gauzes are washed to remove residual plankton and re-spooled, each set having its own pair of supply spools.

Sorting is carried out on a specially designed sorting table (see Fig. 6) which accommodates the take-up and both supply spools. This table allows two patches to be sorted at the same time by one or two pairs of sorters. Before the gauzes are removed from the recorder box the position of the last patch is marked by passing a loop of thread through the meshes. This also ensures that the correct faces of the gauzes are peeled apart. (Because the ends of the gauzes do not finish up in the same place it is possible to search for the catch between the wrong faces of the strips if care is not taken.)

The sampler has been used for both oblique and horizontal hauls but the normal method is to haul the sampler horizontally through an area where the echo-sounder has shown concentrations of krill swarms at a suitable depth.

Results

Two typical examples of krill catches during hauls with the L-LHPR are shown in Fig. 7. The highest number caught on a patch was 3347 (JB III 732) and the highest indicated density was 64.5 individuals/m³ (JB III 710).

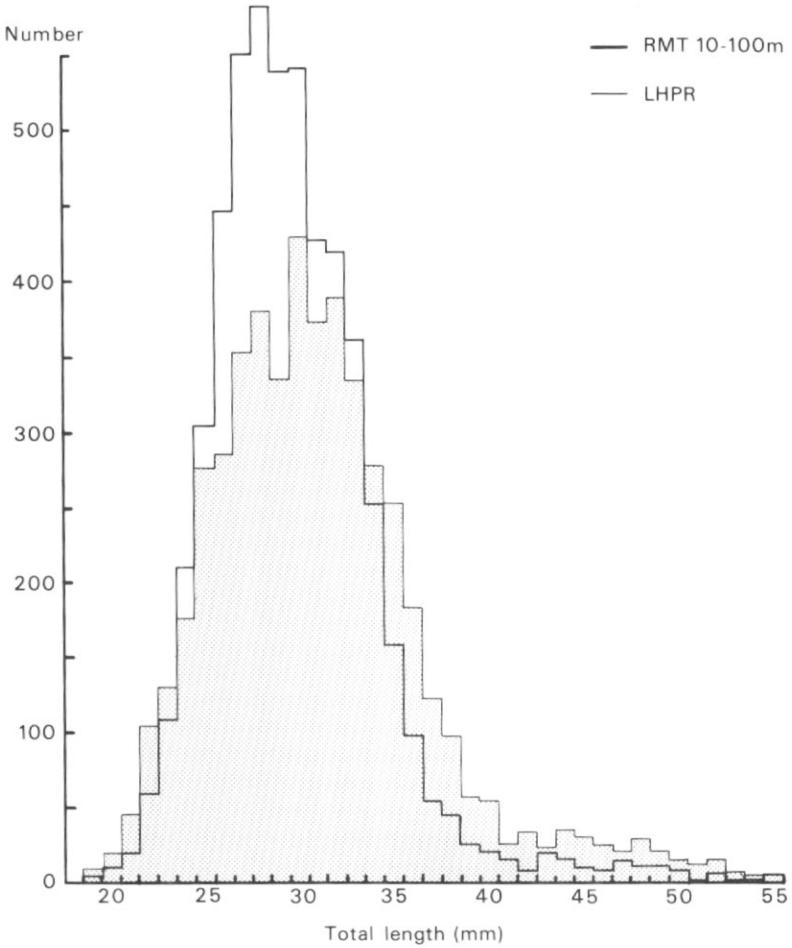

Fig. 8. Length frequency histograms for krill from the same area off the north-east coast of South Georgia caught in a series of RMT 8 net hauls (2–7 January 1982) and in a series of L-LHPR hauls (12–17 January 1982).

Fig. 8 shows a comparison of length frequency distributions of catches by the L-LHPR with those of the RMT 8 all taken in January 1982 in the same general area to the north-east of South Georgia.

Discussion

The work of Tranter and Heron (1967) has given clear guidelines for the design of any plankton net system and Longhurst and Williams (1976) together with Haury and others (1976) set out the criteria for good design in LHPR systems.

When designing this system every effort was made to incorporate the principles set out in these papers and to overcome as far as possible the problem of avoidance. Unfortunately these three sets of requirements conflict to some degree and compromise is necessary.

Clutter and Anraku (1968) conclude that although there is no real answer to the problem of avoidance, increases in mouth diameter and towing speed both reduce the problem.

The dimensions chosen for this sampler give the greatest possible mouth diameter consistent with (a) good hydrodynamic design and filtration efficiency, (b) building and operating a large recorder box, (c) a frame size that could be handled on RRS *John Biscoe*. The normal towing speed of 3.5–4 kn is as great as we consider practical for this machine, higher speeds would lead to structural problems, particularly in rough weather.

The tail plane described replaces an earlier version of steel sheet which proved to have too little lift to bring the sampler frame up to horizontal.

The rotating channel open/close device was adopted in preference to any form of door at the front because it requires much less force to operate and it can be used any number of times without need for resetting.

The entrance cone should considerably enhance the filtration efficiency (Tranter and Heron, 1967) of the sampler while the reduced water velocity inside the net coupled with its high ratio of open area to mouth area (see Table II) should give a low value for pressure holding organisms against the mesh and causing residence time bias. The length increases caused by the entrance cone and the open/close device are an undesirable factor, the distance from the mouth to the centre of gauze patches being 5.3 m. However, at 4 kn an unimpeded particle would cover this distance in 2.6 s, if slowed down to the theoretical speed created at the widest part of the entrance cone it would take 3.5–4 s. These figures are not excessive.

The wide mesh of the net (1550 μm) should prevent clogging by all phytoplankton including the very spiney *Chaetocerus criophilum* Castracane. In operation, the only animal species found adhering to the sides of the net are salps.

Table II compares certain characteristics of the L-LHPR with the main net of the IMER double LHPR described in Williams *et al.* (1983). This paper also gives details for some earlier LHPR systems.

Table II shows the L-LHPR to have better ratios of gauze area/throat area and gauze area to mouth area, while the poorer net open area/mouth area ratio is not very significant.

Both these systems employ a mouth reduction cone and operate with an IOS net monitor.

No gauze slot seals have been employed but the whole of each water exhaust tunnel is movable along its axis allowing the width of the gauze slot to be adjusted as required. In practice the sealing of the Perspex lid is good enough to create a dead space around the gauze slots. This and the relatively large size of the animals being dealt with prevent any serious leakage.

Information on avoidance in general is conflicting and the Antarctic krill *Euphausia superba* is no exception. Logically one would expect such a large and active animal to pose an avoidance problem and indeed Mackintosh (1934) states that he was able to observe krill darting backwards to escape a net being towed a 'few feet' below the surface alongside a ship. Unfortunately he does not say what proportion of the krill were able to avoid the net. Marr (1962) describes how krill were rarely caught in surface nets towed astern of RRS *William Scoresby* during daylight even when passing through swarms. However, when a net was deployed from a boom over the side so that it fished in water undisturbed by the ship's passage, large quantities of krill were caught. Klages and Nast (1981) state that 'only on a few occasions' were krill seen to avoid the head or foot ropes of a midwater trawl as indicated by net-sond traces. Fischer and Mohr (1978) state that reactions of krill to ship and nets are so small that the effect is negligible on commercial fishing operations.

The work of Kils (1979), Semenov (1969) Ragulin (1969) and Everson and Bone

Table II.

	Williams et al. (1983)	
	IMER double LHPR	*L-LHPR*
Net		
Reduction cone mouth area (cm^2)	1029	5000
Area of net (cm^2)	21306	61240
Porosity of net	0.44	0.63
Net open area*/mouth area	9.11	7.716
Cod-end box		
Throat area (cm^2)	58	374
Gauze filtering area (cm^2)	130	1362
Porosity of gauze	0.44	0.63
Gauze open area*/mouth area	0.056	0.171
Gauze open area*/throat area	1.0	2.3

* Open area = filtering area × porosity.

(in press) shows that krill undoubtedly have the ability to avoid quite large samplers if cued in time. Pleopod swimming alone could account for much avoidance without the faster tail swimming avoidance reaction. This ability could be enhanced if krill in swarms acted in unison. Once again different observers report conflicting evidence. Marr (1962) describes seeing whole surface swarms sink away from RRS *William Scoresby* in unison. However, he also reports an observation of Gunther's where a lead line was thrown into a surface swarm which avoided the lead as it passed through then reformed behind it. A similar experience was reported by Hardy (1935) who observed a surface swarm from the Government Jetty at Grytviken. When stirred with his walking stick the swarm parted and re-formed behind it. In December 1981 the author had an opportunity to observe a swarm in the same location. After dark a swarm of immature (*c*. 35 mm) krill was observed to be holding station between the jetty and a moored ship (RRS *John Biscoe*) which was illuminating the area with floodlights. From time to time pieces of kelp (*Macrocystis* sp.) drifted through the swarm which parted ahead of, and re-formed behind, the drifting weed. They reacted in the same way to a broom handle passed slowly through the swarm. In both cases the krill kept about 5 body lengths away from the object. When the broom handle was speeded up to approximately 1 m s^{-1} they were unable or at least they did not, avoid it. Recently Everson and Bone (in press) have reported significant avoidance of RMT 8 nets near to the surface in good light conditions. The towing speed on that occasion was 2.5 kn, significantly slower than that for the L-LHPR.

Other euphausiids also appear to avoid nets. Sameoto (1977) found that *Meganyctiphanes norvegica* were able to avoid a MOCNESS type net when towed at 2 kn but at speeds above 3.5 kn catch/unit volume did not increase. Wiebe and others (1982) found strong evidence that a 1 m^2 MOCNESS was being avoided by *Nematoscelis megalops* in daylight, evidence for avoidance of a 10 m^2 MOCNESS was less conclusive.

Clutter and Anraku (1968) review the literature on avoidance and the possible mechanisms which cue animals to take avoiding action. Visible stimuli and pressure waves ahead of the sampler are the most obvious factors. Even at night visual stimuli cannot be ruled out as bioluminescent animals entrapped by a sampler may cue animals well ahead of it. Bowden (1969) measured bioluminescence above, below, within and ahead of an Isaaks–Kidd midwater trawl. The luminescence ahead of the net was much greater than that above and below suggesting that animals in this region were being warned of the net's approach.

However, when 'target' fishing at krill swarms with the L-LHPR it was consistently easier to 'hit' swarms at night than it was in daylight; even when allowing for the fact that daylight swarms tend to be smaller and more densely packed. The avoidance reported by Everson and Bone did not appear to take place at night, but the situation was complicated by the krill migrating upwards at night and forming a dense layer a few metres beneath the surface.

The relatively large mouth opening and clean profile presented by the entrance cone together with the degree to which it is projected ahead of the frame and bridles should give the L-LHPR fairly good avoidance characteristics. This should hold true whether avoidance is cued by vision or by pressure waves.

The results presented above are not intended to be exhaustive but merely to give an indication of the efficiency of the net. Fig. 7 shows an abrupt increase in numbers of krill/patch when a swarm is sampled, there is also a rapid drop back to low numbers indicating that hang-up in the net is not a serious problem. However, in all cases where large numbers of krill are caught they appear on at least two succeeding patches. This may indicate that the gauze exit slot is too narrow to allow them to pass through during one wind-on period.

The comparison of L-LHPR and RMT 8 shows that in spite of the smaller mouth area of the L-LHPR (0.5 m^2 against 8 m^2) there is no material difference in the size of animals caught by the two systems. In fact the size of the krill caught in the L-LHPR was significantly larger than those caught in the RMT 8 but this could be accounted for by growth (Watkins, personal communication).

The maximum density of 64 krill/m^3 is slightly higher than those achieved by us with the RMT, but these densities are far lower than the usual estimates of density of krill in swarms (Hamner and others, 1983; Witek *et al.*, 1981; Guzman and Marin, 1983) and those cited by Everson (1977). However, they are in the same order as the maximum catch by commercial trawl on the West German Antarctic Expedition 1975/76, 186 g/m^3 (calculated from figures in Sahrhage and others, 1978; Klages and Nast, 1981). The discrepancy between our figures derived from net hauls and the (probably more accurate) higher figures are likely to be accounted for mainly by two factors. Firstly and probably more importantly, the extreme aggregation of krill into compact swarms means that there is a strong possibility that only a portion (perhaps quite small) of the linear path taken by the net during any sampling period actually goes through a swarm. The water volume filtered, however, will be calculated for the whole sampling period. At present we have no way of assessing how long the net is in the swarm. In some cases an assessment can be made on the basis of net depth records and echo-sounder traces. However, often the net does not follow the same path as the ship and the irregularity of krill swarms in all three dimensions means the echosounder may not sample the krill that are actually caught.

Secondly there is the unknown factor of avoidance which in the case of plankton nets almost certainly plays a part. Since the L-LHPR has been fitted with the new tail plane we have not had an opportunity to operate the sampler through larger, more diffuse swarms of krill which might allow a realistic comparison of catch/unit volume with echo-sounder backscattering strength values. If we are able to do this it would give an indication as to how much krill was avoiding the net.

Acknowledgements

I am particularly indebted to Dr Inigo Everson for inspiration and encouragement throughout this project and for his critical examination of the manuscript. Much thanks must go to the staff of the Cavendish Laboratory (University of Cambridge) Student Workshop for much assistance in building the recorder box, and to Dr Alan Packwood of the Institute of Oceanographic Sciences for advice on the hydrodynamics of the tail plane. I also wish to thank my colleagues in the Offshore Biological Programme and the officers and crew of RRS *John Biscoe* for their help with the testing and early operation of this sampler.

Received 22 April 1986; accepted 9 June 1986

References

Baker, A. de C., Clarke, M. R. *and* Harris, M. J. 1973. The N10 combination net (RMT 1+8) and further developments of rectangular midwater trawls. *Journal of the Marine Biological Association of the United Kingdom*, **53**, 67–184.

Bowden, B. P. 1969. Observations on bioluminiscence on Sond 1965 cruise of RRS *Discovery*. *Journal of the Marine Biological Association of the United Kingdom*, **49**, 669–682.

Clarke, M. R. 1969. A new midwater trawl for sampling discrete depth horizons. *Journal of the Marine Biological Association of the United Kingdom*, **49**(4), 945–960.

Clutter, R. I. *and* Anraku, M. 1968. Avoidance of samplers in zooplankton sampling. *UNESCO Monographs on Oceanographic Methodology*, **2**, 57–76.

Everson, I. 1977. The living resources of the Southern Ocean. *Southern Ocean Fisheries Survey Programme GLO/SO/77/1, FAO, Rome*, 156 pp.

Everson, I. *and* Bone, D. In press. Effectiveness of the RMT 8 system for sampling krill (*Euphausia superba*). *Polar Biology*.

Fischer, W. *and* Mohr, H. 1978. Verhaltens beobachungen an krill (*Euphausia superba* Dana). *Archiv für Fishckrei Wissenschaft*, **29** (1), 71–79.

Guzman, O. *and* Marin, B. 1983. Hydroacoustic and photographic techniques applied to study the behaviour of krill, *Euphausia superba* (*In* Nemoto, T. *and* Matsuda, D. *eds. Proceedings of the BIOMASS colloquium 1982. National Institute for Polar Research, Tokyo*, 129–152).

Hamner, W. M., Hamner, P. P., Strand, S. W. *and* Gilmer, R. W. 1983. Behaviour of Antarctic krill *Euphausia superba*: Chemoreception, feeding, schooling and molting. *Science*, **220**, 433–435.

Hardy, A. C. *and* Gunther, E. R. 1935. The plankton of the South Georgia whaling grounds and adjacent waters 1926–1927. *'Discovery' Report*, **11**, 1–456.

Haury, L. R. 1973. Sampling bias of a Longhurst–Hardy plankton recorder. *Limnology and Oceanography*, **18**, 500–506.

Haury, L. R., Wiebe, P. H. *and* Boyd H. 1976. Longhurst–Hardy Plankton Recorders; their design and use to minimise bias. *Deep-Sea Research*, **23**, 1217–1229.

Kils, U. 1979. Swimming speed and escape capacity of Antarctic krill *Euphausia superba*. *Meeresforschung/Reports on Marine Research*, **27**, 264–266.

Klages, N. *and* Nast, F. 1981. Net selection for Antarctic krill by the 1216 meshes krill trawl. *Archiv Fischereo Wissenschaft*, **31, 3**, 169–174.

Longhurst, A. R., Reith, A. D., Bower, R. E. *and* Seibert, D. L. R. 1966. A new system for the collection of multiple serial plankton samplers. *Deep-Sea Research*, **13**, 213–22.

Longhurst, A. R. *and* Williams, R. 1976. Improved filtration systems for multiple serial plankton samplers and their development. *Deep-Sea Research*, **23**, 1967–1073.

Mackintosh, N. A. 1934. Distribution of the macroplankton in the Antarctic sector of the Antarctic. *'Discovery' Report*, **9**, 65–160.

Marr, J. W. S. 1962. The natural history and geography of the Antarctic krill *Euphausia superba* DANA. *'Discovery' Report*, **32**, 33–464.

Ragulin, A. 1969. Underwater observations of krill. *Trudy Vsesoyuznogo Nauchno-Issledovated 'skogo Instituta Morskogo Rybnogo Khozyaistva i Okeanografii*, **66**, 231–234. [In Russian, MAFF Translation NS92].

Sahrhage, D., Schreiber, W., Steinberg, R. *and* Hempel, G. 1978. Antarctic Expedition 1975/76 of the Federal Republic of Germany. *Archiv für Fischerei Wissenschaft*, **29** (1), 1–96.

Sameoto, D. D., Jaroszynski, L. O. *and* Fraser, W. B. 1977. A multiple opening and closing plankton sampler based on the MOCHNESS and N.I.O. nets. *Journal of the Fisheries Research Board of Canada*, **34**(8), 1230–1235.

Semenov, V. 1969. Aquarium observations on the behaviour of krill. *Trudy Vsesoyuznogo Nauchno-Issledovated 'skogo Instituta Morskogo Rybnogo Khozyaistva i Okeanografii*, **66**, 235–239. [In Russian, MAFF Translation NS93].

TRANTER, D. J. *and* HERON, A. C. 1967. Experiments on filtration in planktonnets. *Australian Journal of Marine and Freshwater Research*, **18**, 89–111.

WIEBE, P. H., BOYD, S. H., DAVIS, D. M. *and* COX, J. L. 1982. Avoidance of towed nets by the Euphausiid *Nematoscelis megalops*. *Fishery Bulletin*, **80** (1), 75–91.

WILLIAMS, R., COLLINS, N. R. *and* CONWAY, D. V. P. 1983. The double LHPR system – A high speed micro- and macro-plankton sampler. *Deep-sea Research*, **30**, 331–342.

WITEK, Z., KALINOWSKI, J., GRELOWSKI, A. *and* WOLNUMIEJSKI, N. 1981. Studies of aggregations of krill *Euphausia superba*. *Meeresforsch*, **28**, 228–243.