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INSTRUMENTS AND METHODS

Improved filtration systems for multiple-serial plankton samplers and their deployment

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Abstract—The sampling characteristics of these instruments can be improved to the extent that simple design criteria are satisfied: *minimal* long axis and mesh pressure, *maximal* flow through the recorder. Two new systems are described which appear to give improved performance and have been used operationally at sea. One is a small system for use on vessels with restricted deck space, the other a larger system fitted with a new recorder box having a very large filtering area and active backward water transport achieved with an impeller system. It is also suggested that studies of vertical biotic structure are better performed with oblique, rather than vertical, LHPR hauls.

INTRODUCTION

SECOND generation multiple-serial plankton recorders, or LHPR's (Longhurst–Hardy Plankton Recorders) as they have come to be called, are the result of the commercial development of stable and reliable electronic circuitry, based on logic entirely different from that of the prototype (LONGHURST, REITH, BOWER and SEIBERT, 1966); using this new circuitry, LHPR deployment on a 5-year ecosystem analysis programme at Ocean Weather Sta. INDIA (59°00′N 19°00′W), in the northeast Atlantic, has been completed with a success rate of 90% over a total of 154 LHPR hauls.

However, relatively little attention has been given to the development of second-generation filtration systems for these new recorders in order to overcome such problems as the hang-up of organisms, known to be inherent in the prototype (LONGHURST, REITH, BOWER and SEIBERT, 1966) and subsequently shown by HAURY (1973) and FASHAM, ANGEL and ROE (1974) to be an important source of error under some circumstances.

It is our purpose in this note to discuss some recent developments in system design, and to suggest some ways of improving the performance of currently deployed LHPRs; although we have no exact information, we believe that rather more than 20 LHPR systems are presently in the hands of planktologists and that these are based on between 5 and 10 different filtration systems, none of which appears to have been rigorously tested.

PERFORMANCE OF LHPR FILTRATION SYSTEMS

It is necessary to assume, in analysing data from an LHPR haul, that the plankton caught on the filtering gauze within the recorder represents, for each step of the gauze, the organisms filtered from the water at the depths, temperatures and flow rates registered by the LHPR during that particular gauze-step, usually of 30- to 120-s duration. This assumption is valid only (i) if the time taken for the filtered organisms to pass from the mouth of the net on to the filtering gauze is short in relation to the selected stepping period, and (ii) if some of the organisms which enter the mouth do not hang-up on the conical net, later to pass singly or clumped to the filtering gauze. HAURY (1973) has examined these processes experimentally with a vertically-hauled LHPR of a design likely to maximize them: that is, it had a low mesh aperture/mouth area ratio (Table 1), a longitudinal axis of relatively large dimension and a constricted flow through the recorder. Predictably, he was able to demonstrate that residence time of organisms within the net was related to towing speed and to the nature of the

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Table 1. Dimensions of prototype LHPR, the derivatives of it by Wiebe, Haury and Fasham, Angel and Roe (discussed in the text), and the two new designs. Area ratios assume 100% filtration efficiency; actual ratios will depend on mesh used and will usually be based on factors around 0.45 to 0.55 for mesh aperture/mesh area ratios. Figures in parentheses are estimates.

	Prototype	*Wiebe*	*Haury*	*Fasham*	*IMER*	*NMFS*
Reduction cone (m^2)	–	–	–	–	–	0.18
Mouth of net (m^2)	0.50 □	0.41	0.78	1.00 □	0.20	0.25
Area of net (m^2)	5.25	(5.70)	4.70	5.50	0.80	1.94
Ratio net/mouth areas	10.50	13.90	6.00	5.50	4.00	10.80
Length mouth to sampler (m)	3.50	(5.50)	3.00	2.74	1.20	3.00
Recorder filtration area (cm^2)	103.00	103.00	103.00	200.00	120.00	325.00
Net mouth/recorder filtration	48.50	39.80	75.70	50.00	16.70	5.50
Sampling periods (sec)	30–60	15	*	60	+	+
Vertical, horizontal, oblique	O	H	V	H	O	O

* = continuous drive

□ = square mouth

\+ = option of 30, 60 and 120 sec.

filtered particles. We also expect that differential clogging of the mesh aperture of the conical net and filtering gauze would affect residence time, but this was not demonstrated.

HAURY (1973) suggested that three processes interact to produce the delays he observed in his experimental system: (i) the stalling of a particle in a von Kármán vortex street within the conical net, (ii) the temporary hang-up of a particle in its meshes by partial extrusion, and (iii) the stalling of particles at the entrance tube of the recorder because of a restriction of flow through its water tunnel.

It is difficult to estimate how important these processes are in an operational LHPR; that they occur to some degree is certain, and great care has to be exercised in critical examination of the instrument for stalled or hung-up organisms when it is recovered. It is our normal practice to abandon samples from tows in which this has occurred importantly, making our decisions in each case by comparing the residual quantity of plankton on the posterior part of the net and in the water tunnel with the amounts comprising the blocks of plankton taken on the filtering gauze during each sampling interval. It is our experience that the stalling of organisms in the back end of the net, just in front of the recorder, is by far the most common problem; in the prototype instrument this could usually be prevented by adjusting the ship and winch speeds in order to maintain vehicle speed through the water approximately constant under a variety of weather and sea conditions. It is also our normal practice to examine our data very carefully for indications of entrainment of surface organisms to deep samples, or *vice versa*; it is sometimes also possible to confirm that sampling had occurred unsatisfactorily during a haul by the anomalous occurrence of organisms known to be restricted to relatively narrow strata.

The prototype filtration system, as deployed in EASTROPAC, was designed to minimize the stalling and hang-up that was expected to occur; to some extent the problems encountered by others are the result of their changes from the prototype design. FASHAM, ANGEL and ROE (1974) experienced serious hang-up in bags which formed in front of transverse net-seams in their LHPR: the prototype had no such seams, the net was cut slightly concave-sided to avoid bagging and was tensioned backwards. The recorder used by Haury had a low ratio of gauze aperture area to recorder mouth area of about 0.70 even in the unclogged condition: in the prototype recorder, in clean condition, this ratio was 0.94 to 0.98 depending on the gauze used.

DESIGN STRATEGY FOR IMPROVED PERFORMANCE

The inferences to be drawn from these experiences are fairly clear: an LHPR will be most efficient (that is, there will be least delay between capture at the mouth of the vehicle and entrap-

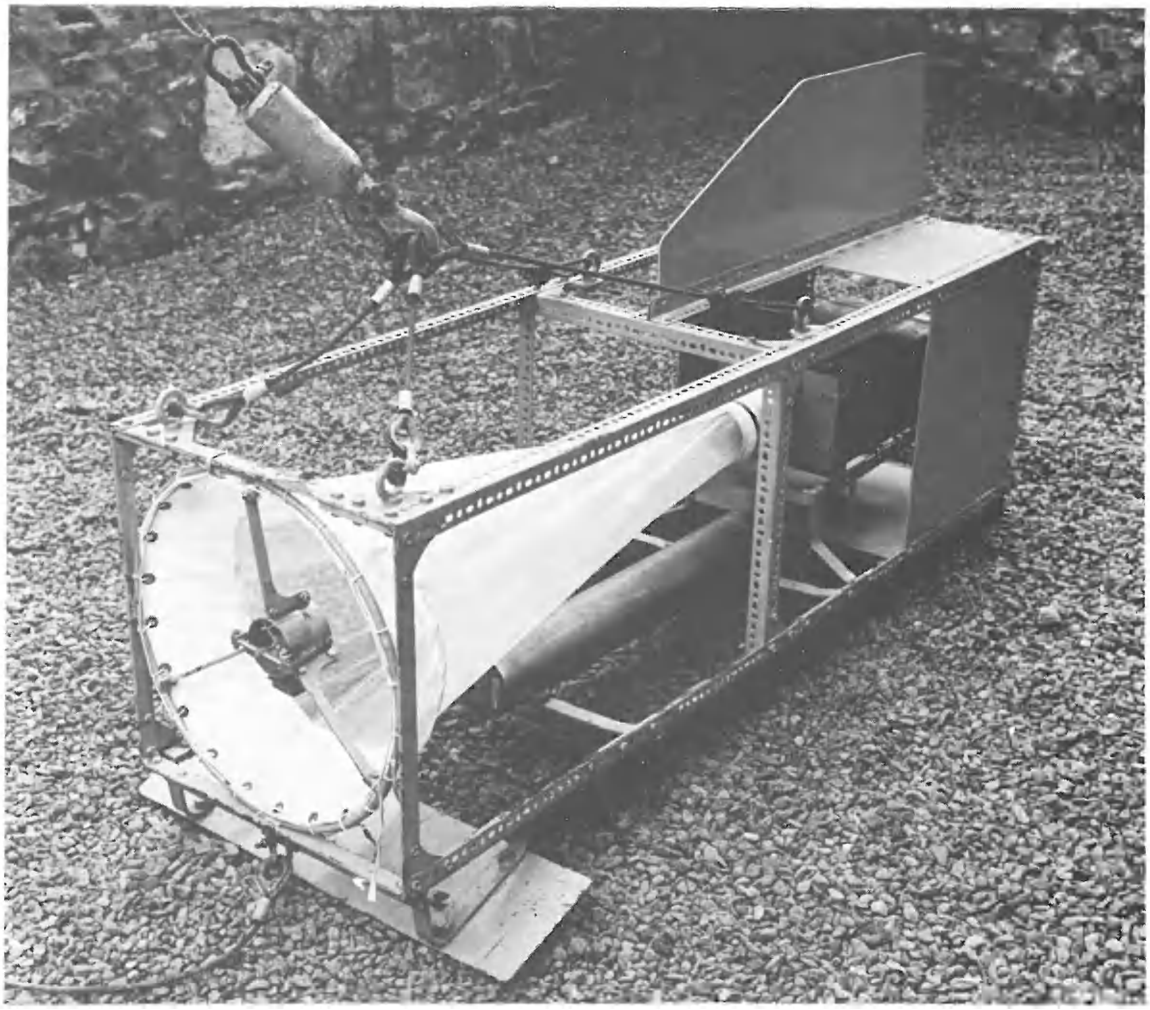

Fig. 1. IMER system showing the arrangement of the recorder box, electronic control unit and the recording flowmeter.

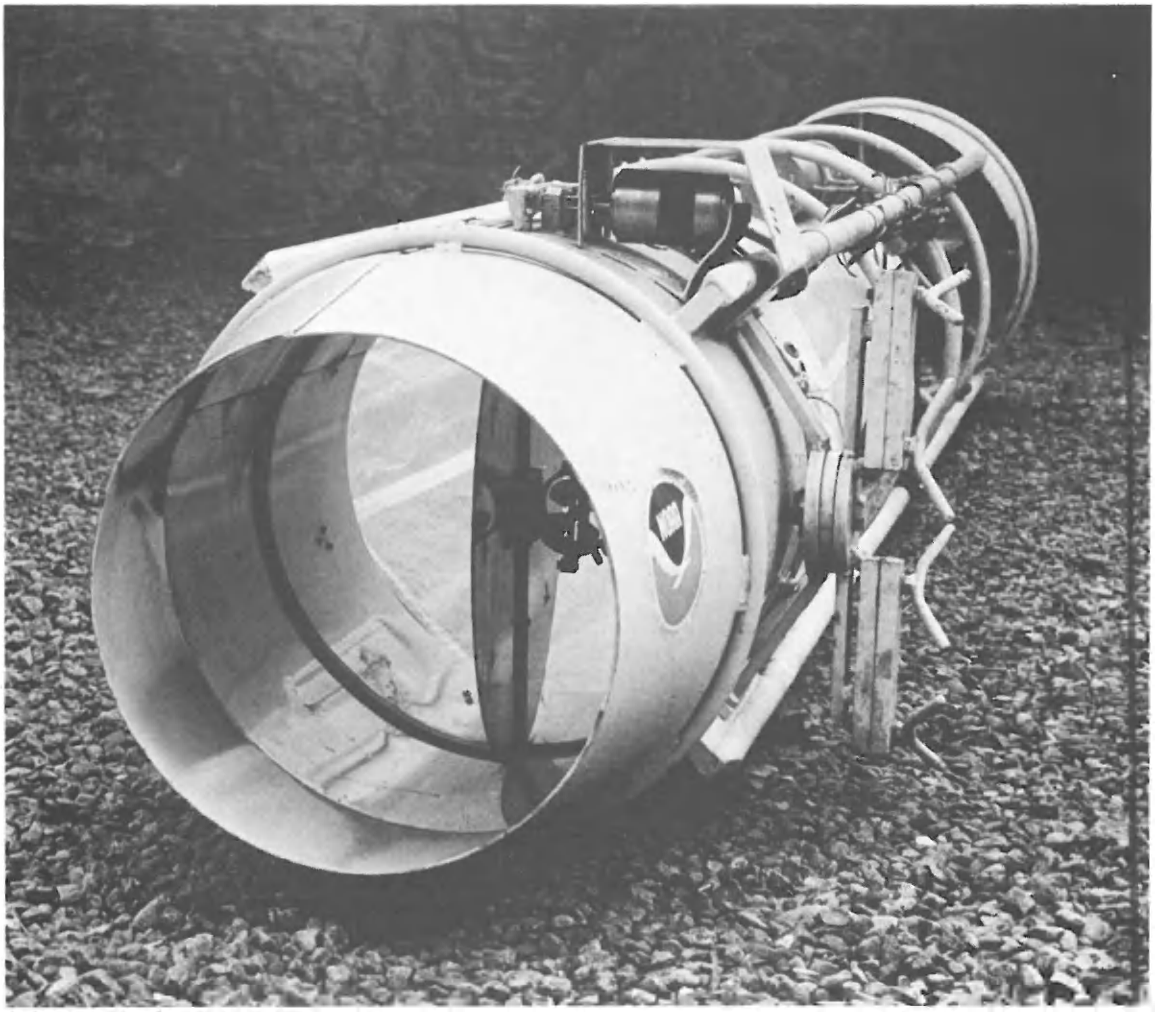

Fig. 3(a). Arrangement of front end of NMFS vehicle showing solenoid lock, hinged door in open position, flowmeter and universal cable clamp.

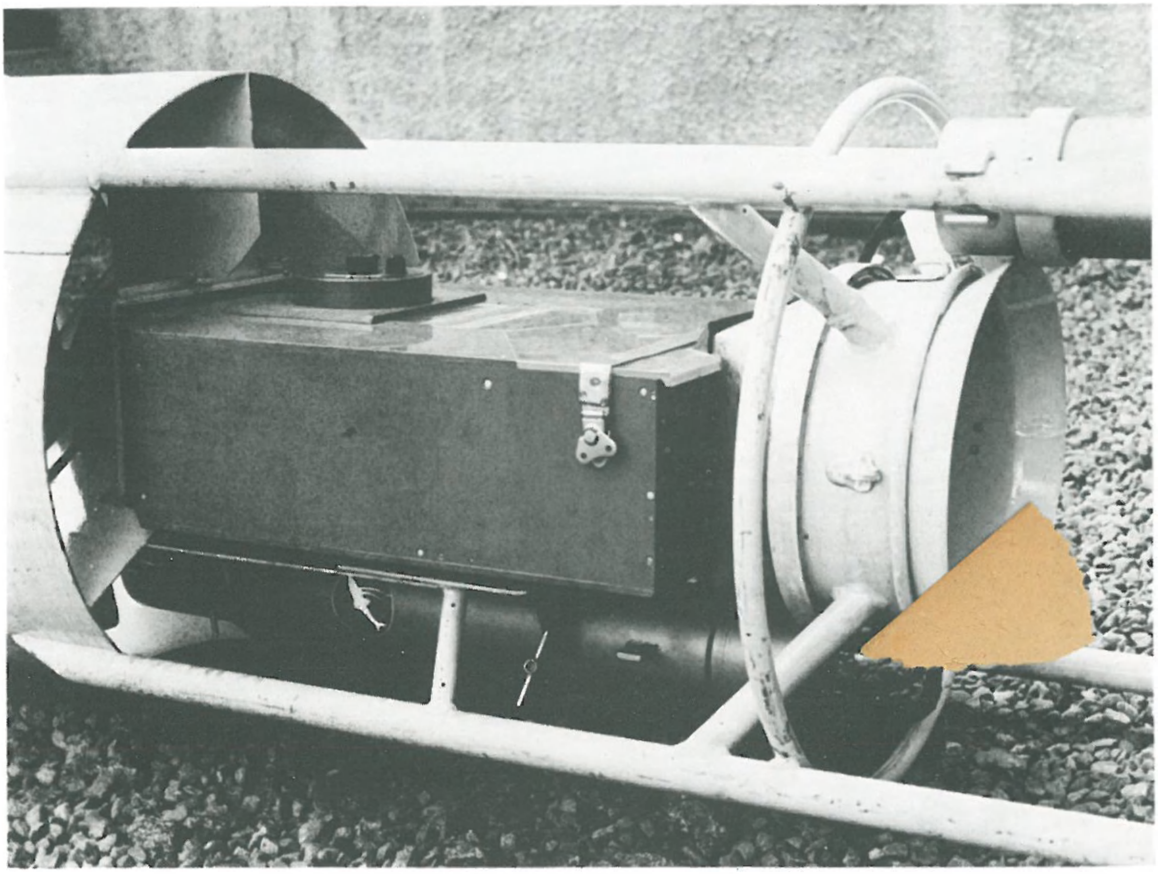

Fig. 3(b). Arrangement of recorder box and electronic control unit on NMFS vehicle.

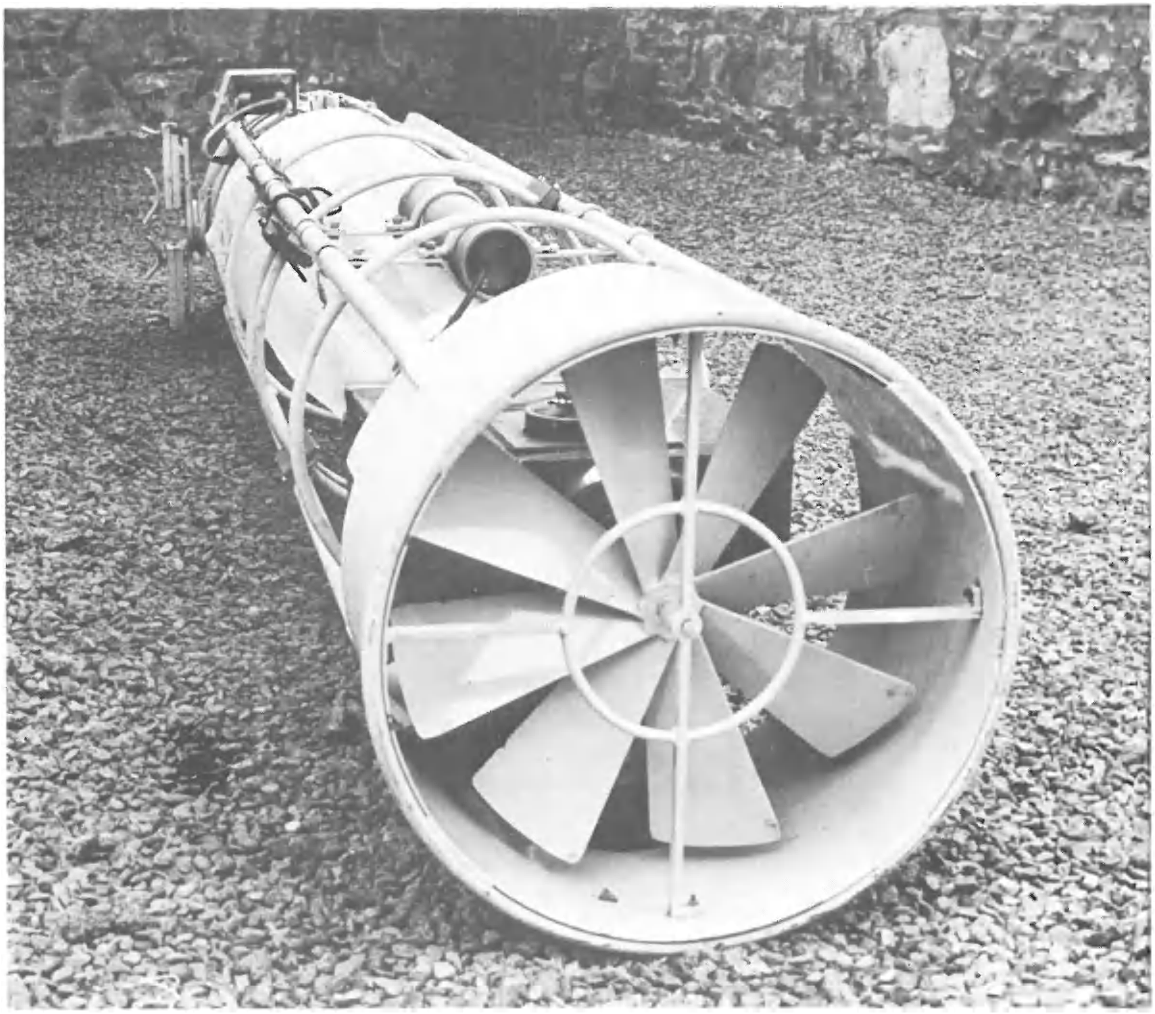

Fig. 3(c). Tail unit of NMFS system with turbine blades driving water impeller in channel connected to channel of recorder box.

ment in the recorder) when the following conditions apply:

(i) the distance from the mouth of the vehicle to the recorder is *minimal*;

(ii) the mesh pressure on the filtering section of the conical net is *minimal*;

(iii) the flow rate through the recorder is *maximal*.

These conditions may be met only when a suitably-designed filtration system is towed through the water at a velocity matched to the design, and modified according to local mesh-clogging conditions caused by phytoplankton.

We have designed and used two new LHPR systems which attempt to satisfy these criteria. The first is a small system (here referred to as the IMER* system) which attempts a very simple solution to the problems for use in special conditions, while the second is a larger system (here referred to as the NMFS† system) based on a more complex design than previous systems. Both are designed for oblique or horizontal sampling trajectories, and both employ the now widely-accepted principle that there shall be no bridles or other encumbrances in front of the mouth.

The IMER system

This LHPR (Fig. 1) was designed for use in the restricted deck-space aboard a British Ocean Weather Ship, and for this reason its overall length was constrained to less than 2 m.

It is carried to depth by a 25 kg weight suspended 4 m below the frame, the bridles being so arranged (Fig. 1) that when hung vertically with no forward motion the vehicle is held in a horizontal position. Diving is assisted by an inclined plane and the vehicle is fitted with a relatively very large box-tail section to assist it to maintain a proper angle of attack during towing. Confirmation that it does, in fact, orient itself parallel with the direction of flow was obtained alongside a vessel at low speeds at sea.

Construction of the vehicle is of painted Dexion®, mild steel and sheet aluminium alloy as appropriate throughout. Using a standard recorder and electronics from Benthos Inc.®, the filtration area in the sampler is more than twice as large in relation to the mouth area—and therefore to the rate of particle capture—than all other LHPRs except the NMFS system (Table 1). This fact, together with the very short net (in which a direct trajectory between mouth and sampler should not take longer than about one second for an unimpeded particle) is probably responsible for its apparently good performance, both on our northeast Atlantic weather ship programme and on studies of the vertical distribution of fish larvae over the British continental shelf at this Institute; performance, in this case, is judged by the relatively very small amounts of plankton normally hung-up on the net or found in the water tunnel and by the clear separation of blocks of plankton on the filtering gauze. Similar samplers have now been employed by the Aberdeen Laboratory of the Department of Agriculture and Fisheries for Scotland, and at Bergen University.

The NMFS system

This LHPR (Figs. 2, 3a, b and c), free of any size constraint, was specifically designed to meet the criteria outlined above and to include some operational capabilities not possible in the prototype; constructed of aluminium alloy, it is fitted with a specially designed recorder which is operated by modified Benthos® motor drive and electronic units. Because we use a one metre V-fin depressor to minimize the length of wire required to reach a desired depth, this LHPR is mounted on a lateral wire clamp fitted with a universal joint. A door at the mouth of the vehicle is opened by a solenoid/elastic shock-cord system coupled to a 0 to 60 min timer; the electronic sensing and programming package is simultaneously switched on, and the recorder begins to function, as the door is opened after a pre-set delay. This allows the system to be switched on at a pre-selected depth before an oblique haul to the surface so that no potential sampling time on the gauze is used during the descent; this facility thus allows for very deep hauls to be made, limited only by the pressure cases of the electronic packages, and makes it impossible for any

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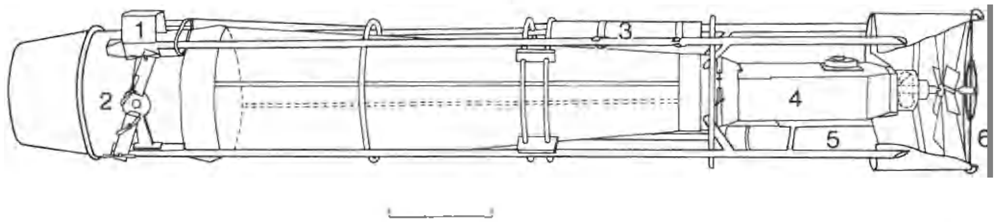

Fig. 2. General arrangement of the NMFS system with the tail unit partially cut away to show water impeller. Numbers refer to the following components: 1—solenoid lock; 2—universal cable clamp; 3—power pack for activation of solenoid lock and electronic control unit; 4—recorder box; 5—electronic control unit; 6—small active impeller in water tunnel, gearbox, and passive 8-bladed turbine fan. (Scale bar—50 cm.)

organisms taken in the net during the rapid descent, when the net is not expected to be delivering plankton to the recorder box properly, to be recorded on the way up.

Using principles investigated by TRANTER and HERON (1967), a reduction cone on the mouth of an almost parallel-sided tubular net is used to reduce mesh pressure and consequent hang-up of organisms by partial extrusion. Observation of the NMFS system running at the surface shows the net to be flaccid and undulating, suggesting that this design strategem has been successful. The tubular form of the net was selected to minimize the long axis while maintaining the mesh area as large as possible to reduce mesh-pressure. The original version of this design had a net of 3.25 m long, which has been reduced, apparently without affecting the turgidity of the net, to 2.5 m in the present version. We do not believe it would be profitable to reduce it further, though this would be possible and might be proper in conditions where no clogging was anticipated.

In order to clear the water contained in the back end of the tubular net, which is attached to the sampler box by a short non-filtering cone, flow through the sampler is increased in three ways: (i) the filtering area of the stepping gauze has been increased three-fold, (ii) the ratio filtering area/mouth area is nine times greater than in the prototype sampler and 14 times greater than in Haury's sampler, and (iii) water is sucked through the water channel of the sampler by an active impeller system mounted in the tail of the vehicle.

The increase in filtration area is simply accomplished by altering the dimensions of the sampler box, and by fitting a more powerful electric drive motor than is standard; it seems probable that continued development in this direction will be constrained primarily by the cost of the increased width of the filtering gauze, and only secondarily by vehicle limitations. The larger the area of filtering gauze at each step, the better. A small impeller (an out-board motor propeller) is mounted in the tail of the vehicle in an extension of the recorder water channel (Figs. 2 and 3c) and is driven—through a 1:7 reduction gearbox—by the action of a much larger 8-bladed turbine fan, itself driven by the forward motion of the vehicle. This system achieves active transport backwards through the recorder and is designed to clear the dead space in front of the recorder mouth.

The NMFS LHPR system has been used at sea in the California Current and in the North Atlantic under a variety of conditions and has proved to give very clean blocks of plankton on the filtering gauze and negligible net-clogging in front of the sampler box.

Each of these new vehicles uses a smaller mouth area than the prototype and than is usual for a normal integrating plankton net. Increase in this dimension in order to achieve larger sample volumes can be balanced by relative increases in most other dimensions up to any reasonable value; only the length of the long axis of the net is important in an absolute sense, and we are not sure what the performance of a larger version would be.

It might be thought that any new design should be subjected to rigorous assessment of its filtration characteristics before it is used; it might also be thought, as HAURY (1973) seems to imply, that the quantification of relative net residence times for various categories of plankters, under different conditions of phytoplankton clogging and towing speeds, was a prior requirement before using an LHPR for ecological investigations. On the contrary, we think that this would be an unrealistic approach, which would ignore the great diversity of form and behaviour of zooplankton, the rapid changes in filtration performance of conical filtering nets in the presence of phytoplankton blooms (SMITH, COUNTS and CLUTTER, 1968) and the occurrence of sub-surface currents which make accurate control of vehicle speed through the water very difficult. Only in a research project requiring repeated, sequential sampling at a single station where only minor changes were expected to occur in the kind of biota present, might such a testing programme be useful: even then it would have to be done at sea, rather than in an experimental flume. In fact, we think it might give a false sense of security to have available for a particular design, that subsequently came to be used under a wide range of environmental and operating conditions, an initial set of performance data supported by statistical analysis.

For these reasons, we have not quantified the flow and attitude characteristics of our equipment beyond, in the case of the NMFS net, using a set of telemetering flow-meters to calibrate system flow meters *in situ* and to determine optimal towing speeds in the unclogged condition.

DEPLOYMENT IN PRODUCTION STUDIES

Even LHPR systems whose design satisfies the criteria discussed above can obtain precise data only if they are deployed in a rational manner. We think that the most important task to which LHPRs can properly be applied is the ecology of the upper few hundred metres of the ocean, where the biota directly concerned with production processes occur. In such studies, emphasis will inevitably be on the vertical rather than the horizontal component of plankton variability, for it is in this plane that the important environmental and biotic gradients lie. HAURY's attempt (1973) to sample in the vertical plane to investigate these gradients was, it seems to us, the wrong solution to this sampling problem.

Clearly, even an LHPR of ideal design with a zero plankton residence time, has a minimum distance of discrimination along its axis of travel: at about 100 cm s^{-1}, and at the most usual filtering period and gauze length, this would be of the order of 30 m, along a path of approximately 2.0 to 2.5 km. Such sampling parameters are not, of course, ideal for the study of production processes along a vertical path: the depth achievable is greater than is desirable and the vertical discrimination is too coarse. On the other hand, oblique hauls from, say, 200 or 500 m will achieve vertical discrimination of about 3 and 10 m, respectively, which is about what is usually thought to be useful. This principle can, of course, be extended to even finer discrimination from even shallower hauls, and is a more realistic solution than one which depends upon shortening the sampling period and hauling vertically.

An oblique haul has the added advantage that it integrates horizontal variability; as is well known, and as WIEBE (1970) and FASHAM, ANGEL and ROE (1974) have used LHPRs to study, horizontal patchiness occurs on the scale of tens to hundreds of metres, and presumably outside this range as well. We do not think that these aggregations, whether behaviouristic or caused by fluid motion, are fundamentally as important in production processes as the vertical aggregation of biota in association with different values along the vertical gradients of physical, chemical and biological variables; only in shallow shelf seas is this perhaps not true. It therefore seems to us a bonus that an oblique haul with an LHPR, designed to achieve adequate vertical discrimination, should also to some extent integrate horizontal patchiness, and so remove some of the variability which would otherwise occur between vertical hauls.

Data obtained by WIEBE (1972) appear to confirm that this occurs in an oblique haul; comparing long (2000 m horizontal) and short (500 m) oblique hauls from 100 m to the surface he found that for the more common species the longer tows—and therefore those with the less steep oblique profiles—had the greater precision: in fact, a 0.25 m^2 net had greater precision when hauled on the less steep profile than did a 1.0 m^2 net on the steeper oblique. Even more importantly, this is a rare case in which the smaller of two experimental filtered volumes yielded the more precise samples; this confirms earlier theoretical studies (WIEBE, 1971) of the relative effects of tow length and filtered volume on sample precision, and supports our oblique haul strategy for studying vertical gradients and stratification.

While there is no doubt that the small mouth area of currently-used LHPRs will increase avoidance (MCGOWAN and FRAUNDORF, 1966) so that organisms capable of rapid 'jumps' will be undersampled and diversity decreased, the relatively very small individual volumes filtered (range approximately 10 to 20 m^3 for our two systems) at each sampling step cannot be assessed in the light of previous investigations of the effect of filtered volume on sample precision through the mediation of non-random spatial distributions of biota.

WIEBE and HOLLAND (1968) analyse the confidence limits of single samples on the basis of 13 published studies of plankton net sampling characteristics, showing that 95% confidence limits commonly exceed half to double the observed value, and that larger filtered volumes yield smaller variability: however, all these samples are of comparatively large volumes taken along long horizontal, oblique and vertical trajectories, relative to the individual LHPR samples, and unlike a typical LHPR sample they must integrate into a single sample in the cod-end of the net many biota which would never otherwise meet. The precision studied, then, in the past has almost always been of completely artificial species assemblages. We have been unable to study the precision attained by the individual LHPR sample, which is typically of a more real biotic community of very much lower diversity than taken with open nets; this could be done with a pair of matched samplers in a single frame, perhaps. At present, it is only possible to say on the basis of profiles such as that shown in Fig. 4 that where biotic gradients do not occur the

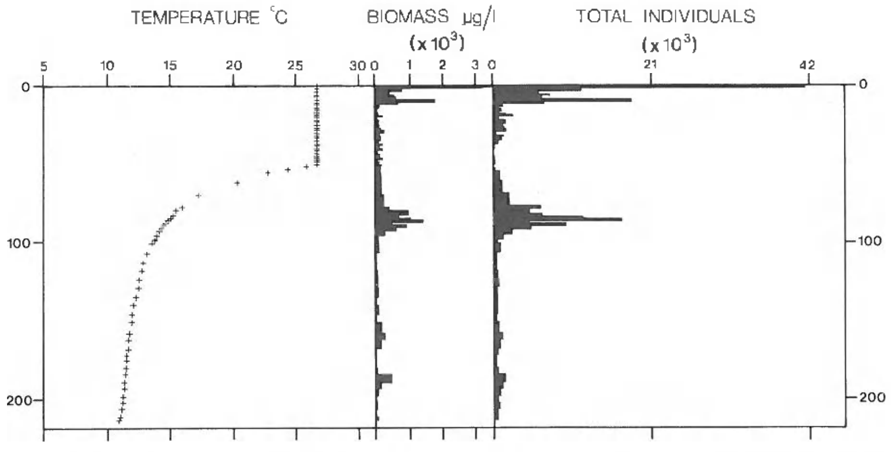

Fig. 4. Profiles of temperature, biomass and total numbers of plankton organisms to demonstrate the kind of data derived from a typical shallow oblique haul, in this case of 34-min duration; this is a low latitude station in the eastern tropical Pacific Ocean (09°40′N 112°02′W, noon, 25 March 1968).

variability between adjacent samples is relatively low, and that where adjacent samples do not quantitatively resemble each other this can be interpreted as reflecting a biotic gradient [e.g. WIEBE (1970) and this paper, Fig. 4]. We have found that even in relatively oligotrophic oceanic conditions LHPRs, with the sampling characteristics described here, give samples which we can accept for quantitative studies because of the above considerations and we have not so far found it necessary to resort to larger systems which we suggest could be feasible.

If, for some reason, it is essential to sample truly in the vertical plane, at a fine level of discrimination, then we suggest that a winched pumping system (e.g. BEERS, STEWART and STRICKLAND, 1967) would be appropriate. Similarly, if very fine discrimination in the horizontal plane is required, then a towed pumping system (e.g. O'CONNELL and LEONG, 1963) would be indicated.

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