452

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CONTENTS

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ABSTRACT

The construction, operation and performance of a towed pump and shipboard filtering system for sampling small zooplankters is described. The system is composed of (1) a collector containing a pump towed by a suspension unit consisting of a hose through which runs a steel cable for support and an electric line to power the pump, (2) a winch, and (3) a filtering unit composed of a watermeter, a double-throw valve and two filtering funnels. The towed collector and its electrically driven pump operate satisfactorily to a depth of 5 or 6 meters at a vessel speed of 9 knots. The winch is inadequate for the task it is meant to perform, but demonstrates that it is practical to use a winch with a hose and cable suspension. The filtering unit, easily operated by one man, is highly satisfactory. Discrete samples can be taken at intervals of a few minutes while traveling at vessel cruising speed by using the two funnels alternately. Special samples and tests indicate that errors due to escapement and entrapment of zooplankters and to mixing of zooplankters between consecutive samples are negligible. It is concluded that the towed pump and shipboard filtering system is a practical sampling tool that needs further modification for the full utilization of its capabilities.

INTRODUCTION

In 1958 the Bureau of Commercial Fisheries Biological Laboratory, La Jolla, California, initiated a study of the relation between the behavior of the Pacific sardine *(Sardinops caerulea)* and the density distribution of its planktonic food. The first phase of the program was largely devoted to the development of a towed pump and shipboard filtering unit for quantitative sampling of the small zooplankters that constitute the bulk of the sardine's diet. Sampling surveys were carried out with this apparatus in the fall of 1961 by the Bureau of Commercial Fisheries research vessel *Black Douglas*. The apparatus will be described and evaluated in this report, and the results of the 1961 surveys will be presented in later reports as the samples are processed.

A study of the density distribution of sardine food organisms requires that the smallest possible zooplankters be collected quantitatively. Hand and Berner (1959) found that small copepods supplied, on the average, 74 percent of the total organic matter in the stomach contents of sardines and that all crustaceans supplied nearly 89 percent. The size range of small copepods is not explicitly stated, but it may be surmised from the data in the above report that the small category includes organisms up to about 1 mm. in length. To collect organisms of the size indicated, filtering screens with mesh openings of 100 microns (μ) or perhaps even less must be used.

The study also requires that estimates of known precision be obtainable for areas as small as 20 square miles or as large as several hundred square miles. This can be accomplished efficiently by subsampling, i.e., taking several small, discrete samples within the specified area, while the vessel is traveling at cruising speed.

The study further requires that areal estimates be made for more than one depth or that they represent some vertical range. To accomplish this the sampling instrument must be capable of collecting samples over some range of depth rather than at a single depth.

A towed pump and shipboard filtering unit appeared to offer the best possibility of satisfying these requirements. Filtering rate and filtering efficiency can be independent of filter mesh size, and they can be directly measured. With the proper mechanical arrangement, discrete samples representing very short segments of the vessel track can be taken at vessel cruising speed. If the pump is suspended at the end of a hose it can be lowered to different depths.

Although self-contained high speed samplers such as the Isaacs high speed sampler (Ahlstrom, Isaacs, Thrailkill, and Kidd, 1958), the Gulf III sampler (Gehringer, 1952), and the Hardy plankton recorder (Hardy, 1939) can be towed at different levels, they do not adequately retain zooplankters less than 1 mm. in length. Filtering screens with meshes fine enough to collect these smaller organisms would adversely effect filtering rate and filtering efficiency by intensifying clogging. The Isaacs sampler and the Gulf III sampler, furthermore, are unsuitable for the collection of short interval samples because they must be retrieved and serviced to terminate each sample. The Hardy recorder does resolve a continuous strip collection into an intergrade series of small samples, but there is a practical limit to how small these samples can be and it is necessary to make assumptions about filtering rate and filtering efficiency.

Other workers have resorted to pumps for plankton sampling from time to time, because this seemed to be the best way to collect numerous small samples in time and/or space to study the variability of plankton density. Aron (1958) lists 17 investigators in addition to himself who have used pumps to collect plankton. Cassie (1959) has also made extensive use of a pump to collect plankton. However, none of the systems used by these investigators would have fulfilled the requirements outlined above. Although several of them have been used to sample from various and considerable depths, this was possible only from vessels that were drifting or moving very slowly. Collier (1957) is the only investigator listed by Aron who sampled with a pump while traveling at vessel cruising speed. He achieved this by using an inboard pump with the intake protruding through the hull of the vessel, an arrangement that offers no potential for sampling at different depths.

The towed pump and shipboard filtering unit described in this report was designed to retain zooplankters, particularly crustaceans, as small as 100 or 200 μ in length and to take samples that would be discrete for time intervals as short as a few minutes. It was designed also with the potential for collecting over some vertical range, though no attempt has yet been made to realize this capability.

DESCRIPTION

The entire system is shown schematically in figure 1 as it is installed on the *Black Douglas*. It is composed of (1) a collector containing a pump and motor towed by a suspension unit consisting of a hose through which runs a steel cable for support and an electric line to power the pump, (2) a winch and auxiliary guide wheel, and (3) a shipboard filtering unit. The towed hose is a 150-foot length of 2-inch internal diameter (I.D.) single-jacket firehose.

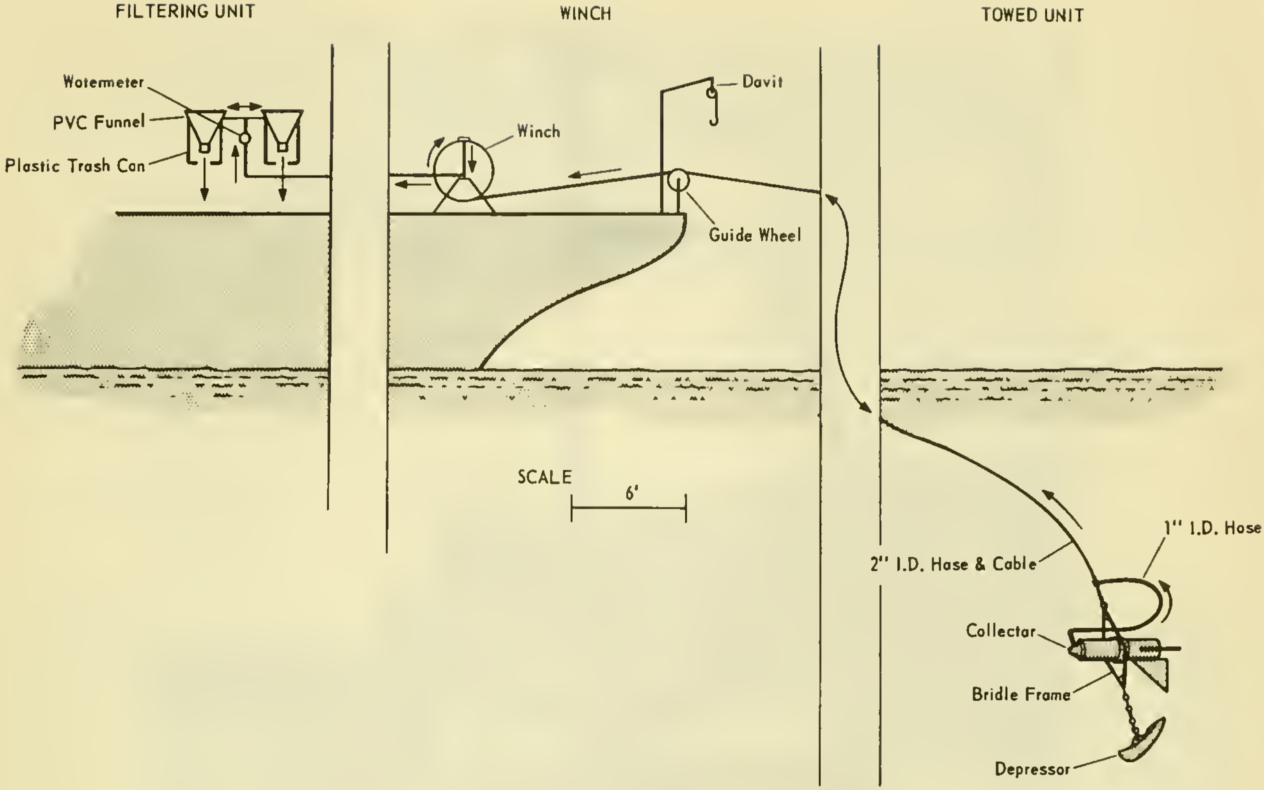

Figure 1.--Schematic drawing of the towed pump and shipboard filtering unit as it is installed on the research vessel *Black Douglas*. The arrows indicate the path of water through the system. From the funnels it flows through drainpipes to the scuppers of the vessel. The collector is drawn larger than scale size.

Both the support cable (1/4-inch stainless steel aircraft cord) and the powerline (#14, 3-conductor, type S.O. neoprene cord) run unattached inside the hose. All three elements extend from a lower terminal connected to the bridle in which the collector is mounted to an upper terminal on the winch. Approximately 100 feet of hose is beyond the guidewheel when the system is set for towing.

The winch is about 10 feet forward of the fantail, and the filtering unit is about 60 feet forward of the winch. They are connected by a 70-foot length of 1 1/2-inch I.D. thick-walled polyethylene hose. The filtering funnel inlets, about 11 feet above sea level, are the highest points in the system. The swinging davit with block and tackle, located just inboard of the guidewheel, is used to set and retrieve the collector.

A detailed description of the system follows.

The Collector

Figure 2 is a photograph of the collector mounted in the bridle and connected to the lower terminal assembly of the hose-cable suspension. The collector is secured in a heavy, steel ring clamp with a pin on each side. The pins project through holes in vertical plates welded to the inside of the rigid diamond-shaped bridle and function as an axle. The bridle is suspended from a connecting rod projecting from the bottom of the hose-cable terminal assembly, and a 43-pound homogeneous depressor (California, State of, Marine Research Committee, 1950) is in turn suspended from the bottom of the bridle on a short length of chain. The pump outlet is coupled to the terminal assembly by a trailing loop of 1-inch I.D. thick-walled rubber hose. The powerline for the electric motor also forms a loop between the collector and the point where it enters the hose-cable terminal assembly. Though not visible in the photograph,

Figure 2.--The collector mounted in the diamond-shaped bridle with the hose-cable terminal assembly above and the depressor below.

there is a Joy plug in the powerline about halfway between the collector and the terminal assembly so that the powerline can be disconnected at this point. The trailing loop of powerline is taped securely to the 1-inch I.D. hose before the collector is set for towing.

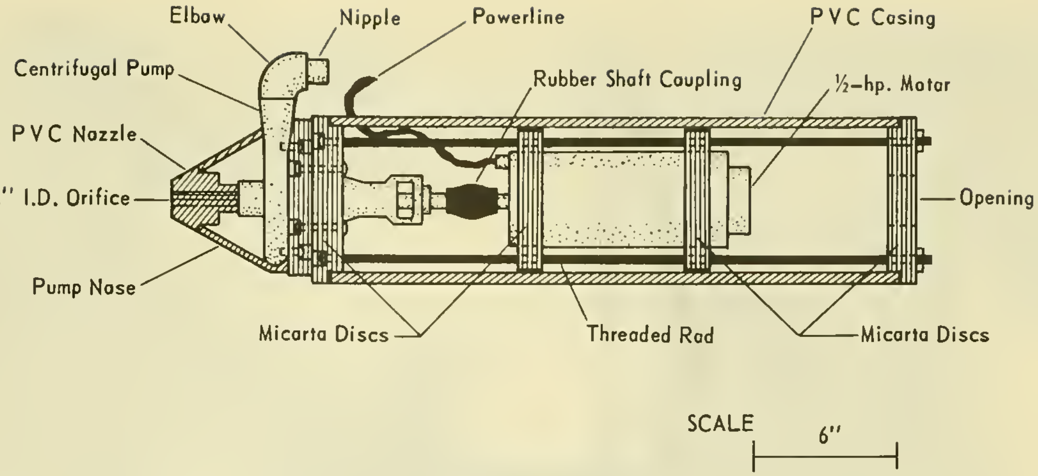

Figure 3.--Schematic drawing of the collector with the outer casing cut away.

Construction details of the collector are shown in figure 3. The outer casing is a 24-inch length of 6-inch I.D. polyvinyl chloride (PVC) tubing slotted on top at the front edge to admit the powerline for the motor. A 1/2-inch bronze centrifugal pump (1/2-inch discharge, 3/4-inch suction) is bolted to a micarta (1-inch linen phenolic sheet) disc that fits in the front opening of the PVC casing. The impeller in this pump is the semi-open type, which, according to specifications, permits pumping a percentage of solids. A capacitor starting, 1/2-horsepower (hp.) A.C. motor (3,450 r.p.m.) is friction mounted in two micarta discs that slide easily into the casing. The motor is an hermatically sealed, water-cooled unit. The pump and motor shafts are connected by a flexible rubber coupling and the entire pump-motor assembly is rigidly aligned by four 3/8-inch threaded rods through the micarta discs. The assembly is secured in the casing by tightening another micarta disc against the back edge with a nut on each of the threaded rods. To insure proper cooling of the motor there are a few small slots at the forward edge of the casing and also on the outer edges of the motor mounting discs. The disc against the back edge of the casing has a large central opening.

The conical nose of the collector is composed of a truncated aluminum funnel held against the face of the pump mounting disc by a specially machined PVC nozzle screwed into the axial intake of the pump. The funnel is strengthened by a coating of fiberglas and has one small hole to admit water so that it will not collapse under external hydrostatic pressure. The back edge of the funnel is cut away on one side to accommodate the outlet of the pump. A street elbow brazed to the outlet contains a "close" pipe nipple to which the end of the 1-inch I.D. delivery hose is coupled.

The one vertical and two horizontal stabilizers, which are not shown in the drawing of the collector, are made of 1/32-inch sheet stainless steel.

The lower hose-cable terminal assembly (fig. 4), which serves to bring water, electrical and support elements together inside the 2-inch I.D. hose, is made of standard galvanized pipe fittings. The hose couplings are secured in the ends of the hoses with heavy-duty hose clamps. The heavy steel rod to which the cable is connected by a swivel and shackle was specially formed and welded through the center of the pipe plug at the bottom of the assembly.

The hose and powerline are a few feet longer than the support cable to insure that the latter bears the entire load of the towed unit. The strain exerted by the towed unit should be approximately 800 pounds, the downward force that the depressor is designed to

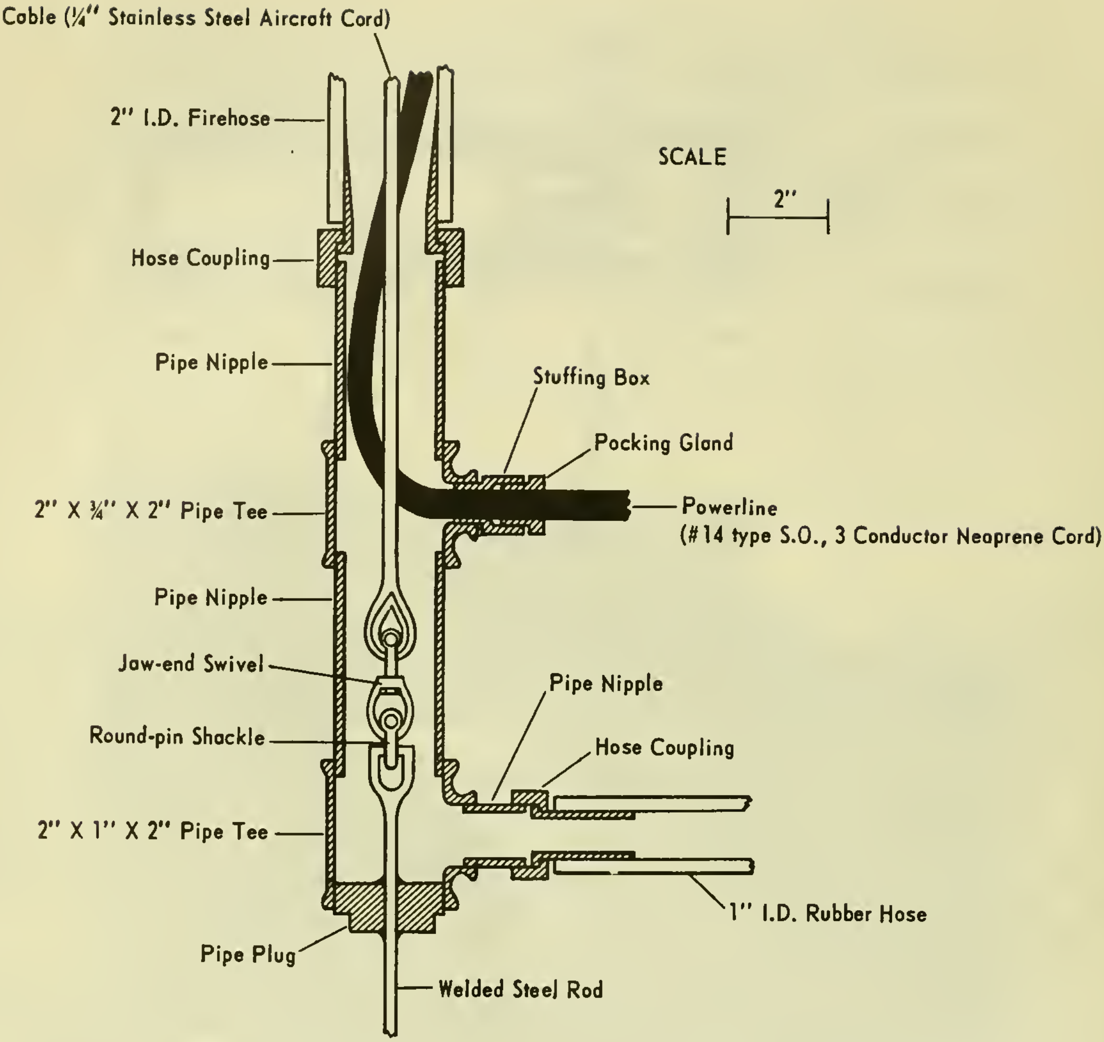

Figure 4.--Schematic drawing of the lower hose-cable terminal assembly. Pipe threads are not indicated.

produce at a speed of 10 knots. The support system has an ample safety factor for this load. The average ultimate breaking strength is 6,000 pounds for the cable and 8,000 pounds for the shackles and the swivels. The recommended safe working load is about 1,600 pounds for all three.

The upper half of the support cable is encased in viny tubing to prevent the inner surface of the hose from being damaged where it rides on the guidewheel when set for towing.

The Winch

The winch (fig. 5) is a steel drum 3 feet in diameter and 4 feet in length with a 1/2-inch I.D. pipe axle supported at each end by a channel iron stand. The base of the stand is bolted through the deck of the vessel. The hose is spooled onto the lower surface of the drum to minimize strain on the deck bolts, and its upper end is connected to a 2-inch plumber's pipe cross mounted near one edge of the drum.

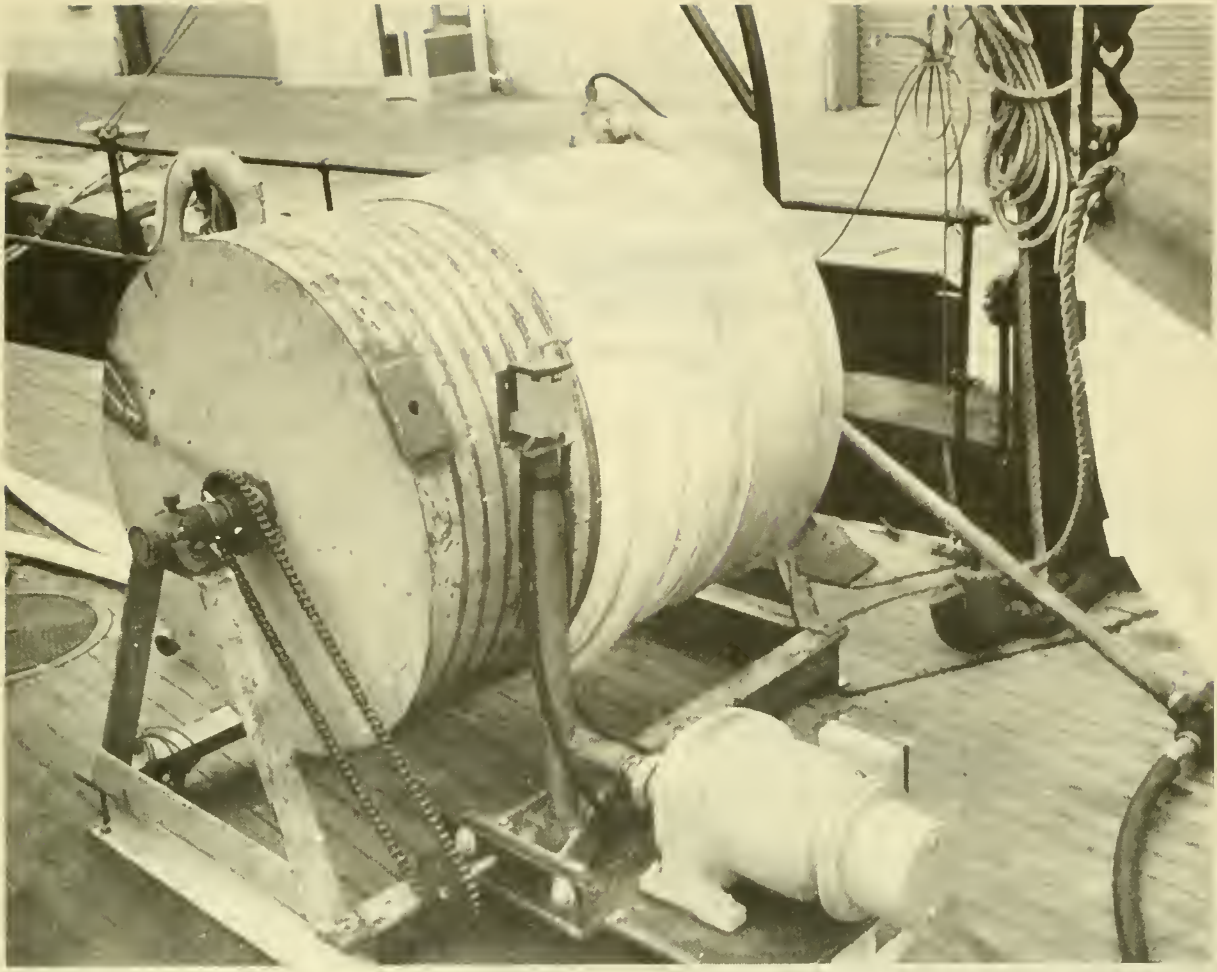

Figure 5.--The winch, showing the plumber's cross and axle delivery and the power drive for the drum.

The plumber's cross (fig. 6) is the upper hose-cable terminal assembly where electrical and support elements are separated from the water. The hose is secured to a close nipple in one horizontal opening of the cross with a standard hose coupling, while the cable is shackled to a ring welded to a pipe plug in the opposite opening. A close nipple in the bottom opening extends through a hole in the surface of the drum. A 2-inch to 1 1/2-inch bell reducer tightened on the nipple against a broad washer facing the underside of the drum surface holds the plumber's cross rigidly in place. A 1 1/2-inch pipe extends from the reducer to a union projecting from an opening in the axle of the drum. The end plate of the drum is set back 6 inches from the edge of the cylinder so that the reducer and connecting pipe are on the outside. The axle is plugged immediately behind the point where the radial pipe joins it so that water flowing from the plumber's cross is forced towards the outer end of the axle. A right-angle 1 1/2-inch swivel coupling turned onto the end of the axle allows the axle to rotate without turning the pipe screwed into the other opening of the swivel coupling. The hose leading to the filtering unit is clampled to this pipe.

The powerline, which passes out of the plumber's cross through a packing gland and stuffing box in the top opening, is connected with a watertight electrical coupling to another line that is bent sharply towards the axle and secured to the radial pipe between the bell reducer and the axle. Free cable beyond this point is spooled onto the axle as the drum is rotated to let the hose out, and reeled off

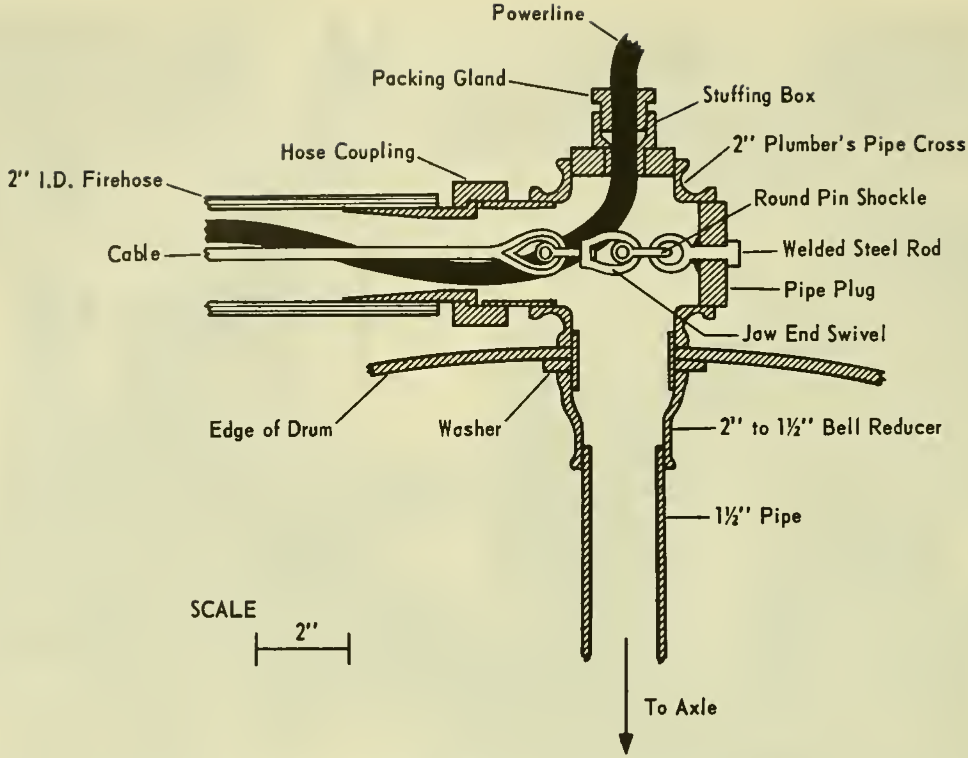

Figure 6.--Schematic drawing of the upper hose-cable terminal assembly mounted near one edge of the winch drum.

again as it is rotated in the opposite direction to pull the hose in. Thus the electrical connection need not be interrupted when the drum is rotated. The end of the powerline is connected to the capacitor starter, which is located near the winch, and the capacitor in turn is plugged into an A.C. outlet on the deck of the vessel.

Rotation of the drum is controlled by a reversible 3/4-hp. A.C. gear motor mounted on the base of the winch stand. The combination reduction gear and chain-sprocket drive to the axle rotates the drum at about 2 r.p.m., which reels the hose in or out at a constant rate of 20 feet per minute. Braking is automatic. The motor shaft is always locked by a built-in brake when the control lever is in the off position.

The guide wheel (fig. 7) is actually a roller cage designed and built specifically for this apparatus. It consists of two horizontal and two vertical rollers made of 2-inch diameter PVC tubing with sintered nylon bushings. The

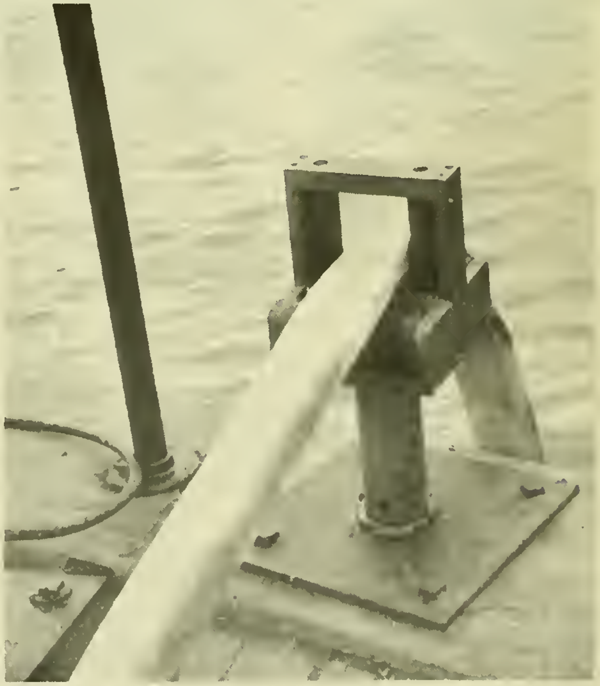

Figure 7.--The guide wheel, composed of 2 horizontal rollers and 2 vertical rollers. It is mounted on a short vertical post and rotates freely in the horizontal plane.

clearance between the two vertical rollers is 3 inches. The top plate of the cage is hinged on one side and secured with wing nuts on the other so that it can be swung out of the way for inserting or removing the hose. The unit is mounted on a short vertical post projecting from the deck of the vessel and rotates freely in the horizontal plane.

The Filtering Unit

The filtering unit (fig. 8) consists of a watermeter, a quick acting double-throw valve and two filtering funnels. These elements are arranged so that water can be directed to either of the funnels after it passes through the meter. A thermister sensing unit mounted in a pipe tee between the watermeter and the double-throw valve is connected to a Rustrak recording unit to provide a continuous record of temperature.

Each funnel is set in a large trash can with two openings in the front. A 4-inch I.D. hose connected to a pipe nipple in the lower opening carries filtered water to the scuppers of the vessel. The upper opening permits the operator to reach the collecting bucket at the bottom of the funnel. The funnels and trash cans are lashed in place.

When desired, water can be diverted to the scuppers before it reaches the filtering unit

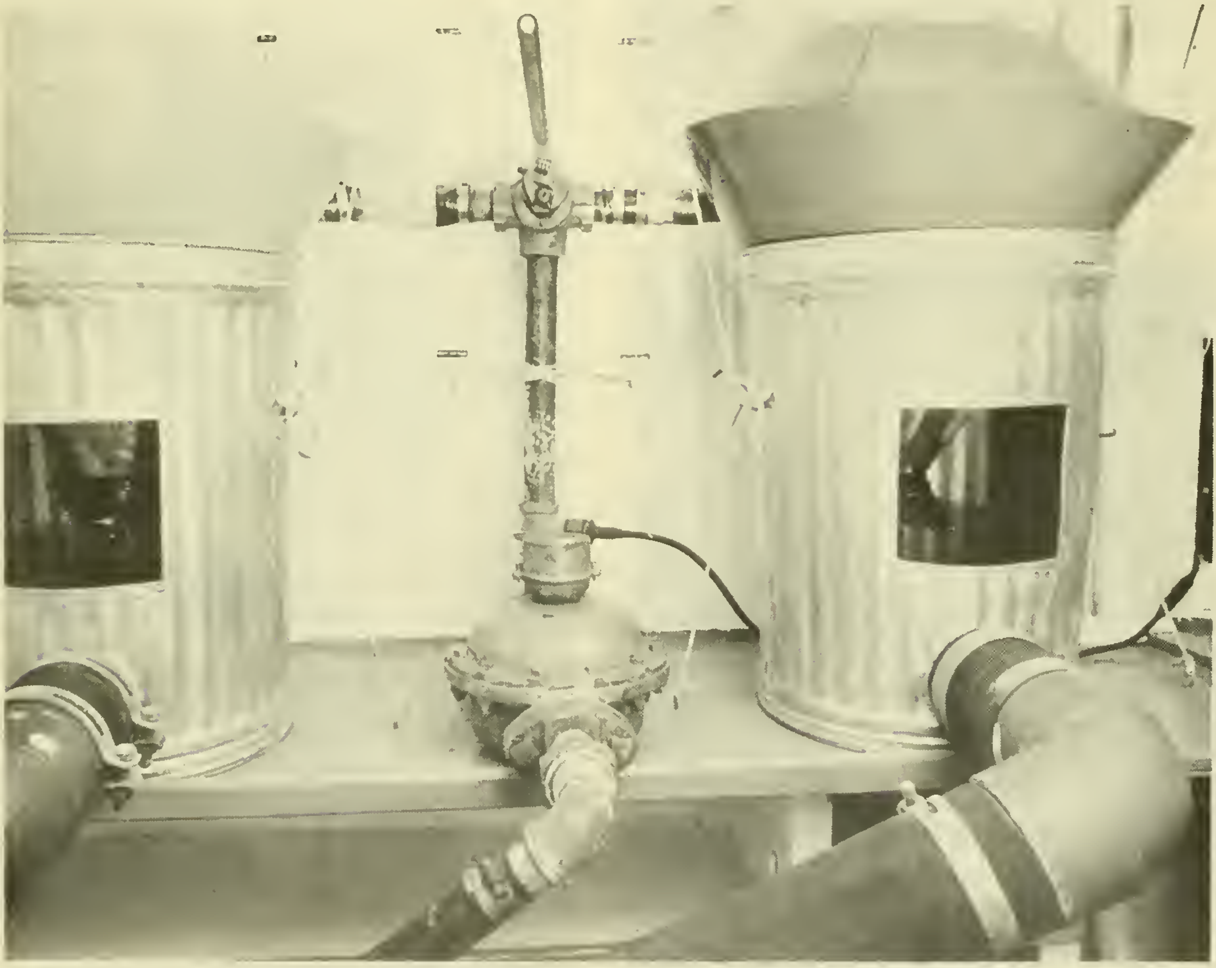

Figure 8.--The filtering unit composed of watermeter, double-throw valve and two filtering funnels mounted in trash cans. The thermister just above the watermeter is connected to a Rustrak recording unit at the far right. The smaller hose is the incoming waterline and the larger hoses are drainagelines.

by opening a valve inserted in the polyethylene hose between the winch and the filtering unit.

The watermeter is a 1 1/2-inch bronze wobble plate type commonly used by utility companies. It registers up to one hundred million liters in hundreds of liters. Tens and units are read from a rotating needle dial. Calibration of the meter by the Helix Irrigation District Laboratory showed that it registers 2.37 percent higher than the true volume at rates of 75 to 98 liters per minute, the delivery rate range within which the towed pump system operates.

Each funnel (fig. 9) is formed of 1/16-inch PVC sheet stock. A short length of 1 1/2-inch PVC pipe glued tangentially into a hole near the top serves as the inlet, and a specially machined PVC neckpiece glued to the bottom serves as the mounting for the collecting bucket. The inlet is connected to a pipe from the double-throw valve by a short length of plastic tubing secured with hose clamps. The greatest portion of the funnel surface between the inlet and the neck consists of windows covered by 105 μ-mesh stainless steel cloth (the diagonals of the mesh openings are 150 μ). The stainless steel cloth is glued along the margins of each window with PVC solvent. All internal areas of glue were made as smooth as possible.

Each collecting bucket (fig. 10) is a 3-inch length of 2-inch I.D. PVC pipe that is bayonet mounted on the neck of the funnel. Two "J" slots in the upper edge of the bucket fit over a pair of pins projecting from a steel clamp around the neck. The steel clamp is set in a groove around the neck and a rubber "O" ring is set in a lower groove to seal the

Figure 9.--The filtering funnel with the bayonet mounted collecting bucket and the friction fitted cap in place.

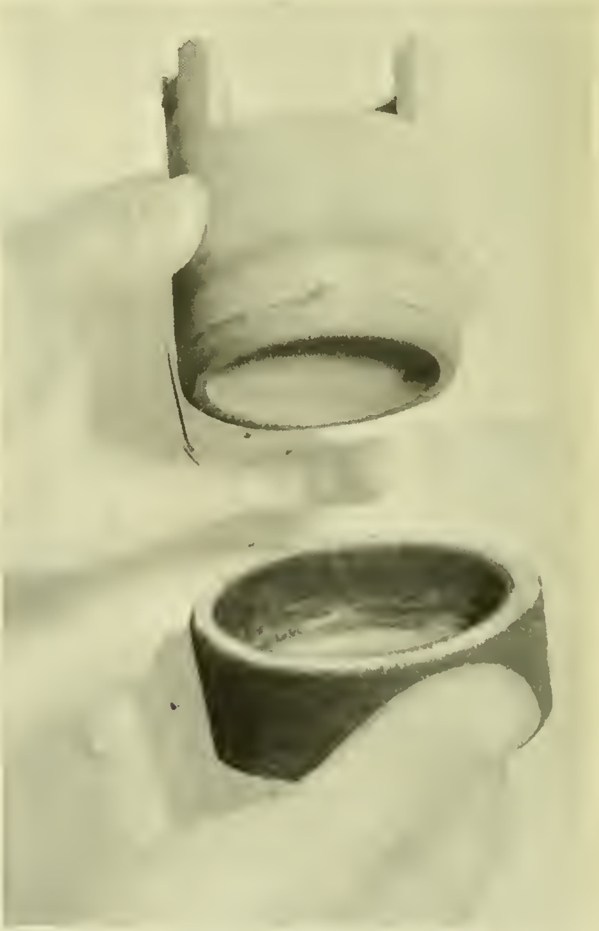

Figure 10.--The collecting bucket with the friction cap detached. The edge of the bucket is recessed to accommodate the tension screw of the steel clamp on the neck of the funnel. The rubber "O" ring on the neck of the funnel seals the bucket below the edge of the large recess.

bucket. The "O" ring is just below the broad slot in the bucket that allows clearance for the tension screw of the steel clamp. As an added precaution, a rubber baffle is attached to the funnel just above the neck to keep the "O" ring seal from being unnecessarily deluged by filtered water coming down the outer surface of the funnel.

The bottom of the bucket is covered by 105μ-mesh stainless steel cloth. When the filter is operating, this screen is covered by a friction fitted cap so that all water filters through the windows of the funnel. The cap is twisted off at the end of a filtering period to allow the small amount of water trapped in the bucket and neck of the funnel to drain out before the bucket is removed.

OPERATION

The collector is set for towing with the vessel running slow ahead. The hook suspended from the davit is placed in the top of the diamond bridle frame, and the collector is hoisted from its cradle on the deck and lowered over the fantail until the hose-cable terminal assembly is just below the guide wheel. The hose is set in the guide wheel, and slack is taken up by the winch. The hook is then removed from the bridle, and the collector is lowered to a depth of a few meters below the surface. The pump is turned on and, after water is flowing satisfactorily through the hose to the laboratory, the hose is reeled out slowly. When the desired length of hose is out, vessel speed is increased to cruising.

The collector is retrieved by the reverse procedure. When the unit is to remain aboard for any length of time the entire system is flushed with fresh water. The nose cone and nozzle are removed from the collector, and a fresh-water hose from the vessel is coupled directly to the pump intake. Water is allowed to run through the system for about 15 minutes.

Once set, the collector is towed and the pump operated continuously for the duration of a survey. The longest continuous runs so far have been approximately 72 hours. When samples are not being collected during such a run, water is diverted to the scuppers through the valve between the winch and the filtering unit.

The sampling patterns carried out in the fall of 1961 required that sequences of 1-mile samples be taken for one to a few hours with interim nonsampling periods of one-half to several hours. The 1-mile sample intervals were taken to be equivalent to 6.5-minute time intervals at vessel cruising speed, which was estimated to average 9 knots. Samples are easily collected by one operator under this regime. The procedure followed is outlined below:

1. A few minutes before arriving at the starting point of a sampling sequence, remove the collecting bucket from one funnel (B), and close the diversion valve so that the flow of water is directed to the filtering unit. Set the double-throw valve so that the water flows through the open funnel.

2. Upon arrival at the starting point, switch on the interval timer (an electric device that gives an audible signal every 6.5 minutes), record the watermeter reading and set the double-throw valve to direct water into filter A.

3. Put the collecting bucket back on funnel B.

4. When the timer rings again, switch the valve to funnel B and record the watermeter reading.

5. Twist the friction cap clockwise off the bottom of the collecting bucket on funnel A and allow the residual water in the funnel to drain through the bottom screen.

6. Twist the bucket counterclockwise off its bayonet mounting.

7. Wash the sample from the bucket into a jar with a gentle stream of water and a spray gun.

8. Fill the jar with water and the necessary amount of formalin to make a 4-percent solution. Label and cap the jar.

9. Put the friction cap back on the bucket and put the bucket back on funnel A.

10. When the timer rings again, switch the valve back to funnel A, record the water-meter reading and remove the sample from funnel B as above.

11. Repeat the procedure to the end of the sampling sequence, at which point the timer can be switched off and the water diverted to the scuppers of the vessel.

This procedure generally requires 2 or 3 minutes work each time a sample is taken, leaving a few minutes for the operator to take care of odd chores, such as making notations on the temperature recorder and preparing labels for the sample jars.

The spray gun referred to in step 7 was found to be very effective in removing the sample from the bucket. Actually the bulk of the plankton is first removed by tipping the bucket over a small powder funnel set in the sample jar and washing the inside down with a gentle stream of water from a small hose connected to a laboratory tap. Organisms remaining on the screen are removed by placing the bucket upside down in the powder funnel (fig. 11) and "blasting"

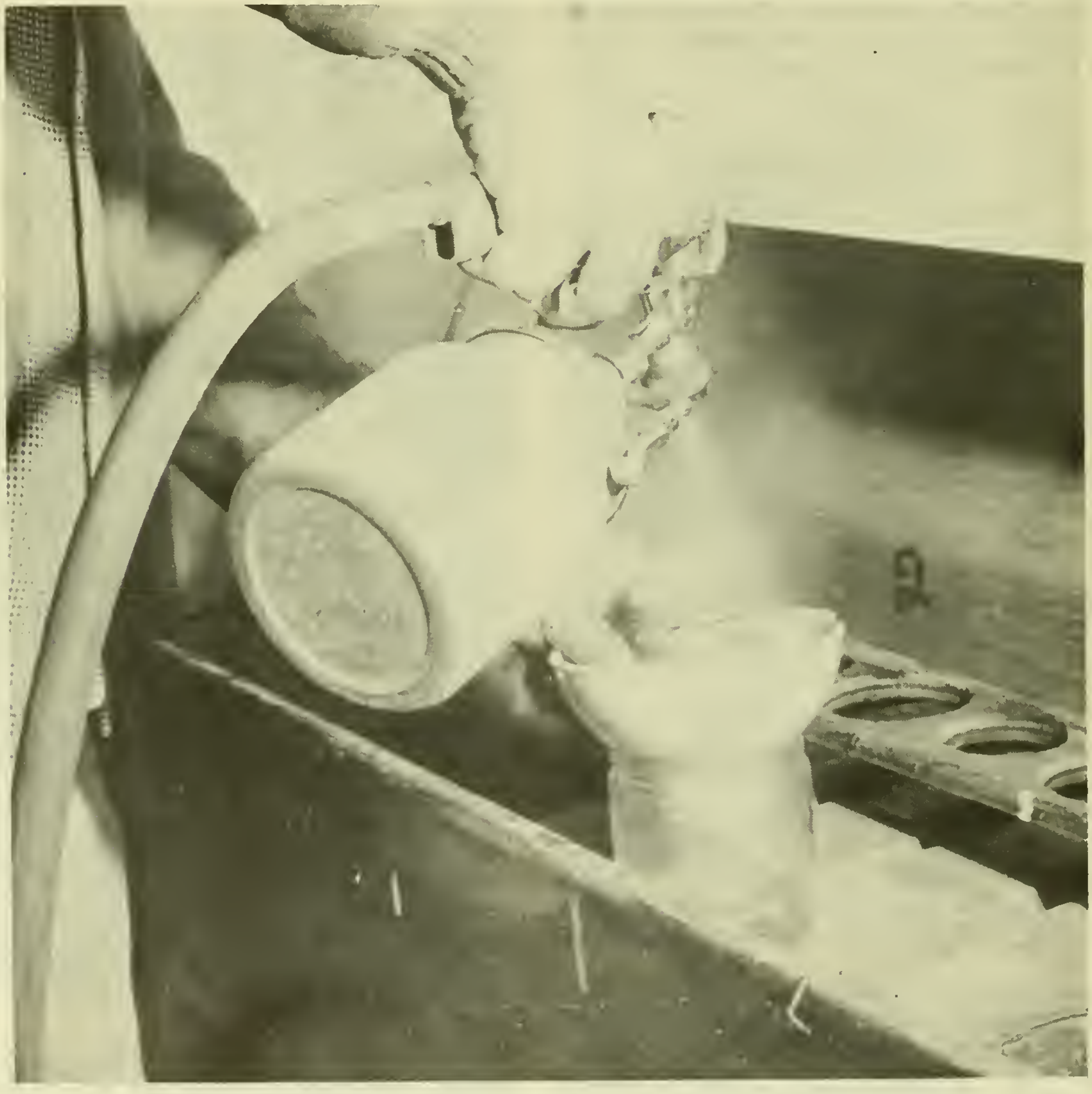

Figure 11.--The collecting bucket being cleaned with the spray gun.

through the bottom screen with the spray gun. Two or three short blasts are usually sufficient. There is no back blast out of the funnel or disturbance to the water in the jar because the screen itself dissipates the force of the spray markedly. The adjustment of the spray gun is not particularly critical, but the instrument seems most effective when the atomizer is set to emit a relatively heavy or "wet" spray under moderate pressure. The pressure for the gun is set by the valve at the outlet of the vessel's compressed air system to which a hose from the gun is attached.

The spray gun is also used to clean the main filtering funnels when they become heavily clogged with phytoplankton. This has to be done at least every 3 or 4 hours and in actual practice it is usually done at intervals of 1 or 2 hours during convenient breaks between sampling sequences. Water entering the funnels forms a rapidly swirling vortex near the lower edge of the screened windows when the funnels are clean. Over a period of a few hours phytoplankton clogs the screens progressively from the bottom, raising the level of the vortex. A funnel is always cleaned before the vortex level rises to two-thirds the height of the screened windows.

To be cleaned, a funnel is uncoupled from the double-throw valve and removed from the trash can. The screens are gone over thoroughly from the outside with the spray gun while the funnel is held over a drain trough. Spray-gun pressure is increased considerably for this operation. After spraying is completed, loose, flocculent clumps of phytoplankton remaining on the inner surfaces of the screens are washed down from the inside with a moderately forceful stream of water. On some occasions the phytoplankton was washed directly into jars for later inspection.

It takes 10 or 15 minutes to clean each filter in the manner described above, thus making it impossible to clean them after every 6.5-minute sampling interval. For present purposes such frequent cleaning is not necessary, but should it be desirable for future operations, a quick-cleaning mechanism could undoubtedly be incorporated into an improved model of the filtering unit.

PERFORMANCE

With approximately 100 feet of hose out the collector tows at a depth of 5 or 6 meters. This was determined early in the fall of 1961 by signals telemetered from a Bourns pressure potentimeter mounted on the lower hose-cable terminal assembly. The device was removed because of frequent malfunction, but since vessel speed (9 knots) and length of hose out (approximately 100 feet) were kept constant during the later surveys, it is assumed that all samples were collected at the same depth. It should be possible to achieve greater depth in the future by increasing the depressing force and length of the hose.

Water is delivered to the filtering unit at the rate of 92 ± 5 liters per minute which is about 16 percent greater than the rate at which water would freely enter a 3/4-inch diameter orifice moving through the sea at a speed of 9 knots. The free flow rate of any orifice is

$$\pi r^2 d_x k = \text{liters per minute}$$

where r is the radius of the orifice, d_x the number of feet traveled per minute at speed x, and k the factor for conversion from cubic feet to liters. Since the pump orifice is three-quarters of an inch in diameter and the cruising speed of the vessel is 9 knots

$$3.1416 \times 0.0312^2 \times 912 \times 28.32 = 78.95 \text{ liters per minute.}$$

Thus there should be a field of suction ahead of the collecting orifice, and the diameter of this field would be the diameter of the core of water being sampled.

Tests carried out on the collector in a laboratory trough with a flow of 3 knots suggests that the diameter of the core is well under 2 inches at a speed of 9 knots. Dyes and particulate matter released in the trough clearly defined a bulbous zone about 2 inches in diameter ahead of the orifice. Particulate matter was instantly pulled into the pump if it drifted into this zone. If it missed the zone, it drifted on past the collector undisturbed.

Whether the size of the zone of suction fluctuates during actual towing due to agitation of the water by the movement of the vessel itself is not known, but it is at least reasonable to assume that the orifice of the collector is always preceded by a field of suction rather than a field of back pressure. Back pressure, which is often produced by clogging in plankton nets, is undesirable because it may delay the passage of some organisms into the orifice or even deflect them from it. Suction, on the other hand, will insure that organisms are transported instantly from the orifice through the hose to the filtering unit.

Wiborg (1948) suggests that the faster moving organisms will succeed in avoiding the currents at the mouth of the suction hose of pump collectors. He concluded, after comparative tests with the Clarke-Bumpus sampler and the Nansen closing net, that a pumping rate of at least 200 liters per minute is necessary for adequate sampling. Though this figure may have some merit for pumps that are virtually stationary, as was the one used by Wiborg, it cannot be arbitrarily applied to a pump intake that is moving through the water at a good rate of speed. The size of the suction zone, which depends on the ratio of the rate of intake to the rate of travel, would be less for a moving collector than for a stationary one. Undoubtedly the movement of the collector, rather than the small zone of suction, would be the major cause of avoidance with an instrument towed at 9 knots.

A second reason given by Wiborg (1948) for the 200 liter-per-minute minimum pumping rate is that at lesser rates it takes too long to collect sufficiently large numbers of some kinds of organisms. During the 1961 fall surveys the towed pump and shipboard filtering unit, with a delivery rate of 92 liters per minute, collected early stages of copepods and even the adult stages of *Calanus heligolandicus* in numbers sufficient for density estimates of good precision. Euphausiids occur in much lower, but still sufficient numbers. The same is true of chaetognaths. Fish eggs and larvae, on the other hand, are among the organisms that occur too rarely in the samples to yield abundance estimates with a satisfactory degree of precision. It is possible that these would occur in greater numbers in other areas and during other seasons of the year.

The upper size limit of organisms collected by the towed pump and shipboard filtering unit is indicated by the condition of the euphausiids and the fish larvae in the samples. Both are mutilated if they are more than a half inch in length, and virtually no organisms longer than three-quarters of an inch occur in the samples. This may be directly related to the physical characteristics of the pump, i.e., diameter of orifices and spacing of impeller blades.

The lower size limit of organisms collected is suggested by the size composition of organisms escaping from the filtering unit. The greatest detectable escapement was through the filtering screen of the collecting bucket. On five occasions the water remaining in the funnel at the end of a 6.5-minute sampling interval was collected in a jar when the friction cap was removed from the bucket screen. The number of organisms in each escapement sample was estimated by volumetric subsampling with replacement. Each sample was stirred in 1,000 cc. of water and 12 aliquots of 25 cc. were removed, examined and returned successively. The mean numbers per aliquot were multiplied by 40 to obtain estimates of the numbers in the samples.

The estimated average numbers of copepods escaping for five samples are tabulated in three size categories in table 1 and illustrated for eight size categories in figure 12. They are not adjusted for differences in the volume of water filtered in each of the five samples, but volume varied very little between samples.

Percentage escapement and along with it the minimum size for quantitative collection cannot be definitely established until the relation between the size composition of escaping copepods can be compared to the size composition of the copepods retained by the filters during the five pertinent sampling intervals. These samples have not yet been counted. However, the numbers of copepods present in 129 samples collected in the same

TABLE 1.--The estimated average numbers of copepods escaping through the bucket screen per 6.5-minute sampling interval in 1961 compared to the average numbers in the collecting bucket per sampling interval in 1958

Copepod length	Average escaping per interval[1]	Average accumulated per interval[2]	Escapement
Mm.	*Number*	*Number*	*Percent*
< 0.2...........	71	--	--
0.2 - 0.5........	31	2,266	1.3
0.5 - 1.0........	2	612	0.3

[1] From 5 sampling intervals taken at various times during 1961 surveys by collecting all the water filtering through the bucket screen after removal of the friction cap at the end of each interval.
[2] From 129 sampling intervals taken on two grid patterns in the fall of 1958 in the same manner but with a different arrangement of hose and pump.

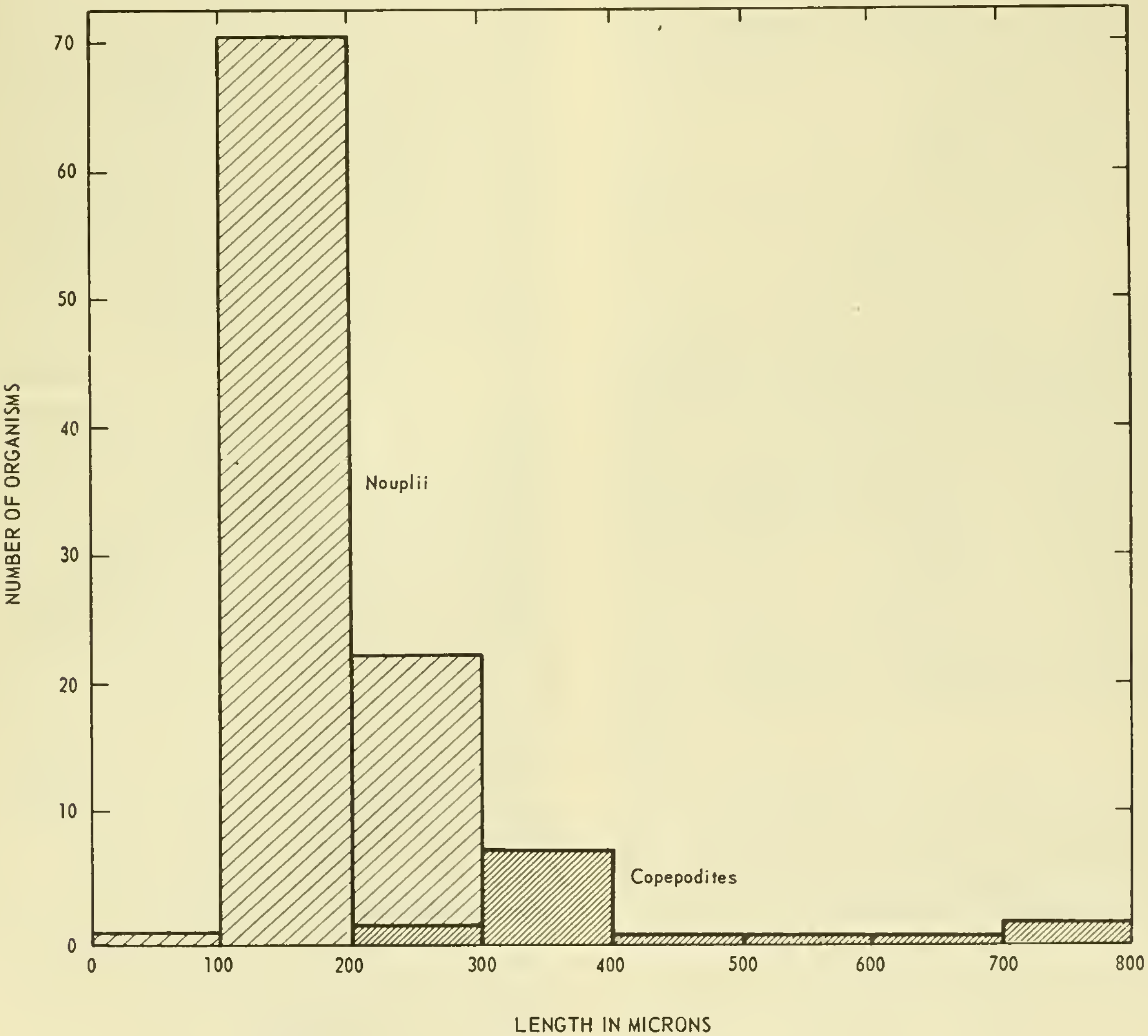

Figure 12.--The average length frequency distribution of copepods escaping through the bucket screen per 6.5-minute sample interval. The light shading denotes nauplii and the heavy shading denotes copepodites. No adult copepods were found in the escapement samples.

manner but with a different arrangement of hose and pump in the fall of 1958 suggest the probable order of escapement (table 1). The average number of copepods between 200 and 500μ in these earlier samples is 2,266, and the average number between 500μ and 1 mm. is 612. Thus escapement of copepods in any size category above 200μ is not likely to be more than a few percent. If necessary, escapement can probably be reduced by using a filtering screen of smaller mesh size in the collecting bucket.

No other zooplankters appeared in the escapement samples except larvaceans. The estimate for the first sample is 23, and none were found in the other 4. Since larvaceans are present in considerable numbers in the samples collected during the fall of 1961, it is assumed that the above represents a negligible escapement.

The main filtering screens in the funnels are the only other obvious site of escapement. Examination of 20 half-liter samples of water taken from these screens at various times during the 1961 fall surveys has revealed no zooplankters. Though this result is encouraging, the observations are too few to permit a conclusive appraisal. The half-liter samples are so small a fraction of the 600 liters or so that are filtered during each 6.5-minute interval, that the absence of zooplankters in 20 such samples could easily have occurred by chance alone. Much more filtered water will have to be examined.

A simple calculation and a laboratory test indicate that organisms are not displaced to any significant degree as they are transported from the collector to the filtering unit. The length of the entire hose is 210 feet. Assuming that 1/2 inch of the 2-inch diameter of the hose on the winch is occupied by the support and electrical cables, the diameter can be considered 1.5 inches for the entire length. The volume of the hose, therefore, is

$$\pi r^2 lk = 72.8 \text{ liters}$$

where r is the radius, l is the length, and k is the factor for conversion of cubic feet to liters. At the average delivery rate of 92 liters per minute the volume of the hose is turned over every 48 seconds, or eight times during the course of each 6.5-minute sampling interval. This was verified by the fact that spurts of dye introduced into the pump intake in a laboratory trough took about 50 seconds to reach the other end of the hose. The spurts of dye, furthermore, showed very little diffusion as they moved through the hose (a transparent vinyl hose was being used at the time of these tests), suggesting that suspended organisms would approximately maintain their relative positions during transport.

Zooplankters that do not descend into the collecting bucket at the end of a sampling interval are either deposited freely on the inner surface of the filtering funnel or trapped in the phytoplankton film clogging the main filtering screens. Those deposited freely on the surface could be washed into some subsequent sample, thus decreasing sampling accuracy. Those entrapped in the phytoplankton would constitute a fraction of the sample that is lost, also decreasing sampling accuracy. Virtually no zooplankters could be detected on the inner surface of the funnels by visual inspection following 6.5-minute sampling intervals, indicating that there is essentially no loss of accuracy due to organisms remaining freely on the filter surface. Considerable numbers did remain on the surface, however, during special sampling sequences where the sampling interval was 2 hours rather than 6.5 minutes. Drainage rate was greatly reduced by heavy clogging of the bucket screens, and many zooplankters settled out and remained on the inner surface of the funnel as the water receded after the friction cap was removed from the bucket screen. Thus rapid drainage is necessary to insure that all or most of the zooplankters captured during a sampling interval are deposited in the collecting bucket. If sampling intervals are to be longer than a few minutes, or if the rate of clogging is increased by a greater rate of water delivery or the use of a finer mesh screen in the bucket, the area of the bucket screen would probably have to be enlarged to achieve rapid drainage.

Examination of the phytoplankton film, which was removed from the funnels and preserved

TABLE 2.--The estimated average numbers of zooplankters per 6.5-minute sampling interval entrapped in phytoplankton on the filter screens in 1961 compared to the average numbers retained in the collecting bucket per interval in 1958

Type organism	Sample periods[1]				Average entrapped per interval, 1961	Average collected per interval, 1958[2]	Suggested entrapment
	1	2	3	Total			
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*
All copepods.....	1,380	540	930	2,850	29	2,907.0	1.0
Larvaceans.......	1,680	1,080	1,020	3,780	38	88.0	30.2
Doliolids........	180	30	30	240	2	0.1	--

[1] Period 1 had 45 sampling intervals, period 2, 18, and period 3, 36 for a total of 99. At end of each period all material adhering to main filter screens was removed and preserved for later enumeration.
[2] 129 sampling intervals.

on several occasions, showed that a small portion of the zooplankters entering the filtering funnels are trapped in this material. The numbers of zooplankters in three such phytoplankton samples, as estimated by volumetric subsampling with replacement, are given in table 2. Since the phytoplankton was accumulated over different numbers of 6.5-minute sampling intervals in each case, the estimates are summed and divided by the total number of intervals for the three samples and expressed as average numbers per sampling interval.

Copepods, larvaceans, and doliolids were the only zooplankters found in the phytoplankton. The larvaceans are somewhat more abundant than the copepods, while the doliolids are far less abundant. Comparison to the average numbers of such organisms present in the 129 samples collected in 1958 suggests that the percentage loss of copepods is negligible, but that the loss of larvaceans may be higher than 40 percent. If entrapment of larvaceans in the phytoplankton proves to be this high in terms of the matching 1961 samples, the towed pump and shipboard filtering unit would have to be considered unsuitable for making quantitative collections of this group. No worthwhile assessment can be made of entrapment of doliolids because they are virtually nonexistent in the 1958 samples.

Except for larvaceans, then, it appears that the loss of zooplankters through escapement and entrapment is probably not more than a few percent, and that loss of accuracy through mixing between consecutive samples is probably negligible. For most purposes such minor losses can be disregarded, but if necessary the losses from escapement and entrapment can be measured directly so that corrections can be applied to sample estimates.

DISCUSSION

The towed pump and filtering unit was designed for the purpose of making estimates of known precision of small zooplankters for areas of specified sizes. Operations during the fall of 1961 indicate that the system performs this task satisfactorily. Zooplankters between the lengths of 0.2 mm. and 12.0 mm. (approximately 1/2 inch) are collected quantitatively and the collection of samples that are discrete for consecutive 6.5-minute intervals of vessel travel at cruising speed is a simple procedure. A number of such small samples can be taken as subsamples from a given area.

The present operational status of the towed pump and shipboard filtering unit, particularly of the collector and the hose-cable assembly, was achieved only after considerable experimentation and modification. The towed pump and hose-cable suspension are patterned after a model originally designed and built for the Bureau of Commercial Fisheries Biological Laboratory, La Jolla, by the Fisheries Instrumentation Laboratory of the Bureau of Commercial Fisheries Biological Laboratory, Seattle, Washington. The original collector was lost due to failure of the support cable during early sea trials, but the trials showed that certain changes were needed to make the unit durable and reliable. Among these were a heavier cable and linkage elements, heavier hoses, enlarged hose-cable terminal assemblies, a rigid bridle, and a smaller pump. The earlier hose, which was 2-inch I.D. thin-walled vinyl tubing had the advantage of transparency, but it stretched excessively with internal pressure and was also susceptible to the development of weakpoints and subsequent small leaks at sites of folding and abrasion. The earlier chain bridle, though simple to fabricate, fouled too easily during setting of the collector. The earlier pump, which had a 1-inch diameter intake, frequently overloaded the electrical system and stopped operating. It required power in excess of that obtainable from the 1/2-hp. motor, and a larger motor would have required power in excess of that obtainable from the vessel.

Though the above changes have made the collector and hose-cable assembly reliable and durable, they do not make the instrument capable of sampling at various depths. This will require, in addition to further changes in the collector and hose-cable assembly, very considerable improvements in the winch. The winch in its present configuration does demonstrate that a hose of considerable length can be reeled in and out while water is being pumped, but the unit is not strong enough to sustain the load that a longer hose and greater depressing force would produce, nor could it accommodate a hose much longer than that now being used.

Sampling at various depths will also require continuous depth-of-tow information. The inclusion of reliable depth sensing and telemetering apparatus will be a priority item in the design of future models of the system.

The only difficulty with the filtering unit was the appearance of pinhead rust spots on the filtering screens after the two funnels together had been exposed to nearly 600 cubic meters of sea water (approximately 100 hours of sampling). These were patched with epoxy to forestall the development of holes. It is probably unreasonable to expect longer service than this from stainless steel screening as delicate as that used here. Future improvement in the filters should include some simple way of replacing these surfaces at intervals. Monel screening might well eliminate this problem, but it is not available in mesh sizes as small as that used here.

The temperature sensing and recording apparatus incorporated into the filtering unit should also be improved in the future. The electronic components do not perform reliably enough for sustained operations, and the location of the sensing element at the filters rather than in the collector is questionable. It may well be that the temperature increases as the water moves from the collector through a few hundred feet of hose to the sensing element. Submersible temperature sensing units and various kinds of telemetering equipment are available so that a satisfactory solution should be a matter of integrating a unit with the desired performance characteristics into the existing system or some later model of it.

SUMMARY

1. A towed plankton pump and shipboard filtering system for sampling small zooplankters has been designed for use aboard the Bureau of Commercial fisheries vessel *Black Douglas*.

2. The system consists of (1) a collector towed by a suspension unit consisting of a hose through which runs a steel cable for support and an electric line to power the pump, (2) a winch, and (3) a filtering unit composed of a watermeter, a double-throw valve and two filtering funnels.

3. The collector, which contains a 1/2-inch bronze centrifugal pump and an hermatically sealed, capacitor starting, 1/2-hp. A.C. motor, is mounted in a frame bridle suspended from a terminal hose-cable assembly made of galvanized pipe and fittings. A 43-pound homogeneous depressor is suspended from the bottom of the bridle.

4. The hose is a 2-inch I.D. single-jacket firehose and both the 1/4-inch stainless steel support cable and the neoprene covered powerline extend to the deck of the vessel through the hose.

5. The winch is a steel drum 4 feet long and 3 feet in diameter with a 1.5-inch pipe axle. The water stream is dissociated from the support cable and the powerline at a terminal assembly mounted on one edge of the drum. Rotation is controlled by a reversible 3/4-hp. A.C. gear motor with an automatic brake.

6. A 1.5-inch I.D. polyethylene hose extends from the winch to the filtering unit, which consists of a wobble plate type watermeter, a quick acting double-throw valve and two filtering funnels set in trash cans. Filtered water flows from the cans through outlet hoses to the scuppers of the vessel.

7. Each filtering funnel has windows screened with 105 μ-mesh stainless steel filtering cloth. A collecting bucket bayonet mounted on the neck of the funnel has a bottom screen of the same cloth which is covered by a friction-fitted cap while the funnel is filtering.

8. Removing and preserving a sample takes 2 or 3 minutes, so the filtering unit is easily operated by one man.

9. With 100 feet of hose out, the collector tows at a depth of 5 or 6 meters at a vessel speed of 9 knots. It has been operated continuously for periods of about 72 hours.

10. Escapement through the screen of the collecting bucket and the size of mutilated zooplankters indicate the lower and upper size limits of quantitative collection to be 0.2 mm. and 12.0 mm. respectively.

11. The error due to escapement through the filtering surfaces appears to be negligible between the above sizes.

12. Better sensing and recording apparatus is needed for depth-of-tow and temperature information and considerable improvement is needed in the winch if the system is to be used for towing at various depths.

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