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The Propagation of Cod *Gadus morhua* L.

SAMPLING FISH LARVAE WITH LARGE PUMPS; QUANTITATIVE AND
QUALITATIVE COMPARISONS WITH TRADITIONAL GEAR

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ABSTRACT

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Different types of submersible pump systems, ranging in capacity from 3 to 60 m³/min, have been tested during the period 1977-83 to collect fish eggs and larvae from discrete depths in the Lofoten area.

Comparisons have been made with regard to the quality and quantity of eggs and larvae sampled with different plankton nets. Almost without exception the pump samples contain more cod eggs and larvae per m³ than vertical net hauls, indicating a significantly lower filtration efficiency than the 100% used in the calculations. The quality of larvae sampled by vertically hauled nets was very good.

The quality of the larvae depends upon the filtration pressure and time from capture to fixation of the larvae. Thus larvae sampled by pumps with high water velocity and the high speed sampler Gulf-III had a high percentage of damaged larvae. Due to the time lag from capture to fixation, most of the larvae collected with the MOCNESS were also in a bad condition.

A large filtration system, 60 m³/min, based on a submersible 80 cm slow-rotating propeller, is described. Comparisons with MOCNESS for quantitative reasons and to the vertical net for qualitative reasons showed good agreement.

INTRODUCTION

The survival, growth and drift of the larvae of Arcto-Norwegian cod has been investigated since 1975 at the Institute of Marine Research, Bergen (Ellertsen et al., 1981a,b, c).

The idea of Hjort (1914) that the variations in year class strength are caused by varying densities of prey organisms available for the fish larvae starting exogenous food uptake, is still in focus. The lack of adequate methods for a proper documentation has been stressed by May (1974). Testing the hypothesis of starvation needs sampling equipment for both prey organisms and the fish larvae from discrete depths. The in situ particle counter has solved the problem of a fast vertical profiling of nauplii concentrations (Tilseth and Ellertsen, 1984).

Methods involved in field studies of fish larvae have improved considerably in recent years. Different horizontally towed nets with opening/closing devices, volume control and several nets have been developed (Wiebe et al., 1976), and new systems, such as large pumps, have also been introduced to sample fish larvae from discrete depths (Portner and Rhode, 1977; Ellertsen et al., 1977, 1981a; Fridgeirsson, 1984). Especially emphasized is the search for and comparison of new ichthyoplankton sampling gears in larval entrainment investigations in the U.S. in connection with power generation plants (see Bowles and Merriner, 1978).

The present paper is a summary of the developments of and experiences with five different large pump systems for sampling fish larvae and other planktonic animals during the years 1977-83.

Some general characteristics of a successful pump system are:

- A. The pump system must sample quantitatively within the larval size range of interest.

- B. The filtration capacity must be large enough to provide an adequate number of larvae from areas or depths with low larval concentration within a reasonable time.
- C. The fish larvae should be in proper condition for qualitative investigations.
- D. The operation of the pump system must be easy, fast and more or less independent of weather conditions.

MATERIAL AND METHODS

The main technical specifications are found in Table 1.

The systems used in 1977 and 1979 were commercial submersible fish pumps used for pumping the catch from the purse seine or cod-end on board a fishing vessel. The water was pumped through rubber hoses from the sampled depth and filtered through nets either along the ship side, (Fig. 1), or on deck, (Fig. 2). Due to poor volume control, the filtration system along the ship side was abandoned in 1977. The net used for filtration on deck was an ordinary 36 cm Juday net, with 180 μm mesh size, which was fitted to a stiff pipe at the end of the rubber hose. The water flow was calculated by filling a 400 l plastic barrel in 1977, and a special 1284 l plastic vessel in 1979. To improve the quality of the cod larvae, sampling experiments with varying hose length, U-shaped bends, polishing the innerside of the pipes with polyester etc. were carried out with moderate success. In practice, the method of filtering seawater on deck proved cumbersome and susceptible to the weather conditions, since the vessel had to be anchored. In 1981 an in situ filtration system was introduced using the 36 cm Juday net, mesh size 180 μm , directly attached to the head of the pump, Fig. 3. Due to the weight of the bucket, the net closed when the motor stopped and the system lifted to the surface. After washing the net and collecting the sample the system was lowered to a new depth.

TABLE 1

Technical characteristics of the five pump systems.

Year	1977	1979	1980	1981-82	1983
Pump code	U 230	U 880	2125	S 181	4500
Power supply	Hydraulic	Hydraulic	Electric, 8 kW	Electric, 4.4 kW	Electric, 15 kW
Weight	50 kg	460 kg	90 kg	ca 100 kg	450 kg
Type of pump	Submersible, centrifugal	Submersible, centrifugal	Submersible, centrifugal	Submersible, propeller	Submersible, propeller
Rev. pr minute	900	550	2800	2900	360
Max. cap. m ³ /min.*	10	19	3	5.4	60
Max. water vel. m/s	5.0	6.5	2.8	2.9	1.3
Optimum cap. m ³ /min.	2	3	-	2.7	-
Optimum water vel. m/s	1	1	-	1.5	-
Diameter of hose, cm	20	25	15	20	100
Filtering system	On deck	On deck, in situ	On deck	In situ	In situ

* Data given by manufacturer

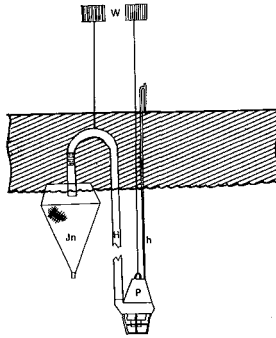


Fig. 1. The pump (U230/U880) and filtration system; the filtration taking place beside the hull. P=pump, H=hose, Jn=Juday net, h=hydraulic cable, and W=winch.

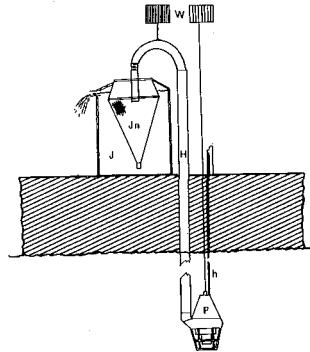


Fig. 2. The pump (U230/U880/2125) and filtration system; the filtration taking place in a jar on deck. P=pump, H=hose, Jn=Juday net, H=hydraulic cable, W=winch, and J=jar.

A similar, somewhat larger system was used in 1982, connected to a frequency-converter, to investigate the effects of water velocity on larval quality.

In 1983 a significantly larger system was constructed based on the following experiences from earlier years:

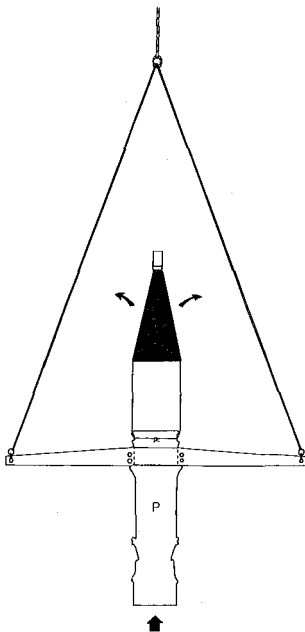


Fig. 3. The pump, S 181, and the filtering net used in 1981-1982. P=pump.

1. Water velocity should be less than 1.5 m/s.
2. Increase in capacity produced by a large propeller rotating slowly at 300-400 r.p.m.
3. Filtration in situ.

The system is described in Table 1 and Fig. 4, and a picture is shown in Fig. 5. The electrically driven propeller, a 4500 Flygt mixer, 15 kW, 380 V AC, depth range 0-300 meters, pumped water through the U-shaped funnel, made of 2 mm stainless steel. The net had a diameter of 1 m and a length of 5.15 meters. The mesh size was 375 μm , except for the 0.5 meter at the end which was with 180 μm . A MOCNESS-bucket was used to collect the sample (Wiebe et al., 1976).

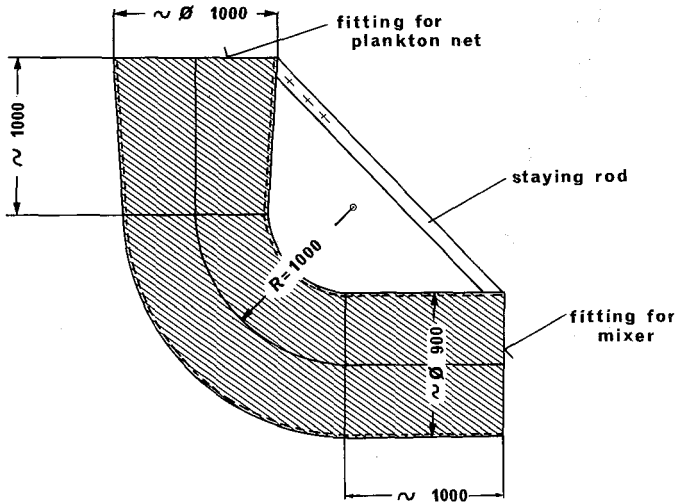


Fig. 4. The bend of the Flygt mixer used in 1983. For explanation see text and Fig. 5. (Measures in mm).

The bucket was buoyed to be just slightly heavier than seawater. In this way the net was stretched during filtration and closed as soon as the propeller stopped. The construction was very stable during filtration.

The vertical nets were towed with a speed of 0.5 m/s, the Bongo-60 was towed with a speed of 1.5 m/s and the Gulf-III with a speed of 2.5 m/s. The comparisons with the Bongo-60 were performed by towing the Bongo at different depths for 100-300 meters up to the ship side by means of the hydrographic winch, and simultaneously performing the pump profile. The Gulf III tows were performed as close to the pump profiles as possible in space and time. The mesh sizes and open area ratios (surface of mouth opening/surface of openings in the net) of the different nets used are shown in Table 2. The nets were not equipped with flowmeters.

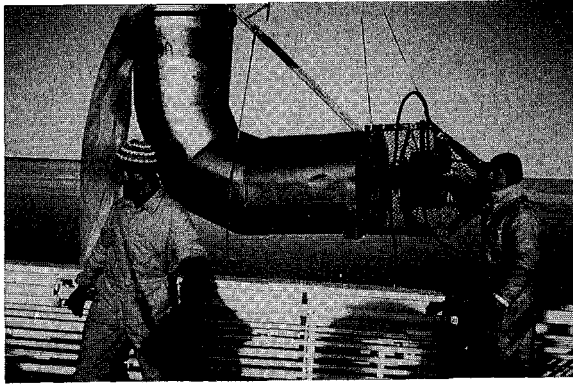


Fig. 5. The sampling system for cod eggs and larvae used in 1983. The Flygt mixer to the right, the bend (Fig. 4) and the filtration net to the left. For further explanation see text.

The pump systems, see Table 1, were tested one at the time so no direct comparisons between different pumps were performed. All systems were tested under field conditions mostly in the Austnesfjord providing higher densities of eggs and larvae than the Vesterålsfjord. The S181P-system was also tested in a tank. To compare larval density, length, quality and number of prey items in the guts, vertical net hauls were performed as close to the pump samples as possible, both in time and space.

The samples were conserved and processed according to Ellertsen et al. (1984). Laboratory hatched cod larvae were used both in tank experiments and under field conditions to test the effects of sampling time and water velocity on quality, length distribution and number of prey items in the stomach of the larvae.

The quality of the larvae was classified as follows:

1. Larvae straight, easy to measure, with all organs intact.
2. Larvae curved, organs intact.
3. Larvae curved, yolk sac, intestines or other organs lacking.

TABLE 2

The mesh sizes and open area ratios of the nets used in the investigations.

Net	Mesh size	Open area ratio
Bongo-60	375 μm	4.6
Gulf III	270 μm	19.0
MOCNESS 1-meter	333 μm	6.6
Juday-80	375 μm	3.3
Juday-36	180 μm	3.0
Egg-net 112 cm	375 μm	3.0
Flygt mixer net	375/180 μm	3.8

The mean density of a vertical density profile from discrete depths was calculated from the formula:

$$A = \frac{1}{H} \int_0^H C(Z) dz$$

where A=mean concentration in the water column 0-H (numbers/ m^3), and C(Z)=concentration at depth Z (numbers/ m^3).

The systems were tested in tank experiments, during cruises in Lofoten in 1977-83 and under ice conditions off Spitsbergen in May-June 1983.

RESULTS

To illustrate the problems of choosing the right sampling gear according to the density of the organism investigated, cod larvae densities based on vertical net hauls from the Vesterålsfjord for the years 1979-81 are given in Table 3.

TABLE 3

Density of cod larvae in Vesterålsfjord 1979-81, from vertically hauled Juday-nets, diameter 80 cm, 50-0 m.

Year	Period	Cod larvae/m ³ \bar{x}	No. hauls
1979	26-27 April	1.3	92
	6 May	0.5	
1980	1-8 May	0.003	46
1981	25 April- 1 May	0.01	87
	2-8 May	0.04	

The Vesterålsfjord is a representative hatching area of cod eggs spawned in Lofoten, and the investigated period is within the main hatching period. The Table clearly shows that larval densities vary considerably between years, from the order of 1 per m³ in 1979 to 10⁻² per m³ in 1981 and as low as 10⁻³ per m³ in 1980. It is obvious that these facts call for different types of plankton gear to obtain adequate samples of cod larvae. The vertical net hauls give a mean larval density in the water column. Because of vertical gradients in larvae density (Ellertsen et al., 1977, 1984) a significant part of the water column will have larval densities considerably lower than indicated in Table 3. The towing distance or number of vertical net hauls from 50-0 m, and the time to collect an adequate number of cod larvae, say 30, have been calculated for the range of densities shown in Table 3.

The results of these calculations for different types of plankton gear are presented in Table 4. It is clearly shown that larval densities of only 0.001 per m^3 make it practically impossible to collect the "30 cod larvae" samples. At densities of 0.04 larvae per m^3 the 1 m^2 MOCNESS, the Bongo-60 and the large pump will provide the larvae sample within 12.5 min. It should be noticed that the distances for the Bongo-60 and MOCNESS to obtain 30 cod larvae are 1327 and 750 meters, respectively.

As part of a vertical profile the pump sample will be the most defined and will therefore give the most correct picture of the vertical distribution within a defined watermass. This is often required when larval feeding conditions are compared to food density and physical factors.

At larval densities of 0.5 per m^3 all types of gear can collect 30 cod larvae within 12 min., though the Gulf III has to be towed 1910 m to achieve this. It should also be noticed that one haul with the large vertical Juday also captures 30 cod larvae.

Experiments with different types of large pumps and nets

1977. Fig. 6 shows larval density (A), length distribution (B) and quality (C) as means of 4 net hauls and pump profiles. Notice the difference in mean density between net hauls and pump profiles which will be discussed later. As seen from Table 1, the pump volume was reduced to an optimum level, which is reflected in the good larval quality.

In Fig. 7, 2 pump profiles are compared to a profile performed with a Bongo-60. The vertical pump profiles were very similar with significantly higher mean larval density than the profile from the Bongo-60. The length distribution and quality of the larvae were very similar for the 2 gears.

1979. Fig. 8 shows the comparisons between the pump system U880 (Table 1, Fig. 2), 80 cm Juday net, Bongo-60 and Gulf III. For practical reasons the larval density tests (A) were performed at 10 meters depth, which is within the maximum larvae stratum, and as close as possible to the pump

TABLE 4

Time and distance for different plankton gears to catch 30 cod larvae at 3 densities: 0.5 larvae/m³ (1979), 0.04 larvae/m³ (1981) and 0.001 larvae/m³ (1980). Values in () are the numbers of net hauls.

Type of gear	Opening, m ²	Speed, m/s	0.001			0.04			0.5		
			Distance, m	Time, min	Distance, m	Time, min	Distance, m	Time, min			
Juday-net	0.5	0.5	(1 200)	3 600	(30)	90	(3)	9			
Juday-net	2.0	0.5	(300)	900	(8)	23	(1)	3			
Bongo-60	0.57	1.5	53 080	480	1 327	12	106	1			
Gulf III	0.031	2.6	955 400	6 000	23 885	150	1 910	12			
MOCNESS	1.0	1.0	30 000	500	750	12.5	60	1			
MOCNESS	10.0	1.0	3 000	50	75	1.3	6	0.1			
Pump	3 m ³ /min	3.0		10 000		250		20			
Pump	60 m ³ /min	1.3		500		12.5		1			

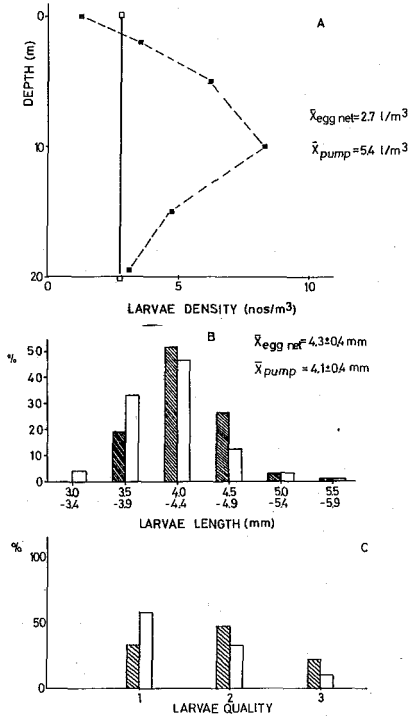


Fig. 6. Comparison between Juday net (diam. 80 cm, 375 μm mesh size, speed 0.5 m per sec, vertically hauled from 20-0 meter) and hydraulic fish pump, U230 (capacity 2.0 m³ per min, water velocity 1.0 m per sec).

- A. Larvae density per m³. ■ Pump, □ Juday net.
 B. Larvae length in mm. □ Pump (n=536), ▨ Juday net (n=167).
 C. Larvae quality. □ Pump, ▨ Juday net.

profiles in space and time. The densities are the mean of 5 Bongo-60 and pump samples and 4 Gulf III samples. The standard deviations are indicated in the figure.

Length distributions are similar for larvae caught by Juday net, Bongo-60 and pump, the Gulf III larvae being significantly larger (Fig. 8(B)), but of worse quality (C). This reflects the high speed of this gear, 2.6 m/s.

During the post-larvae survey in June 1979, an attempt was made to profile the density of about 20 mm long cod post-

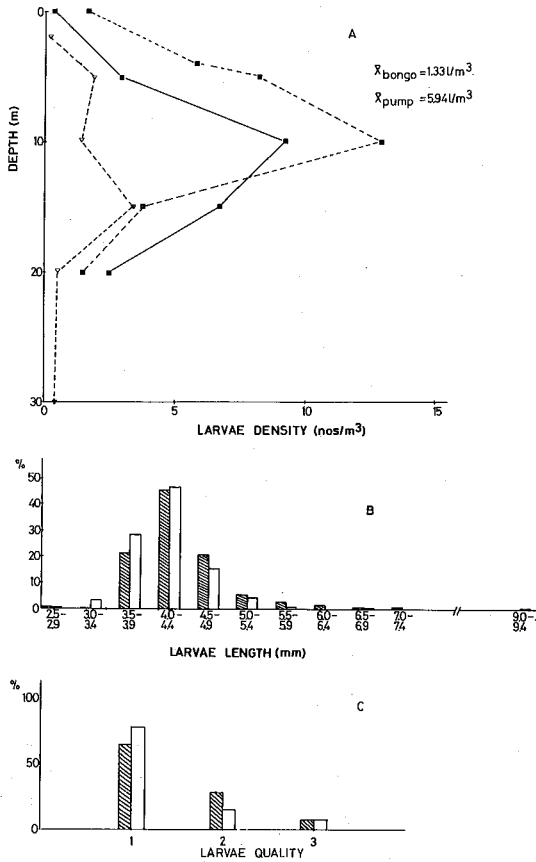


Fig. 7. Comparison between Bongo-60, speed 1.4 m/s, and fish pump U230, 1977.

- A. Larvae density pr. m³. ▽----▽ Bongo-60, ■——■ Pump profile, before Bongo-sampling, ■-----■ Pump profile, after Bongo-sampling.
- B. Length of cod larvae, mm. ▨ Bongo-60 (n=259), □ Pump (n=269).
- C. Quality of cod larvae. ▨ Bongo-60, □ Pump.

larvae in depths from 1 to 30 m. The same pump, U880, was used with a capacity of about 10 m³/min. The filtration was performed through an 80 cm Juday net in situ. Each depth

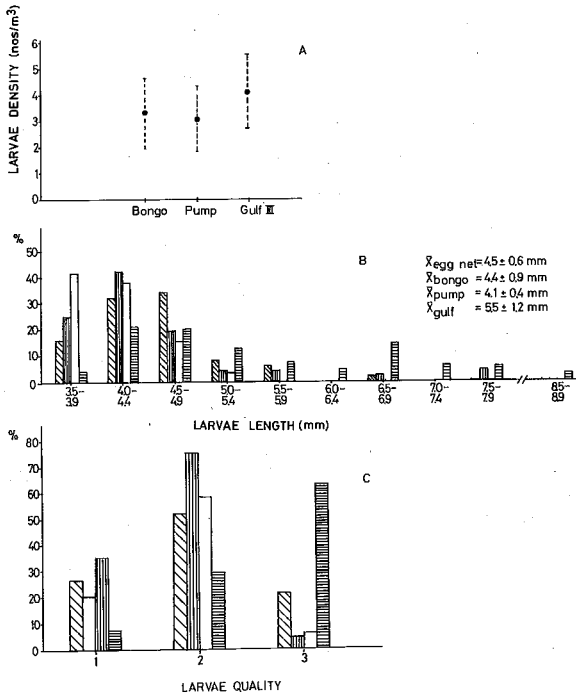


Fig. 8. Comparisons between Bongo-60, Gulf III, vertical Juday-net and hydraulic fish pump U880, 1979.

A. Density of cod larvae at 10 meters depth.

B. Length of cod larvae, mm. ▨ Juday-net (n=49), ▩ Bongo-60 (n=52), □ Pump (n=57), ▤ Gulf-III (n=69).

C. Quality of cod larvae. ▨ Juday-net (n=49), ▩ Bongo-60 (n=52), □ Pump (n=57), ▤ Gulf-III (n=69).

was sampled for one hour, which means 600 m³ of sea water was filtered. Because of large uncertainties in the effective volume sampled by the routine gear, a Harstad-trawl with fine meshed cod-end, it was impossible to calculate post-larvae densities using this gear. Because of this it is difficult to decide if the result from the pump samples, where no cod post-larvae were caught, is the result of avoidance or too low larval density in the sea. Only *Sebastes* larvae occurred in densities high enough to be caught by the pump. The mean length* of *Sebastes* larvae caught by the pump was 8.1 mm ± 3.2, (range 5-18 mm) compared to 11.9 mm ± 1.4, (range 9-15 mm)

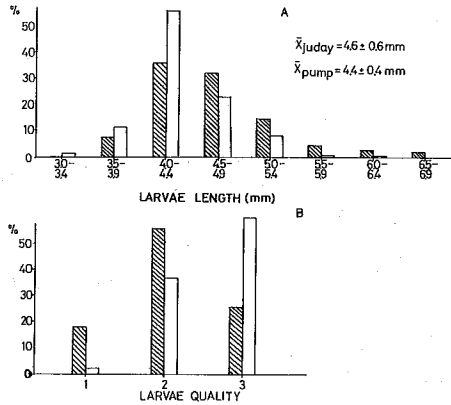


Fig. 9. Comparison between vertical Juday net and submersible electric pump, capacity 3.4 m³/min, water velocity 2.8 m/sec, 1980.

A. Length of cod larvae in mm. ▨ Juday-net (n=212), □ Pump (n=176).

B. Quality of cod larvae. ▨ Juday-net (n=248), □ Pump (n=1034).

from the trawl catches. The similar maximum length from the 2 gears indicates that avoidance of the pumping gear was not very significant. The highest densities of *Sebastes* during night time were found at depths of 10-15 m.

1980. The comparisons between the electric centrifugal pump 2125, Table 1, and the 80 cm Juday net are given in Fig. 9. No full pump profiles were taken. According to length distribution the two gears sampled similarly, but the quality of the pump larvae were rather bad, most probably because of the high water velocity of 2.8 m/s through the hose, (Table 1).

1981 and 1982. The same pump was used in both years (Table 1, Fig. 3). At full speed (2.9 m/s) the larvae were of bad quality. Reducing the speed to 1.5 m/s, (see Table 1) improved the quality considerably and also the length distribution was very similar to the larvae caught with Juday nets.

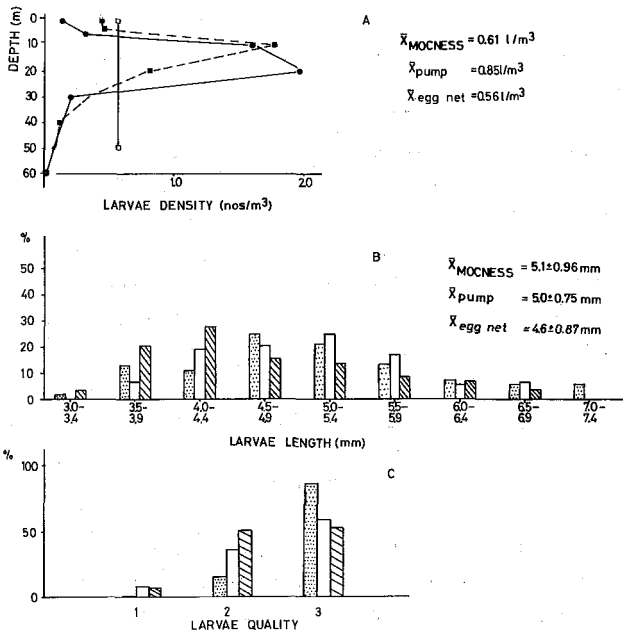


Fig. 10. Comparison between 1 m^2 MOCNESS, speed 1 m per sec, submersible electric propeller pump, 60 m^3 per min, water velocity 1.3 m per sec, and egg net, diam. 112 cm, 1983.

- A. Density of cod larvae per m^3 . ■ Pump, ● MOCNESS, □ Egg net.
- B. Length of cod larvae in mm. □ Pump (n=80), ▨ MOCNESS (n=58), ▩ Egg net (n=60).
- C. Quality of cod larvae. □ Pump (n=145), ▨ MOCNESS (n=398), ▩ Egg net (n=110).

1983. This year a new large pump system was developed and compared with the MOCNESS and a vertical net with a 1 m^2 mouth opening. The comparisons with the MOCNESS were performed by simultaneously performing pump profiles and MOCNESS-hauls around the "pump-vessel" with a radius of about 1 cable length (182 m). The mean values of three paired sets of comparisons are shown in Fig. 10 indicating larval density, size distribution and quality. The larval densities for depth integrated MOCNESS and Juday net samples are more or less identical, those based on pump samples were signifi-

cantly higher as usual. Length distributions from the 3 gears were in good agreement. Larval quality was bad for all gears, the percentage of stage 3 larvae from the vertical net samples was especially high compared to other years. The same filtration system was also used on a cruise with R/V "Lance" in the ice close to Spitsbergen in May-June 1983 to investigate the vertical distribution of plankton under the ice. Both for quantitative and qualitative investigations the system was very suitable. The quality of the plankton, mostly calanoid copepods, ctenophores and chaetognaths, was similar for pump samples and vertical net samples (Hassel and Omli, Institute of Marine Research, Bergen, 1983, pers. comm.).

Factors affecting larval quality

Though the water velocity during filtration is of the same order as in ordinary vertical hauls, it is our experience that adjustment of the mesh size has to be performed with reference to the specific pump system used.

TABLE 5

Larval density at different water flow velocities, filtered through a Juday-net of 375 μm mesh size. Pump U230 (1977, see Table 1).

Mean water velocity m/s	Filtration rate m^3/min	Larval density larvae/ m^3
1.0	1.3-2.0	3.4
1.7	2.4-3.3	1.3
3.4	4.3-7.0	0.4

Table 5 shows the larvae density from the same depth by successive pump samples at different water velocities. The reduced larval density is simply an artifact caused by larvae being squeezed through the meshes at high water velocities.

By changing to a 180 μm mesh size similar larval densities were observed despite different water velocities.

The effect of water velocity on the quality of larvae has also been investigated under laboratory conditions (Fig. 11). In 1981 a series of tank experiments were carried out to investigate the effect of water velocity on larval quality. Laboratory reared cod larvae, 4-5 days old, were released into an outdoor tank and the following samples were taken daily:

1. Control. Larvae kept in a bucket at the same temperature as in the tank were sampled with a pipette and preserved in 4% formaldehyde.
2. Horizontal tows with a 36 cm Juday net of 180 μm mesh size. The net was hauled in the upper meters at speeds of 0.5 and 1.0 m/s and the larvae were preserved immediately in 4% formaldehyde.
3. Pump sampling. 5 min pump samples with pump S181P, 3 m³/min, water velocity 1.5 m/s, filtered in situ in the tank through the same Juday net as in 2.

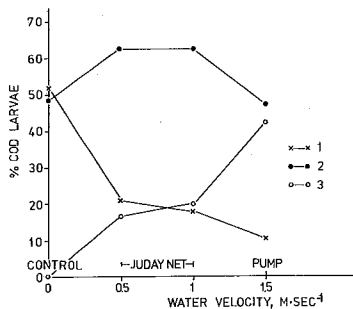


Fig. 11. Tank experiments. Cod larvae sampled by different gears and velocities divided into three categories according to quality. (For further explanation see text).

The results clearly demonstrate the detrimental effects of high water velocities on larval quality. The stomach con-

tents of approximately 30 larvae of similar size from each gear, caught at the same time and space with Bongo-60, Gulf III and pump U-880 in 1979, was investigated with respect to number of nauplii. Bongo-net and pump caught larvae showed an average of 2.8 and 3.0 nauplii per larva, respectively, the Gulf III larvae 1.2 nauplii per larva. The same comparison with MOCNESS, Flygt mixer, and egg net in 1983 showed 2.9, 2.5, and 2.5 nauplii per larva, respectively.

The time from capture to preservation of cod larvae varies considerably between gears, years, vessels etc. It is a multifactor effect where handling, washing routines etc. are also of importance. Fig. 12 summarizes the available data concerning this problem where the quality of cod larvae caught with different gear with partly a similar sampling period, but different water velocity is compared. The sampling period is calculated as the haul period with an addition of 5 min for washing the net and the preserving procedure. Fig. 12 shows that the pump samples from 1977, 1979, 1981, the Juday net hauls and Bongo-60 samples contained the lowest percentage of poor quality (stage 3)

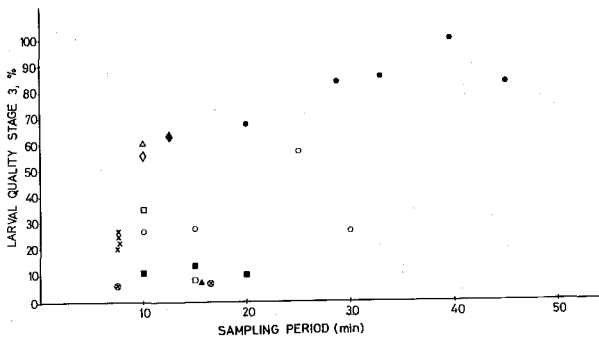


Fig. 12. Proportion of poor larvae quality (stage 3) from different filtration systems as a function of the time period from catching to preservation. ▲ Pump 1977, ■ Pump 1979, △ Pump 1980, ○ Pump 1981, □ Pump 1982, ◇ Pump 1983, ● MOCNESS, x Juday-net, ⊗ Bongo-60, ◆ Gulf-III.

larvae. The effect of sampling time within these gears was not very pronounced. In fact, sampling for 10 or 30 minutes with the 1981-pump did not affect larval quality.

Gear giving high filtration velocities, such as the Gulf III and the 1980-pump, showed a high percentage of stage 3 larvae. The same was the case with the low water velocity, large capacity system in 1983, and the MOCNESS. However, in 1983 the vertical net larvae were also of an exceptional poor quality (Fig. 10). It is also obvious that those larvae caught in the first net of the multinet MOCNESS with a period of 45 min from catch to preservation, were of particular poor quality.

The mean vertical density of the cod larvae based on discrete pump samples has been compared to densities based on vertical net hauls taken simultaneously to the pump profiles. The results are shown in Table 6 and show that the efficiency of the nets is approximately 60% that of the pump.

Student t tests based upon the data given in Table 6 give statistically significant differences in numbers of eggs and larvae caught in the pumps and nets ($0.05 < P < 0.10$ for both eggs and larvae). When taking the separate data for each of the 28 parallels into account, this difference in catch between the two types of gear was very pronounced; a $P < 0.005$ was found for both eggs and larvae.

DISCUSSION

As indicated in the introduction, our objective of this study was to develop a fish larvae sampler which would procure larvae for qualitative studies and data on the concentration of larvae. In addition, the system should allow discrete depths to be sampled and have capacity high enough to ensure adequate samples from strata with very low larval densities. A final requirement was that the system should be suitable for routine use. Of course, the final product had to be the result of compromises.

TABLE 6

Mean densities of cod eggs and larvae sampled with vertical nets and pump systems.

Mean densities, org. per m ³									
Year	Pump type	Vert. net	No. of parallells	Pump		Vert. net.		Vert. net as a % of pump	
				Larvae	Eggs	Larvae	Eggs	Larvae	Eggs
1977	U 230	Juday 80	4	5.40	9.74	2.70	6.68	50	69
1979	U 880	"	8	4.80	9.50	2.70	5.30	56	57
1982	S 181 P	"	13	0.34	0.86	0.20	0.44	59	51
1983	Flygt 4500	Egg net	3	0.85	2.21	0.56	1.52	66	69

The technical solutions of the pump systems developed from the use of submersible, hydraulic centrifugal pumps with moderate numbers of r.p.m. to a slow-rotating propeller of a large diameter.

The on-deck filtration system had the advantage of very accurate volume control, but working the large seawater hose and the stiff hydraulic hoses turned out to be very cumbersome. Filtration was also performed alongside the ship, but with less control of volume. In addition, the hydraulic pump/filtration on-deck system had limited capacity, since filtration volumes $>3 \text{ m}^3/\text{min}$ were detrimental to the cod larvae.

The further developments were based on electrical propeller pumps. Experiments showed that the water velocity greatly affected the condition of the larvae. The final system was built with a water velocity of about 1.5 m/s.

The filtration system was changed to an in situ system. In this way the sampling procedure was greatly simplified and the filtration rate could be increased considerably. The volume control was more problematic, but this problem will be solved by the use of acoustic instrumentation.

In other investigations the pumps used for fish eggs and larvae sampling were not submersible, centrifugal pumps with a filtration rate in the order of 1-9 m^3/min . They were mostly used for surface sampling or sampling on the bottom of shallow areas with a depth of about 10 m (Portner and Rhode, 1977).

Both the on-deck (Leithiser et al., 1979; Aron, 1958) and the alongside-ship methods (Portner and Rhode, 1977; Gale and Mohr, 1978; Cada and Loar, 1982) of filtration have been used.

Fridgeirsson (1984) used a similar submersible hydraulic fish pump as was used in 1977 and 1979 in the present study, with filtration rates ranging from 6 to 30 m^3/min . The samples were filtered through a plankton net in situ, with a flowmeter for volume control. Vertical density profiles of the most common fish eggs and larvae from the surface to 35 m depth are given together with length distributions and number of food organisms in the stomachs. To avoid filtration of the same water twice Fridgeirsson (op. cit.) used a 10 meter rubber hose

from the pump to the net. In 1983 this hose was reduced to 2 m.

The same question about the method arises in the present investigation when filtering large volumes (up to $60\text{m}^3/\text{min}$) in situ from an anchored ship. To illustrate the problem, data from the large system shown in Figs. 4 and 5 are used. The largest samples filtered were 180m^3 . The water entered from a sphere around the entrance of the system, the radius of which would have been about 3.5 metres. Considering the dimensions given in Fig. 4, and remembering that the filtered water was directed away from the system, the mixing of filtered and nonfiltered water would have been negligible.

The size distribution of larvae captured by the pumps was always similar to that of larvae from the vertical net hauls. Both gears seem to sample larvae up to a length of 6 mm which is within the period of first feeding of cod larvae. However, parallel hauls with the Bongo-60 and particularly with the Gulf III high speed sampler demonstrated the existence of larger larvae. In 1983 pump, MOCNESS and vertical net samples had a similar length distribution up to 6.5 mm.

No ichthyoplankton sampling technique is completely effective in collecting all size-groups of fish larvae. Investigations comparing larval size distribution from pumps and net sampling are conflicting. The catching efficiency of different gears depends upon larval size (Portner and Rhode, 1977; Leithiser et al., 1979) and hours of sampling (Cada and Loar, 1982). In some investigations pumps and nets were found to catch equally well (Gale and Mohr, 1978). Against this background it is difficult to generalise on the comparisons of pumps and plankton nets according to size distribution of larvae. It should be borne in mind, however, that most of the comparisons were carried out in the surface layers of rivers and estuaries with probably larger horizontal density gradients than in the marine water sampled in the present investigation.

In case the larvae sampled are to be subject to individual analyses of e.g. gut content, age staging, length and weight measurements, it is of importance that as few larvae as pos-

sible are damaged during sampling, and therefore appear in stage 3 (poor quality). It has often been observed that planktonic organisms are taken in poorer condition at high towing velocities. Small changes in velocity will lead to relatively large changes in filtration pressure (Tranter and Smith, 1968). Our tank experiments have shown an obvious detrimental effect on cod larvae due to increasing approach velocities.

During field sampling the first pump systems tested had the lowest water velocity and procured the best quality larvae, better than larvae sampled with vertical nets. Larvae caught by vertical nets showed a very stable quality throughout the period. Larvae sampled with the Bongo-60 were also of very good quality.

On the contrary the Gulf-III high-speed sampler procured a large proportion of quality stage 3, i.e. they could only be used for enumeration. Further, the usual sampling volume is too small to give adequate numbers of cod larvae with this gear (Fridgeirsson, 1984).

The filtration rates of the first pump systems were rather low ($2-3 \text{ m}^3/\text{min}$) and for practical purposes could only be used at high larval densities. Increasing filtration rates and changing to in situ filtration procured a larger number of acceptable quality larvae, though the percentage of damaged larvae increased. It should be borne in mind that not only the water velocity but also the time from catch to preservation seriously affects the quality of the cod larvae. This was most pronounced during sampling with the MOCNESS, where the time lag between the first and last sampled cod larvae was more than 25 min.

Cod larvae of acceptable quality, i.e. stages 1 and 2, were also examined for to numbers of food particles in the stomach. Larvae sampled with the Gulf-III in 1979 had significantly lower numbers of nauplii in the gut compared to simultaneous samples with the pump and Bongo-60 from the same depth. No difference in numbers of nauplii in the gut of larvae caught by pump and MOCNESS were found in 1983. It must be concluded that

the pump procures representative larvae for qualitative investigations up to a size of 6.0-6.5 mm.

Few systematic investigations exist on the quality of fish larvae sampled by different gear, and no investigations include cod larvae. Gale and Mohr (1978) tested net material, mesh size, net shape and pumping duration, and found the best condition in 5 min samples pumped into slender nets.

Leithiser et al. (1979) simply states "The condition of pump-caught larvae (all sizes) was similar to that of larvae in net samples." The same is reported by Portner and Rhode (1977). King et al. (1981), however, considered pump damage to be a potential factor in their comparisons.

Of marine fish larvae, herring seems to have been investigated most systematically with regard to quality. When catching herring larvae using Bongo nets it was found that only 3% of the larvae had an intact yolk sac at a towing speed of 3.5 knots, while 50% were intact at 1.5 knots (Colton et al., 1980). Similar results on Pacific herring larvae were reported by Hay (1981). This clearly demonstrates the difference in susceptibility to damage during capture between cod and herring larvae, obviously related to the anatomical differences in the gut system.

Quantitative comprehensive comparisons between pump systems and other samples are few (Bowles and Merriner, 1978). The present investigation does not allow quantitative comparisons between pump systems since the towed plankton nets were not equipped with flowmeters. The volumes were calculated on the basis of net diameter and towing distance.

However, the present investigation shows that the nets, and especially the vertically hauled nets, have a rather small and unsatisfactory catching efficiency both with regard to cod eggs and larvae. If there had been a pronounced difference in the quantities of cod larvae sampled in nets and pumps, but not in egg numbers, this discrepancy could have been explained by a higher avoidance in nets by the larvae, due to their swimming ability, as the water velocities in the entrance of the pumps and nets are approximately 1.0 and 0.5 m per sec., respectively.

Since the egg numbers are also subject to this discrepancy, it seems that the reason is a lower filtering efficiency of the nets. The "open area ratio" of the nets used in the present investigation was always 3.0 or higher, and should theoretically provide efficient filtration (Tranter and Smith, 1968). The causes for the reduced filtration in the nets may be several; e.g. clogging in cases of rich primary production, bridles in front of the nets.

Comparisons between pump sampling and nets equipped with flowmeters show conflicting results. Generally, Cada and Loar (1982) state: "Based solely on a consideration of sampler intake velocities and the resultant potential for avoidance, it would generally be expected that pumps are more effective than fixed nets, that towed nets are more effective than low volume pumps, and that high volume pumps are equally or more effective than towed nets in collecting ichthyoplankton." These patterns have been demonstrated in some studies (Leithiser et al., 1979; Leithiser and Davidson, 1981; Zeitoun et al., 1981; Cada and Loar, 1982). Other studies conflict with the general statement given above (Portner and Rhode, 1977; Gale and Mohr, 1978; King et al., 1981).

Though no quantitative comparison with traditional gear is possible for the pump system used during the years 1977-82, the large filtration system introduced in 1983 was compared to the MOCNESS, which had a volume control. The larval densities estimated by the 2 gears were very similar, and it is concluded that the large filtration system, which will be developed further, gives quantitative samples of cod larvae within the size groups up to 6.5-7.0 mm.

REFERENCES

- Aron, W., 1958. The use of large capacity portable pump for plankton sampling, with notes on plankton patchiness. *J. Mar. Res.*, 16: 158-173.
- Bowles, R.R. and Merriner, J.V., 1978. Evaluation of ichthyoplankton sampling gear in power plant entrainment studies. In: L.D. Jensen (Editor), Fourth National Workshop on

- entrainment and impingement. EA Communications, Melville, NY, pp. 33-43.
- Cada, G.F. and Loar, J.M., 1982. Relative effectiveness of two ichthyoplankton sampling techniques. *Can. J. Fish. Aquat. Sci.*, 39: 811-814.
- Colton, J.B., Green, J.R., Byron, R.R. and Frisella, J.L., 1980. Bongo net retention rates as effected by towing speed and mesh size. *Can. J. Fish. Aquat. Sci.*, 37: 606-623.
- Ellertsen, B., Moksness, E., Solemdal, P., Strømme, T., Tilseth, S., Westgård, T. and Øiestad, V., 1977. Vertical distribution and feeding of cod larvae in relation to occurrence and size distribution of prey organisms. *Coun. Meet. int. Coun. Explor. Sea*, 1977(L:33): 1-31. (Mimeo.)
- Ellertsen, B., Solemdal, P., Sundby, S., Tilseth, S., Westgård, T. and Øiestad, V., 1981a. Feeding and vertical distribution of cod larvae in relation to availability of prey organisms. *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, 178: 317-319.
- Ellertsen, B., Solemdal, P., Strømme, T., Sundby, S., Tilseth, S., Westgård, T. and Øiestad, V., 1981b. Spawning period, transport and dispersal of eggs from the spawning area of Arcto-Norwegian cod (*Gadus morhua* L.). *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, 178: 260-267.
- Ellertsen, B., Solemdal, P., Sundby, S., Tilseth, S., Westgård, T. and Øiestad, V., 1981c. Some biological aspects of cod larvae (*Gadus morhua* L.). *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, 178: 316-319.
- Ellertsen, B., Fossum, P., Solemdal, P., Sundby, S. and Tilseth, S., 1984. A case study on the distribution of cod larvae and availability of prey organisms in relation to physical processes in Lofoten. In: E. Dahl, D.S. Danielsen, E. Moksness and P. Solemdal (Editors), *The Propagation of Cod (Gadus morhua L.)*, Flødevigen Rapportser., 1, 1984: 453-477.
- Fridgeirsson, E., 1984. Cod larvae sampling with large pump at SW-Iceland. In: E. Dahl, D.S. Danielssen, E. Moksness, and P. Solemdal (Editors), *The Propagation of Cod (Gadus morhua L.)*, Flødevigen Rapportser., 1, 1984: 317-333.
- Gale, W.F. and Mohr, H.W. Jr., 1978. Larval fish drift in a large river with a comparison of sampling methods. *Trans. Am. Fish. Soc.*, 107: 46-55.
- Hay, D.E., 1981. Effects of capture and fixation on gut contents and body size of Pacific herring larvae. *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, 178: 395-400.
- Hjort, J., 1914. Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. *Rapp. P.-v. Réun. Cons. int. Explor. Mer*, 20: 1-228.
- King, L.R., Smith, B.A., Kellogg, R.L. and Perry, E.S., 1981. Comparison of ichthyoplankton collected with a pump and stationary plankton net in a power plant discharge canal. In: L.D. Jensen (Editor), *Issues associated with impact assessment. Proceedings of the fifth national workshop on entrainment and impingement*. EA Communications, Melville, NY, pp. 267-275.
- Leithiser, R.M., Ehrlich, K.F. and Thum, A.B., 1979. Comparison of a high volume pump and conventional plankton nets for

- collecting fish larvae entrained in power plant cooling systems. *J. Fish. Res. Board Can.*, 36: 81-84.
- Leithiser, R.M. and Davidson, B.M., 1981. Evaluation of a sampling methodology used for assessment of plankton entrainment rates and source water plankton abundance. In: L.D. Jensen (Editor), *Issues associated with impact assessment. Proceedings of the fifth national workshop on entrainment and impingement.* EA Communications, Melville, NY, pp. 247.
- May, R.C., 1974. Larval mortality in marine fishes and the critical period concept. In: J.H.S. Blaxter (Editor), *The early life history of fish.* Springer-Verlag, Berlin, pp. 3-19.
- Portner, E.M. and Rhode, C.A., 1977. Tests of a high-volume pump for ichthyoplankton in the Chesapeake and Delaware Canal. Report JHU PPSE-T-3 Applied Physics Laboratory, John Hopkins University, Laurel, MD, USA, 50 pp.
- Tilseth, S. and Ellertsen, B., 1984. The detection and distribution of larval Arcto-Norwegian cod, *Gadus morhua* L., food organisms by an in situ particle counter. *U.S. Fish. Bull.*, 82(1). In press.
- Tranter, D.J. and Smith, P.E., 1968. Filtration performance. In: D.J. Tranter (Editor), *Zooplankton sampling. Monographs on oceanographic methodology 2,* UNESCO, pp. 27-56.
- Wiebe, P.H., Burt, K.H., Boyd, S.H. and Morton, A.W., 1976. A multiple opening/closing net and environmental sensing system for sampling zooplankton. *J. Mar. Res.*, 34: 313-326.
- Zeitoun, I.H. and Gulvas, J.A., 1981. Effectiveness of fine mesh cylindrical wedge-wire screens in reducing entrainment of Lake Michigan ichthyoplankton. *Can. J. Fish. Aquat. Sci.*, 38: 120-125.