Journal of the Marine Biological Association of the United Kingdom Vol 31 No 1 1952

THE AQUARIUM AND SEA-WATER CIRCULATION SYSTEM AT THE PLYMOUTH LABORATORY

By Douglas P. Wilson, D.Sc., F.R.P.S.
Zoologist at the Plymouth Laboratory

(Plate I and Text-figs. 1–4)

Introduction

The aquarium or tank room, to which visitors are admitted on payment of a small charge, was not designed primarily for public display, but was intended principally to facilitate scientific observations on the habits and life histories of marine animals. This original purpose it has never lost, but of recent years it has increasingly catered also for the steadily growing number of people interested in natural history, and for numerous classes of school-children brought by their teachers. Since the aquarium was re-opened in November 1946 attendances have shown a big increase over comparable pre-war figures.

The aquarium is over sixty years old. The fact that during the whole of that time the same tanks, the same reservoirs and much of the same piping have continued to serve without major trouble is a tribute to its designer and builders. The circulating system still in use was invented by W. Lloyd and was widely adopted for the public aquaria which were a popular feature of many towns towards the end of the last century. The system was also adopted at Naples. That is not to say, however, that the design and construction at Plymouth are ideal. Long experience, greater knowledge and changing function all emphasize the desirability of alterations for the benefit of the inhabitants of the tanks, for greater efficiency in working and for better viewing conditions for the observers, be they naturalists or general public.

Some improvements have been made since the war, during the repair and re-establishment necessitated by the damage suffered during air-attacks in 1941. These chiefly concern the erection of new rockwork in several of the large tanks, and the provision of boards along the top edges of the latter to shield the viewer's eyes from window-glare. Electric lighting for dull days has also been provided.

That the reputation of the Association's aquarium stands high is shown by the numerous inquiries concerning its size, construction and maintenance received during the post-war years. Promoters and architects for aquarium schemes at home and abroad have written, or called for information and advice. Some have even brought plans for criticism. It is probable that not a few large public aquaria projected or building have been influenced in design by ideas and suggestions based on experiences at Plymouth. This world-wide interest in aquarium construction and management, and the rising numbers of visitors to our own aquarium, implies a need for a fairly detailed published account of the Plymouth aquarium as it exists to-day. Many details are equally applicable to marine aquaria anywhere, and should therefore be of interest to planners of all large installations.

The Aquarium or Tank Room

The last fairly detailed account published is that by Allen & Harvey (1928). The dimensions they gave were from an old plan and differ a little from those given here, based on new measurements. Widths and lengths of tanks are given to the nearest $\frac{1}{4}$ ft.; these measurements are all internal. The reader will find it helpful to refer frequently to the plan and section shown in Text-figs. 1 and 2.

The tank room or aquarium (Pl. I) is situated on the ground floor of the south building. It is a single large room measuring internally 70 ft. × 30 ft. (Allen & Harvey give the width as $34\frac{1}{2}$ ft., but this includes the thickness of the walls), with a minimum ceiling height of $11\frac{1}{4}$ ft. The ceiling consists of seven shallow vaults. The room is entered and left by a wide doorway at the west end (seen in the photograph). A private doorway at the east end is normally kept locked.

South-Side Tanks

The whole of the south side is occupied by nine tanks built close against the wall. All are a little over 4 ft. wide (front to back) and $4\frac{1}{4}$ ft. high with a water depth of about $3\frac{1}{4}$ ft. Their lengths, in order from the west end, are $10\frac{1}{2}$, 10, $15\frac{1}{4}$ ft. and six tanks averaging about 5 ft. each. The viewing panels or openings of the four cast-iron frames holding the glass fronts are all about 4 ft. $7\frac{1}{2}$ in. long × 3 ft. high. The first two tanks have two viewing panes each (one frame holding all four), the third three (one frame). The plate-glass panes are all $1\frac{1}{16}$ in. thick and the slate backs, sides and bottoms are $1\frac{1}{2}$ in. thick. The slate bottoms of these tanks are $2\frac{1}{4}$ ft. above the tank-room floor. The lower edges of the viewing panels are $29\frac{1}{2}$ in. above floor-level.

North-Side Tanks

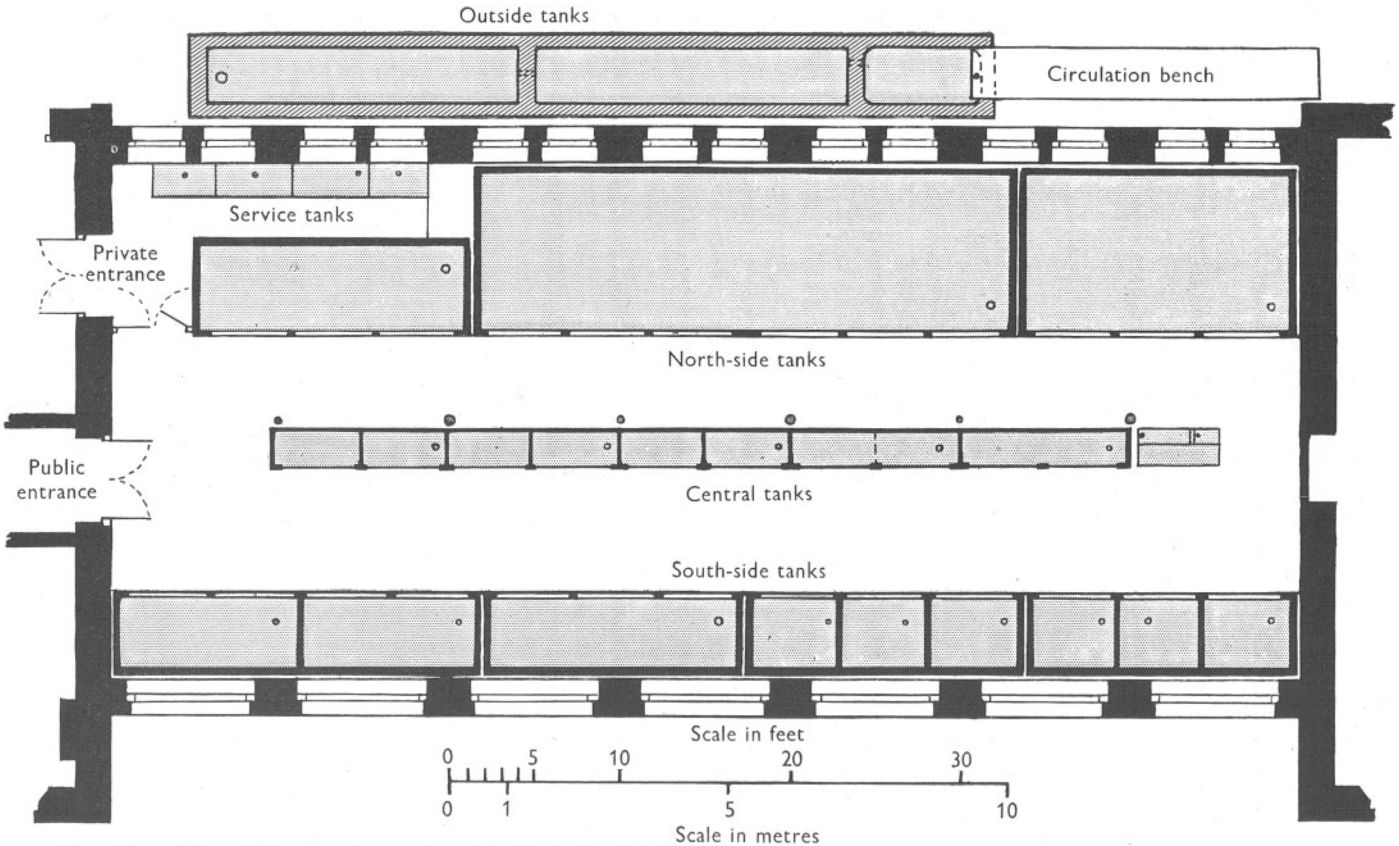
On the north side of the aquarium there are three large tanks, all about $5\frac{1}{4}$ ft. high with a water depth of about $4\frac{1}{4}$ ft. Their lengths and widths, in order from the east end, are $15\frac{3}{4} \times 9$, 31×9 and $15\frac{3}{4} \times 5$ ft. The first two back against the north wall, but the last has a $4\frac{1}{4}$ ft. wide passage between it and the wall; this passage contains four shallow service tanks. A doorway between the west end of this tank and the west wall of the room excludes the public from this passage and serves as a private entrance to the aquarium.

The viewing openings of the four cast-iron frames (each of three openings) holding the glass fronts of these north-side tanks are all about 4 ft. $7\frac{1}{2}$ in. long $\times$ 4 ft. high. The two shorter tanks have three glass panes each, the longest six. The plate-glass panes are all $1\frac{1}{16}$ in. thick and the slate backs, sides and bottoms are 2 in. thick. The internal bottom-level of these tanks is 2 ft. 2 in. above tank-room floor-level. The lower edges of the viewing panels are about 29 in. above floor-level.

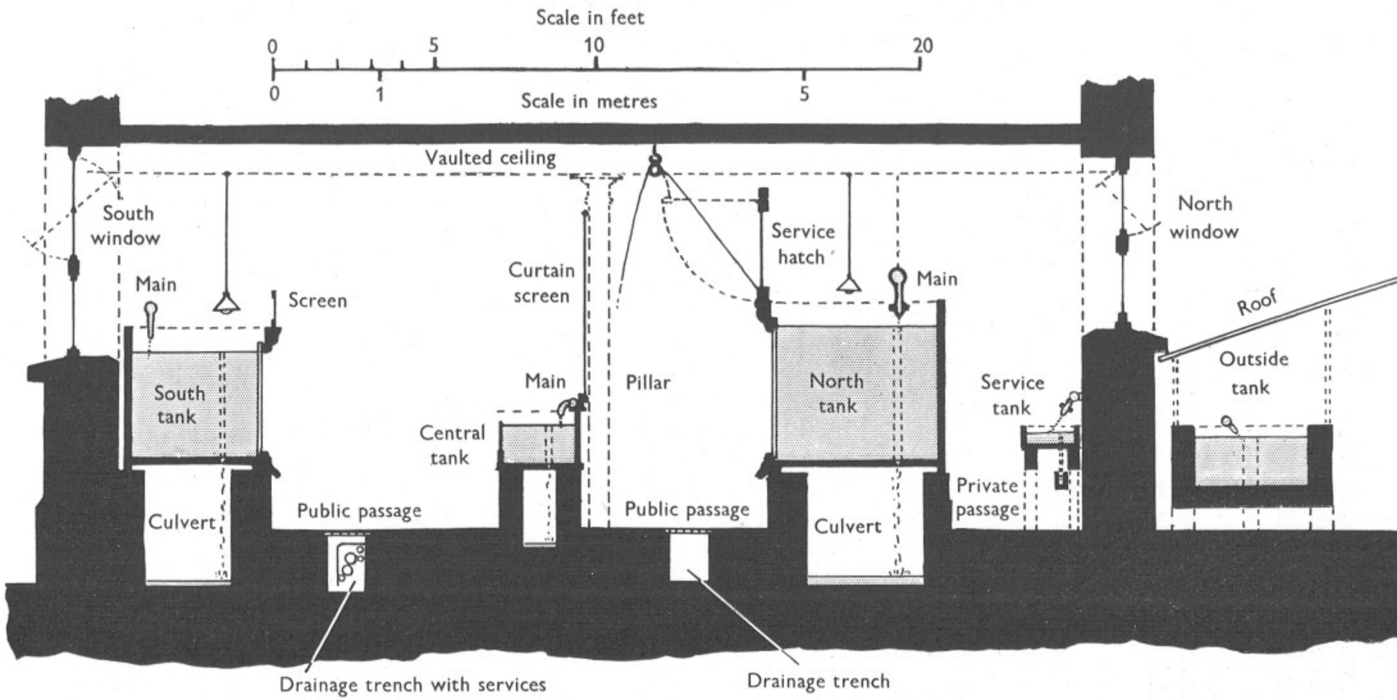
Glazing

The plate-glass panes of the north- and south-side tanks are not set in grooves. The cast-iron frames have machined facings which, when a pane is to be set, are covered with a suitable composition. The bottom edge of the pane is placed on two small composition-covered hardwood blocks, one at each end, and is eased into contact with the composition on the facing along the bottom edge of the frame. The whole pane is then raised into the vertical position and pressed home against the composition all round. It is then tightened against the composition with the aid of wooden shores, battens and folding wedges until the composition begins to ooze out all round in front. The tank is now flooded and the rising water pressure forces the pane in more firmly still. Eventually no more composition is squeezed out and battens and boards float to the surface. To ensure that no air pockets remain in the sealing composition a wooden wedge is used to ram in all round as much composition as can be forced between the glass and the facings of the iron frame. A wooden turn-buckle fixed to the top of the frame ensures the safety of the glass should it accidentally be pushed backwards when the water-level in the tank is lowered during cleaning or other operations. When the tank is full the pressure of water is amply sufficient to keep it in place.

For many years the sealing composition was a mixture of white lead ($7\frac{1}{2}$ lb.), powdered whiting ($1\frac{1}{4}$ lb.) and russian tallow ($\frac{1}{2}$ lb.). This mixture eventually sets hard and may crack away from the glass, giving rise to leaks. When a pane had been set for several months it was no longer advisable to lower the water level, or to empty the tank, without being prepared to reset the pane. More recently the commercial preparation 'Glasticon' (manufactured by Industrial Engineering Ltd., Mellier House, Albemarle Street, London, W. 1) has proved superior; it does not dry hard and therefore does not crack away from glass or frame. It has the additional advantage that should a leak develop (a rare occurrence) caulking can often be undertaken successfully from the *outside*. This preparation is now used for all the tanks and over a period of five years has given no trouble.



Text-fig. 1. Plan of the aquarium and outside circulation. Tanks containing sea water stippled. The small circles inside the tanks mark the positions of the overflows.



Text-fig. 2. Section through the aquarium near the west end. Sea water stippled.

Central Pillars and Screen

Down the middle of the tank room a row of six iron or steel pillars support the vaulted ceiling and the first floor of the laboratory. These are centrally placed between the outside walls of the building, but because the north side tanks are wider than those on the south side they appear to be sited asymmetrically. A screen or curtain of dark painted fabric is hung between these pillars to prevent the reflexion in the north-side glass panes of the south-side windows which are visible over the tops of the south-side tanks.

Central Table Tanks

Backing up against the pillars and the curtain is a series of five slate table tanks with glass fronts facing south. They are nearly 10 ft. long and $2\frac{1}{4}$ ft. wide and have a height of $1\frac{1}{2}$ ft. at the front, being some inches higher at the back and sides. The top edges of the ten $\frac{1}{2}$ in. plate-glass panes held in grooves in the slate are rounded and polished, and are only $3\frac{1}{2}$ ft. above floor-level. An adult is thus able to bend over the tank and inspect the contents from above, in addition to viewing them from the front if he stoops down. The water-level in these tanks varies from 8 to 15 in. according to the nature of the display. Most of the tanks are divided into two by a central partition. At the east end of the series a shallow wooden table tank has been added and above it are two small wooden tanks with glass fronts and backs so that they may be viewed from both sides. There is also a small glass-fronted slate tank above the central table tanks near the middle of the series. This is seen in the photograph in Pl. I, but has not been indicated in the plan (Text-fig. 1.)

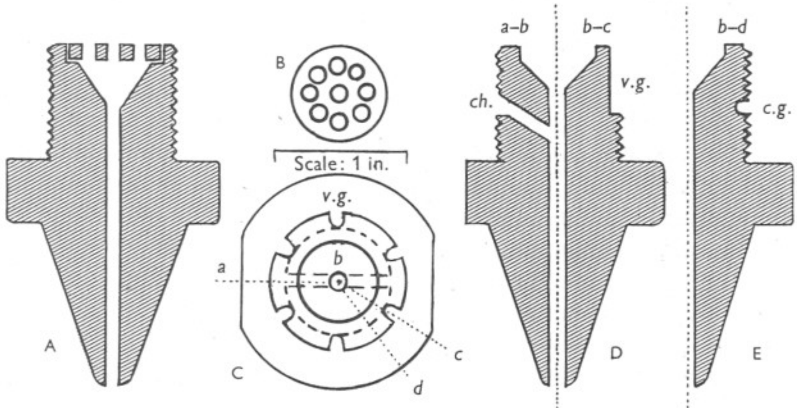
Designers of new aquaria should note that open table tanks are not entirely satisfactory for public display; they are a temptation to boys and some adults to interfere with their contents.

Culverts

The tanks are all built over culverts (originally termed 'circulating reservoirs') which receive the overflow water and return it to the reservoirs. The culverts on the north and south sides are about 3 ft. 9 in. high and almost as wide as the tanks above. Entry to the south-side culvert is through the floor of the westernmost tank; it is normally covered by a large slate sealed around the edges. This is an unsatisfactory arrangement, for the culvert can only be entered when this tank is drained. The north-side culvert can be entered by the west end of the largest tank at any time; the culvert of the central table tanks cannot be inspected at all. Under the two largest tanks on the north side a series of 9 in. brick pillars are staggered down the centre of the very wide culvert to support the weight of the tank floor near the middle. All culverts are lined with asphalt.

Inflow nozzles

Sea water pumped from the reservoirs enters the main tanks through a series of vulcanite nozzles situated generally towards the backs of the tanks and a few inches above water-level. Some nozzles are controlled by stopcocks. The smallest tanks are each supplied with two nozzles, the others with more according to size. Two nozzles are an absolute minimum for safety, owing to the risk of occasional blockage by foreign bodies. A blocked nozzle may not be noticed for hours, especially during the night, and there is a real danger of fishes in a tank dying before the absence of circulation to that tank is noticed.



Text-fig. 3. Diagrams of vulcanite nozzles modified to delay blockage by debris. A, vertical section of a nozzle provided with a perforated Perspex plate, shown in plan at B. Another method of modification, devised by Mr A. N. Bennett, is shown at C–E. C, plan from above; D, sections *a–b* and *b–c* as indicated on C. E, section *b–d* indicated on C. Six vertical grooves, or channels, *v.g.*, are cut through the screw thread to conduct water to a circular groove, *c.g.* From opposite sides of this circular groove are bored two downwardly sloping holes or channel-ways, *ch.*, to tap the central bore of the nozzle. Until the entrances to the central bore and all six vertical channels are blocked the nozzle continues to function.

Blockage of the nozzle is caused generally by pieces of sponges (*Halichondria bowerbanki* and *Sycon coronatum*) breaking off from growths in the pipes. This is a constant source of trouble. Most nozzles are now provided with a perforated disk fitted internally across the full bore of the pipe (Text-fig. 3 A, B), or have several channel-ways cut so that all channel-ways have to become blocked before the nozzle ceases to function (Text-fig. 3 C–E). This latter method, devised by Mr A. N. Bennett, the engineer in charge of pumps and pipes, has proved very satisfactory.

The water passing through a nozzle is forced down into the tank as a strong jet, often carrying with it an inverted fountain of bubbles. It is certain that only a fraction of this water reaches the bottom, much of it being quickly lost down the overflow, which draws off surface water. To lessen this loss of newly injected circulation water there have in most tanks been placed one or more pipes of 3–4 in. bore, hung vertically from just above surface-level to within a few inches of the bottom. Water from one or more nearby inflow nozzles is conducted by rubber tubing into the top of each such pipe which ensures that the whole of it is led to the bottom. This arrangement has improved the health of the inhabitants of all tanks where it is in use. In the central table tanks glazed earthenware pipes, painted with black bitumastic paint, serve a similar purpose and keep the surface free from the ripples which, before they were used, obscured much of the view.

Overflow pipes

Each of the tanks has a single overflow pipe at one side and usually to the front. This is a vulcanite pipe of bore varying from 1 to 4 in. according to the tank. Its lower end is tapered and fits into a vulcanite seating, tapered to receive it, in the bottom of the tank. To empty a tank the overflow pipe is simply pulled up and the water rushes out through the hole thus opened in the tank floor. Overflowing water drains into the culvert under the tanks and is thereby returned to the reservoir in use, flowing into it at the surface against the north wall. The depth of water in the wide airy culverts (there are ventilators to the culverts through their walls from the outside of the building) increases from a fraction of an inch to 1 or 2 in. towards the reservoir end; good aeration therefore takes place before the water reaches the reservoir.

To obviate flooding in the event of an overflow pipe becoming blocked there are perforated vulcanite grids let into the slate sides of the tanks just above water-level. A stoppage of the overflow pipe results in a slight rise in the water-level of the tank which then overflows into its neighbours on either side.

Drainage Trenches

The floor of the aquarium in the public gallery contains two trenches 18 in. wide and 18 in. to 2 ft. deep, running the whole length of the tank room about 2 ft. in front of the north and south tanks. They are covered by iron gratings level with the rest of the floor, which is of concrete. In addition to containing various service pipes for the laboratory they function as drains running to waste and will carry away water overflowing on to the floor. They are useful when a tank is cleaned by siphoning, as described below (p. 206).

Lighting

Tanks are normally lit only by daylight through the windows. The tanks of the south side receive most light, but direct sunlight is now diffused by ground glass fitted into the south-side window frames. Formerly, when the windows were of clear glass, narrow sunbeams passed through the tanks and their dazzling brilliance made it difficult to see anything outside their range.

On the north side the lighting is always diffused and, except on bright days, is insufficient to light the tanks adequately. The smallest tank on this side is especially dark for, owing to the passage behind it, direct light from the windows hardly penetrates into it and what it does get is mainly reflected from the white ceiling above. Various devices have been tried to improve the lighting of this tank; at the present time independent electric lighting by three 60 W. daylight bulbs raises the intensity of the illumination to near that of the largest tank next to it, and is proving more satisfactory than reflectors.

The top front edge of the row of south-side tanks is only $6\frac{1}{4}$ ft. above floor-level and before the war the eyes of visitors were dazzled by direct light from the sky seen through the high arched windows behind the tanks. If the eyes were shielded with the hand, or the rim of a hat, visibility into the tanks was greatly increased, details not before visible becoming apparent. Therefore, during the reconstruction after the war, a 14 in. high plywood screen was erected along this top front edge so that the tops of the windows could no longer be seen from a normal viewing position. It was not possible to carry this screen close up to the ceiling (as was done on the north side) on account of the central table tanks. These are lit only by light passing over the screens to be reflected from the white ceiling above them. The screen is painted white on the window side to reflect light on to the backs of the tanks which formerly were barely visible. The screen is easily removable in sections to facilitate siphoning or other work.

The north-side screen almost reaches the ceiling, leaving a narrow gap for ventilation. At intervals there are hatchways for feeding, glass-cleaning and similar purposes. If ever the central table tanks are removed it would be advantageous to treat the south side in the same way, namely to extend the present low screen to near the ceiling and to provide appropriate hatchways. If this were done the central screen between the pillars would no longer be needed and the aquarium would become a fine hall lit only by light passing through the tanks.

In addition to the special electric lighting of the dark tank on the north side, electric lighting has recently been installed over all tanks (except the table tanks) for use on dull days, or after dark. Ordinary 60 W. pearl bulbs (not daylight type) in white plastic reflectors, approximately one to every glass pane, give very good illumination; they hang a few inches above water-level towards the fronts of the tanks. The general appearance of the tanks after darkness with these lights on is better than their appearance by day without them. This is probably due almost entirely to the direction of the light, coming from the top front of the tank instead of from the back. By day the side of the fish away from the observer is more brightly illuminated than the side which is on view. Only a few semi-transparent organisms are enhanced by back-lighting in the absence of frontal lighting.

Decorative Rockwork

To relieve the bare appearance of the slate tanks, and to improve living conditions for the inhabitants, most of the large tanks have rockwork built into them. Some of the original rockwork, dating from the time the tanks were first erected, can be seen in the largest tank on the north side. This original rockwork consists of lumps of calcite stuck together and to the slate walls with pitch. No attempt was made to achieve a natural effect. In 1946, when war damage to the aquarium was repaired, new rockwork was added to several of the tanks and much of the old rockwork reinforced with concrete. For the new rockwork, which was built by our own staff, waterworn limestone was obtained from the foreshore at Cattedown (district of Plymouth) and care was taken to arrange and cement the slabs to give an appearance of natural stratification and to provide suitably shaped holes for octopus, lobsters, conger eels, etc. In one tank stalagmitic rocks have been used with good effect. The floors of the tanks are covered with sand or shell gravel or with water-worn pebbles in accordance with the species kept in them. Wherever slate backs and sides are uncovered by rockwork they are painted over with 'Bituros', a black bituminous paint used for drinking-water tanks and manufactured by Wailes-Dove Bitumastic Ltd., Hebburn, Durham.

Labelling

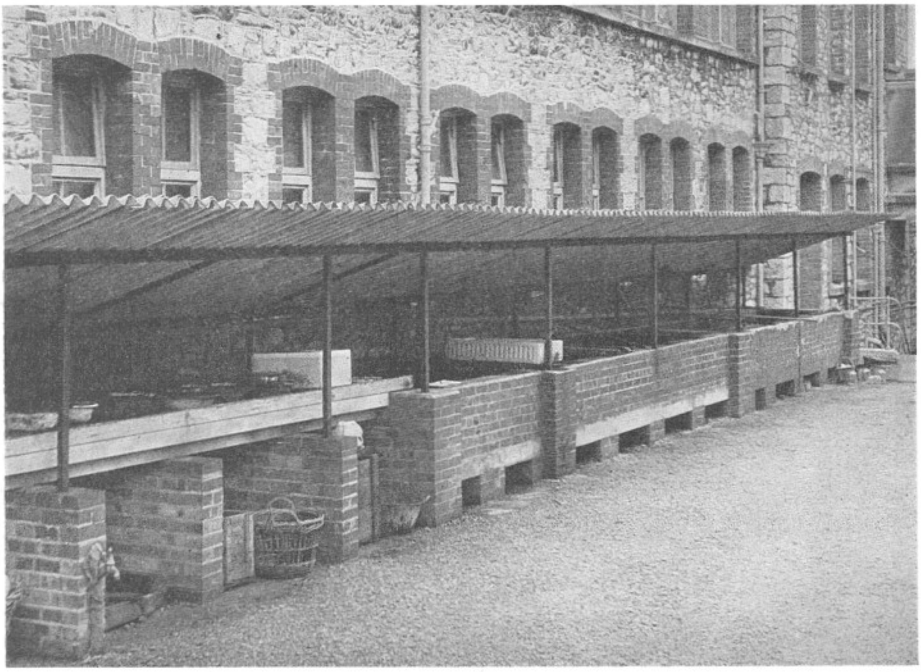
Lead frames containing labels are screwed to moulded wooden sills on the north- and south-side tanks. Name labels are constructed by pasting a printed paper sheet face down on to glass and backing with a sheet of white opal glass stuck on with paraffin wax. Picture labels are painted and lettered in water colour on good quality drawing paper and sandwiched between thin sheets of Perspex sealed around the edges. This is undertaken by a firm specializing in the process. Such Perspex labels should be permanently waterproof.

Outside Circulation

In the yard between north and south laboratory buildings there are three asphalt-lined brick and concrete storage and acclimatization tanks and a circulation bench for bowls (Text-fig. 4). They are built against the north wall of the south building and are screened from sky and rain by a pitched roof of corrugated asbestos but are otherwise open to the outside air. Two of these measure internally approximately 18 ft. 6 in. × 3 ft. 6 in., the water depth being 1 ft. 6 in.; they can be divided into smaller compartments by movable wooden partitions. The third tank is only 7 ft. long, but is similar in width and depth. Water is supplied by a series of jets from an iron pipe. Although very rusty, this pipe has already given adequate service for several years.

Laboratory Tanks

In the main laboratory on the first floor are tanks of various sizes for storage and research. There are eight rustless-steel framed tanks with 1 in.-thick slate bottoms and sides and $\frac{1}{2}$ in.-thick plate-glass fronts. The three largest measure 4 ft. × 2 ft. 4 in. × 1 ft. 6 in. deep externally. There are also sixteen porcelain sinks, 2 ft. × 1 ft. 6 in. external measurements, eight 10 in. deep externally, four 8 in. deep and four 6 in. deep. Two shallow table tanks, made



Text-fig. 4. View of the outside circulation showing portion of circulation bench and the three asphalt-lined brick and concrete tanks. The two sink-tanks are temporary additions.

from $1\frac{1}{2}$ in. thick teak measure externally 7 ft. × 5 ft. × 9 in. and 5 ft. × 3 ft. × 9 in. The water depth is only $6\frac{1}{2}$ in. With such a relatively great surface area one or two small nozzles suffice to keep a great variety of small animals alive. These tanks are indeed among the most successful for small organisms. Such tanks are unfortunately not suitable for public display owing to the ease of access to their contents.

Most of the tanks just described can be seen in photographs reproduced by Russell (1948, plate XIX). In these photographs it will be observed that provision is also made for giving circulation to bowls, etc., placed on slate circulation benches.

Overflow water from these laboratory tanks and from the circulation benches runs directly into exhibition tanks in the public aquarium on the ground floor below. This is a bad arrangement, because from time to time silty water produced by activities in the laboratory clouds the exhibition tanks into which it is discharged and adds considerably to the labour of siphoning needed to keep them reasonably clean.

In conjunction with the Specimen Supply Department in the north building there are four sink tanks and a small circulation bench. Formerly this had its own separate pump to supply water from one of the reservoirs, but of recent years an iron pipeline has been installed to supply it direct from the main pump.

The Reservoirs

Sea water is pumped into the tanks from one of two large reservoirs, each 37 ft. × 21½ ft., holding water 11 ft. deep. They are used alternately. The reservoirs were excavated in the solid limestone north of the aquarium at the time the latter was built; they were completed with concrete and lined with asphalt. They lie below general ground-level and are roofed over with a concrete flat to shield them from light and rain. Each holds about 55,000 gallons, or about two and a half times the total volume of water in the tanks, including those in the main laboratory on the first floor and the large specimen storage tanks in the yard outside.

Overflow water from the aquarium is discharged into the reservoir in use at the surface in a corner by the north wall. The outflow to the pumps is sited about 3 ft. from the bottom not far from a corner on the south wall. A complicated swirl is set up throughout the reservoir and there is no completely stagnant corner. In some parts the water moves extremely slowly; in other places and at different levels it moves much faster (determined by drift-bottles). It seems possible that some of the water returned from the aquarium is drawn off again to the pumps before water which has been in the reservoir for a longer time. The swirl must hinder the settlement of slowly sinking detritus brought from the tanks and much of this detritus is pumped back into the tanks again (see p. 209 for a suggested method of dealing with this problem).

The Engine Room

The engine room is in the basement and its floor is about level with that of the reservoirs. Circulation is maintained by one of two centrifugal pumps driven by electric motors. The older pump is a cast-iron 2 in. pump driven by a 3 h.p. motor; the newer one is a cast-iron 2½ in. pump driven by a 2 h.p. motor. Water drawn from one or other of the reservoirs at a point in the south wall about 3 ft. above the bottom is pumped at over 50 gallons a minute against a head of about 40 ft. through 2 in. cast-iron glass-lined piping to the main vulcanite pipes serving the tanks.

The pump impellers are of cast-iron mounted on stainless-steel spindles. A cast-iron 2 in. centrifugal pump driven from shafting by a 5 h.p. Crossley gas engine is a stand-by in the event of electrical failure. Except for two periods of about 1½ hr. in the morning and for ½ hr. in the evening, for cooling motors and for maintenance, pumping continues day and night.

The engine room also contains two air-compressors, but of recent years compressed air has had little use in the tank room though it is supplied to, and has its uses throughout, the laboratory.

Pump House

Reservoirs are periodically emptied, hosed down, and refilled from the sea. For this purpose there is housed in a small brick and concrete building on the rocks just above sea-level, which is about 97 ft. below laboratory ground-level, a cast-iron 4 in. centrifugal pump driven by a 14 h.p. motor. This is capable of delivering about 215 gallons a minute against a head of 150 ft. and can fill a reservoir in about 4 hr. A good spring tide in calm dry weather is chosen, and pumping commences 1–2 hr. before high water and continues for about the same time afterwards. Usually part of the volume required is pumped on one tide and the remainder the next day. The water is drawn through a suction rose situated near low-water mark at the base of the rock on which the pump house is built. The Shone's Ejector mentioned by Allen & Harvey (1928) was dismantled years ago, as was the last of the 'Otto' gas engines.

Maintenance

Treatment of the Stored Sea Water

During the summer one reservoir may be emptied, cleaned and refilled every month, but during the winter several months may go by without new water being obtained from the sea. Sometimes reservoirs are merely lowered a few feet and then filled up. In normal practice a reservoir is in use for 1 week, while the other rests. At the end of the week there is a change over. The reservoir passing out of use is then limed, that is to say, a bucket is one-third filled with quicklime and slaked under a freshwater tap. The slaked lime is spread as evenly as possible over the reservoir and sinking through the water restores the pH to that of natural sea water. It has been found advantageous to treat (with slaked lime) the reservoir actually in use about the fourth day, especially during hot weather. Water newly drawn from the sea often decreases in pH more quickly than old established water which has been frequently limed. This limed water is very satisfactory for ordinary aquarium purposes. For notes on the chemistry see Atkins (1931) and Cooper (1932).

Temperature

There is no means of artificially heating or cooling the aquarium water, its temperature varying with the seasons. The upper and lower limits are roughly 17–18° C. in summer and 7–8° C. in winter, occasionally being exceeded in both directions. For the fauna kept in our tanks temperatures above 16° C. and below 9° C. are undesirable. Quite a number of species suffer when the temperature changes rapidly (2–3° C. in a week), especially near the upper and lower limits.

The water flowing through the outside circulation bench and tanks, exposed to the outside air, is almost invariably cooled down and returned to the reservoir at a lower temperature than that from the rest of the system, the general effect being to cool the whole. Very rarely in summer the reverse may happen. In hard frosty weather it has sometimes been necessary to cut off this outside circulation to conserve the heat of the main system.

Salinity

Few data on the salinity of the aquarium water are available. The salinity of the water pumped at high tide is about 35 ‰, but increases somewhat with storage; for instance Cooper (1932) mentions a figure as high as 38·0 ‰, and Brown (1929) had previously given figures 37·0–37·9 ‰. It has never been necessary to add fresh water to make up for that lost by evaporation, and no effects on the animals attributable to increased salinity have been noted.

Servicing the Large Tanks

There are no service galleries behind the large north- and south-side tanks in the Tank Room and all work, such as feeding, glass cleaning and siphoning has to be carried out over the front of the tanks from a ladder propped up against them. On the south side the attendant can make his way along the backs of the tanks via the internal window sills, on the north side along an inconvenient cat-walk of planks placed across girders just above water-level (the two largest tanks only). There is insufficient head room to walk upright on this cat-walk.

Glasses are cleaned once or twice a week internally with a scrubbing brush attached to the end of a pole, or with a straight edge of Perspex on a long handle. This latter will remove quite hard growths without scratching the glass. Old newspaper serves for the exterior of the panes.

Silt which accumulates on the bottom of the tanks is removed by siphoning with a rubber hose, the siphoned water running to waste through the drainage trenches in the aquarium floor. Sand or fine gravel brought over from the tank is trapped in a galvanized iron bath into which the siphoned water first discharges. It is sometimes useful to fit a large funnel on to the end of the hose inside the tank. By choosing one of the right size flocculent silt may be separated from fine gravel. A tap on the outer end of the hose, to regulate rate of water flow, can be of assistance in this.

Feeding

The main food used in the aquarium is the common squid, *Loligo forbesi*, obtainable at Plymouth in quantity most of the year round. The uncooked white mantle flesh of this animal, cut into suitable sized pieces, is relished by almost all the species kept, while the heads are eaten by the conger eels and nursehounds. The contents of ovaries dispersed in the water have proved excellent for feeding very small fishes such as young grey mullet. At times, when squid is not to be had, herring, mackerel, conger eel and some white fishes are used. The oily fishes tend to foul the water and the white fishes are not relished and are generally not eaten at all unless really fresh. Iced fish obtained from the fishmonger is often left uneaten by hungry fishes. Worms (*Nereis diversicolor*) are also an excellent food for smaller fishes.

A few animals need a specialized diet. Octopuses and cuttlefishes must be supplied with living crabs or prawns, although they can occasionally be induced to take dead fishes. John Dories generally require whole fishes but can be trained to take squid, especially if it be cut into an elongate shape. Pipefishes need living plankton. The overflow from a main laboratory tank leads into the pipefish tank and jars of living plankton, after satisfying the needs of workers in the main laboratory, are tipped directly down this overflow. Most fishes need to be fed at least twice a week, but daily is too often. Successful feeding demands care and attention to the varied ways of catching prey natural to the different species kept. A complete account would occupy several pages.

General Remarks and Suggestions

During the last few years a number of plans for proposed new aquaria have been submitted for criticism. A common fault has been that the sizes of proposed tanks have been too small, especially widths in relation to lengths. Except for quite small fishes a width of 3 ft. (commonly adopted) is insufficient, especially when it is proposed to fix rockwork inside on the back. Quite apart from matters concerning the health of the fish it is often forgotten that a tank full of water viewed through the glass appears to be considerably less wide than it actually is. While for viewing small organisms lying at the back of the tank this may even be an advantage, an aquarium consisting solely of apparently narrow tanks fails to give that illusion of an underwater world which is one of the charms of a properly designed aquarium.

There is no doubt, too, that large tanks are better for their inhabitants and give less trouble than do small tanks. In general the smaller the tank the more often does it require attention and the more likely are the results of a temporary stoppage of circulation to prove fatal. Some small animals, vertebrate and invertebrate, which have never done well in our smaller tanks have flourished and lived a full natural life in our larger ones. Thus the little Two-spot Goby (*Gobius flavescens*), which never lived for long in small tanks, does extremely well in the largest tank of all. Presumably in a very large tank the goby readily finds scraps of food left over by the big fishes, as well as small worms, crustaceans, etc.; it is itself too small for the big fishes to eat. A great improvement in health and vigour has often been noted when fishes such as pollack, whiting, red mullet and sea-bream have been transferred from tanks on the south side to north-side tanks with several times the capacity.

A tank floor need not be level; it could be constructed to slope downwards from the front towards the back. This would give increased depth (at the back) without undue pressure on the glass. It may also slope upwards when it is desired to construct a series of rising terraces for anemones, sea-fans and other sedentary organisms.

Another point is the size of reservoirs. In a closed circulation the bigger the reservoir in relation to the inhabited tanks the better. During the war when most of our big tanks were broken and empty, the inhabitants of those which remained did noticeably better, and delicate organisms survived longer than they did before the war or do now, and sometimes even bred. As the capacity of one of our reservoirs is roughly two and a half times the capacity of the tanks it seems reasonable to conclude that a reservoir capacity double or treble this would give noticeably improved results. The relative proportions needed are influenced, of course, by the density of stocking, by liming, filtration and other treatments of the water, but there seems little reason to doubt that in designing a closed circulation aquarium it is advisable to construct the reservoirs on as generous a scale as possible. Such reservoirs must be darkened to inhibit the growth of water-clouding phytoplankton organisms; they should not be tanks exposed to the atmosphere and thereby able to gain or lose heat relatively rapidly. In the same way exhibition tanks should not be exposed to the sun or directly to the outside air; the whole system should be enclosed in a building. If the reservoirs be well insulated and if the building itself be centrally heated there should be little difficulty, in our climate, of maintaining a reasonable temperature during the winter months.

No public aquarium should be designed without service galleries behind the tanks. Such galleries not only greatly ease and expedite attention to inflows and overflows and all work of feeding, cleaning, addition and removal of specimens, but their lack can lead to difficulties on crowded days when it becomes scarcely practicable to give emergency attention from a ladder over the front of a tank. If during a Bank Holiday anything goes wrong it may not be possible for several hours to do anything to put it right.

Similarly, all aquaria should be provided behind the scenes with tanks for acclimatization and excess stock, living food and for sick fishes. It is bad practice to put freshly caught fishes into the exhibition tanks. Even those that will survive often show bruises, torn fins and other injuries during the first 2 or 3 weeks and a damaged fish always attracts attention. Acclimatization tanks must be large and deep, otherwise they will fail in their purpose. Storage tanks and tanks for sick fishes can be appreciably smaller. In cases of infectious sickness the overflow water should run to waste; it may be wiser not to attempt to keep the fish alive at all.

A frequent inquiry concerns filtration; should the water be filtered? Many well-known aquaria do possess elaborate filter beds and the water in their tanks is crystal clear. This condition seems to suit most fishes, but some invertebrates, and especially filter-feeding invertebrates, do not seem to do so well. The filter-feeders could be provided with suitable cultures of micro-organisms, but on the whole for them the water is better not filtered. It should, however, be allowed to sediment while passing through the reservoir. This could be achieved by partitioning the reservoir so that it becomes in effect a long broad passage way, repeatedly bent back upon itself, through which the water would flow slowly from inflow to outflow. Overflow water from the aquarium would be conducted through a very broad pipe, or shaft, straight to the bottom at one end of the passage, and water to the pumps would be drawn off above the bottom at the far end. During the hours the water would take to traverse the passage sediment would be deposited on the bottom. Sedimentation would remove unwanted detritus without removing swimming micro-organisms.

A disadvantage of encouraging filter-feeders is the likelihood of sponges and other organisms growing in the pipes through which the sea water is pumped to the tanks. The blockage of nozzles from pieces of sponge has already been mentioned (p. 199). The trouble would not be so great if pipes were provided with some easy means of access at all bends and elbows; internal growths could than be scraped off from time to time.

In a permanent installation pipes conveying water under pressure need to be made of vulcanite or some other material not affected by sea water. This applies equally, of course, to all parts in contact with the circulating sea water. Copper, brass, zinc and galvanized iron are the metals most likely to be encountered in constructors' plans. In sea water they dissolve to a sufficient extent to poison marine organisms. Pure lead is permissible in small quantity but should be avoided if possible. In our experience vulcanite pipes and cocks have proved perfectly satisfactory; some of the original ones are still in use after sixty years of service. On the other hand, stainless, or rustless steel pipes installed to supply new tanks erected in the main laboratory during reconstruction in 1938–9 rusted through, especially at bends, in only a few years, though stainless-steel has been satisfactory for the outside framework of small slate and glass tanks and for pump spindles. Ordinary iron piping, in spite of extensive rusting (which is harmless) has given better service and is very satisfactory for a temporary installation which is expected to last only for a few years. Internal rust must be scraped out from time to time. Rubber hose can also be used for temporary erections. Some of the newer plastic materials may prove excellent for sea-water aquarium pipes but we have had no experience with them. Pipes of transparent or translucent materials would need to be darkened to prevent algal growths inside.

For overflow water not under pressure ordinary earthenware drain piping, or asbestos pipes or troughs may be used.

Finally, there is the appearance of the tanks to be considered. The aim should be to present the animals in surroundings as natural to their species as is possible; this is not only good showmanship but is also beneficial to the animals. Carefully chosen natural rocks placed in position with due regard to their normal geological formation, sand or gravel or pebbles on the bottom (not too deep a layer), whatever is suitable, can greatly enhance the attractiveness of the display, but over-elaboration should be avoided. It is not desirable that the rockwork should attract the eye away from the fish. All inflows and overflows should be concealed. Inflows, of which even the smallest tanks should have at least two, can be placed in the forward corners of the tank, behind rockwork or anywhere else out of sight. Inflow nozzles should discharge into wide pipes passing from just above surface-level to near the bottom (see pp. 199–200) to ensure good circulation throughout the tank. Overflow water should pass through a hole in the back of the tank and should draw off surface scum. There is no need for unsightly pipes stuck into a seating on the tank floor.

Tanks can always be emptied by siphoning, but a plug could be provided in the tank floor in case of need. Aeration by compressed air forced through pieces of cane, or through diffusers manufactured for the purpose, should not generally be required, but when the temperature is high can be used with advantage. One use is to assist circulation in the tank by creating an upward current from the bottom. This is most effective if the air be bubbled up through a wide tube opening near the bottom and just below the surface. It should be noted that water supersaturated with air, or containing an excess of fine air bubbles, may not be good for the health of the fish. It may be a cause of the gas blisters which from time to time occur in the eyes, fins and skin of some fishes.

Excess daylight must be avoided if too vigorous a growth of algae is to be prevented. A slow growth of small red weeds can be permitted and will occur if the amount of daylight allowed is not reduced too much in intensity. Electric lighting for dull days and at night should be fitted, especial care being taken to ensure perfect insulation and water-proofing. Lights should be situated well forward (see p. 201), and close to the water surface, but it is a matter for choice whether fluorescent tubes or ordinary bulbs are used. The former give a shadowless light, the latter throw shadows and when the surface of the water is rippled there is produced a play of light on rocks and sand which adds liveliness to the appearance of the tank.

In designing the layout of an aquarium care is necessary to ensure that no bright reflexions obscure the view. Windows, doorways, brightly lit tanks opposite, and even white labels reflected in the glass can distract from and obscure the tank contents. All paint-work should be very dark, for the same reason.

The slate backs and sides of the Plymouth tanks where not covered by rockwork are painted black (see p. 202). This is not always ideal. The system adopted at the Danish Aquarium at Charlottenlund has much to recommend it. Tanks are lined with various blue and green toned semi-opaque or enamelled glass, enhancing the brilliance of the tank, and showing off some fishes to better advantage than does black. A system of false backing, a sheet of ground or semi-transparent glass, perhaps lightly coloured, placed a few inches in front of the real back of the tank gives an impression of distance, especially if fish can penetrate behind the false back to be dimly seen. The edges of the false back must be concealed.

There are no guard-rails at Plymouth and on crowded days people crush up against the glass and hide the labels from view. A leaning rail in front of the tanks should always be provided, as it not only protects the glass and labels but is a definite comfort to the visitor.

REFERENCES

ALLEN, E. J. & HARVEY, H. W., 1928. The laboratory of the Marine Biological Association at Plymouth. *Journ. Mar. Biol. Assoc.*, Vol. 15, pp. 735–51.

ATKINS, W. R. G., 1931. Note on the condition of the water in a marine aquarium. *Journ. Mar. Biol. Assoc.*, Vol. 17, pp. 479–81.

BROWN, E. M., 1929. Notes on the hydrogen ion concentration, excess base, and carbon dioxide pressure of marine aquarium waters. *Proc. Zool. Soc. Lond.*, pp. 601–13.

COOPER, L. H. N., 1932. On the effect of long-continued additions of lime to aquarium sea-water. *Journ. Mar. Biol. Assoc.*, Vol. 18, pp. 201–2.

RUSSELL, F. S., 1948. The Plymouth laboratory of the Marine Biological Association of the United Kingdom. *Journ. Mar. Biol. Assoc.*, Vol. 27, pp. 761–74.

EXPLANATION OF PLATE I

The aquarium viewed from a height of 7 ft. close to the wall at the east end. Left to right: south-side tanks with low anti-dazzle screen along front top edge; cast-iron gratings covering drainage trench in floor; central table tanks with small glass-fronted slate and wooden tanks above; six central pillars with curtain screen hung on them (three sections of the screen near to the camera have been removed); north-side tanks with service hatch in screen open and service ladder in position. The public entrance, closed by double doors, is at the far end. The pipes crossing the ceiling in the middle distance are sea-water mains and overflows to and from tanks in the main laboratory above. Some details of the electric lighting to the tanks are also visible.