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DESIGN, CONSTRUCTION, AND USE OF A NEW LIGHT TRAP FOR SAMPLING LARVAL CORAL REEF FISHES

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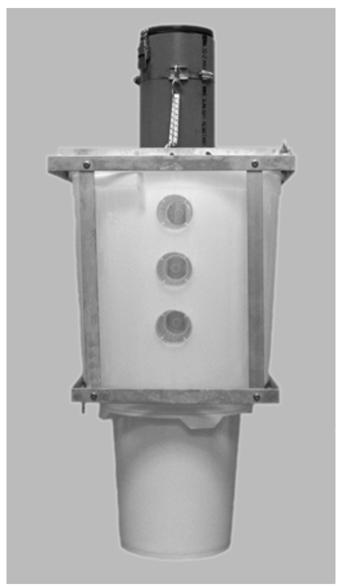

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1 Introduction

1.1 Advantages of Light Traps

A variety of methods have been developed in order to sample the larval stages of marine fishes, including towed nets (Tucker, 1951; Miller, 1961; McGowan and Brown, 1966; Weibe et al., 1976; Methot, 1988), purse-seines (Kingsford and Choat, 1985), channel nets (Shenker et al., 1993), crest nets (Dufour and Galzin, 1993), settlement coils (Leis et al., 2002), and light traps (Doherty, 1987). However, light traps have become the preferred gear for many who work in tropical reef environments, especially when live specimens of late stage larvae are needed for grow-out (Doherty, 1994; Doherty et al., 1994; Hair and Doherty, 2003; Watson et al., 2001), behavioral (Leis et al., 1996; Stobutzki and Bellwood, 1994; Stobutzki and Bellwood, 1997), or tagging work (Watson et al., 2002). The high quality of the condition of specimens collected by light traps is also an important consideration when the material is used in construction of developmental series for taxonomic work, for identification of new characters for phylogenetic analysis, and sources of material for otolith-based ageing and microchemical analyses. Light traps also offer some additional advantages over the more traditional methods that rely on towed nets by allowing workers to sample multiple locations simultaneously (Wolanski et al., 1997; Doherty and Carleton, 1997; Carleton et al., 2001), make collections in areas where it is impractical to pull a net (Brogan, 1994; Dennis et al., 1991; Hernandez and Shaw, 2003; Strydom, 2003), and sample older larvae which, due to net avoidance, are usually under represented (Doherty, 1987; Gregory and Powles, 1988; Choat et al., 1993; Hickford and Schiel, 1999). The latter should be of particular concern when sampling the oligotrophic waters surrounding coral reefs, as gear avoidance by larval fishes has been shown to be a function of water clarity (Brander and Thompson, 1989).

1.2 Background

Light traps were first used to collect the larval stages of fishes inhabiting freshwater lakes (Faber, 1981) and were subsequently developed to monitor the supply of marine fish larvae to coral reefs (Doherty, 1987). In both environments, light traps tend to collect more of the older stages of fish larvae than towed nets (Gregory and Powles, 1988; Choat et al., 1993; Hickford and Schiel, 1999). Both of the original designs of light traps (Faber, 1981; Doherty, 1987) were constructed from clear acrylic; had rectangular, inwardly tapered openings; and utilized battery-powered lights contained within a waterproof housing. Positively phototaxic organisms are drawn into the tapered entrances of these traps which makes it difficult for them to exit. The Faber trap had a single chamber while the Doherty trap consisted of one entrance chamber and two additional collection chambers connected via downwardly tapered passages. Each chamber in the Doherty trap had a separate light source controlled by a mechanical timer which alternated the lighting of the top and middle chamber. This was designed to progressively draw organisms deeper into the trap to minimize their chance of escape. Since there was no gradient in the intensity of the light emitted externally from the tapered entrances vs. that coming from the clear acrylic walls, larval fishes entered the Doherty (and Faber) trap only after finding the entrances by haphazard searches (Meekan et al., 2000). The quatrefoil light trap (Floyd et al., 1984) solves this problem by having clear acrylic outer walls that, by forming a clover leaf in cross section, direct organisms seeking greater light intensities towards the entrance slots. However, light traps based on this design are difficult to construct and must be fabricated by a machine shop—although simpler versions have been used (Secor et al., 1992; Ponton, 1994).

Doherty's (1897) automated, multi-chamber light trap remains one of the most complex and expensive designs to date. Construction requires either an in-house machine shop or out-sourced fabrication costing ~ US$3000 per trap (Hernandez and Lindquist, 1999). Additionally, due to its size and weight the Doherty trap is also difficult to deploy and retrieve since it requires a boat with a davit (Doherty, 1987). The Brogan trap (Brogan, 1994) is a smaller, less expensive version of the Doherty trap with only two chambers, each with a separate light source, and no timing device. The main body of the light trap was made of wood making it relatively easy to construct and inexpensive, ~ US$300 (Hernandez and Lindquist, 1999). Since most of the trap was constructed of an opaque material, illumination from the interior lights was only transmitted from the trap through four clear plastic entrance funnels in the upper chamber and a clear plastic window located on top of the trap. A comparison of catch rates between the three chamber Doherty trap and the two chamber Brogan trap was made over a temperate rocky reef off North Carolina, USA (Hernandez and Lindquist, 1999). While the taxonomic composition of the samples collected by each trap was similar, the Doherty trap had a higher capture rate than the Brogan trap. The authors attributed these higher catch rates to the greater proportion of transparent, light emitting surface area and more entry slits in the Doherty trap than in the Brogan trap. A similar comparison of trap designs was made in the subtropical mangrove and coral reef habitats of the Florida Keys, USA (Lindquist et al., 2001). In this study, the Doherty trap was again found to provide higher catch rates; however, it also yielded a greater taxonomic composition of fish larvae and a wider range in fish size than the Brogan trap. The authors suggested these differences in catches were due to the same structural design issues mentioned in Hernandez and Lindquist (1999).

The Stobutzki trap (Stobutzki and Bellwood, 1997) is a modified version of the Doherty trap that is smaller, so it can be deployed from small boats, and less expensive in terms of construction and maintenance—one version of this trap costs ~ US$300 (Watson et al., 2002). Like the Doherty trap, it was constructed from clear acrylic and had rectangular entrance funnels. However, the Stobutzki trap had only one chamber, no timing device, and used a fluorescent bulb that was brighter than that used in the Doherty trap (i.e., 8 vs. 6 W). The collection efficiency of the Stobutzki and Doherty traps were compared in a study conducted on the NW shelf of

Australia in the Indian Ocean using both drifting and moored traps (Meekan et al., 2001). While no differences were found in the size or taxonomic composition of the fishes collected by each of the two designs, the Stobutzki trap yielded greater numbers of reef fishes. The authors suggested that the Stobutzki design was better at directing fishes towards the trap's entrances since, unlike the Doherty design, all of its light emitting panels had entrance funnels. This agrees with Doherty's (*unpubl. data* in Meekan et al., 2001) observations that fish larvae gain entrance to his trap only after a significant amount of haphazard searching along the lighted panels of the lower two chambers, which lack entrances.

The Sponaugle trap (Sponaugle and Cowen, 1996) is a relatively inexpensive, single chamber light trap made from plankton netting with three clear entrance funnels, cut from soda bottles, sewn into the sides. Since this trap is made mostly of fabric, it is easy to store, transport, and deploy (D. Jones, *pers. obs.*). The difference in transparency between the mesh walls and entrance funnels creates a gradient in the intensity of transmitted light that helps direct fish towards the trap's openings (R. Cowen, *pers. comm.*). While no timing device was used, the 6 W fluorescent bulb was turned on during deployment by a magnetic switch. While its light weight makes it easy to deploy and retrieve, each trap must be rinsed and air-dried prior to re-deployment (Sponaugle and Cowen, 1996; Valles et al., 2001)—presumably to remove the nightly buildup of silt and debris that clogged the plankton mesh. The potential effect of accumulation of silt/debris on the Sponaugle trap's fishing ability raises questions concerning the level of constant illumination provided by the trap over the course of a night.

Fisher and Bellwood (2002) designed a single chamber light trap to examine the vertical distribution of presettlement stage fish larvae. The Fisher trap used a series of opaque acrylic rings that blocked all but the light emitted along a narrow horizontal plane, which restricted its attraction to only those larvae that occurred in the same depth strata as the trap was moored. Because most of the light within the trap was blocked, the intensity of emitted light was up to two orders of magnitude less than other designs. This significantly reduced the volume of water sampled and likely accounts for the relatively low catches, in terms of total numbers and diversity, reported for this trap (Fisher and Bellwood, 2002). This reduction in catch rate may be more than compensated for in applications where increased resolution in vertical distribution is of primary concern.

The Brogan, Stobutzki, Sponaugle, and Fisher traps all lack an automated timing device so they must be turned on during deployment and off at retrieval; in addition the Sponaugle trap must be rinsed and air-dried after each use. A light trap having one or both of these features makes it necessary to visit each sampling site twice daily: once in the morning for retrieval and later in the afternoon for deployment. This may impose a heavy restriction on sampling logistics when rough seas occur, the sampling area is of large spatial extent, and/or long travel times are required to visit a single sampling site. Ponton (1994) constructed an improved version of the quatrefoil light trap (Floyd et al., 1984) which used a photocell-based electronic switch to turn the lamp on at dusk and off at dawn. This was done in order to automatically and simultaneously switch several traps on, regardless of the distance separating them, and increase the life of the rechargeable batteries, regardless of any delays in trap retrieval. Watson et al. (2002) built Stobutzki traps that also had photocell-based dusk/dawn switches, primarily to eliminate the need to visit the traps more than once daily. However, stormy weather, overcast skies, and/or depth of deployment may vary the actual fishing times of light traps with photocell-based switches on a night-to-night basis, which may be a concern in situations where collection effort needs to be standardized or burn time affects subsequent battery recharging.

Other light traps include two inexpensive designs that utilize 20 liter opaque plastic buckets with either rectangular (Riley and Holt, 1993) or conical (Watson et al., 2002) clear plastic funnels that served as entrances and the sole source of transmitted light.

2 Design of the New Light Trap

2.1 Design

A new light trap was designed and constructed in order to have a reliable, inexpensive, and easy to build method to collect the pre-settlement stages of gray snapper (Lutjanidae: *Lutjanus griseus*) as part of a larger study examining settlement, age, and growth of this species in Florida Bay, USA. Through numerous deployments off the Florida Keys, the US Virgin Islands, and the Mexican Yucatan the new trap has proved effective in collecting the larval stages of a wide range of coral reef and tropical seagrass fishes. The basic components of the new light trap consist of two plastic buckets (a 38 l attached to a 9.46 l), an aluminium frame, and a waterproof housing encasing a fluorescent light bulb, a rechargeable battery, and an electronic timer. These light traps are lightweight and easy to manipulate from a small boat or even underwater by a single diver on SCUBA where they are only slightly negatively buoyant (~ 2.2 kg).

The new light trap was designed to be constructed as inexpensively as possible; made from off-the-shelf, readily obtainable, or easily constructed parts; and require a minimum of specialized tools. It was also important that the trap be as effective as possible in attracting and trapping larval fishes; be easy to deploy and retrieve in the field; and be portable, rugged, and reliable. Since the majority of the trap is constructed out of plastic, aluminum, and PVC most of its parts are relatively inexpensive and lightweight. Once assembled, the light traps can stored, transported, and deployed with minimal additional effort beyond routine battery charging, setting the programmable timer switch, and rinsing. For deployment in remote field sites requiring airline transport (i.e., as checked baggage), traps can be partially disassembled, stacked and boxed, transported, and re-assembled at the field site by only removing and replacing a portion of the attachment screws and threaded monofilament line.

One of the most important considerations during the design of the new light trap was that it be as effective as possible in attracting and trapping larval fishes while remaining inexpensive and easy to build. A single-chamber light trap was chosen since these have been shown to be just as effective in collecting coral reef fish larvae as larger, multi-chamber traps (Meekan et al., 2001)—the latter being an order of magnitude more expensive to build (Hernandez and Lindquist, 1999). A lighted, semi-transparent entrance chamber with completely transparent entrances was used to provide a strong gradient in light intensity to direct fish inside the trap (Meekan et al., 2001). The brighter of two fluorescent light bulbs appropriate for remote, battery-powered operation (i.e., 8 vs. 6 W) was used since the strength of the phototactic response in fish larvae (Gehrke, 1994; Stearns et al., 1994) and the volume of illuminated water surrounding the trap both increase with light intensity. While the larger bulb draws twice the voltage (12 vs. 6 V) which requires a larger battery and a bigger waterproof housing, the costs are justified as the gain in intensity is nearly two-fold (i.e., 400 vs. 230 lumens). Finally, an electronic time switch was use to control the activation time of each light trap. This allows simultaneous sampling of a number of different sites, irrespective of their spatial separation; saves batteries from being over discharged, which is a particular concern for sealed lead acid batteries; and eliminates the need to visit each trap more than once daily (Ponton, 1994; Watson et al., 2002). It also allows control over the exact time of each trap's operation, which is necessary when standardization of fishing times is important or when only a specific portion(s) of the night is to be sampled.

2.2 Basic Components

The main body of the light trap (Figure 1) consists of an entrance chamber made from a 38 l plastic storage bucket fitted with 9 clear plastic cups that serve as entrance ports. These are arranged in three, equally spaced columns of three. Each entrance port is initially 5.40 cm in diameter, extends 10.16 cm into the interior of the entrance chamber, and tapers down to a final opening of 13 mm in diameter. An 8 W fluorescent light bulb sits in the center of the semi-transparent entrance chamber, which glows evenly like a lamp shade when illuminated from within. Since the entrance ports are transparent, they emit more light than the main body of the trap which acts to draw zooplankton and fish larvae attracted to the immediate vicinity of the trap into its interior. The inwardly projecting, tapered entrance ports then make it difficult for organisms drawn inside the chamber to exit. A waterproof housing made from PVC sits on top of the entrance chamber enclosing the electronic components needed to power a fluorescent light bulb that sits in a clear PVC pipe extending from the bottom of the housing (Figure 2). A 9.46 liter opaque plastic bucket with a mesh-lined drain port fitted to the bottom of the entrance chamber filters out the water and retains zooplankton and ichthyoplankton when the trap is removed from the water. A aluminium frame built around the entrance chamber provides strength, protection, and attachment points for the waterproof electronics housing and the mooring and float lines.

The 13 mm diameter of the entrance ports was estimated to be a size which would allow unrestricted entrance of settlement-stage lutjanid larvae (~ 10–15 mm SL) recruiting to the Florida Keys—which is what the trap was originally designed to capture. Entrances larger than this were not considered for this trap as the main design goals were to maximize the exclusion of predators of larval fishes within the trap and minimize the escapement of zooplankton and ichthyoplankton that entered the trap. Repeated deployments of the trap in waters off the Florida Keys, the US Virgin Islands, and the Yucatan Peninsula proved these design considerations were effective in capturing settlement-stage lutjanid larvae as well as a wide range of other reef fish larvae. An example of this comes from a recent deployment (March, 2006) of four traps at two depths over three consecutive nights in waters in the Mexican Caribbean. A total of 1,282 larvae were collected from 25 families of reef fishes whose sizes ranged from 2.6–54.0 mm SL (D. Jones and M. Lara, *unpubl. data*); this diversity exceeds that reported by a number of studies conducted on the Great Barrier Reef (Doherty, 1987; Milicich, 1988; Choat et al., 1993; Doherty and Carleton, 1997; Fisher and Bellwood, 2002; Fisher, 2004; Simpson et al., 2004). During another deployment along the Mesoamerican Barrier Reef System (March, 2005), a single trap fished overnight yielded 1,784 bonefish (Albulidae: *Albula* sp.) leptocephalus larvae, an amount which exceeds all previous reports (Vásquez-Yeomans et al., *unpubl. ms.*).

3 Construction of the New Light Trap

3.1 Sources of Parts

The following subsections provide a detailed description of the parts required and the methods used to construct the new light trap. A complete parts list with estimated prices for all of the components needed for construction is provided in Table 1. During the design phase and initial construction of the light trap, an effort was made to utilize as many locally obtained and readily available parts as possible. However, in order to avoid sacrificing affordability, functionality, and reliability it was necessary to obtain some of the components from more specialized vendors, usually through mail order or via the Internet. Table 2 provides a list of vendors of those parts that could not usually be obtained from most hardware stores or other local sources. This information is provided to assist the reader in obtaining the parts needed to build a light trap at reasonable cost and should not necessarily be interpreted as an endorsement of any of the vendors listed. The reader is encouraged to seek out alternative sources and/or parts where appropriate.

3.2 Units of Measure and Abbreviations

Note that in the general description of the light trap above, the units of measure were provided in the Metric system, as is the usual practice for conveying technical information to the scientific community. However, since the majority of the hardware sold and the tools used within the U.S. are based on the Imperial system, English fractional units are used throughout the construction instructions and parts list. The following includes italic abbreviations in parentheses for each component of the light trap in order to facilitate cross-referencing them in the included tables and figures.

3.3 Main Body/Entrance Chamber

A 10 gal plastic storage container served as the main body (*Tb*) of the light trap (Figure 1). A series of 9 holes were cut in the side of the container using a $2\frac{1}{2}$" diameter hole saw. A 6 oz clear plastic tumbler (i.e., juice cup; *Te*) with a $\frac{1}{2}$" diameter hole drilled in the bottom was held firmly in place within each hole by threading a section of 300 lbs test monofilament fishing line (*Tml*) through four pairs of $\frac{5}{16}$" diameter holes drilled equidistant around the outer rim of the tumbler (Figure 3). The snap-on lid (*Tl*; Figure 4) was secured to the top of the entrance chamber with 8 evenly spaced sheet metal screws (*NS1*). A hole was cut in the center of the snap-on lid (*Tfb*) using a $1\frac{1}{4}$" diameter hole saw and enlarged to $1\frac{5}{16}$" in diameter by hand using a knife and sand paper. This allowed the fluorescent light bulb (*Efb*) enclosed within the transparent portion of the electronics housing (*Hp*) to be inserted into the center of the entrance chamber with a fit tight enough to prevent the escape of trapped zooplankton. A drain plug (*Tdp*) for plastic ice chests was also installed in the lid of the entrance chamber to break the air lock formed when the trap is submerged. This facilitates draining when the trap is removed from the water. A 3" ABS slip hub (*Tsh*) was used as a flush-mount fitting to allow the contents of the entrance chamber to completely drain into the sample collection bucket (*Tcb*) when the trap is removed from the water. The slip hub was installed by first cutting a hole in the floor of the entrance chamber using a $3\frac{1}{8}$" diameter hole saw and enlarging it to $3\frac{7}{32}$" in diameter by hand using a knife and sand paper. A hole was then cut in the center of the collection bucket lid using a 4" diameter hole saw. Four additional $\frac{1}{4}$" holes were then drilled into the bottom of the entrance chamber and the collection bucket lid, which allowed the slip hub and the lid to be bolted to the bottom of the entrance chamber using machine screws (*Tsn*; Figure 5).

3.4 Sample Collection Bucket

The sample collection bucket (*Tcl*) was made from a $2\frac{1}{2}$ gal opaque plastic bucket which had a threaded, screw-on lid (*Tcl*) that allowed quick removal and retrieval of the sample. The swing handle was removed from the bucket and the locking mechanism was cut from the lid. The bottom of the collection bucket was fitted with a 3" ABS slip hub (*Tsh*) in a fashion similar to that described for the entrance chamber (Figure 6). Note that a layer of silicone sealant had been applied around the outer circumference of the slip hub to prevent small zooplankters from becoming lodged in the gap formed between it and the collection bucket. The slip hub was used to hold the draining unit (Figure 7), a 6" section of 3" PVC pipe with two $4\frac{3}{8}$" by $3\frac{1}{4}$" windows cut out and covered by a scrap piece of 1 mm mesh plankton netting (*Tmw*). The top of the draining unit was capped with a 3 1/2" diameter disc cut from a sheet of 1/8" thick PVC sheet (*Tpc*) using a variable-size circle cutter mounted in a drill press. The plankton mesh was held tightly over the PVC pipe with two hose clamps (*Thc*). The draining unit allowed most of the water to exit the trap when it was removed from the water while retaining the organisms of the size of interest (> 1 mm) in ~ 1 l of seawater. This allowed the smaller zooplankton (e.g., copepod nauplii, etc.) to exit the trap during draining, reducing subsequent sorting efforts in the laboratory. Plankton netting having a finer (or coarser) mesh size could be used depending upon the application. The draining unit is held within the slip hub by friction and is easily removed and replaced for rinsing and storage.

3.5 Frame

A reinforcement and mounting frame was built around the entrance chamber using 1" by 1/8" aluminum angle and aluminum straight. The top portion of the frame (Figure 4) was made from six 16" sections and two 8 3/4" sections of angle (*Faa*) bolted together using machine screws (*Fsn*). Two eyebolts (*Feb*) held bungee loops with S-hooks (*Fsh*) which served to securely attach the electronics housing to the frame (Figure 1). Two additional eyebolts were added to the frame to allow attachment points for the float line (Figure 4). The bottom portion of the frame (Figure 5) was made from four 13 3/4" sections of angle (*Faa*) and had two eyebolts that served as attachment points for the mooring line. The top and bottom portions of the frame were connected by four 16" sections of aluminum straight (*Fas;* Figure 1).

3.6 Electronics Housing

A waterproof housing enclosed the electronic components of the light trap (Figure 2) and was designed as a modified, fluorescent version of the incandescent canister lights developed by cave divers (Lindblom, 2003). The main body of the housing (*Hmb*) was constructed from an 8 1/2" section of 5" Sch-40 electrical conduit PVC. The waterproof housing held a 12 V, 7 Ah sealed lead acid rechargeable battery (*Erb*), a 12 V fluorescent ballast/inverter (*Ebi*), an industrial digital timer with a programmable electronic time switch (*Et*), and an F8T5/CW+ 12 VDC, 8 W fluorescent light bulb (*Efb*) 12" in length that emitted ~ 400 lumens of light (Figure 8). The ballast/inverter was embedded in epoxy resin to insulate the electrical contacts exposed on its printed circuit board and to protect it from salt spray and minor splashing while changing batteries in the field. The electronic timer was enclosed in a plastic bag (*Esg*), which served as a splash guard, and was screwed to a 1" x 4 3/4" mounting plate (*Emp*) cut from a 1/2" thick sheet of PVC to secure it within the housing. Two 1/4" sections of 3/4" diameter clear plastic tubing served as bumpers (*Eb*) for the fluorescent bulb by minimizing movement within the housing and reducing the chance of breakage when deployed in rough seas.

The lid of the housing was constructed by laminating together two discs cut from PVC sheet using a variable-size circle cutter mounted in a drill press. The edges of each disc were sanded smooth using a graded series of sand paper (80, 100, 220, and 300 grit size). The larger disc was $5\,{}^{17}/_{32}$" in diameter by ${}^{1}/_{2}$" thick and the smaller was $4\,{}^{61}/_{64}$" in diameter by ${}^{1}/_{4}$" thick after sanding. The discs were centered and glued together using a medium grade PVC glue. The larger disc formed the outer, exposed part of the lid while the smaller disc formed the inside groove where an O-ring (*Hor*) was placed to provide a watertight seal. The lid was attached to the housing by two spring latches (*Hsl*).

The bottom (*Hb*) of the housing was constructed in a manner similar to that of the lid, with a 1" diameter hole drilled through its center to form a port for installation and removal of the fluorescent bulb (*Hbp,* Figure 9). The bottom was then permanently attached to the main body of the housing using a generous amount of medium grade PVC glue. A $1\,{}^{1}/_{2}$" x 1" PVC slip bushing (*Hsb*) was cut down to a length of ${}^{3}/_{4}$" and its surfaces squared and smoothed with sand paper. This was then glued to the outside of the housing bottom by aligning its hole with the fluorescent bulb port. This served as a flush-mount flange for gluing a plugged, 15" section of 1" clear PVC pipe (*Hp*). The clear pipe had been plugged with a ${}^{3}/_{4}$" PVC slip plug (*Hsp*), which first required softening in boiling water before it would stretch over the slip plug. The clear pipe was allowed to completely cool and harden after stretching before the slip plug was glued in.

A battery cage was screwed to the floor of the waterproof housing to securely mount the battery and other electronic components during trap deployment (Figure 9 and Figure 10). The holes needed in the housing bottom (*Hb*) for attaching the battery cage with sheet metal screws (*Hs*) were pre-drilled before the bottom was permanently glued to the main body (*Hmb*) of the housing. Each side of the battery cage was made from a $3\,{}^{1}/_{2}$" length of 1" x ${}^{1}/_{8}$" aluminum angle held to a smaller, ${}^{3}/_{4}$" length of angle with a machine screw (*Hsn*). The smaller length of angle had been drilled to accommodate a 7" section of threaded rod (*Htr*), which served as a guide rail for the mounting plate (*Emp*) holding the electronic timer (*Et*). The threaded rod also functioned as a retainer for the bungee cords (*Hbc*) that held all of the components in place. Zip ties (*Hzt*) were added to facilitate grasping the bungee loops when needed to stretch them into position.

4 Use of the New Light Trap

The new light trap has been used to sample settlement-stage reef fish larvae in both inshore and offshore waters of the Florida Keys, the US Virgin Islands, and the Mexican Caribbean. Light traps deployed in shallow inshore waters were set 1 m below the surface while those deployed in offshore waters were set either 1 m or 10–20 m below the surface in waters 20–30 m deep. Light traps were moored to sandy substrate using either concrete or small boat anchors and were held upright with styrofoam fishing floats. Subsurface floats were used for those traps deployed at depth and an additional anchor with a surface marker float was used to locate the general vicinity of each subsurface mooring. Surface marker floats were placed a sufficient distance from the deeper light traps to prevent disturbance or entanglement that might have occurred with changes in current due to tides, etc. Figure 11 provides a schematic diagram illustrating the deployment of surface and subsurface light traps.

To sample a light trap deployed just below the surface, a free diver on snorkel would remove a small weight attached to the bottom of the trap by unclipping a quick-release carabiner. The weight was then attached to the trap's surface float and the trap was detached from the float, by removing a locking carabiner, and passed to a person on a small boat. The drain plug in the top of the trap was opened to break the air lock before the trap was removed from the water. The water was allowed to drain, the waterproof electronics housing was removed, and the sample collection bucket was unscrewed from the light trap. The sample was poured into an aquarium dip-net and transferred to a plastic sample bottle containing 95% ethanol. The draining unit in the collection bucket was removed, rinsed, and replaced before the latter was re-attached to the trap. The rechargeable batteries were changed, the electronic timer was tested, and the O-ring was cleaned and greased before the waterproof housing was re-attached. Re-deployment was then simply a matter of immersing the light trap until if filled with water, closing the drain plug, re-clipping the trap to the surface float, and re-clipping the weight to the bottom of the trap.

The deeper, subsurface light traps were sampled by divers on SCUBA. At each of these sites, two divers would descend the surface marker line with one carrying a new light trap (usually a surface trap that had already been sampled). Once at the mooring, both divers would assist in replacing the old trap with the new one which involved removing two locking carabiners holding the old trap to the mooring block and the subsurface floats and attaching the new trap. Both divers would then ascend along the surface marker line, with one carrying the old trap (Figure 12), until reaching a depth of 5 m where they would begin a 3 min precautionary decompression stop. During this stop a free diver on snorkel would descend to 5 m and take the light trap from the diver to the surface where, on board a small boat, the sample was removed and the trap prepared for the next deployment.

5 Concluding Remarks

The new light trap described in the present work was designed to be an inexpensive, easy to construct, and effective solution for workers needing multiple traps to simultaneously sample the supply of settlement stages of coral reef and tropical seagrass fishes over multiple spatial scales. When deployed over a series of consecutive nights, light traps allow the collection of time series of biological data that match the temporal scales of the underlying ecological and/or oceanographic phenomena responsible for fluctuations in population replenishment. Multiple, simultaneous sampling provides the replication of data needed for the appropriate, statistical testing of hypotheses. This is particularly important given the known patchiness in the distribution in offshore ichthyoplankton and the variation in frequency and occurrence of small-scale physical oceanographic phenomena which are thought to have great influence on the planktonic distribution and settlement patterns of the larval stages of marine fishes. The new light trap was built on the strengths of former designs with some features that are offered as improvements to what were considered inefficiencies in previous light traps. While effective in collecting reef fish larvae this new design, along with two other traps currently in use in Atlantic waters (Lindquist and Shaw, 2005; Sponaugle et al., 2005) and the design popular in the Indo-Pacific (Stobutzki and Bellwood, 1994) have yet to be formally compared to one another in terms of catch efficiency and taxonomic composition. Further work is planned to mitigate this lack of information.

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Table 1. List of parts needed for construction of a light trap; prices are estimates in U.S. dollars as of August 2006. For vendor codes L = local hardware, home improvement, or marine supply store; all others are defined in Table 2.

Abbreviation	Description	Price	Vendor
Housing:			
Haa	Two 3 1/2" and 3/4" lengths of 1" x 1/8" aluminium angle	$1.80	L
Hb	Bottom of electrical housing (made from 1/2" and 1/4" thick PVC discs)	$3.62	M
Hbc	Two 12" sections of 1/4" diameter bungee cord	$1.00	L
Hbp	Fluorescent bulb port (1" diameter hole)	--	--
Hdh	Two SS D-ring holders	$4.00	D
Hdr	Two 1" SS D-rings	$1.20	D
Hhc	Two SS hose clamps (size 52 = 2 13/16" to 3 3/4" size range)	$2.10	L
Hhr	Two 1/4" hog rings	$0.25	L
Hl	Lid for electrical housing (made from 1/2" and 1/4" thick PVC discs)	$3.62	M
Hmb	Main body (8 1/2" section of 5" Sch-40 electrical conduit PVC)	$1.00	L
Hn	Four SS #10 hex nuts	$0.25	L
Hor	Buna-N O-ring (Dash #352)	$1.00	M
Hp	15" section of 1" clear PVC pipe	$3.25	U
Hsp	3/4" PVC slip plug	$0.80	L
Hls	Eight #6-32 x 1/2" SS pan head screws for mounting *Hsl*	$0.40	L
Hs	Four #8 x 1/2" SS flat head sheet metal screws	$0.20	L
Hsb	1 1/2" x 1" PVC slip bushing	$0.70	L
Hsl	Two SS internal compression spring latches	$12.88	M
Hsn	Two #8-32 x 3/8" SS flat head machine screws with #8 SS lock nut	$0.30	L
Htr	Two 7" sections of #10-24 SS threaded rod (with two *Hn*'s per rod)	$0.50	L
Hzt	Two zip ties	$0.02	L
Electronics:			
Eb	Two bumpers (1/4" section of 3/4" diameter clear plastic tubing)	$0.04	L
Ebi	Ballast/inverter (2 5/8" x 7/8" x 1/2" when embedded in epoxy resin)	$16.00	C
Efb	F8T5/CW+ Fluorescent light bulb	$4.00	L
Efd	Two 22-18 gauge female disconnect terminal connectors	$0.12	L
Emp	Mounting plate (made from a piece of 4 3/4" x 1" x 1/2" PVC sheet)	$0.50	M
Erb	Sealed lead acid rechargeable battery 12VDC, 7Ah (2 1/2" x 3 5/8" x 5 7/8")	$13.00	L
Esg	Splash guard made from a clear plastic bag	--	L
Et	Programmable digital timer with 12 VDC electronic switch	$30.00	B
Etc	Electrical trailer connector	$1.50	L
Ew	20 gauge hook-up wire	$1.00	L

Table 1. List of parts needed for construction of a light trap; prices are estimates in U.S. dollars as of August 2006. For vendor codes L = local hardware, home improvement, or marine supply store; all others are defined in Table 2. (Continued)

Abbreviation	Description	Price	Vendor
Frame*:*			
Faa	14' of aluminium angle	$34.00	L
Fas	5' of aluminium straight	$6.00	L
Fbc	Two 8" sections of $^5/_{16}$" diameter bungee cord	$1.00	L
Feb	Two $^1/_4$" x 2" SS eye bolts, $^1/_4$" SS hex nuts, $^1/_4$" SS lock washers	$2.00	L
Fhr	Two $^5/_{16}$" hog rings	$0.20	L
Fsh	Two $^1/_4$" x 1 $^1/_2$" SS S-hooks	$1.64	L
Fsn	24 of $^1/_4$" x $^5/_8$" SS machine screws, $^1/_4$" SS hex nuts, $^1/_4$" SS lock washers	$3.00	L
Trap*:*			
Tb	Main body/entrance chamber	$15.81	U
Tcb	2 $^1/_2$ gal sample collection bucket	$6.21	U
Tcl	Threaded lid for *Tcb*	--	U
Td	Drain port (3 $^7/_{32}$" diameter hole cut in the bottom of *Tcb*)	--	--
Tdp	Standard drain plug for plastic ice chest	$4.99	L
Te	Nine 6 oz. clear plastic tumblers	$4.50	L
Tfb	Fluorescent bulb port (1 $^5/_{16}$" diameter hole cut in *Tl*)	--	--
Thc	Two SS hose clamps (size 52 = 2 $^{13}/_{16}$" to 3 $^3/_4$" size range)	$2.10	L
Tl	Lid for *Tb*	$4.83	U
Tml	10' of 300 lbs test clear monofilament fishing line	$1.00	L
Tmw	Scrap piece of 1 mm mesh plankton netting	--	L
Tp	6" section of 3" Sch-40 PVC pipe	$0.50	L
Tpc	Pipe cap (3 $^1/_2$" diameter disc from a $^1/_8$" thick sheet of PVC)	$1.00	M
Tsh	Two 3" ABS slip hubs	$4.80	P
Tsn	Eight $^1/_4$" x 1 $^1/_2$" SS machine screws, $^1/_4$" SS hex nuts, $^1/_4$" SS lock washers	$0.35	L
Not shown*:*			
NS1	8 of #6 x $^3/_8$" SS pan head sheet metal screws	$0.40	L
NS2	Charger for 12VDC sealed lead acid batteries	$50.00	W
NS3	Epoxy embedding resin and hardener	$5.00	L
	Total Cost =	**$254.38**	

Table 2. Definition of vendor codes used in Table 1 for sources of specialized and/or hard to find light trap parts.

Vendor Code	Vendor Address and Part Numbers
A	**Arrow Plastic Manufacturing Co.** 701 East Devon Avenue Elk Grove, IL 60007 USA http://www.arrowplastic.com *Te* = Clear 6 oz. (180 ml) tumbler; part # 00115
W	**Batteryweb** 6495 Sunrise Strip Sunrise, FL 33313 USA http://www.batteryweb.com *NS2* = 12VDC, 1.3A BatteryMINDer Plus; part # 12117-12V 1.3A
C	**The Bodine Company** 236 Mount Pleasant Rd. Collierville, TN 38017 USA http://www.tran-bal.com *Ebi* = Series A 12VDC inverter ballast; part # 12F4-8A
D	**Fill Express, LLC** 2045 North Dixie Highway Pompano Beach, FL 33060-4957 USA http://www.diveriteexpress.com *Hdh* = SS D-ring holder; part # HW1081 *Hdr* =1" SS D-ring; part # HW1019
B	**Borg General Controls** 1386 Jarvis Avenue Elk Grove Village, IL 60007 USA http://www.borggeneral.com *Et* = Diehl series 884 12VDC, 1 channel digital time switch
M	**McMaster-Carr** 6100 Fulton Industrial Blvd. Atlanta, GA 30336 USA http://www.mcmaster.com *Hb*, *Hl*, *Emp*, *Tpc* = 1/8", 1/4", 1/2" thick PVC sheet; part # 8747K112, 8747K114, 8747K116 *Hor* = Buna-N O-ring, Dash # 352; part # 9452K103 *Hsl* = Nielsen-Sessions internal compression spring latch; part # 1794A43
P	**PPL Motor Homes** 10777 SW Freeway Houston, TX 77074 USA http://www.pplmotorhomes.com *Tsh* = Valtera 3" ABS slip hub; part # 89-8288

Table 2. Definition of vendor codes used in Table 1 for sources of specialized and/or hard to find light trap parts. (Continued)

Vendor Code	Vendor Address and Part Numbers
U	**United States Plastic Corp.** 1390 Neubrecht Rd. Lima, OH 45801 USA http://www.usplastic.com *Tb* = Prolon high density polyethylene 40 qt. food storage container; part # 81067 *Tl* = Prolon high density polyethylene lid; part # 81086 *Tcb*, *Tcl* = M&M Industries 2 $^1/2$ gal life latch bucket with lid; part # 2477 *Hp* = Harvel clear rigid 1" PVC pipe; part # 34104

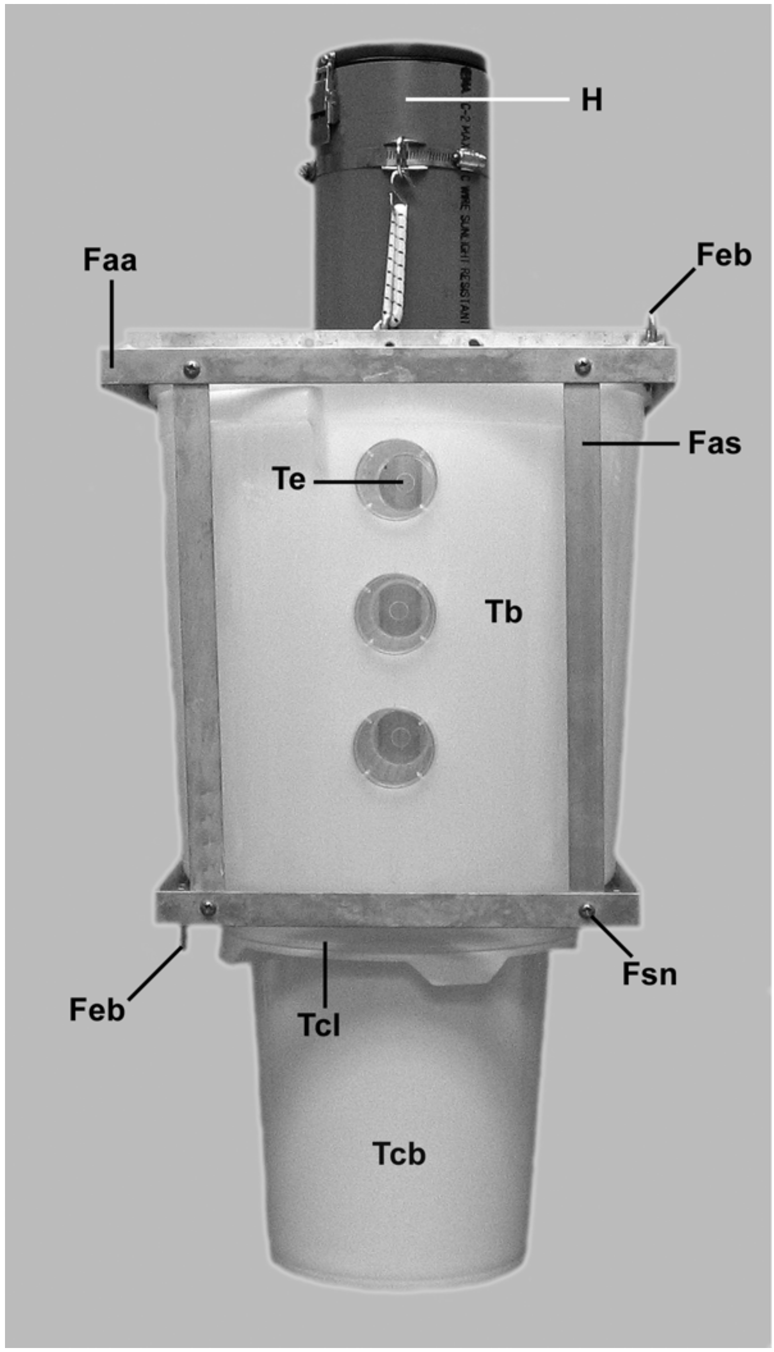

Figure 1. Complete assembled light trap; for clarity the mooring lines have been removed; *H* = waterproof electronics housing constructed from PVC; *Faa* = aluminum angle; *Feb* = SS eye bolt; *Fas* = aluminum straight; *Te* = transparent, tapered trap entrance; *Tb* = main body/entrance chamber constructed from a semi-transparent plastic bucket; *Fsn* = SS machine screw/nut; *Tcb* = sample collection bucket constructed from an opaque plastic bucket with threaded lid; *Tcl* = sample collection bucket lid.

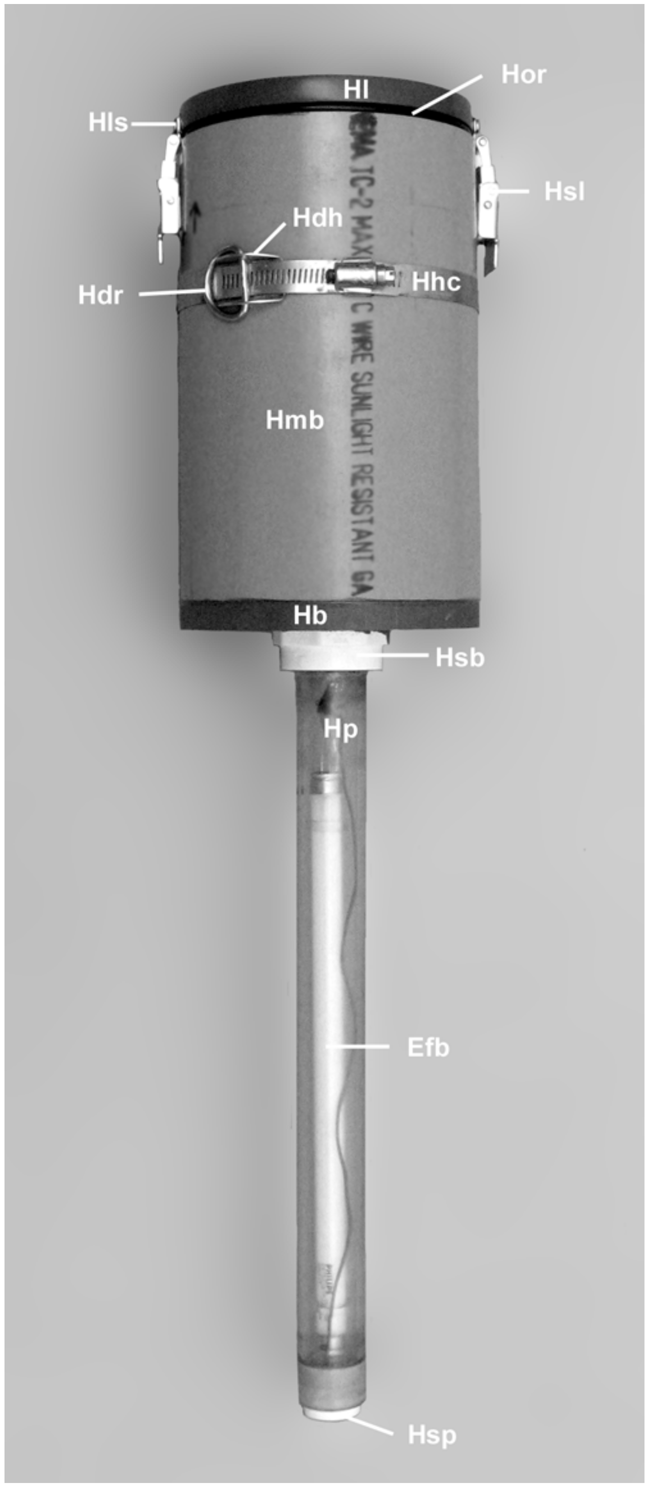

Figure 2. Waterproof PVC housing enclosing the battery, electronics, and fluorescent bulb; *Hl* = lid, *Hor* = O-ring, *Hsl* = spring latch, *Hls* = latch mounting screws, *Hdr* = D-ring, *Hdh* = D-ring holder, *Hhc* = hose clamp, *Hmb* = main body, *Hb* = bottom (floor), *Hsb* = PVC slip bushing, *Hp* = clear PVC pipe, *Efb* = fluorescent bulb, *Hsp* = PVC slip plug.

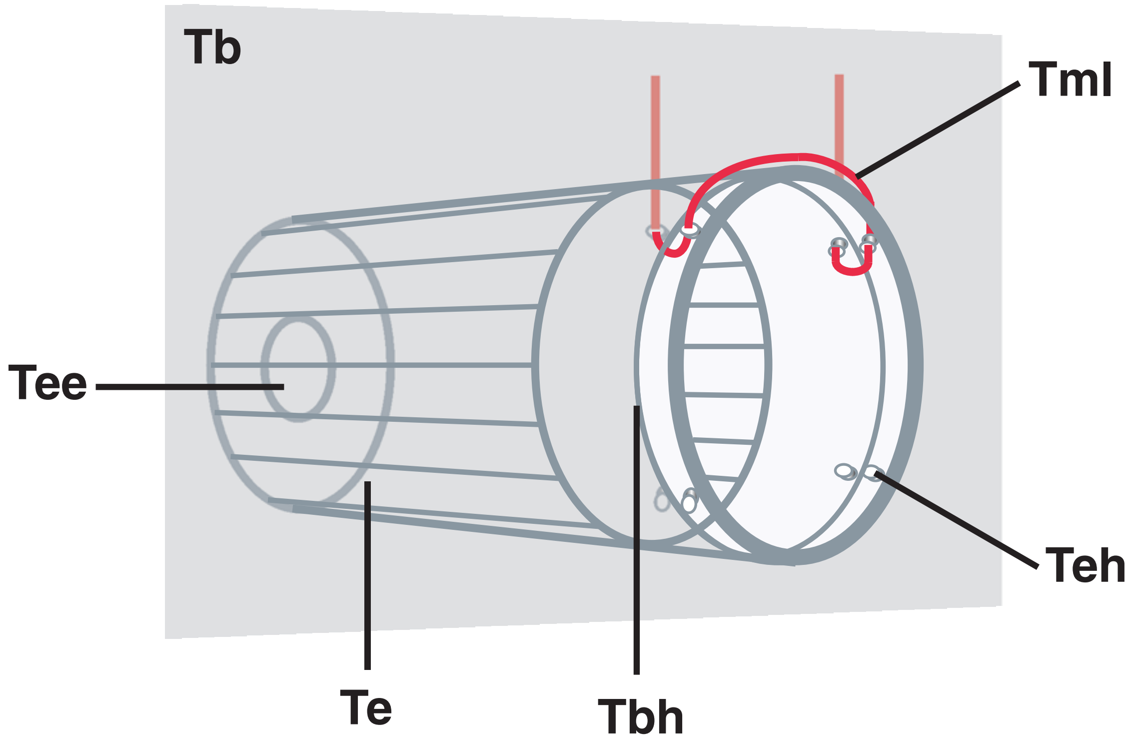

Figure 3. Schematic diagram illustrating the method of attachment of tumblers (*Te*), which serve as tapered entrances, to the light trap; *Tbh* = 2 $^1/2$" diameter hole cut into main body of the light trap (*Tb*, shown as a cut-away), *Teh* = four pairs of $^5/16$" holes drilled equidistant around outer rim of tumbler, *Tml* = section of clear 300 lbs test monofilament fishing line threaded through the tumbler to hold it securely in place, *Tee* = $^1/2$" hole drilled in the bottom of the tumbler. After threading, the monofilament line (*Tml*) was pulled tight and the excess trimmed. For clarity, only the upper section of monofilament line is shown. Drawn by A. Shiroza.

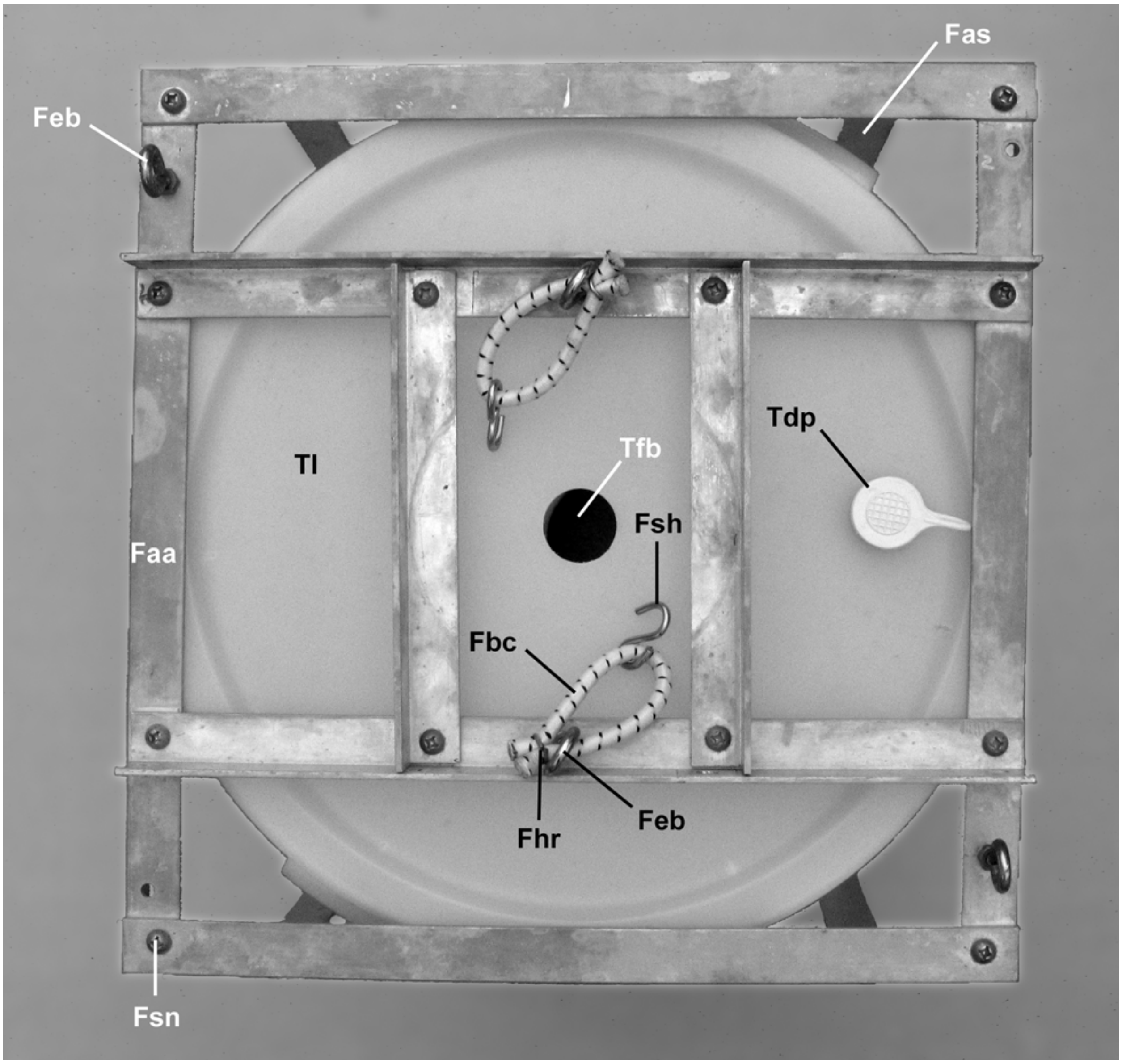

Figure 4. Top view of the light trap; for clarity the waterproof electronics housing has been removed; *Feb* = eye bolt, *Faa* = aluminum angle, *Fsn* = machine screw/nut, *Tl* = entrance chamber lid, *Tfb* = fluorescent bulb port, *Fsh* = S-hook, *Fbc* = bungee cord, *Fhr* = hog ring, *Feb* = eye bolt, *Fas* = aluminum straight, *Tdp* = drain plug.

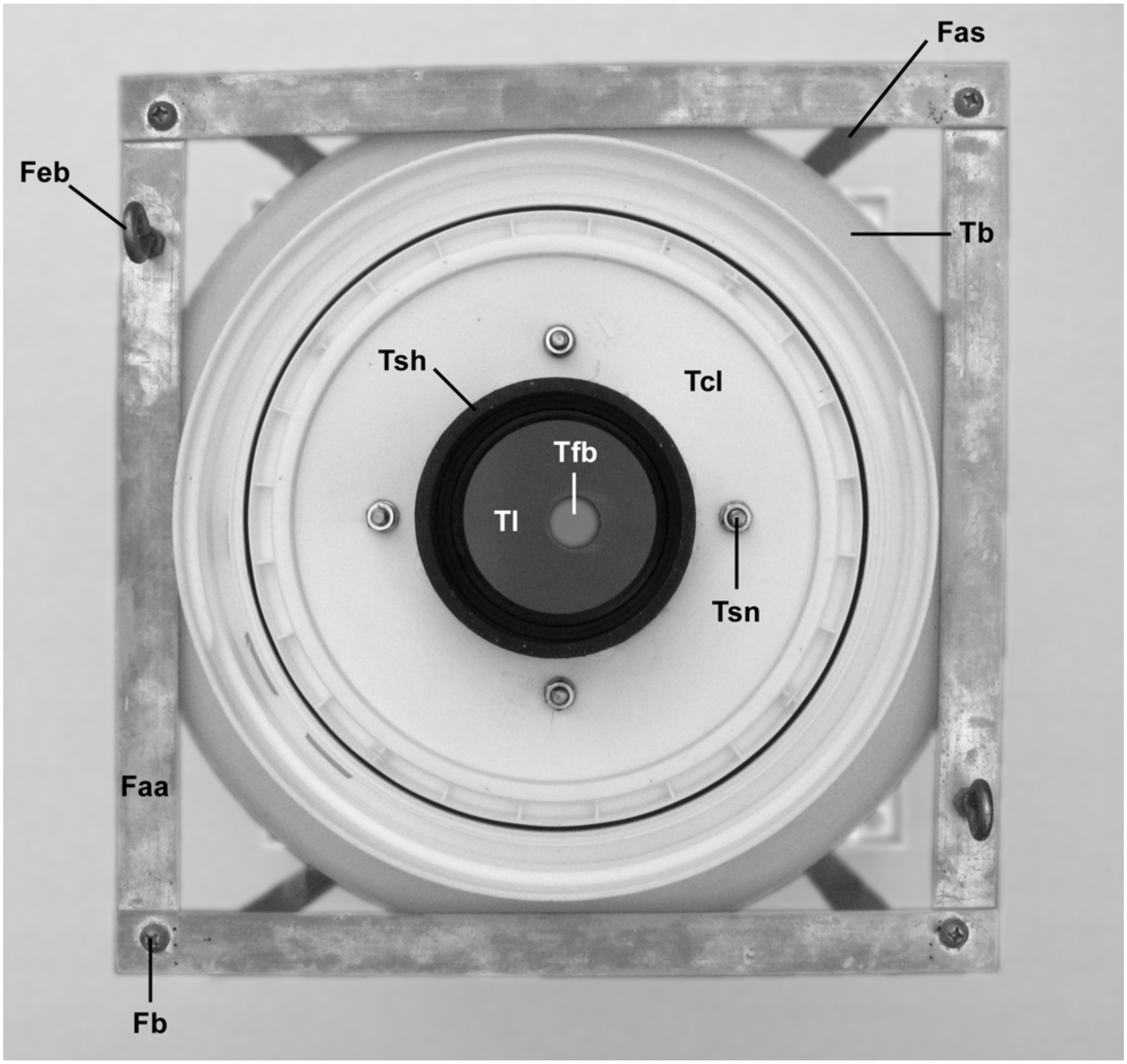

Figure 5. Bottom view of the light trap; for clarity the sample collection bucket and waterproof electronics housing have been removed; *Feb* = eye bolt, *Faa* = aluminum angle, *Fsn* = machine screw/nut, *Tsh* = ABS slip hub, *Tl* = entrance chamber lid, *Tfb* = fluorescent bulb port, *Tcl* = sample collection bucket lid (threaded), *Tsn* = machine screw/nut, *Fas* = aluminum straight, *Tb* = main body/entrance chamber.

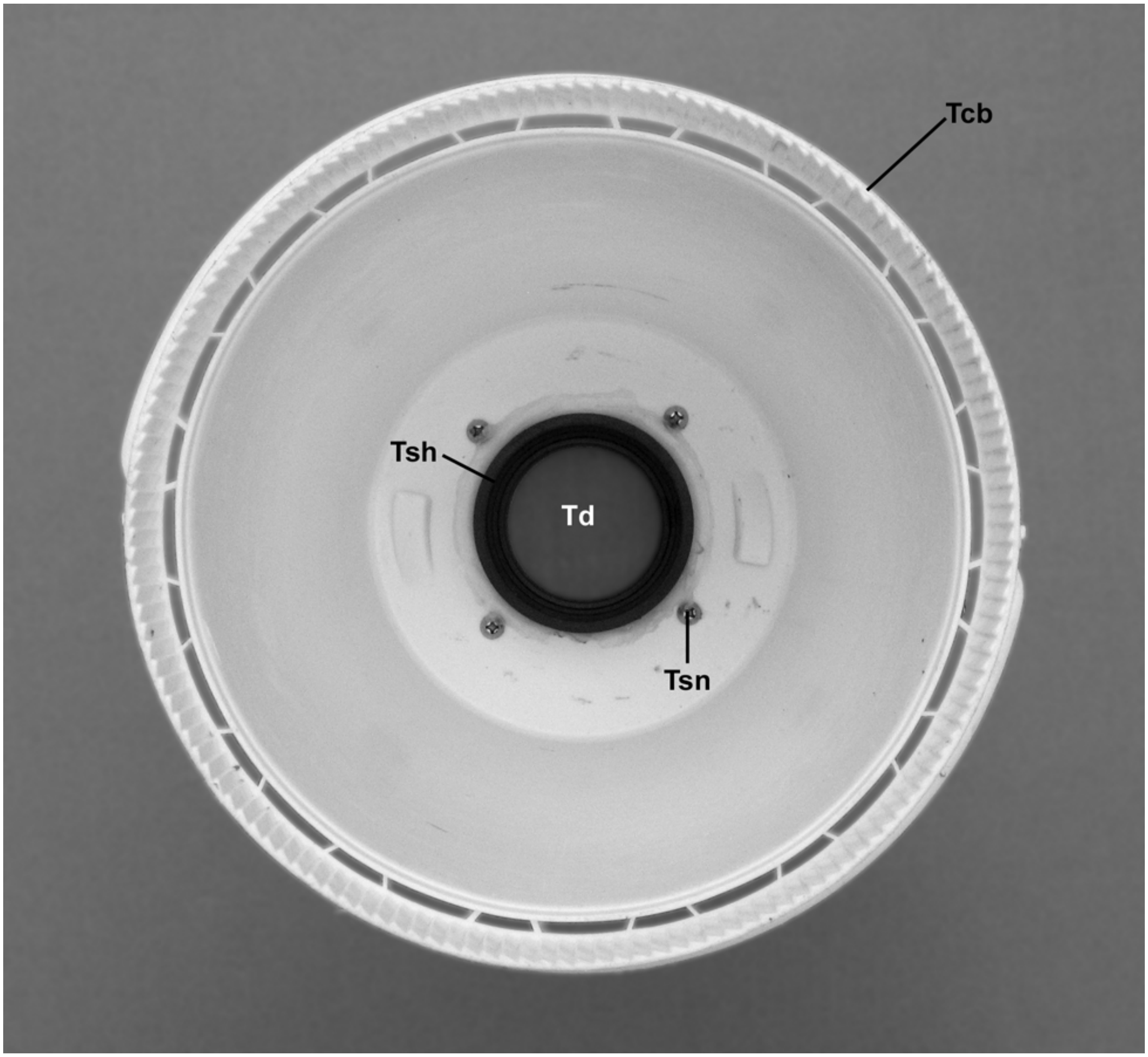

Figure 6. Top view, looking into the sample collection bucket; for clarity the mesh-covered draining unit has been removed from the ABS slip hub (*Tsh*); *Tcb* = sample collection bucket (threaded), *Tsh* = ABS slip hub, *Tsn* = machine screw/nut, *Td* = drain port.

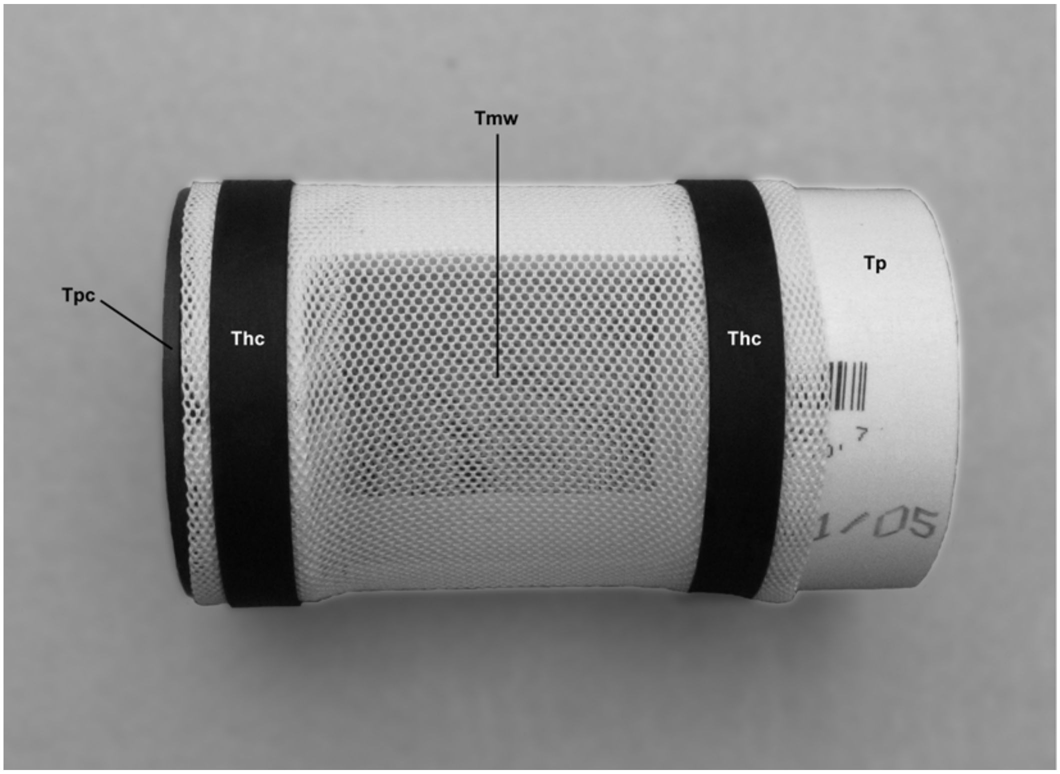

Figure 7. Horizontal view of the mesh-covered draining unit that fits vertically within the ABS slip hub, on the bottom of the sample collection bucket; *Tpc* = pipe cap; *Thc* = shrink wrap-covered hose clamps, *Tmw* = mesh-covered draining window, *Tp* = PVC pipe.

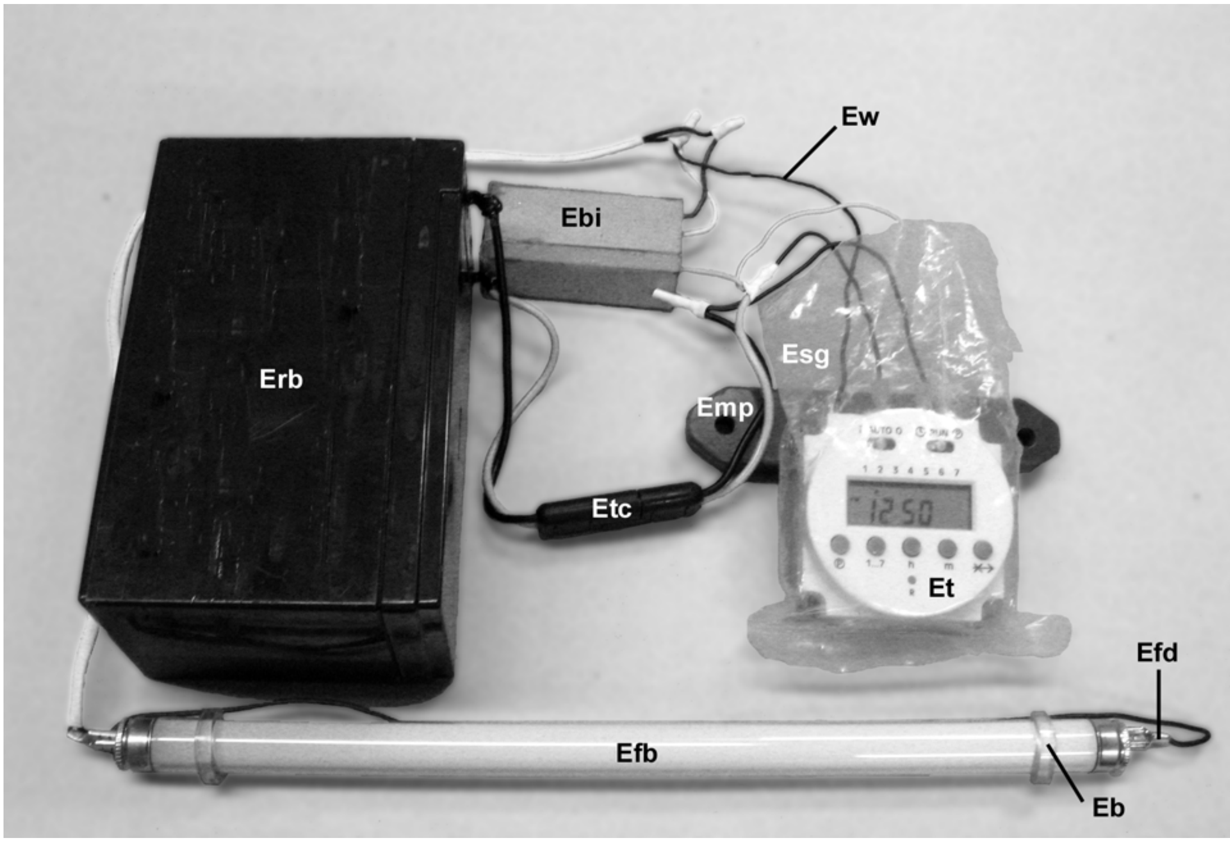

Figure 8. Electronic components enclosed within the waterproof housing; *Erb* = rechargeable battery, *Ebi* = ballast/inverter embedded in epoxy resin, *Ew* = hook-up wire, *Etc* = trailer connector, *Esg* = splash guard, *Emp* = mounting plate, *Et* = digital timer, *Efb* = fluorescent bulb, *Eb* = bumper, *Efd* = female disconnect terminal connector.

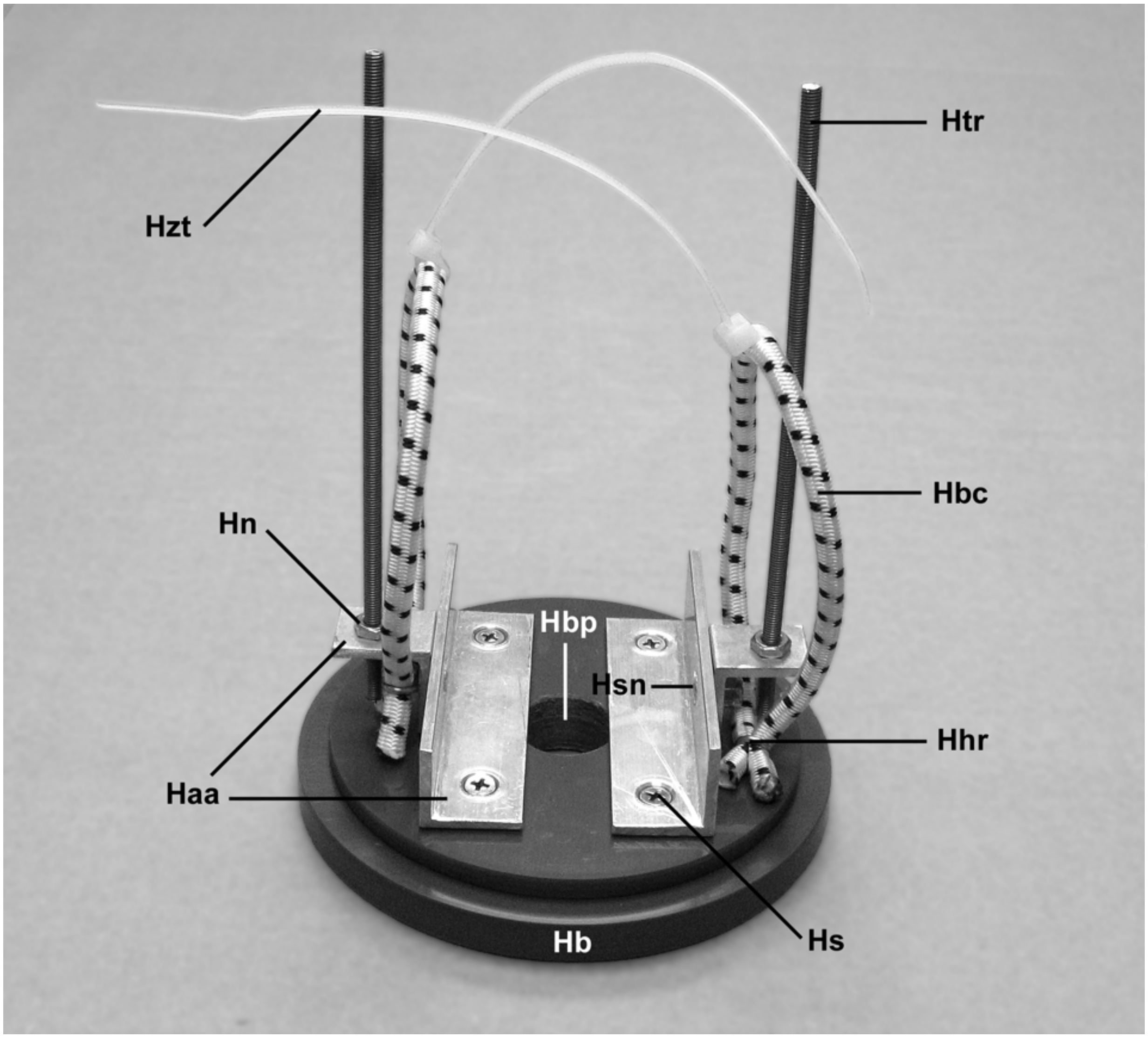

Figure 9. Battery cage used to secure the electronic components within the waterproof housing; for clarity these parts are shown before the bottom (*Hb*) was permanently attached to the main body of the housing; *Hzt* = zip tie, *Hn* = hex nut (one pair for each threaded rod), *Haa* = aluminum angle, *Hbp* = fluorescent bulb port, *Hb* = bottom (floor) of waterproof housing, *Htr* = threaded rod, *Hbc* = bungee cord, *Hsn* = machine screw/hex nut; *Hhr* = hog ring, *Hs* = sheet metal screws.

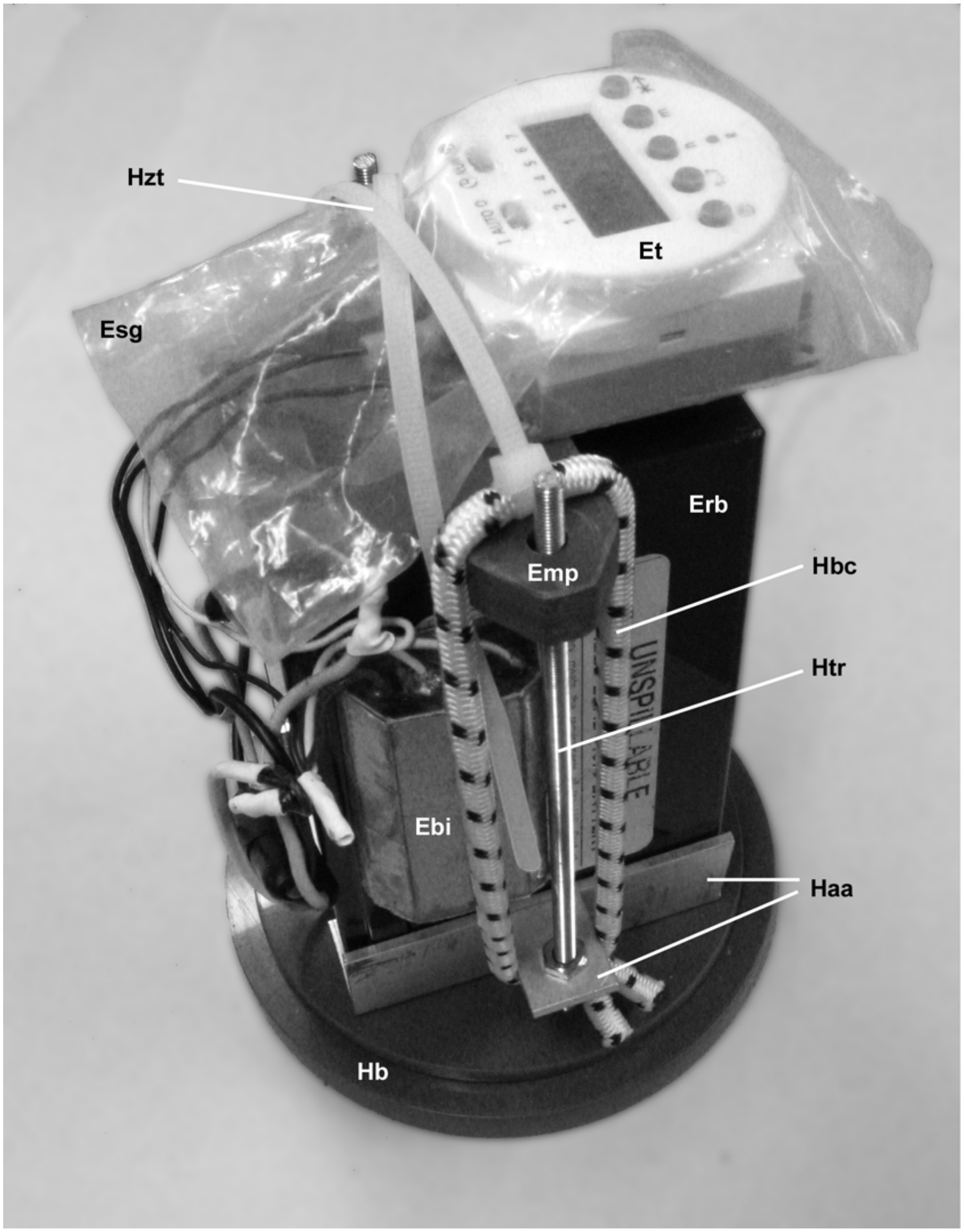

Figure 10. Battery cage used to secure the electronic components (shown installed) within the waterproof housing; for clarity these parts are shown before the bottom (*Hb*) was permanently attached to the main body of the housing; electronic components are easily removed from the housing after loosening the bungee cords; zip ties facilitate grasping the bungee cords; *Hzt* = zip ties, *Esg* = splash guard, *Et* = digital timer, *Emp* = mounting plate, *Erb* = rechargeable battery, *Hbc* = bungee cord, *Htr* = threaded rod, *Ebi* = ballast/inverter embedded in epoxy resin, *Haa* = aluminum angle, *Hb* = bottom (floor) of housing.

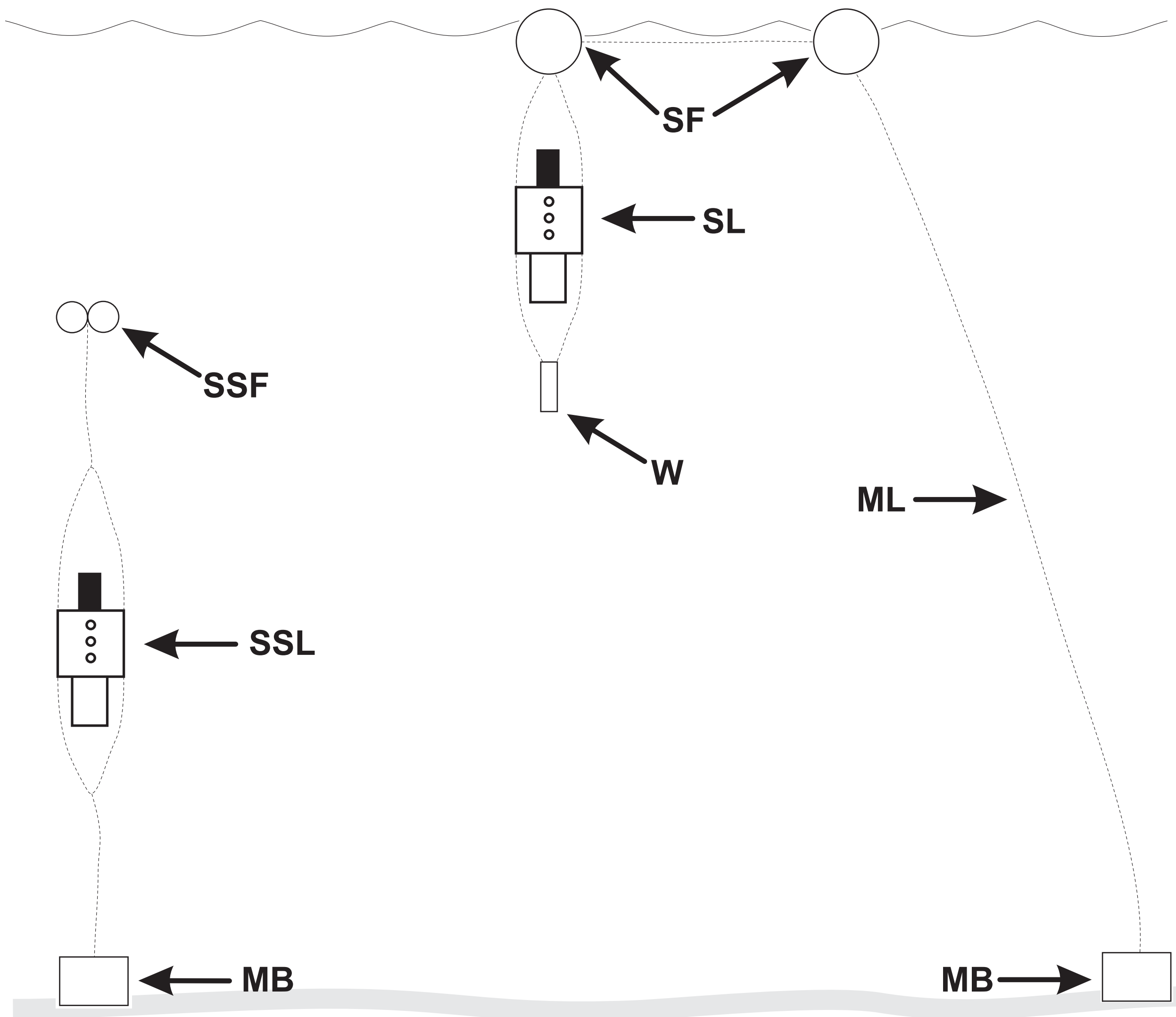

Figure 11. Diagram illustrating the deployment of light traps at depth (left) and just below the surface (right); SSL = subsurface light trap deployed at a depth of 10–20 m, SSF = two 19 cm diameter styrofoam fishing floats, MB = concrete mooring block (38 l plastic bucket filled with concrete), SL = surface light trap placed at a depth of 1 m, SF = two 28 cm diameter styrofoam fishing floats, ML = mooring (anchor) line, W = 4.5 kg weight (PVC pipe filled with concrete).

Figure 12. NOAA science diver replaces a light trap deployed at a depth of 20 m on a spur-and-groove coral reef off the Mexican Yucatan, August 2005.