Philips CoralCare LED unit

Preliminary Field Test Report

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MARINE CONSULTANCY AND SCIENCE WRITING

Produced by Tim Wijgerde, Ph.D., Coral Publications. Commissioned by Philips Advanced Development Europe, Philips Lighting.

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Summary

This report presents the preliminary results obtained during a field test of the CoralCare LED unit developed by Philips. The goal of the field test was to evaluate the performance of the CoralCare unit as a light source for marine aquaria, in particular corals. Two 190W CoralCare units were placed above a 490L aquarium (dimensions 200 x 70 x 35 cm), as well as two T5 reference luminaires (ATI Sunpower, 6x54W dimmable each). The aquarium was divided into two sections using a PVC separator, to prevent cross-over effects of each light source. Quantum irradiance (photosynthetically active radiation, ~400–700 nm) was set to ~560 µmol photons m^{-2} s^{-1}. Water flow was created by placing one flow pump (Maxspect Gyre 150) in each section, operating at 20% power at constant forward flow, resulting in a water flow rate of 10–15 cm s^{-1} around the corals. In each section, three scleractinian coral species (N=5 fragments per species for each light source) were cultured; a pink morph of *Stylophora pistillata*, a purple morph of *Acropora* sp., and a green morph of *Acropora cf. muricata* (N_{total}=30 fragments). The performance of both light sources was evaluated by measuring the specific growth rate of each coral species, as well as by subjective photographic analysis of their morphology and colour. After one month of culture, growth rates obtained under the T5 and CoralCare LED units were 2.7±0.3% and 2.8±0.4% day^{-1} for *Stylophora pistillata*, respectively. For the purple *Acropora* sp., growth rates were 1.7±0.4% under T5 and 1.7±0.3% day^{-1} under CoralCare LED. *Acropora cf. muricata* exhibited growth rates of 2.5±0.3% and 2.2±0.3% under T5 and CoralCare LED, respectively. No significant growth differences between T5 and CoralCare LED were found, for any species, although growth differences between species were detected, irrespective of light source. Subjective evaluation of photographs suggests that coral morphology and colouration are similar between light sources after one month of culture. In preliminary conclusion, the newly CoralCare unit developed by Philips delivers results which seem equal to conventional T5 technology, at 30% higher wall–plug efficiency. This report will be followed up by a more detailed analysis of coral growth, morphology and colouration after several months of culture.

Introduction

This report presents the preliminary results obtained during a field test of a new LED unit developed by Philips, entitled CoralCare. The aim of the field test was to determine the performance of the new LED unit as a light source for marine aquaria, in particular scleractinian (stony) corals.

Proper lighting is one of the key aspects when maintaining a marine aquarium with corals and reef fishes. First, light is essential to the growth of reef-building corals. These corals are host to symbiotic dinoflagellates known as zooxanthellae, which use light energy for photosynthesis, a biochemical process in which carbon dioxide (CO_2) is converted to organic compounds such as glycerol, carbohydrates, fatty acids and amino acids. These compounds are in part translocated to the tissues of the host coral, which uses these for growth and metabolism (Muscatine et al. 1981; Muscatine 1990; Furla et al. 2005). In addition, light is important to create a photoperiod in the aquarium, i.e. a day/night simulation. This stimulates the natural behaviour of fishes and other aquarium life.

When regarding light for aquaria, three factors are important; light intensity (irradiance), spectral distribution and light distribution. For corals specifically, sufficient light intensity is required to stimulate photosynthesis and growth, and in particular colouration (Muscatine et al. 1981; Muscatine 1990; D'Angelo et al. 2008). For corals of the genus *Acropora*, for example, an irradiance of at least 700 µmol photons m^{-2} s^{-1} as photosynthetically active radiation (PAR, ~400–700 nm) is required to fully saturate host pigmentation (D'Angelo et al. 2008). In terms of spectrum, sufficient blue radiation is required to evoke healthy zooxanthellae and coral growth, and chlorophyll synthesis (Kinzie et al. 1984, 1987; Wang et al. 2008; Wijgerde et al. 2014). In addition, to properly visualise the colours of all aquarium life, all wavelengths must be present in a given spectrum. This means that the "ideal" light spectrum for the average marine aquarium is continuous, with a blue peak to create a natural effect. This is comparable to a seawater depth of approximately 10 meters, where all colours are still found, but with decreased presence of red and orange. This is due to the fact that seawater selectively attenuates sunlight, with light of longer wavelengths being filtered more effectively (Mass et al. 2010). The CoralCare LED unit provides such a spectrum with high colour rendering, well–suited for marine life. Next to high colour rendering, marine aquarists seek a homogeneous light source, which is beneficial to the aquarium's inhabitants as well as aesthetically pleasing. A subset of aquarists also seeks a dynamic shimmer effect, which mimics a sunny day on a coral reef. In this respect, Philips has found an optimum between homogeneity and natural shimmer by designing special patented optics.

To determine the suitability of the new CoralCare LED unit, subjective field tests were performed at various locations, with the assistance of several aquarium hobbyists. In addition, a more scientific field test was conducted, for which the following research question was formulated:

What is the performance of the CoralCare LED unit, in terms of stimulating coral growth, shape and colouration, compared to conventional T5 technology?

To address this question, coral growth was measured by weighing corals cultured under T5 reference luminaires and Philips CoralCare LED units. In addition, corals were photographed to document their health, colouration and morphology. The following report presents the preliminary findings of this field test, and will be followed up by a more detailed one after several months of experimentation.

Materials and Methods

Culture system

The experiment was performed at a private residence, where a complete Berlin system was in operation. This system consisted of a main display aquarium, with dimensions 300 x 100 x 85 cm (length x width x height), a filtration sump (dimensions 120 x 60 x 60 cm) and an aquarium for maintaining coral fragments (dimensions 230 x 70 x 30 cm). The total system volume was 3,465 liters. The main filtration unit was foam fractionator (Bubble King 400 internal with ozonator, Royal Exclusiv, Köln, Germany). A DIY calcium reactor was used to maintain stable calcium, magnesium and alkalinity/KH levels. Trace element additions were done regularly to maintain natural trace element levels. A return pump (ATK–MP1206, 12 m^3 $hour^{-1}$, Aqualight GmbH, Bramsche/Lappenstuhl, Germany) constantly exchanged water between the three basins. The coral experiment was conducted in the refugium (see below).

Experimental setup

Two 190W CoralCare units were placed above the refugium (see above), in addition to two T5 reference luminaires (ATI Sunpower, 6x54W dimmable each, with a total of 12 Aquablue Spezial 12,000 Kelvin bulbs). The aquarium was divided into two sections using a PVC separator panel, to prevent cross–over effects of each light source. Spacings on both sides of the PVC panel allowed water to flow freely between both compartments. A small circulation pump (Nanostream 6020, Tunze, Penzberg, Germany) was added to promote water exchange between the compartments.

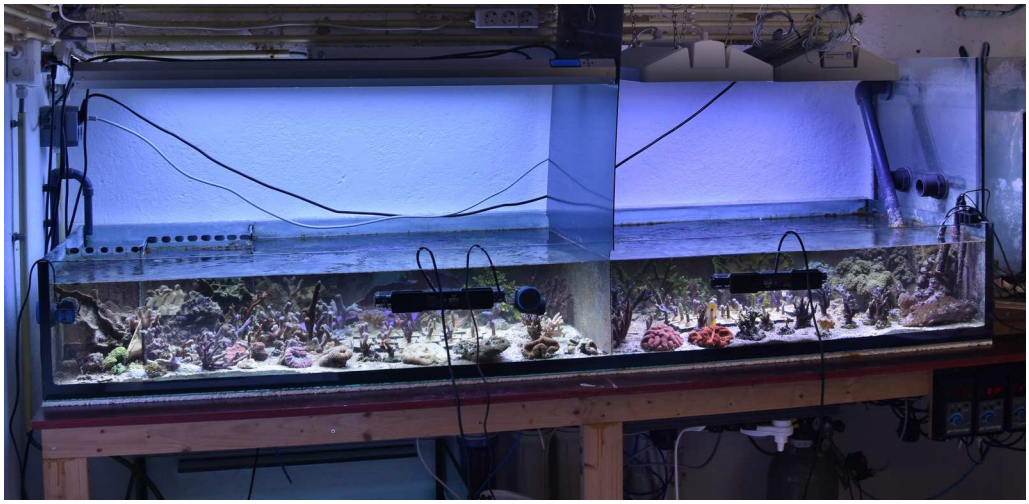

Figure 1: Overview of the experimental setup.

Irradiance

Irradiance was measured at 5 cm space intervals at the water depth of the corals using a LI–COR LI–192SA quantum underwater sensor with computer (LI–COR, Lincoln, USA), which measures

photosynthetically active radiation (PAR, ~400–700 nm). For both setups, PAR was set to ~560 µmol photons m^{-2} s^{-1} (figure 2). Only the areas in which the corals were placed were measured for PAR levels and plotted in figure 2.

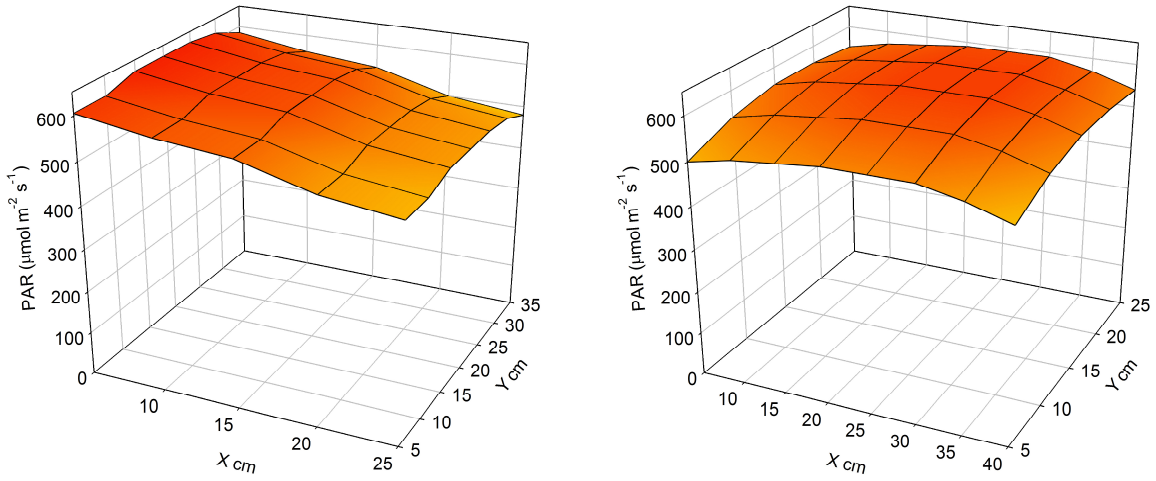

Figure 2: PAR landscape of the T5 luminaires (left) and the CoralCare LED units (right) as seen from the front of the experimental setup. Mean PAR values of the T5 luminaires and CoralCare LED units were 561±42 S.D. and 565±29 S.D. µmol m^{-2} s^{-1}, respectively. Only the areas in which the corals were placed are plotted. Note that corals within both treatments were randomly rotated weekly to cancel out local PAR variations.

Colour point

The colour point of light is standardized in an x–y coordinate system, which translates the contribution of all spectral wavelengths in a unified coordinate on a colour diagram. With such a diagram, a given colour, but also the difference between colours can be described.

When six Aquablue Spezial 12,000K bulbs are mounted, as in this experiment, (), the conventional T5 luminaire operates with a colour point of x=0.238, y=0.202 (figure 3). This configuration was chosen to match previous coral experiments (Wijgerde et al. 2014; Hylkema et al. 2015), allowing for better comparison. The CoralCare unit is able to produce a range of colour points between x=0.151, y=0.021 (CoralCare #1) and x=0.317, y=0.337 (CoralCare #2, figure 3). To allow for a fair comparison between the two light technologies, the colour point of the Philips CoralCare unit was matched to the T5 luminaire as closely as possible. This was done by setting channel 1 to 60%, and channel 2 to 100%, which is perceived as a rather “warm” colour point by marine aquarists.

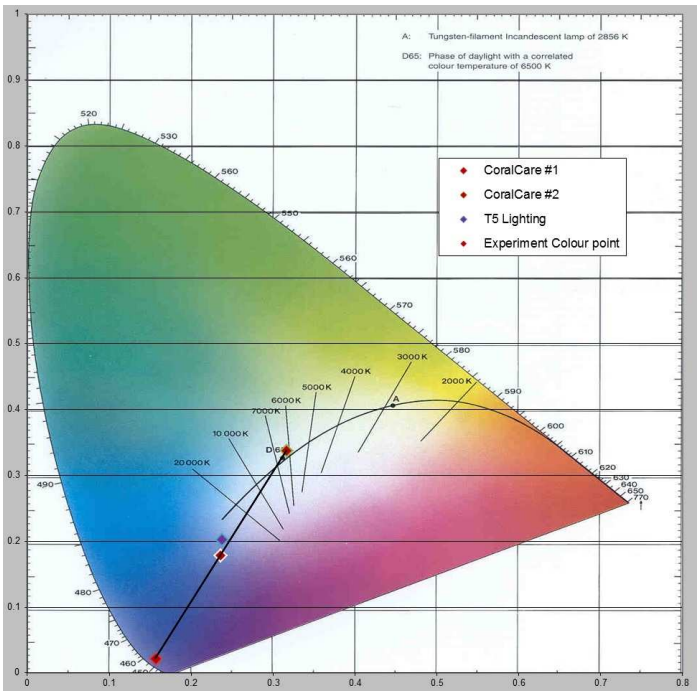

Figure 3: CIE 1931 xy chromaticity space of both light sources, with T5 represented by a purple diamond, and the CoralCare LED by red diamonds. The red diamond in the middle of the black line, close to the purple T5 diamond, represents the LED colour point used in this experiment.

Wall–plug efficiency

Wall–plug efficiency (or radiant efficiency) is a key aspect of an aquarium light, which is defined as the amount of visible light (optical power or radiant flux) generated from the ingoing electrical power. For instance, an incandescent lightbulb converts only 2.1% of the input power to optical power, whereas the remaining energy is converted to heat. With an optical measurement sphere at the Philips laboratory (figure 4), all key parameters were measured to calculate the wall–plug efficiencies of the T5 luminaires and the CoralCare LED units.

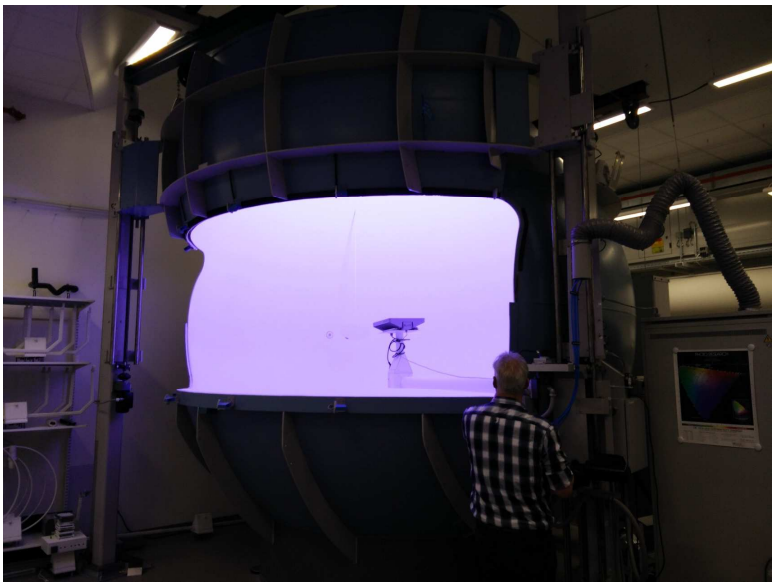

Figure 4: The optical measurement sphere at Philips, used to determine the wall–plug efficiency of both light sources. Only the CoralCare LED unit is shown here. During measurements, the sphere is completely closed to measure all light emitted by the source.

Water flow and water quality

Water flow was created by placing one flow pump (Maxspect Gyre 150, 60W) in each section, operating at 20% power at constant forward flow. Water flow was measured with a current velocity meter (Model 2100, Swoffer Instruments, Seattle, USA) and recorded at 10–15 cm s^{-1} around the corals.

Water quality was measured weekly using home test kits (Salifert BV, Duiven, The Netherlands). In addition, a broad elemental analysis using ICP–OES was performed once at a commercial lab. Temperature was maintained at 24°C, salinity at 35 g L^{-1} (ppt) and pH at ~8.

Corals

In each section, three scleractinian coral species (N=5 fragments per species for each light source, N=30 fragments in total) were cultured; a pink morph of *Stylophora pistillata* (Esper 1797), a purple morph of *Acropora* sp. (Oken 1815), and a green morph of *Acropora cf. muricata* (Linnaeus 1758, outdated synonym *A. formosa* Dana 1846). All fragments within a given species originated from the same parent colony, i.e. they were genetically identical to rule out intraspecific variation. All corals were glued onto 5x5 cm Trespa tiles using two–component epoxy resin (Tunze Aquarientechnik GmbH, Penzberg, Germany). Each tile was labelled with a unique number, ranging from 1 to 40. After fragmentation, coral samples were randomly assigned to either the T5 or LED treatment, to prevent a possible selection bias for either treatment. Under each light source, all corals were rotated weekly within their group to cancel out local variations in irradiance, spectrum and water flow rate.

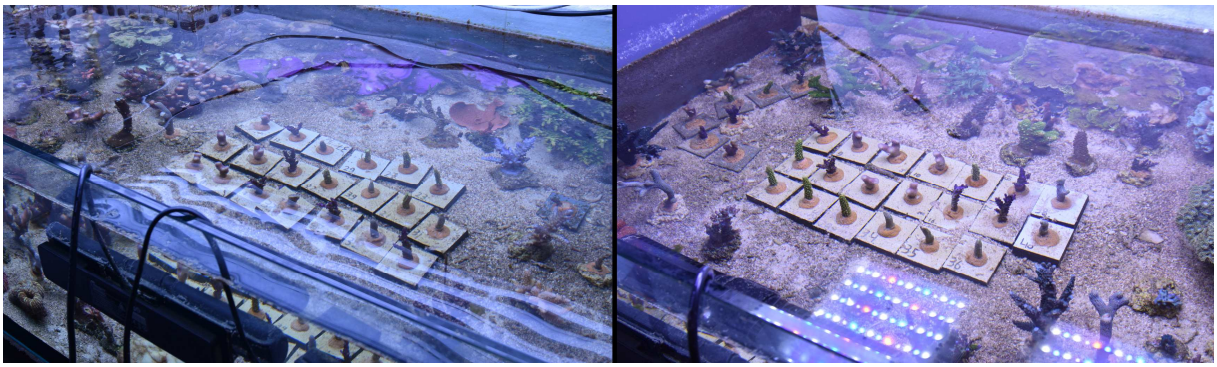

Figure 5: In both sections of the setup, corals were placed randomly and rotated weekly within their group to cancel out local variations in irradiance, spectrum and water flow rate. Left: T5, right: LED.

Specific growth rate

Corals were weighed at the start of the experiment, and after one month of culture. Each coral fragment was weighed before and after being glued onto its Trespa tile, to determine the combined weight of the tile and glue. After one month, the corals were removed individually from the aquarium, tiles were carefully cleaned with a small brush and dried with a cloth, and total weights were obtained. To calculate net coral weights, the combined weight of each coral's tile and glue was subtracted from the total weight. To calculate specific growth rates (SGR) for each individual, a first order kinetics exponential growth model was used (Wijgerde et al. 2012):

$$SGR\ (day^{-1}) = ln\ (W_T / W_{T-1}) / \Delta t$$

where W_T is the net weight of a given coral expressed in grams (g) at the end of an interval, W_{T-1} is the net weight of a coral in grams (g) at the start of an interval, and Δt is the growth interval in days. SGR is expressed in gram coral gram coral^{-1} day^{-1}, which can be simplified as day^{-1}. When SGR is multiplied by 100, the daily percent growth in coral biomass is obtained. As branching corals bifurcate continuously, they increase their growing surface area over time. Thus, the amount of biomass they produce every day increases with time. In other words, branching corals do not grow linearly, but exponentially (Leal et al. 2014). For this reason, the natural logarithm *ln* is used in the formula, which takes this exponential growth of branching corals into account.

Coral colouration and morphology

For subjective analysis of coral colouration and morphology, a photographic setup was used. All corals were photographed at the start of the experiment and after one month. A Nikon D700 with Nikkor 70–180 mm micro lens and SB600 speedlight (Nikon Corporation, Tokyo, Japan) was used for all photographs. All camera settings, including zoom factor, were kept constant. White balance was manually corrected using Capture NX-D (Nikon Corporation, Tokyo, Japan).

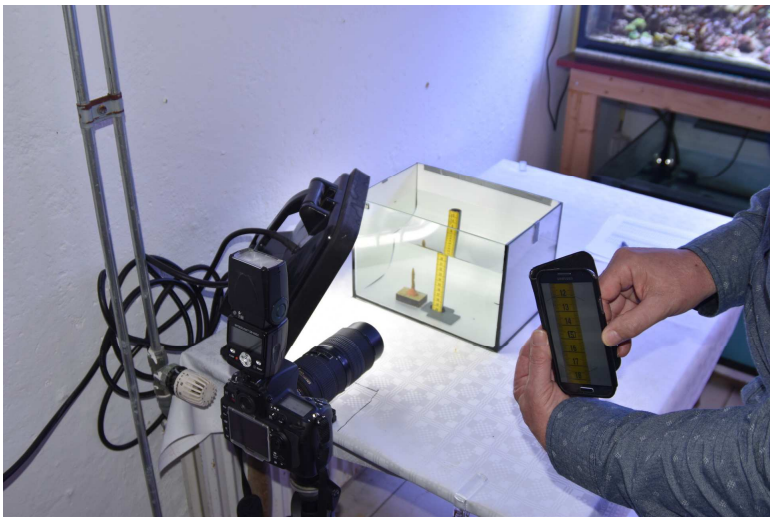

Figure 6: The setup used to photograph the corals. A ruler was used for scale.

Statistical analysis

Normality of specific growth data was evaluated by plotting residuals of each dataset versus predicted values, and by performing a Shapiro–Wilk test. Homogeneity of variances was determined with Levene's test. All data were found to be normally distributed and showed homogeneity of variance after a square root transformation ($p>0.050$). A two–way factorial analysis of variance (ANOVA) was used to determine the main and interactive effects of light source and species on coral specific growth rate. Simple effect contrasts were used to elucidate interactive effects. Statistical analysis and graph plotting was done with IBM SPSS Statistics 22 (IBM Corp., Armonk, USA).

Results, Discussion and Conclusion

Water quality

Water chemistry was close to natural conditions (Spotte 1992), although phosphate was elevated compared to pristine coral reefs (Tanaka et al. 2007). No elevated levels of potentially toxic trace elements, such as chromium, copper or aluminium were found. Table 1 shows water quality during the experiment.

Table 1: Water quality during the course of the experiment. Values are means ± s.d. (N=1–4).

Parameter	Value
Sodium (mg L^{-1})	10,513
Magnesium (mg L^{-1})	1,415±25
Sulphur (mg L^{-1})	803
Calcium (mg L^{-1})	429±8
Potassium (mg L^{-1})	396
Bromine (mg L^{-1})	50.59
Strontium (mg L^{-1})	10.85
Boron (mg L^{-1})	4.62
KH (°DH)	7.1±0.3
Alkalinity (mEq L^{-1})	2.54±0.12
Nitrate (mg L^{-1})	< 0.2
Phosphate (mg L^{-1})	0.038±0.014

Wall–plug efficiency

Table 2 lists the electrical power, optical power and wall–plug efficiency of the T5 luminaires and CoralCare LED units. Using the settings of this experiment, the CoralCare LED units generate a similar colour point compared to T5 at 30% (or 7.3 percentage point) higher efficiency (i.e 32% versus 24.7% WPE for LED and T5, respectively).

Table 2: Electrical power (P_{elec}) and optical power ($P_{optical}$) measured in Watts (W), and wall–plug efficiency (WPE) of the T5 luminaires and CoralCare LED units. WPE values in bold are representative for the experiment.

Fixture	P_{elec} [W]	$P_{optical}$ [W]	WPE [%]
T5 Lighting	386.7	92.4	23.9
T5 Lighting dimmed to test value	273.2	67.5	**24.7**
Philips CoralCare	189.7	60.4	31.9
Philips CoralCare set at test colour point	158.1	50.6	**32.0**

Specific growth rate

Stylophora pistillata exhibited similar growth rates under both light sources, with 0.027±0.003 day^{-1} under T5 and 0.028±0.004 day^{-1} under LED (figure 7). This is equal to 2.7% and 2.8% day^{-1} for T5 and LED, respectively. The survival rate was 100%.

Acropora sp. showed equal growth under both light sources, with 0.017±0.004 day^{-1} under T5 and 0.017±0.003 day^{-1} under LED (figure 7). This is equal to 1.7% day^{-1} under both light sources. The survival rate was 100%.

Acropora cf. muricata also exhibited similar growth under both light sources, with 0.025±0.003 day^{-1} under T5 and 0.022±0.003 day^{-1} under LED (figure 7). This is equal to 2.5% and 2.2% day^{-1} for T5 and LED, respectively. The survival rate was 100%.

Statistical analysis revealed that the factor light source had no significant main or interactive effect on coral specific growth rates (Table 3). Thus, for each species, specimens cultured under T5 grew at an equal rate as those under LED. Species, on the other hand, did have a significant effect on growth rates (Table 3), with *Stylophora pistillata* and *Acropora cf. muricata* showing higher growth rates than *Acropora* sp. (P=0.000 and P=0.001, respectively), independent of the light source. No significant growth difference was found between *S. pistillata* and *A. cf. muricata* (P=0.068).

A possible explanation for the lack of statistically significant growth differences between light sources is the resemblance of light intensity, colour point, spectrum and light distribution when comparing the T5 luminaires and CoralCare LED units. However, subtle differences between the two light sources tested here could result in medium– to long–term growth differences, which will be evaluated in a follow–up report.

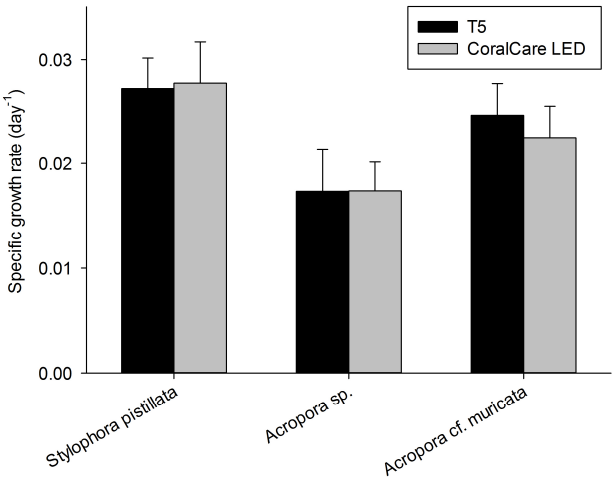

Figure 7: Specific growth rates of Stylophora pistillata, Acropora sp. and Acropora cf. muricata under T5 and CoralCare LED, at an irradiance of ~560 µmol m^{-2} s^{-1}. Growth interval was one month. Data are means + standard deviation (N=5).

The observed growth rates in the range of 1.7 to 2.8% day^{-1} can be regarded as high when compared to those found in the literature (Schutter et al. 2010; Wijgerde et al. 2012; Wijgerde and Laterveer 2013). This is most likely due to the high irradiance applied in this experiment, which is known to be close to growth–saturating for scleractinian corals (Chalker 1981; Wijgerde and Laterveer 2013). Calcium and alkalinity levels are also known to significantly affect coral calcification (Chisholm and Gattuso 1991; Marshall and Clode 2002; Hylkema et al. 2015). However, as these parameters were close to natural during this experiment (Spotte 1992), and therefore still in the growth–limiting range, they are a less likely explanation for the high growth rates found. The same is true for temperature, which was kept around 24 degrees Celsius, a value also known to be growth–limiting for scleractinian corals (Carricart–Ganivet 2004).

Table 3: Two–way factorial ANOVA, showing main and interactive effects of light source and coral species on specific growth rates of the first one–month growth interval (N=5 fragments per treatment). SGR: Specific growth rate.

Factor	**F**	**df**	**error**	***P***
Light source	0.171	1	24	0.683
Coral species	24.014	2	24	0.000*
Light source * Coral species	0.422	2	24	0.660

*Indicates significant effect (P<0.050).

Coral colouration and morphology

After one month of culture, all corals appeared healthy. No signs of bleaching or necrosis were observed. Corals grown under T5 lighting showed comparable colouration compared to LED (figure 9). As corals require more time to develop their complex threedimensional architecture it is as of yet not possible to determine whether morphological differences have occurred between the two light sources. Differences in coral shape can also affect the light microenvironment around the corals due to self–shading (Wangpraseurt et al. 2014), and as a result affect overall colouration. In a final report, the medium–term results, in terms of coral colouration and morphology, will be presented.

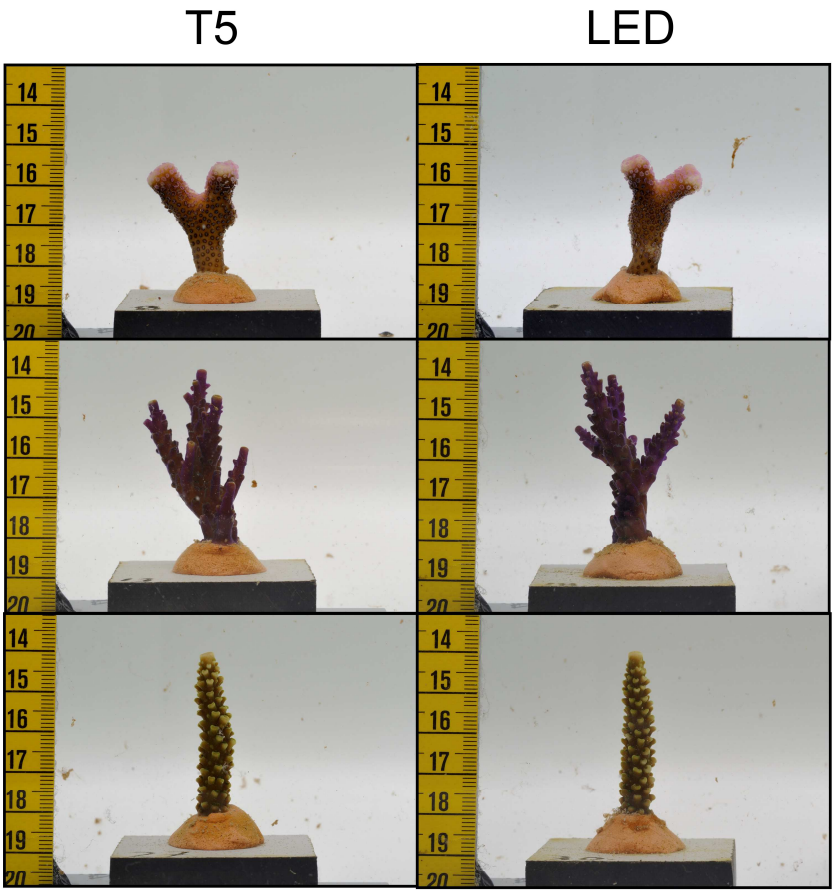

Figure 8: Representative photographs of Stylophora pistillata (top row), Acropora sp. (middle row) and Acropora cf. muricata (bottom row) at the start of the experiment. All scale bars depict centimeters.

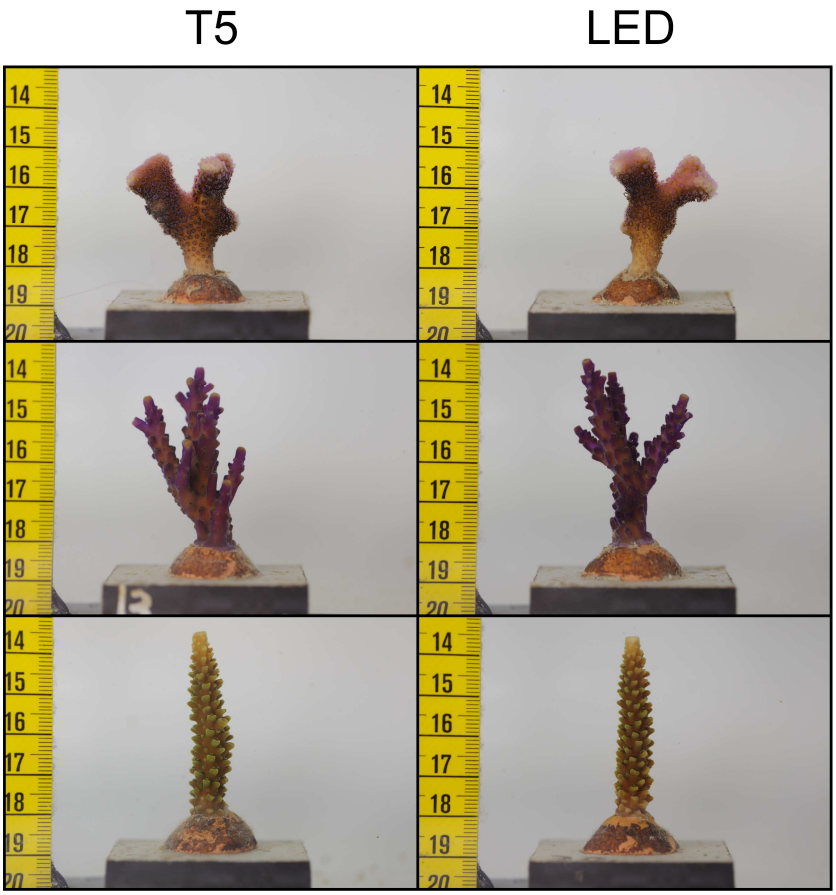

Figure 9: Representative photographs of Stylophora pistillata (top row), Acropora sp. (middle row) and Acropora cf. muricata (bottom row) cultured under T5 or CoralCare LED for a period of one month. All scale bars depict centimeters.

Conclusion

The preliminary conclusion is that the CoralCare unit developed by Philips delivers results which are highly comparable, or perhaps equal to conventional T5 technology, at 30% higher wall–plug efficiency. This report will be followed up by a more detailed analysis of coral growth, morphology and colouration after several months of culture, scheduled for publication in Q2 of 2016.

Acknowledgements

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