Spectral Error for Apogee Instruments 500 Series Quantum Sensors/Meters

Summary

Apogee Instruments 500 series quantum sensors and meters read lower than expected under radiation sources that have a high fraction of violet and blue radiation (lamps sometimes used in aquariums). The low readings are caused by low sensitivity to photons between 400 and 420 nm. Measurements for most customers will not be affected by this. Errors are only visible for lamps that have a high percentage of output between 400 and 420 nm (for example, Actinic and Blue T5 Lamps for aquariums). Errors for typical broadband radiation sources (for example, sunlight, cool white fluorescent, metal halide, high pressure sodium) and most LEDs (peaks greater than 450 nm) are negligible. Sensitivity of 500 series sensors/meters can be improved by sending units back to Apogee for an update. Data in the tables below can also be used to correct measurements for Actinic and Blue Plus T5 lamps.

Measurements Under Actinic and Blue Plus T5 Lamps

Apogee Instruments recently evaluated the Actinic (violet) and Blue Plus T5 lamps designed for use in aquariums. We found that 500 series quantum sensors/meters read 19 % low under Actinic lamps and 8 % low under Blue Plus lamps when compared to measurements from a spectroradiometer (Apogee Instruments model SS-110). Spectral response analysis of 500 series quantum sensors indicates that low readings are caused by low sensitivity between 400 and 420 nm. Based on empirical testing, this reduced sensitivity only affects measurement accuracy for radiation sources that have a high proportion of photosynthetically active radiation (PAR, sum of all photons between 400 and 700 nm) near 400 nm. Spectral errors were less than 2 % under blue/red LED mixtures (450 and 670 nm peaks) and red/white LED mixtures, typically used to grow plants, and all full spectrum radiation sources (for example: sunlight, cool white fluorescent, metal halide, high pressure sodium). The following tables list measured errors for Apogee 100 series (original model) and 500 series (new model) quantum sensors/meters under Actinic and Blue Plus T5 lamps used in aquariums.

Ratio of Actinic Lamps to Standard T5 Lamps	**500 Series Error**	**100 Series Error**
1	-19 %	-14 %
0.5	-9 %	-6 %
0.25	-4 %	-3 %
0	0 %	0 %

Ratio of Blue Plus Lamps to Standard T5 Lamps	**500 Series Error**	**100 Series Error**
1	-8 %	3 %
0.5	-4 %	2 %
0.25	-2 %	1 %
0	0 %	0 %

Users can correct readings for a given fraction of Actinic or Blue Plus lamps. For example, for a radiation source with 25 % Actinic lamps (75 % standard T5 lamps) multiply the 500 series reading by 1.04 to get an accurate measurement of PAR.

Reduced spectral sensitivity (for wavelengths near 400 nm) of Apogee 500 series quantum sensors/meters has been corrected by an update to the housing and filter. All 500 series sensors and meters built previous to March 28, 2017 (table below provides the serial number ranges), can be updated if desired. All 500 series sensors/meters built after this have the update in place.

Serial Numbers Affected:
For a list of affected models and serial numbers visit http://www.apogeeinstruments.com/apogee-instruments-500-quantum-series-product-announcement/

The following table lists measured error for updated Apogee 500 series quantum sensors/meters under Actinic and Blue Plus T5 lamps.

Ratio of Actinic Lamps to Standard T5 Lamps	**500 Series Error**
1	-10 %
0.5	-4 %
0.25	-2 %
0	0 %

Ratio of Blue Plus Lamps to Standard T5 Lamps	**500 Series Error**
1	-3 %
0.5	-2 %
0.25	-1 %
0	0 %

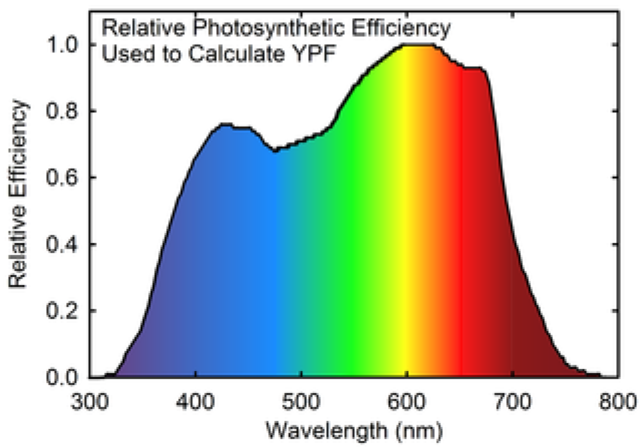
Underwater Measurements in Outdoor Environments

Transmission of radiation in water is dependent on wavelength (blue wavelengths are attenuated the least and red wavelengths are attenuated the most) and depth, thus spectral errors underwater are dependent on the radiation source and the water depth. The following table lists error estimates for Apogee 500 series quantum sensors/meters when measuring sunlight transmitted underwater.

Water Depth [meters]	**500 Series Error**
0	0 %
1	1 %
5	2 %
10	4 %
20	5 %

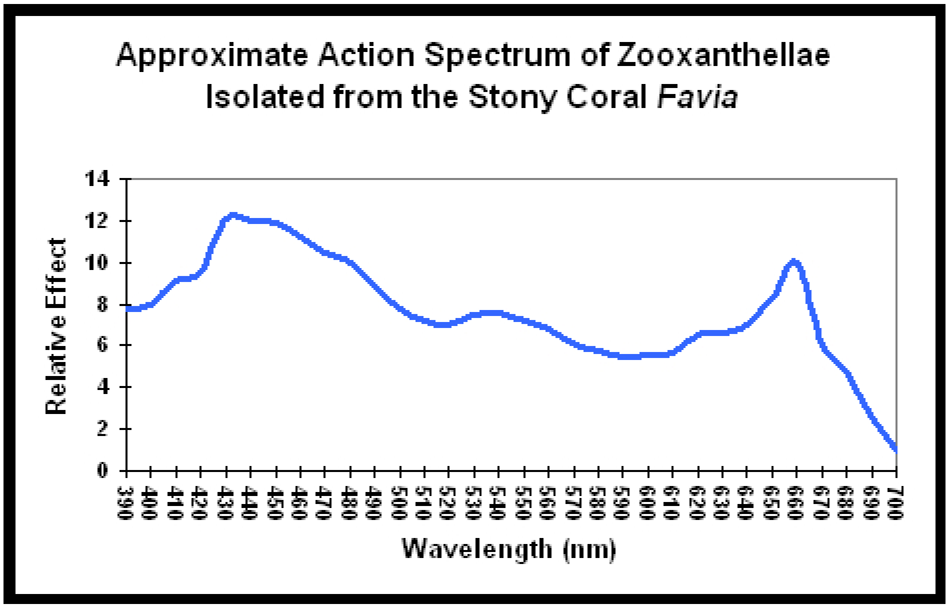
Underwater measurement errors are negligible for updated 500 series sensors/meters.

Photosynthetic Radiation from Unusual Lamps: Advantages of a Spectroradiometer
Although photobiologists have defined photosynthetically active radiation (PAR) as photosynthetic photon flux density (PPFD, in units of μmol m^{-2} s^{-1}) as the number of equally-weighted photons between 400 and 700 nm, they realize that a sharp cutoff at 400 nm does not provide the best measure of PAR for higher plants. Studies by McCree (1972a, 1972b) indicate that photons from 400 to 500 nm are used with only about 70-80 % of the efficiency of yellow, orange, and red photons (see graph below). This means all quantum sensors over-measure the photosynthetic radiation from the Actinic (violet) lamp used in aquariums if the weighting factors shown in the graph are used. Photobiologists sometimes use a spectroradiometer that has weighting factors for calculating yield photon flux density (YPFD) as defined by the response measured by McCree (graph below).



In addition to the ability to measure YPFD, spectroradiometers more accurately measure PPFD than quantum sensors because they measure radiation intensity at multiple wavelengths and are calibrated at each of these wavelengths, eliminating spectral errors caused by sensor spectral sensitivity. Fortunately, recent advances allow spectral measurements to be made underwater at a much lower cost than a few years ago (http://www.apogeeinstruments.com/field-spectroradiometers/).

Unlike plants, coral do not make their own food, but rely on unique microscopic photosynthetic algae that live symbiotically and provide it with glucose and amino acids. A major symbiotic algae is *zooxanthellae*. These algae have unique pigments, thus the action spectrum for photosynthesis is not the same as the action spectrum for higher plants. An approximate action spectrum is shown in the graph below.



Although quantum sensors are the lowest cost devices for estimating photosynthetic radiation in symbiotic algae in coral, an ideal quantum sensor (exact cutoffs at 400 and 700 nm, equal sensitivity between 400 and 700 nm) may poorly represent photosynthetic radiation because they are designed to equally weight all of the photons between 400 and 700 nm. A waterproof spectroradiometer is an elegant solution to this problem.

References

McCree, K.J., 1972a. The action spectrum, absorptance and quantum yield of photosynthesis in crop plants. Agricultural Meteorology 9:191-216.

McCree, K.J., 1972b. Test of current definitions of photosynthetically active radiation against leaf photosynthesis data. Agricultural Meteorology 10:443-453.

Additional Information

Muscatine, L., 1980. Productivity of zooxanthellae. In: Falkowski, P.G. (ed). Primary Productivity in the Sea. Plenum Press, New York. Pp. 381-402

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