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JellySpec: feasibility study for determining the spectral characteristics of jellyfish from Belgian waters.

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Introduction

There is considerable scientific debate about the possible increase in jellyfish occurrence over the last few decades (1-3) and possible relationships to human activities via modifications to the physical habitat (temperature, turbidity, benthic sediments), prey or competitors. This increase in jellyfish populations and the increasing occurrence of jellyfish blooms has brought with it negative effects to human activities, particularly aquaculture and tourism. Harmful jellyfish can be responsible for painful stings to bathers (4) and can have a negative impact on coastal tourism. Jellyfish may impact negatively fisheries by preying directly on fish larvae of eggs and/or competition for prey with adult fish (1,5). Jellyfish have been reported to disrupt the operations of power plants by blocking the intake of cooling seawater (6) and to disrupt fishing operations by clogging nets and/or contaminating catch (7).

Unfortunately relatively few quantitative scientific data exist regarding jellyfish occurrence or concentration. Airborne visual observations of subsurface jellyfish beyond the range of conventional ship-based techniques have been successfully demonstrated (8). It was noted that the visibility of the jellyfish to the naked eye was quite remarkable enabling species identification from a survey height of 152m. Also, automatic seaborne optical detection techniques have proven to be successful. The JEROS system uses a camera on an unmanned surface vehicle to automatically detect jellyfish using pattern recognition techniques (9). Still, despite the strong user interest in jellyfish detection and the emergence of pre-commercial systems there is limited scientific literature regarding the optical properties (absorption, backscattering, refractive index, etc.) of various species. For example, the colourings of many species are easily recognizable by human observers – if these correspond to pigments absorbing light at specific wavelengths then sensors can be designed to measure at such wavelengths and typically nearby “normalization” wavelengths.

In this feasibility study, the optical properties of different jellyfish species (i.e. *Aurelia aurita, Chrysaora hysoscella and Rhizostoma octopus)*) were collected both in high spectral and high spatial resolution with the JellySpec system. This jellyfish observation system combines a hyperspectral TriOS-RAMSES spectroradiometer (400nm-900nm) with a THORLABS imaging camera to provide optical information on the jellyfish (i.e. color, backscatter, absorption) at high spectral and spatial resolution. An overview of the spectral characteristics of these jellyfish species will be presented demonstrating the functionality of the JellySpec system in support of the development of optical detection techniques for jellyfish.

2. Materials & Methods

2.1 Jellyfish

This study focused on three common jellyfish species in the Southern North Sea: *Aurelia aurita* (Aa), *Chrysaora hysoscella* (Ch) and *Rhizostoma octopus* (Ro) (Fig. 1). Aa were caught in the harbor of Zeebrugge of which three specimens were chosen for further measurements. Two Ch specimens and one Ro jellyfish were collected at the beach near Oostende while they were washing up on the coastline. All jellyfish were alive when caught except for the Ro specimen. The Jellyfish were all measured within a time span of 3 hours after being caught and were kept in a large plastic container with seawater during this time.

Fig. 1. Three studied jellyfish species as they appear in seawater beached: Aurelia aurita (left, photo by Wim Decock), Chrysaora hysoscella (middle, photo by Nanne Nicolai) and Rhizostoma octopus (right, photo by Jan

2.2 JellySpec system

The JellySpec system combines a hyperspectral TriOS system with a Thorlabs imaging camera providing the spatial distribution of the color of the jellyfish in three bands (i.e. blue, green, red). The TriOS-system consists of three sensors used to make measurements of upwelling radiance (L^{0+}_{u}), sky radiance (L^{0+}_{sky}) and downwelling irradiance (E^{0+}_{d}). They are mounted on an aluminum frame enabling an L^{0+}_{u} zenith viewing angle θ of 0°+/-1° and L^{0+}_{sky} - E^{0+}_{d} zenith viewing angle of 180°+/-1°. It is mounted 0.75m above the base plate on which the container with jellyfish is placed. The THORLABS camera is aligned with the TriOS L^{0+}_{u} sensor of which the footprint, determined by its field of view of 7° and the measurement height, is detected and marked in the RGB images using laser pointers mounted on the frame. Subsequently, the laser pointers are used to position jellyfish directly in the field of view of the L^{0+}_{u} sensor and are turned off during measurements to prevent light contamination of the hyperspectral measurements. The jellyfish specimens are placed in an optically black tray with seawater. Different backgrounds can be placed in the tray (i.e. spectralon, white plaque, optically black material). The experimental set-up is shown in figure 2. For each sample the TriOS-system scanned L^{0+}_{u}, L^{0+}_{sky} and E^{0+}_{d} every 10s for a total of 3 minutes resulting in 18 hyperspectral scans. Guidelines provided by (10) suggest 10 minutes of measurements at sea deployments. As there is no water movement in the tray, the TriOS scans proved to be stable when measuring under cloudless skies allowing a reduction of the scan time. Calibrated data for L^{0+}_{u}, L^{0+}_{sky} and E^{0+}_{d} were directly interpolated to 2.5 nm intervals and exported to Microsoft Excel for further processing.

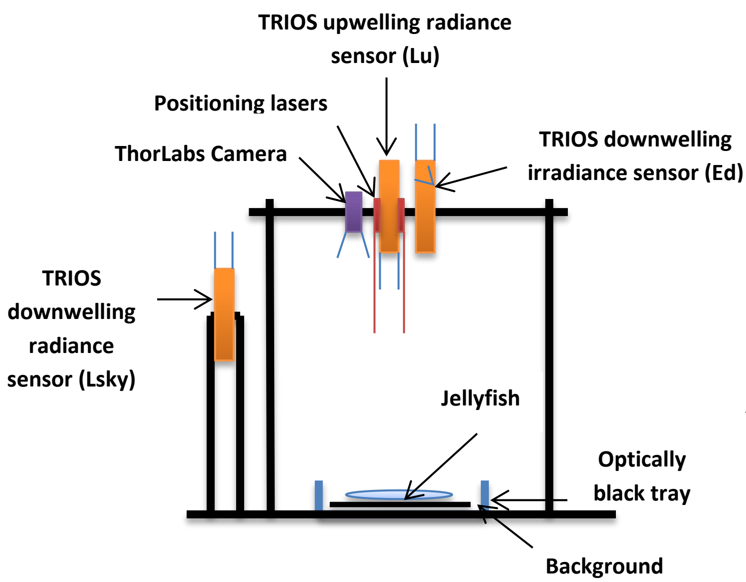

Fig. 2. JellySpec setup consisting of a TriOS-system, Thorlabs RGB camera and laser pointers for footprint marking. The jellyfish specimens are placed in an optically black tray with seawater. Different backgrounds can be placed in the tray (i.e. Spectralon, white plaque, optically black material).

The RGB-camera is a high-resolution USB CCD camera (Thorlabs inc., UK) providing 3-band images in 1024 x 768 pixels. The diaphragm opening is manually adjustable and the exposure time is set digitally using the camera's software. The exposure time and diaphragm opening are set so that the digital number (DN) output of the RGB-bands is between 220-250 (256 max) when measuring a Spectralon® plate under clear sky light conditions. With the spectralon being the most reflective object measured, sensor saturation is avoided and the sensitivity of the RGB camera is optimally used. During each TriOS measurement a total of five color images were collected.

2.3 Measurement protocol

Three Aa's, one Ch and one Rh were studied. Each Jellyfish was measured on a sequence of different backgrounds. For measurements in wet conditions the Spectralon was replaced by a white plaque to avoid fouling the spectralon. Reference measurements were made of the white plaque and an optically black background submerged in the container filled with seawater (approximate depth of 10 cm). Subsequently a jellyfish specimen was placed submerged in the container and measured with both the white and black background. The black background (reflectance 400nm-700nm < 0.012) was used to determine the backscatter properties of the jellyfish and the white plaque (430nm-700nm > 0.387) to determine the absorption characteristics. Table 1 shows the sequence of the different measurement set-ups per jellyfish with their respective codes.

Table 1. Measurement sequence by JellySpec system for each jellyfish specimen to obtain optical characteristics (i.e; backstatter and absorption). S=spectralon, B=black background, W=white background, d=dry, w=wet, c=calibration, m=jellyfish measurement.

nr	Experimental setup	Reflectance	code
1	Spectralon dry background	R_s	Sdc
2	Black wet background	R_b	Bwc
3	White wet background	R_w	Wwc
4	White wet background with jellyfish	ρ_w	Wwm
5	Black wet background with jellyfish	ρ_b	Bwm

2.4 Data processing

The reflectance of the samples (ρ_i) and of the reference targets (R_j) is calculated from simultaneous above-water TRIOS measurements of downwelling irradiance, E^{0+}_d; total upwelling radiance (i.e., from the water and from the air-sea interface) at a zenith angle of 0°, L^{0+}_u; and sky radiance, L^{0+}_{sky}, in the direction of the region of sky that reflects into the seaviewing sensor, by

$$\rho_i = \pi \frac{L_u^{0+} - \rho_{sky}^{0+} L_{sky}^{0+}}{E_d^{0+}} \quad (1)$$

where ρ_{sky} is the Fresnel air-water interface reflection coefficient and is set to be constant with a value of 0.0211 for all wet measurements (11). The reflectance was calculated for all measurements providing R_S, R_b, R_w, ρ_w, ρ_b for each target. A relative measure of bulk backscatter (B) and bulk absorption (A) for the jellyfish individuals are calculated from the four measurements (R_b, R_w, ρ_w, ρ_b) via:

$$\mathrm{B} = \frac{R_w\rho_b - R_b\rho_w}{R_w - R_b - R_bR_w(\rho_w - \rho_b)} \quad (2)$$

$$\mathrm{A} = 1 - \mathrm{B} - \sqrt{(\rho_w - B)(\frac{1}{R_w} - B)} \quad (3)$$

The output of the RGB-camera for the footprint zone is converted from digital numbers to radiance values in µW/nm/m²/sr based on the TriOS measurements of the Spectralon. The L^{0+}_u spectrum is spectrally integrated based on band sensitivity (data not presented) providing a L^{0+}_u value per DN in the red (R), green (G) and blue (B) bands. In a similar fashion also L^{0+}_{sky} and E^{0+}_d are spectrally integrated for the three bands to calculate the ρ_w for each pixel using equation 1.

3 Results and Discussion

3.1 Reflectance spectra of Jellyfish

Figure 3 displays the reflectance spectra (400nm-700nm) of the three jellyfish species on an optically black background with the reflectance spectra of the black background shown as R_B. The reflectance spectrum of the jellyfish samples (ρ_B) and the relative bulk backscatter (B), calculated using equation 2, are presented per jellyfish species. The Aa reflects in average 5.83% more light with a maximum relative backscatter of 7.14% at 430 nm and a minimum of 4.78% at 700 nm. The Ch reflected in average 0.57% of incoming light with a maximum relative backscatter of 0.83% at 700 nm and a minimum of 0.22% at 400 nm. The Ro specimen reflected in average 1.33% more than the black background with a maximum relative backscatter of 1.52% at 460 nm and a minimum of 1.13% at 620 nm. Directly comparing the three species reveals that the reflectance of Aa is significantly higher compared to Ch and Ro. This may be explained by the fact that the Aa jellyfish was larger than the Ch and Ro specimens. Also, the Aa completely filled the footprint of the L^{0+}_u sensor which was not the case for the latter. Additionally, the Aa measurements show direct reflection of sun light (see fig 4 left) by the gelatinous material of the jellyfish which is expected to create a white shift of the Aa measurements. The spectral shapes of Aa and Ch reflection do not show strong features except for increased reflection in the 380-450 range compared to the 600-700 range for Aa while this is the opposite for Ch. The spectral shape of Ro is more flat with a drop in reflectance at 425 nm and between 560 nm and 670 nm.

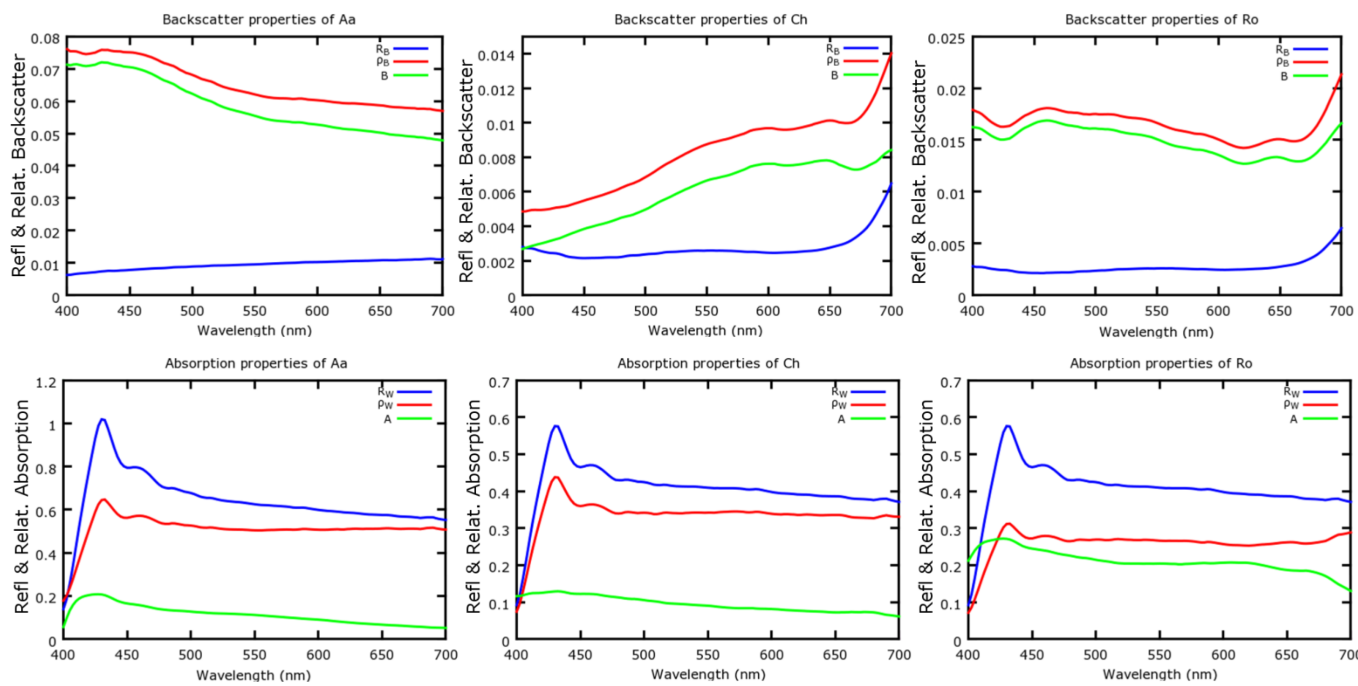

Fig. 3. Reflectance spectra (red line) and relative backscatter (greenline) of *Aurelia aurita* (left column)*, Chrysaora hysoscella* (middle column) *and Rhizostoma octopus* (right column) on an optically black background (blue line, top row) and white background (blue line, bottom row).

The reflectance spectra (400nm-700nm) of the three jellyfish species on a white board is presented in the bottom row of figure 3. The reflectance spectrum of the jellyfish samples (ρ_W) and the relative bulk absorption (A), calculated using equation 3. The jellyfish species absorb in average 11.26%, 9.48%, and 20,81% of available light for Aa, Ch and Ro respectively.

3.2 Spatial distribution of reflectance

RGB photographs captured with the Thorlabs camera provided the spatial distribution of the colour of the jellyfish in three bands. Figure 4 shows for each species a color image combined with the reflectance in the blue (B), green (G) and red (R) bands. The ρ_B-images show the specimens on the optically black background. For Aa it are especially the gonads that are reflective while the gelatinous material is more transparent. Hotspots can be observed where there is a direct reflection of sunlight at the jellyfish surface into the camera. For Ch the highest reflection is visible in the red band, especially by the manubrium with the long thick red arms. The Ro is less transparent with a robust structure and solid rubbery bell. The center of the rubbery bell is visibly blue which can be observed in the B-band of figure 4.

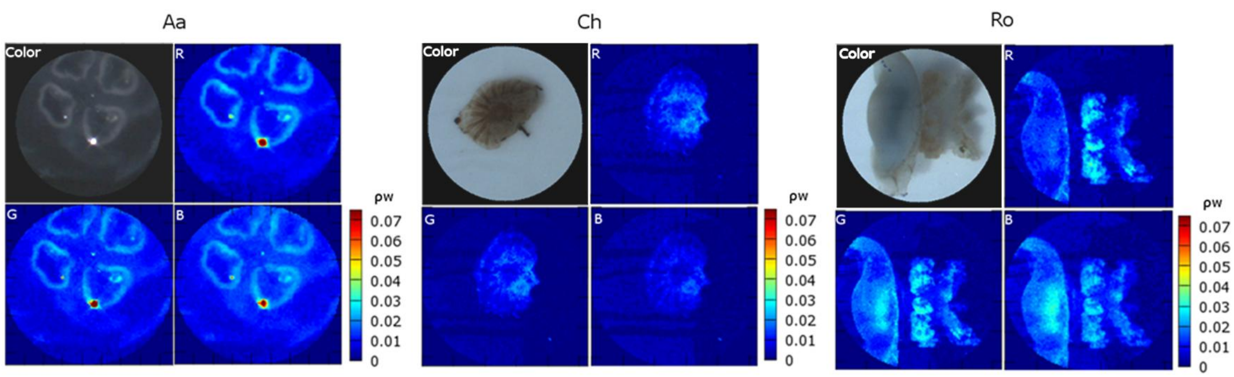

Fig. 4. Calibrated RGB images providing the spatial distribution of $\rho_{B.}$ Per jellyfish specimen the color image is accompanied with the ρ_B its red, green, and blue band.

4 Discussion and Conclusions

With these preliminary results the functionality of the JellySpec system to study the optical features of jellyfish was demonstrated. While the color features of the jellyfish were present in the hyperspectral measurements, distinct features in the spectrum were not obvious. The 'bulk' absorption and backscattering parameters presented here are not inherent optical properties but will vary with illumination conditions and viewing geometry. While sufficient for assessing feasibility of the method, more precise optical modelling is required for a more detailed assessment.

Acknowledgements

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5 References

1. C. P. Lynam, M. R. Heath, Stephen J. Hay, Andrew S. Brierley**.** Evidence for impacts by jellyfish on North Sea herring recruitment. *Marine Ecology Progress Series* **298**, 157–167 (2005).

2. J. E. Purcell, S. Uye, W. Lo. Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. *Marine Ecology Progress Series* **350** (2007)

3. A. J. Richardson, A. Bakun, G. C. Hays, M. J. Gibbons. The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. *Trends in Ecology and Evolution* **24**, Issue 6 (2009.)

4. P. J. Fenner, J.A. Williamson. Worldwide deathsand severe envenomation from jellyfish stings. *Medical Journal of Australia* **165**, 658 (1996).

5. Daslakov, G.M. and Mamedov, E.V., Integrated fisheries assessment and possible causes for the collapse of anchovy kilka in the Caspian Sea. ICES Journal of Marine Sciences, 2007. 64(3): p 503-511.

6. N. Matsueda, Presentation of Aurelia aurita at thermal power station. *Bull Mar Biol Stn Asamushi* **13**, 187-191 (1967).

7. A. Ramsak, K. Stopar. Dispersal ecology and phylogeography of Scyphomedusae in the Mediterranean Sea. *MarBEF newsletter*, 20-21 (November 2007).

8. J. Houghton, T. Doyle, J. Davenport, G. Hays. Developing a simple rapid method for identifying and monitoring jellyfish aggregations from the air. *Marine Ecology Progress Series* **314**, 159–170 (2006).

9.K. Donghoon, S. Jae-uk, K. Hyongjin, K. Hanguen,Lee Donghwa, L. Seung-Mok, M. Hyun Design and Implementation of Unmanned Surface Vehicle JEROS for Jellyfish Removal. *Journal of Korea Robotics Society* **8**(1), 51-57 (2013).

10. K. Ruddick, V. De Cauwer, Y. Park, G. Moore (2006). Seaborne measurements of near infrared water-leaving reflectance: The similarity spectrum for turbid waters. *Limnology and Oceanography* **51**(2), 1167–1179 (2006).

11. C.D. Mobley. *Light and Water: Radiative Transfer in Natural Waters*. San Diego: Academic Press (1994).