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FINAL REPORT

TO THE

Florida Fish & Wildlife Conservation Commission
Fish and Wildlife Research Institute
100 8th Avenue, SE
St. Petersburg, Fl 33701

DEVELOPMENT OF AN UNDERWATER INFRARED CAMERA TO DETECT MANATEES

MANATEE AVOIDANCE TECHNOLOGY; CONTRACT #FWC 03/04-28

BY

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EXECUTIVE SUMMARY

In calendar year 2004, watercraft related mortality was the second leading cause of death of the Florida manatee (*Trichechus manatus latirostris*) accounting for 25% of total known manatee deaths. In an attempt to reduce this significant cause of manatee mortality, the Florida Fish and Wildlife Research Institute has instituted two rounds of Manatee Avoidance Technology grants. Herein I report the results of an evaluation of the ability of underwater infrared video cameras to detect captive manatees and other non-living targets. If such cameras could detect manatees at sufficient distances, they could be mounted in the bows of watercraft and the resultant images could be projected at the helm of the vessel, enabling the vessel operator to reduce speed, take evasive action, or both.

Two types of cameras were examined: 1) A SeaView underwater video camera system from PowerLinx, St. Petersburg, FL, and 2) An Atlantis underwater camera system (AUW-535C) from JJC Communications, Inc., Englewood, NJ. Preliminary investigations of the ability of these cameras to detect small objects indicated that their resolution decreased with distance from the target and depth, with the highest resolution closest to the target and near the surface. However, even at optimal depth, the maximum detection distance for the small target with the SeaView Camera was less than 3 m, and less than 5.5 m for the Atlantis camera. Thus, the Atlantis camera was marginally better able to detect the small target than was the SeaView camera.

The cameras were then tested on a plywood silhouette of a manatee placed vertically in the water. In this case the detection distance increased with depth, being greatest at a depth of 2 m, but in no case was the detection distance greater than 5 m. As before, the Atlantis camera was marginally better able to detect the plywood manatee silhouette than was the SeaView camera.

The cameras were then tested using living captive manatees at the Lowry Park Zoo (LPZ). Due to the clarity of the water at LPZ, manatees were visualized by both cameras at a distance of up to approximately 15 m, independent of depth. The Atlantis camera was better able to detect the living manatees than was the SeaView camera. Because these cameras emit infrared light in order to enhance their water penetration and image detection, there was some concern on the effect of this light on the manatees. However, the infrared light emitted by the cameras appeared to elicit no alarm or aversion from the manatees, and in fact seemed to increase their curiosity about the cameras and to attract them to the cameras. The larger size of the Sea View camera also appeared to draw the attention of the animals to the camera, and to prompt them to approach it in a playful manner.

Over the course of this investigation, one NSU Oceanographic Center graduate student has started on a thesis research project. The results of this investigation were presented at the second Florida Marine Mammal Health Symposium, held 7-10 April 2005 in Gainesville, FL (Wright and Keith 2005).

The currently available underwater infrared camera technologies evaluated here do not seem to have sufficient detection distances to enable their immediate incorporation into a operator manatee awareness system, in order to utilize the cameras as described above. Our future plans are to approach the manufacturers of these cameras to determine if the technology can be enhanced to enable the cameras to detect manatees at sufficient distance to enable them to be used as described above.

INTRODUCTION

In calendar year 2004, watercraft related mortality was the second leading cause of death of the Florida manatee (*Trichechus manatus latirostris*) accounting for 25% of total known manatee deaths (Figure 1). Such watercraft related mortality is defined by the Florida Fish and Wildlife Conservation Commission as “manatees hit by boats, barges or any type of watercraft. Death may result from propeller wounds, impact, crushing, or any combination of the three” (FWC 2005a). In an attempt to reduce this significant cause of manatee mortality, the Florida Fish and Wildlife Research Institute has instituted two round of Manatee Avoidance Technology grants.

I have previously proposed the use of infrared imaging technologies to achieve manatee detection, and was able to demonstrate that some commercially available technologies showed promise for future application (Keith 2002). Recently a variety of underwater infrared video cameras have come to market, and it was my intent to test the ability of these cameras to visualize manatees underwater, to determine if they could be incorporated into a variety of applications designed to reduce watercraft related mortality.

One such application would be an operator alert system whereby the camera could be mounted in the bow of the vessel, and images obtained by this camera could be projected on a CRT screen near the helm of the vessel, in view of the operator. If the camera could penetrate the water to a sufficient distance to enable detection of a manatee, the operator would see the animal, and have time to slow the vessel or take evasive action. An added benefit of these camera systems is that they can be used to see fish, and are currently purchased by many recreational fishermen for just that purpose.

The target range for the maximum detection distance of these cameras is on the order of 10 – 30 m. Assume a vessel going 25 miles per hour (11 meters/sec) equipped with the operator alert system that I have envisioned. This system would consist of a camera mounted below the surface of the water in the bow of the boat, with a small television-like screen near the helm of the vessel where the operator can see what is in front of the boat, as visualized by the camera. If one assumes that it will take the vessel operator 2.0 seconds to see the image of the manatee on the screen, mentally evaluate the image, and take the appropriate responsive action, the vessel will travel 22 m. This distance increases with vessel velocity, for instance it is 31 m at 35 mph.

Figure 2 displays the response distance for the operator of a hypothetical vessel traveling at various rates of speed. The different lines in the graph indicate the response distances required based upon differing assumed response times. Studies of humans driving automobiles indicate that response times depend on a wide variety of factors (Triggs and Harris 1982) and vary from 0.75 sec when the driver is fully aware of the time and the location of the brake signal, to 1.25 sec when the driver is responding to unexpected, but common, signals such as brake lights. Reaction times for surprise events, such as an object moving into the driver's path is about 1.5 sec (Green 2000). For the purposes of roadway planning and design, several organizations have established norms for response times of 2.5 sec in the United States and 2.0 sec in Europe (Green 2000). The Florida Driver's Handbook indicates that average reactions times are approximately 1.5 sec (Anonymous 2004). Figure 1 shows the response distances based on five different assumed response times, 1.0, 1.5, 2.0, 2.5, and 3.0 sec.

Depending on their individual response time, the operator of a hypothetical vessel approaching a manatee at 25 mph will need to be able to detect the manatee when it is a minimum of 11 m (1.0 sec response time) and a maximum of 33 m (3.0 sec response time). The optimal range for manatee detection in this scenario will be 22 m (2.0 sec response time).

A second application of an enhanced ability to detect manatees underwater would be to develop and install a boater manatee awareness system designed to increase boater compliance with posted manatee speed zones near areas where manatees congregate, and thus reduce the potential for collisions between boats and manatees and the resultant mortality. Boat strikes continue to be the major source of known manatee mortality in the state of Florida (FWC 2005b) and reducing this mortality factor would significantly increase the rate of population growth (Runge et al. 2004). This method of reducing manatee mortality is based on the assumption that if boaters could be informed of the presence of manatees, and their numbers, on a real-time basis then they would be more likely to comply with posted manatee speed zones.

Gorzelany (2004) found that overall boater compliance with manatee speed zones was 65% in Sarasota County, FL, and 58% in Lee County, FL. Compliance varied significantly with vessel type and size, with smaller vessels having lower levels of compliance. Personal watercraft operators had the lowest levels of compliance. The presence of law enforcement vessels significantly increased boater compliance by 13 percent in Sarasota County and by 10 percent in Lee County. The levels of blatant noncompliance decreased 10 percent in Sarasota County and 6 percent in Lee County when law enforcement vessels were present in the survey area. These results were statistically significant ($P < 0.0001$) and indicate that boater compliance with manatee speed zones is plastic and subject to a variety of factors. It may be that compliance can be enhanced by improved informational signage near manatee congregation sites. Additional studies of boater compliance are needed to provide important baseline information for the development of future management plans, to test and evaluate the effectiveness of existing management plans, to identify and assess areas of potential human-manatee conflict, and to better understand the variables influencing boater compliance with manatee speed zones (Gorzelany 2004). Additionally, the continued assessment of boater compliance has been identified as a priority objective in the U.S. Fish and Wildlife Service Florida Manatee Recovery Plan (USFWS 2001) and for these reasons I have another student initiating a boater compliance study in Port Everglades, FL.

A third potential application of an enhanced ability to detect manatees underwater would be to install such imaging technology in canal locks and gates. Mortality from such locks and gates remains a relatively minor source of manatee mortality in the state of Florida, but because the total population of manatees is only about 3000 animals, reduction of all types of mortality becomes a high priority. Because of the cost effectiveness of the existing underwater video systems on the market, it is probable that an enhanced manatee detection system could be developed and installed on locks and gates where manatee mortality has historically been a problem with only a minimal investment by the water management authorities.

The underwater infrared cameras are already being marketed and are not harmful to humans, fish, or other aquatic animals. When infrared light impinges on an object, it imparts heat to the object. High levels of infrared radiation can cause burns and cataracts in the lens of the eye. However, the levels of infrared radiation used by the underwater camera are of low intensity, and any thermal effects resulting from this radiation will be dissipated by the water, which has a very high specific heat (ability to absorb heat).

In addition, infrared light similar to that used in the underwater camera has been incorporated into instruments that are used to measure body composition (Conway, et. al. 1984), and which are currently for sale by Futrex, Inc., Gaithersburg, MD, USA. This methodology has been termed infrared interactance, and measures the composition of the subcutaneous tissue by monitoring the difference in reflection of infrared radiation between adipose tissue and lean body mass (Conway and Norris 1984). Note that this involves the penetration of the skin by the infrared light. These instruments have been well validated (Fogelholm and Marken Lichtenbelt 1997, Rubiano, et. al. 2000), and have been found safe for use on normal human adults of varying skin pigmentation (Wilson and Heyward 1993), obese human adults (Pantopoulos, et. al. 2001), children (Fuller, et. al. 2001), and newborns (Demarini and Donnelly 1994). More information is available on the Futrex, Inc. web page (http://www.futrex.com/f5tech.html).

MATERIALS AND METHODS

Two cameras were tested, the Sea View BW Cam 150 (PowerLinx, St. Petersburg, FL), and the AtlantisAUW-525C (JJC Communications, Inc., Englewood, NJ)(Figure 3). Each camera was connected to a remote video monitor and a videocassette recorder. The Sea View video monitor was a 5.5” black and white monitor and the Atlantis video monitor was 5.5” green tube monitor. A shade hood was attached to each monitor to minimize glare. Prior to testing water clarity was measured with a Secchi Disk and notes were made regarding cloud cover, sunlight intensity, tidal level, and time of day.

Each camera was supported by a length of 2 inch PVC pipe. The pipe was capped on each end to eliminate water penetration. The cameras were mounted on a section of 2 inch PVC pipe that extended 12 inches (30.5 cm) perpendicular to the long section of the pipe. Once assembled, the pipe was marked in black at one inch increments, with red markings at the 6 inch increments, and blue markings at the 12 inch (30.5 cm) increments. These markings were used to monitor the depth of the camera during testing.

Initial testing of the camera was conducted using a standard dish sponge as a target. The sponge was mounted on a 10 foot (3.1 m) 1/2 inch diameter PVC pipe with a zip strip. The pipe was then attached to the seawall using a zip strip. Both cameras were tested on this target at 6 inch (15.2 cm) intervals beginning at the surface and extending down to the limit of visibility or to the bottom, whichever came first.

Once mounted the camera was placed in the water just below the surface and was moved away from the target until it was no longer visible. This was designated the maximum detectable distance. The camera was then moved back towards the target at the same depth until the target appeared. Once the target appeared, a measurement was taken from the target to the PVC pipe supporting the camera to determine the distance between the camera and the target, with correction for the distance the camera extended out from the PVC pipe.

Subsequent testing of the camera was conducted using a manatee silhouette cut out of 1/2 inch plywood (Figure 4), and mounted vertically in the water. The ability of the cameras to visualize this target was measured at two depths, 1 meter and 2 meters. The cameras were moved away from the target at one-half meter increments until the silhouette could not be visualized on the camera monitor, and then the camera was moved towards the target again, to provide a replicate measurement.

Final testing of the camera occurred at the Lowry Park Zoo in Tampa, FL. The cameras were lowered into the manatee pool, and the animals were visualized using both cameras. The distance from the camera to the animal was estimated using a rope marked in 1 meter increments that was stretched out along the edge of the manatee pool.

Image quality and resolution were measured using the following criteria. Zero (0) signified no image detection. One (1) signified some degree of shadowing but no identifiable objects. Two (2) signified that there was a definite shape detectable, but discernable, with definite shading variations being present. This designation was considered fair image quality and resolution. Three (3) signified that there were detectable shapes present, with larger shapes being identified but no distinguishing details present. This designation was considered good image quality and resolution.

A four (4) designation indicated that definite shapes could be distinguished with some detail. Most shapes were identifiable although minute details were not distinguishable. This designation was considered clear visibility. A five (5) designation signified the clearest image with maximum resolution. Detection of small objects and shapes with definite details were present. A five (5) was considered maximum clarity.

PERMITS

Testing of the underwater infrared video cameras at the Lowry Park Zoo was authorized under a permit from the U.S. Fish and Wildlife Service (Permit #MA080580-0).

RESULTS

Figure 5 shows representative results of testing the ability of both cameras to detect the sponge target. The pink squares indicate the data for the Atlantis camera and the blue diamonds indicate the data for the Sea View camera. The Atlantis camera clearly performs better than the SeaView camera at detecting this small target under these conditions.

Figures 6 and 7 summarize the results of testing of both cameras with the sponge target at a variety of depths and distances. Note that the resolution of both cameras decreases with distance and depth and that the Atlantis Camera had generally better resolution than the SeaView Camera at all depths and distances.

Figures 8 and 9 show how well the Atlantis camera could visualize the plywood manatee silhouette. The white object at the bottom of Figure 9 is the end of the PVC pipe that was supporting the camera. Figure 10 quantifies how well the Atlantis camera was able to distinguish this target at distance.

Figures 11 and 12 show images captured at about the maximal distance at which the Atlantis camera would still yield images of good quality and resolution. Figure 13 quantifies how well the Atlantis camera was able to detect the manatees at distance. As is evident, the maximum distance that the camera yielded images of quality designation 3 was 14-15 meters. Figures 14 and 15 show images captured by the Atlantis camera at distances that yielded images of fair to good quality and resolution.

DISCUSSION

My results indicate that the Sea View camera did not have the enhanced imaging capabilities claimed by the manufacturer. In fact, it performed more poorly than the Atlantis camera under identical conditions in all three testing situations. The Sea View camera may have been more durable, but durability added to the weight and size of this camera. At close range the Sea View did allow for visual identification of the targets, but the images were unfocused and therefore received only a fair rating. The Sea View camera was more likely to lose resolution as depth increased, as opposed to the Atlantis camera. This was especially true under poor light conditions. My results also indicated that the Sea View camera had a more limited range than the Atlantis camera. The only advantage to the Sea View camera was in the monitor, which was black and white camera, giving greater contrast than the green monitor of the Atlantis camera.

The Atlantis camera performed much better under poor light and bright light conditions with substantially better range than the Sea View camera. This camera was much smaller and easier to mount on the testing apparatus and the Atlantis camera came with a rechargeable battery allowing for remote operation supply. The Atlantis camera achieved higher resolution at greater distances, and with few exceptions maintained this level of performance as depth increased. The Atlantis camera also maintained a high level of resolution at very close range to the to the target. The main drawback to the Atlantis was found to be the green monitor display. This green display was very difficult to view even with a shade hood over the monitor. The green color did not allow the viewer to distinguish between shadows and areas of light gradient as easily as the black and white monitor of the Sea View camera.

Because these cameras emit infrared light in order to enhance their water penetration and image detection, there was some concern about the effect of this light on the manatees. However, the infrared light emitted by the cameras appeared to elicit no alarm or aversion from the manatees, and in fact seemed to increase their curiosity about the cameras and to attract them to the cameras. The larger size of the Sea View camera also appeared to draw the attention of the animals to the camera, and to prompt them to approach it in a playful manner.

As light passes through water, its intensity and illuminance are attenuated, or decreased. This attenuation increases exponentially according to Lambert's Law:

$$I_z = I_0 \exp(-k_d z) \qquad \text{Eqn. 1}$$

where I_z is the irradiance at depth z, I_0 is the irradiance at the source of the light, or the surface if the light is penetrating vertically into the water, k_d is the extinction coefficient, and z is the depth (Gallegos N.D.). The extinction coefficient can be broken down into the sum of the attenuation due to the water itself plus the dissolved organic matter ($k_{(W + DOC)}$), the attenuation due to the presence of chlorophyll *a* (k_c[Chl]) and the attenuation due to total suspended solids (k_s[TSS]):

$$k_d = k_{(W + DOC)} + k_c[\text{Chl}] + k_s[\text{TSS}] \qquad \text{Eqn. 2}$$

Substituting Equation 2 into Equation 1 yields an equation that can be used to predict the light irradiance at any distance from a light source or object based on some often measured water quality parameters:

$$I_z = I_0\exp\{(-k_{(w\ +\ DOC)} + k_c[\mathrm{Chl}] + k_s[\mathrm{TSS}])z\} \qquad \text{Eqn. 3}$$

For waters in the Chesapeake Bay, Gallegos (N.D.) derived estimates for $k_{(w\ +\ DOC)}$ of 0.32 m^{-1}. An estimate for $k_{(w\ +\ DOC)}$ in seawater is 0.038 m^{-1}, and the value of $k_{(w\ +\ DOC)}$ in some Florida waters has been estimated at 0.28 m^{-1} (Canfield and Hodgson 1983). Likewise, Gallegos (N.D.) derived estimates for k_c of 0.016 m^{-1} and for k_s of 0.094 m^{-1} in Chesapeake Bay. Similar values have been found in Florida waters (Canfield and Hodgson 1983). The actual concentrations of chlorophyll *a* ([Chl]) and total suspended solids ([TSS]) are more highly variable and site specific.

In an attempt to model the results of the camera testing, I used Equation 3, and parameterized it in different ways, selecting values representative of very clear seawater (e.g., $k_{(w\ +\ DOC)} = 0.038$, [Chl] = 0, and [TSS] = 0), values representative of moderately colored Florida waters (e.g., $k_{(w\ +\ DOC)} = 0.28$, [Chl] = 8, and [TSS] = 8), and values representative of highly colored, almost opaque, waters (e.g., $k_{(w\ +\ DOC)} = 0.32$, [Chl] = 16, and [TSS] = 25). The results of this modeling exercise are shown in Figure 16. Notice that in the case of extremely clear water with no chlorophyll *a* and no suspended solids (solid line – squares), even at 20 meters the illumination or intensity of the light would still be approximately 50%. This situation probably approximates the water quality at LPZ, and accounts for the relatively good performance of the cameras at that facility.

Assuming a more representative value of 0.28 for $k_{(w\ +\ DOC)}$, and leaving the concentration of chlorophyll a and suspended solids at zero(solid line – triangles) results in a 50% attenuation distance of approximately 2.5 m, and a 90% attenuation distance of 7.5 m. These values are only slightly decreased by increasing $k_{(w + DOC)}$ to 0.32 (solid line – circles). However, increasing the concentration of chlorophyll and suspended solids has a drastic impact on light attenuation, with almost all of the light being attenuated within 2.5 m, with the exception of the line representing values of $k_{(w + DOC)}$ for pure seawater, and low Chl and TSS values (dotted line – triangles). These estimates are probably representative of the results of testing the cameras in natural waters in and around Port Everglades. Figure 7 shows that the resolution of the Sea View camera using the sponge target was almost zero (except very near the surface) at 2.3 m distance, and Figure 8 shows that the resolution of the Atlantis camera using the sponge target was poor at 2.5 m, again except near the surface. Even the large plywood manatee silhouette became undetectable by the Atlantis camera at 4.75-5.0 m, a distance at which the simulations indicate 80-90 percent of the light from the target would have been attenuated.

When I submitted my original grant proposal to the FWC in the fall of 2003, my proposed time line involved testing the cameras on captive animals during the summer of 2004, and testing the cameras on free ranging animals at the FPL Port Everglades power plant during fall-winter 2004-2005, when the animals are congregated there. Due to the time required to receive my permit from FWS (more than a year), I was not able to start this project until early 2005 using captive animals at the Lowry Park Zoo. At this point, no manatees remained at the Port Everglades power plant, and in order to test the camera on free ranging animals, I tried to find another location where there would be a good probability that manatees can be reliably found and the cameras tested on them. I contacted the Crystal River National Wildlife Refuge, and began the process of receiving their permission to conduct the remainder of this study there. I submitted an application to amend my permit from FWS to allow me to test the cameras at

CRNWR on 2 May 2005. However, on 13 May 2005 I received an email from the FWC notifying me that they would not support my application for an amended permit, and requesting I submit this final report to contain only the results of the captive manatee testing.

Also included in my original schedule was time to allow the manufacturers of the cameras to modify their technology in order to increase the underwater detection distance of the cameras. Again, circumstances did not allow me the time to do this before the final project report was due. In addition, the manufacturer with whom I had originally planned to collaborate on this project underwent a change in ownership, and the new ownership was not as interested in collaborating with me. In the interim, another manufacturer marketed a better quality camera and I tested it along with the first camera, and had intended to contact the manufacturer regarding improving their technology but did not have time to do so given the time constraints under which I was operating.

The underwater infrared camera technologies evaluated here do not appear to have sufficient detection distances to enable their immediate incorporation into a boat operator manatee awareness system. Our plans at this time are to approach the manufacturers of these cameras to determine if the technology can be enhanced to enable the cameras to detect manatees at sufficient distance to enable them to be used for such a system. We also plan to evaluate the ability of these cameras to detect free ranging manatees, once the appropriate permits are obtained from the U.S. Fish and Wildlife Service.

AKNOWLEDGEMENTS

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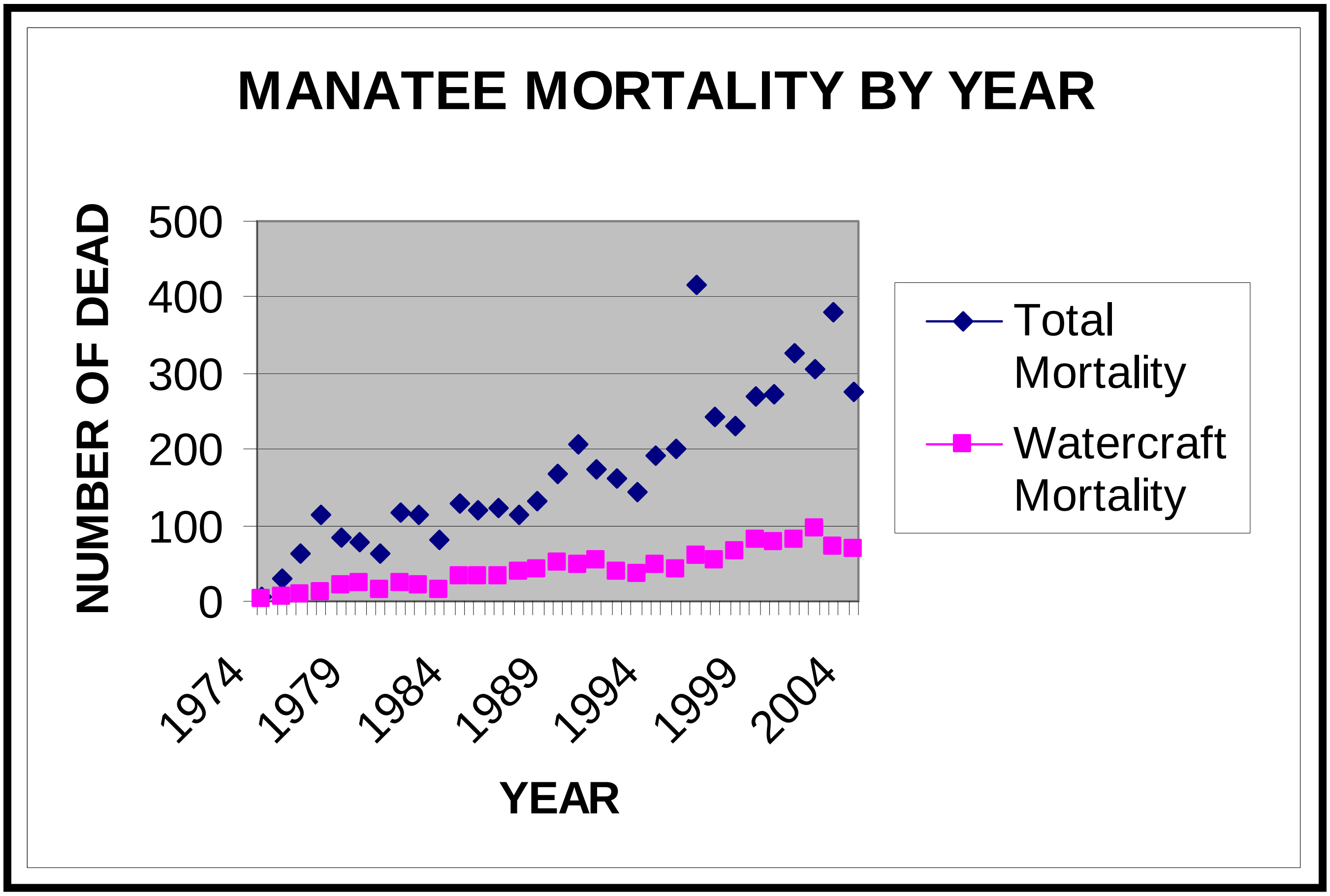

Figure 1. Manatee mortality over the past 30 years (FWC 2005b).

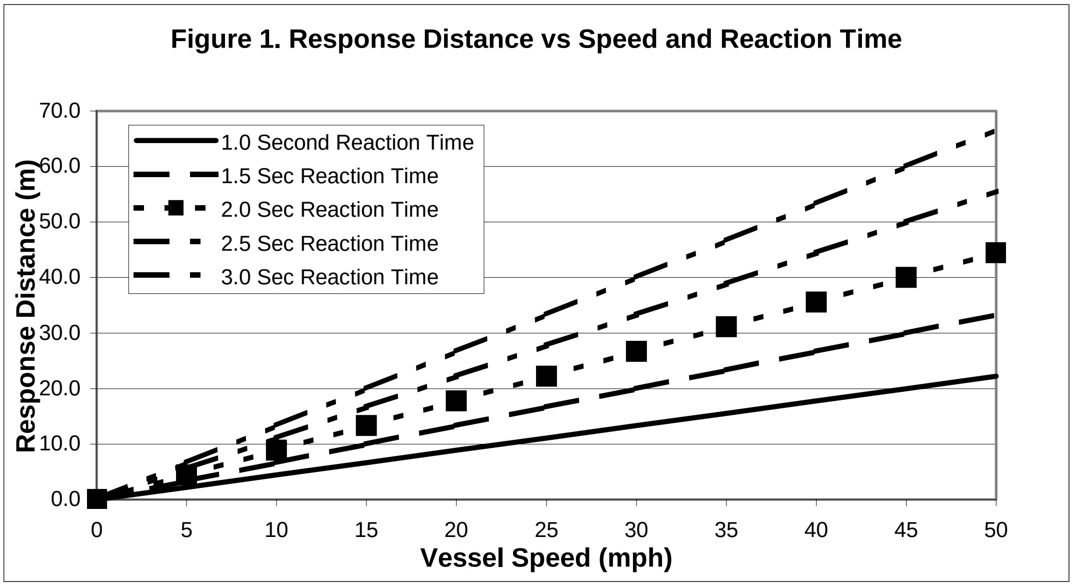

Figure 2. The distance required for a vessel operator to respond to a visual image and take appropriate action depends on vessel speed and assumed operator reaction time.

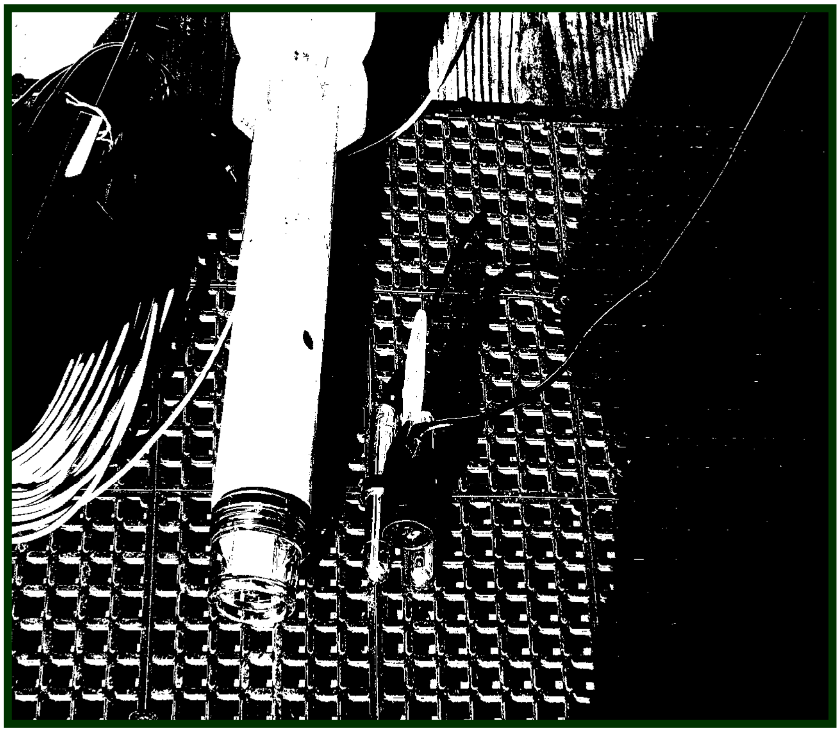

Figure 3. The SeaView Camera (left) and the Atlantis camera.

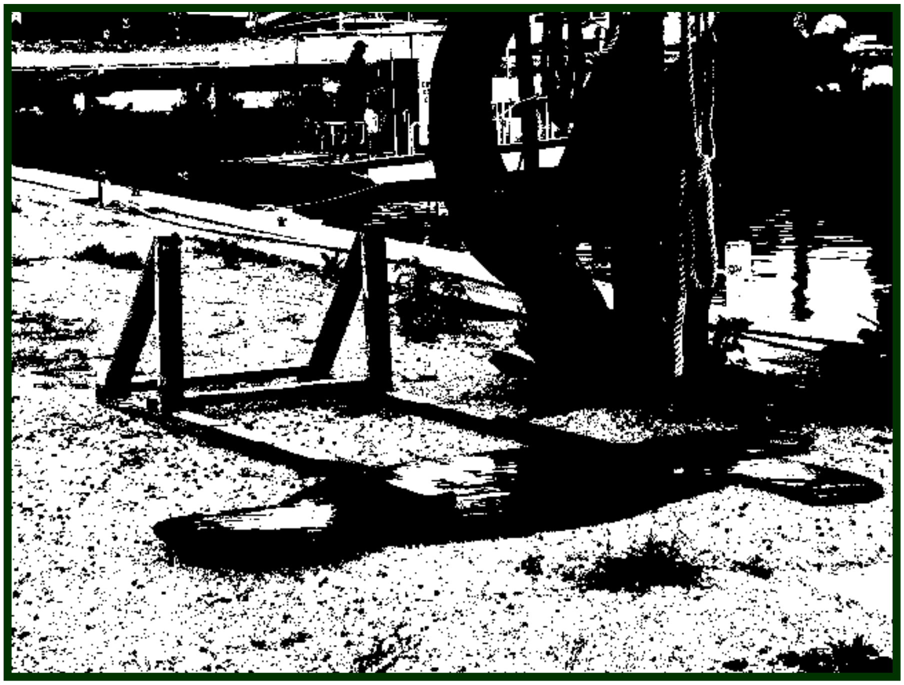

Figure 4. Plywood manatee silhouette used to test cameras.

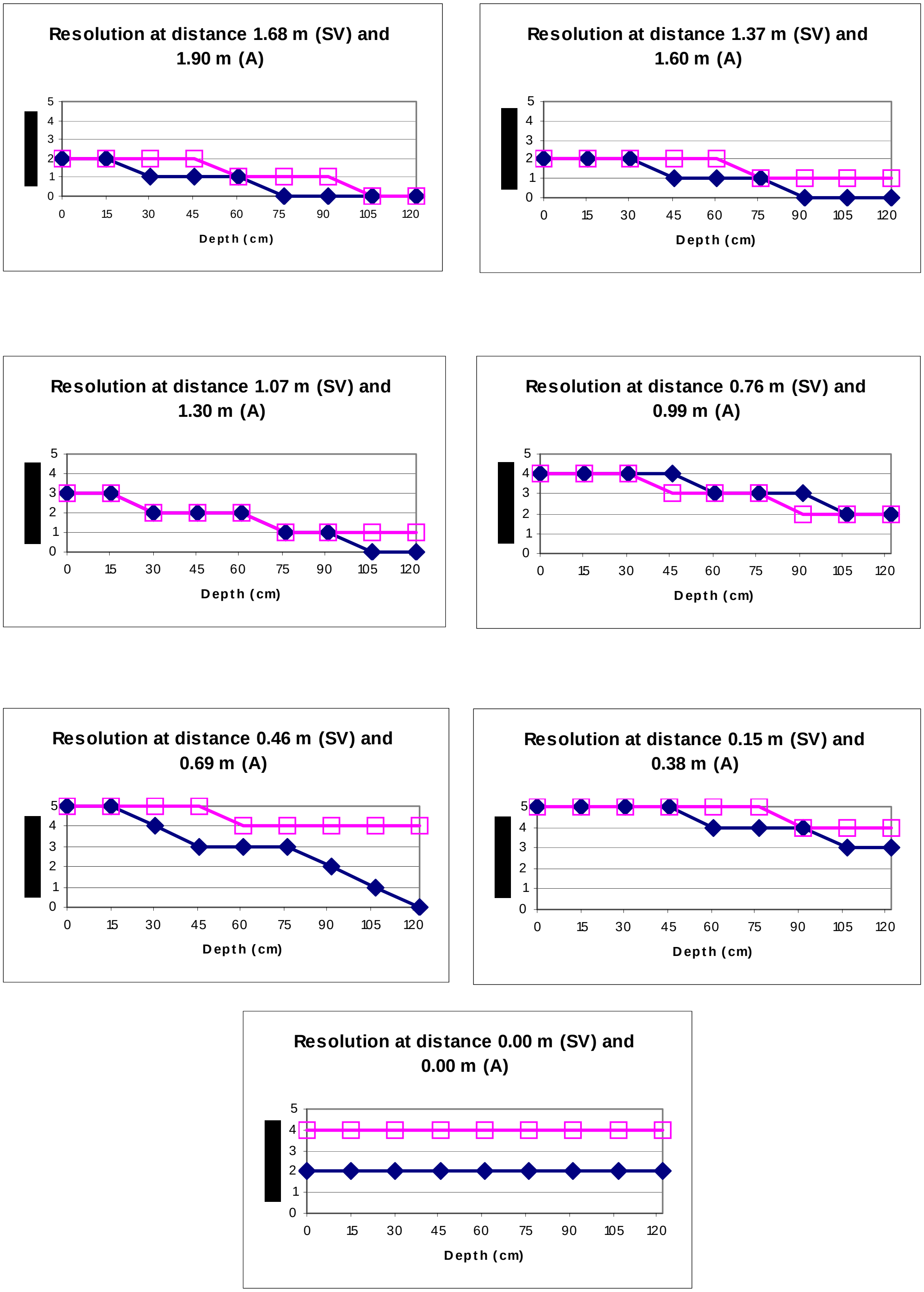

Figure 5. Representative results of camera testing against sponge target.

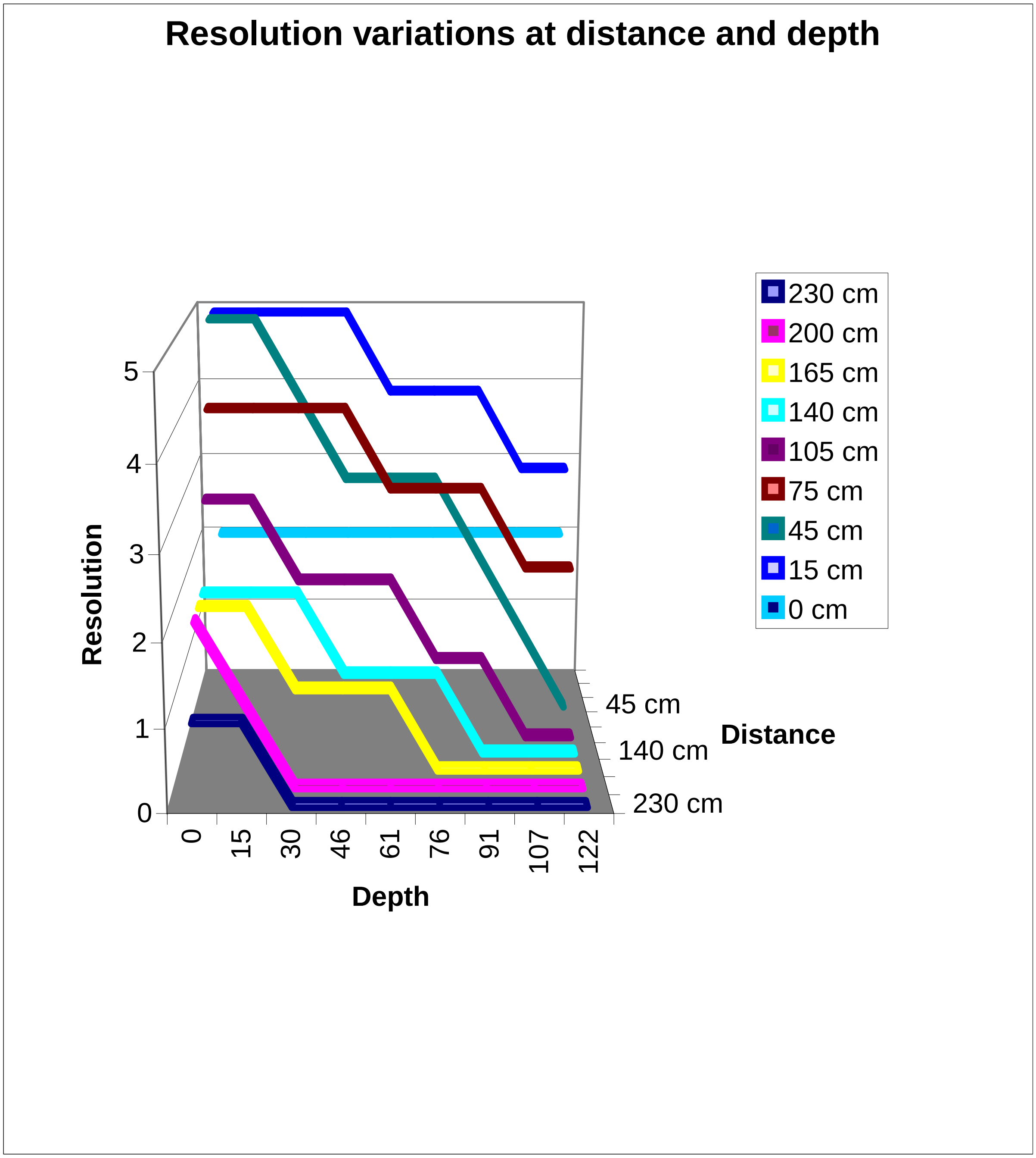

Figure 6. Resolution of the SeaView Camera varied by distance and depth when using the sponge target.

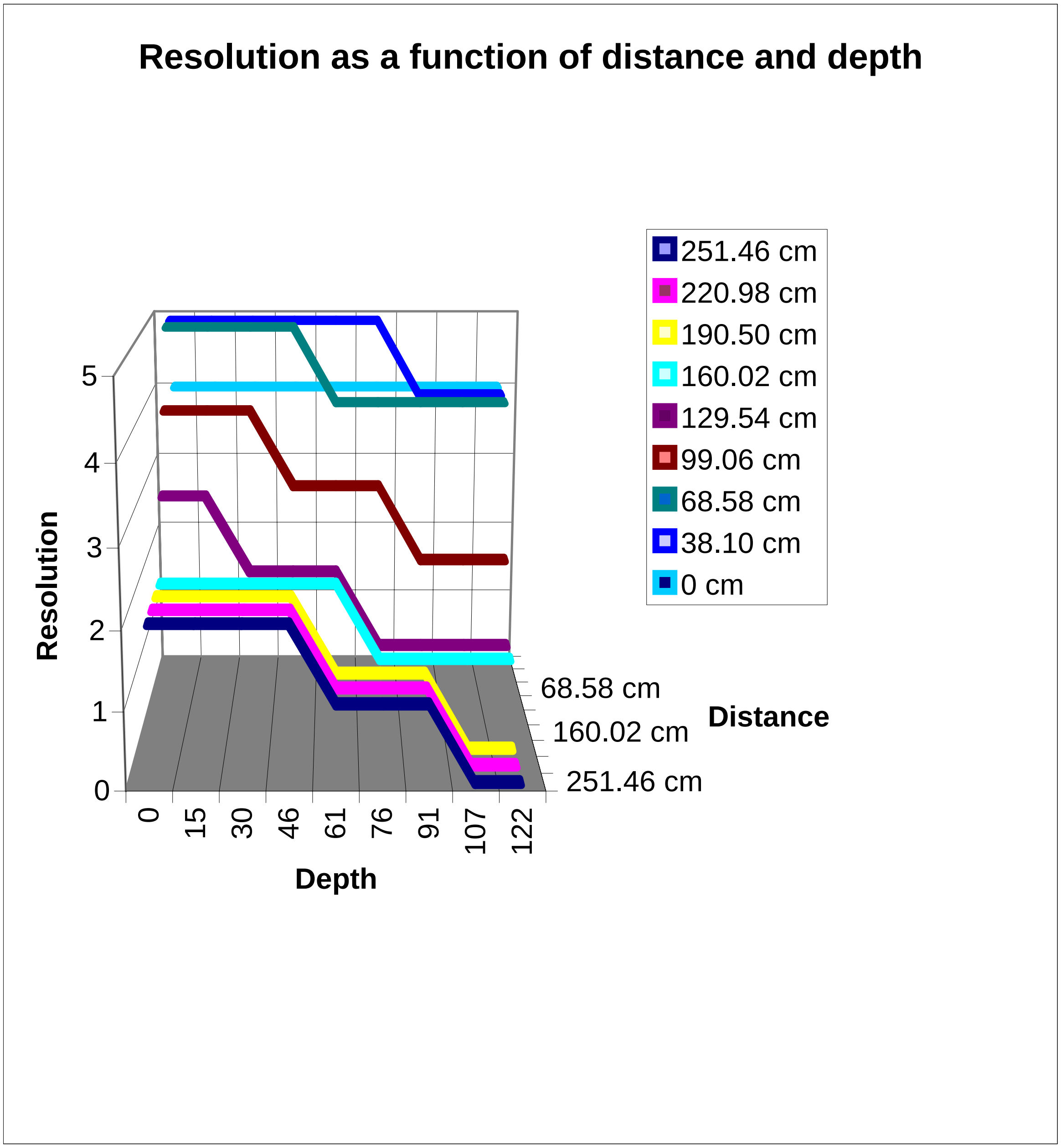

Figure 7. Resolution of the Atlantis Camera varied by distance and depth when using the sponge target. Note that generally this camera had greater resolution than the SeaView Camera.

Figure 8. Plywood manatee silhouette visualized by the Atlantis camera at 1.5 m.

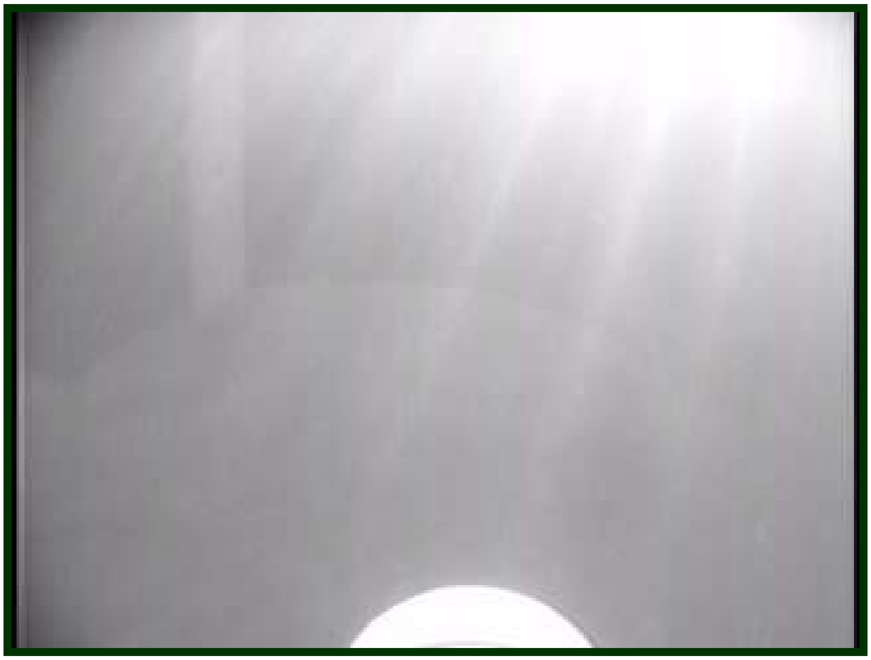

Figure 9. Plywood manatee silhouette visualized by the Atlantis camera at 3.0 m.

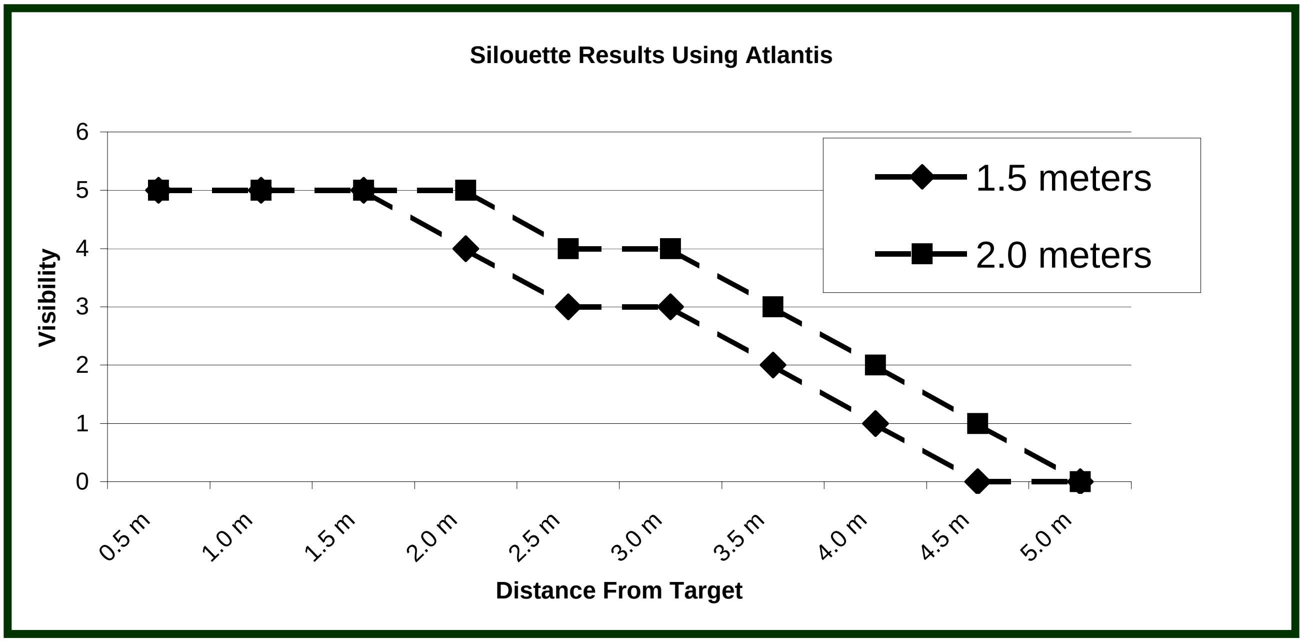

Figure 10. Quantification of the ability of the Atlantis camera to detect the plywood manatee silhouette at 1.5 and 2.0 meters depth.

Figure 11. Atlantis camera image of manatee at a distance of 15 m.

Figure 12. Atlantis camera image of manatee at a distance of 14 m.

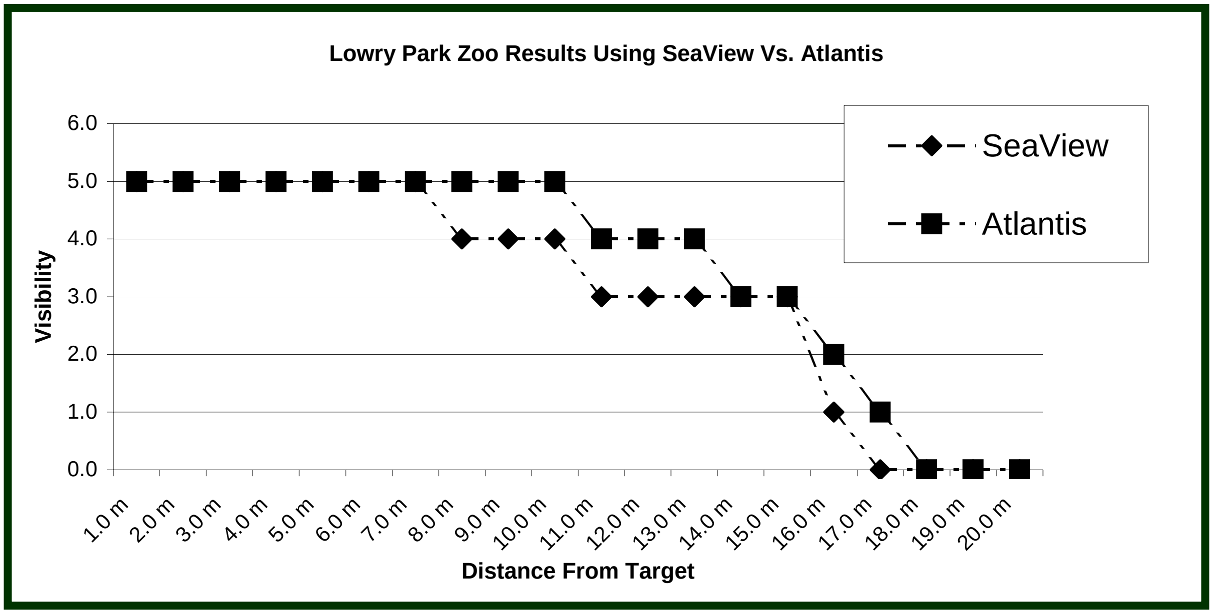

Figure 13. Quantification of image quality versus distance at LPZ.

Figure 14. Atlantis camera image of manatees at a distance of 11 m.

Figure 15. Atlantis camera image of manatees at a distance of 2 m.

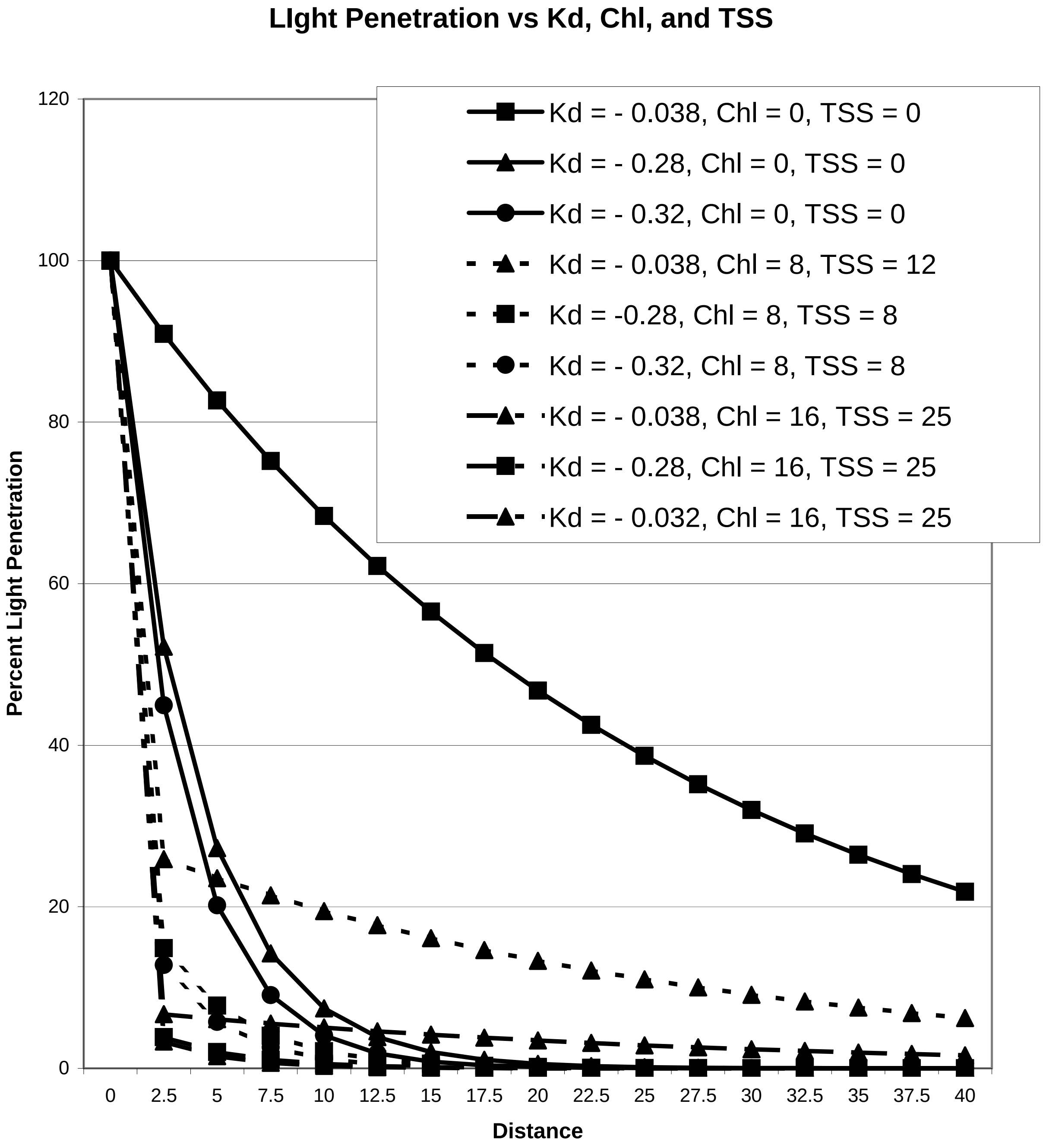

Figure 16. Light penetration depends on the clarity of the water (Kd), the concentration of chlorophyll (chl), and the total suspended solids (TSS). Representative values were chosen for Florida waters, and indicate that under optimal conditions, the underwater video cameras could only visualize objects less than 5 m from the cameras.