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BOATER MANATEE AWARENESS SYSTEM

FINAL REPORT

TO THE

Manatee Avoidance Technology Program
Florida Fish & Wildlife Conservation Commission
Florida Marine Research Institute
100 8th Avenue, SE
St. Petersburg, Fl 33701

BY

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EXECUTIVE SUMMARY

A variety of "see-in-the-dark" technologies have been evaluated with the objective of adapting them to detect Florida manatee (*Trichechus manatus latirostris*) aggregations in specific high-use areas, such as warm water refuges in the winter time. Once it is possible to passively detect manatee aggregations in these sites, the construction of boater awareness signs that would indicate how many manatees are in the area, on a real-time basis, is envisioned. The contention is that boaters would be more likely to obey speed restrictions if these restrictions were accompanied by this type of information. The ability to do this also might enable such speed restrictions to be more flexible, and only enforced when manatees are actually present. This would make such speed restrictions more palatable to boaters.

The three technologies that I have examined are: (1) infrared cameras that detect infrared (heat) radiation emitted by all warm objects, (2) "night-vision" viewers that emit infrared radiation and then use the reflected radiation to generate an image, and (3) “night-shot" video cameras that also emit infrared radiation and then record the images generated by the reflected radiation. Each of these technologies have advantages and disadvantages.

The true infrared cameras provide the best images, at least in air. Water absorbs most infrared radiation, and so these cameras cannot penetrate water to image submerged objects such as manatees. I knew this prior to beginning my investigations, but thought that this technology might be able to detect manatee exhalations, which I anticipated would be warmer than the ambient air. It turns out that this is not the case, in that manatees appear to exhale air from their nostrils at close to ambient temperature. It has long been known that desert animals, and other marine mammals such as northern elephant seals (*Mirounga angustirostris*) also do this, and that this constitutes a water conservation mechanism. However, these cameras can detect the actual nostril openings of the manatees. Their images can also be sharply focused, and are not diminished by ambient light sources such as streetlights. This technology can also be used during daylight hours. The major drawback of these cameras is their expense, $15-30,000.00, and the need for a portable video recorder (also expensive) to capture images.

Because of the limited success of the infrared cameras, I also evaluated a night-vision scope. These are much less expensive, $300-500.00, which makes their deployment more economically feasible. They also appear to be able to penetrate the water to a depth of 0.5-1.0 meter. However, the images generated by this technology are of poorer quality, and this quality is deleteriously impacted by other ambient light sources. In addition, these scopes cannot be used during daylight hours. Capturing images on film also requires a 35 mm camera and adaptor.

I also found that many current models of "handy-cam" videocassette recorders have a "night-shot" capability, that utilizes a similar technology to the night-vision scopes, and can be purchased for $300-500.00. I anticipated that the ability to directly record the images detected by the camera would be a distinct advantage, as would the ability to switch from regular daytime video recording to nighttime video recording with the flip of a switch. However, the drawback of these video cameras is that they do not penetrate the water as well as the night-vision scopes, resulting in poor quality video images.

All of these technologies have their advantages and disadvantages which limit their application to the proposed boater awareness system. I believe that the night-vision technology might be best adapted to the system that I envision, but this would require more time and funding to fully explore and develop. I are also investigating the possibility that the manufacturer of the expensive infrared cameras might donate one of their demonstration models to Nova Southeastern University, which would enable us to more completely explore the use of this technology, and its potential for modification for my system. The "night-shot" video cameras might likewise be able to be modified to enhance their water penetrating ability and image quality. It might also be possible to adapt this technology to other applications, such as placing one on the bow of the boat, and projecting the image at the helm of the boat, so that the boat operator could, possibly, detect manatees in the water, or after dark, that they would not otherwise see. The appeal of this type of technology is that it is already familiar to most people, and thus learning to use it would not be a major burden on the operator. The cost of such a system would also probably not result in a major increase in the cost of the boat itself.

Over the course of this investigation, one NSU Oceanographic Center graduate student has almost completed her thesis, and another has started on her thesis. Preliminary results of this investigation were presented at the second annual Southeast and Mid-Atlantic Marine Mammal Symposium (SEAMAMMS) held 12-14 April 2002 in Conway, SC. Ms. Paine is currently in the final stages of completing her master's degree thesis.

> Paine, A.L, W.E. Baxley, and E. O. Keith. (2002). Investigating the feasibility of thermal infrared imaging technology for passive marine mammal detection. Southeast and Mid-Atlantic Marine Mammal Symposium. 12-14 April, Conway, SC.
>
> Paine, A. (In Prep). Investigating Applications of Thermal Infrared Technology for Passive Marine Mammal Detection. M.S. Thesis. Oceanographic Center, Nova Southeastern University, Ft. Lauderdale, FL

Finally, I believe that there has been a significant scientific spin-off from my investigation. The inability to detect manatee exhalations using the true infrared camera, or any of the technologies I examined, provides the first evidence that I are aware of that manatees exhale air at near ambient temperature, which as was mentioned above, has been documented in other animals as a water conservation mechanism. In their natural environment manatees almost never encounter fresh water, and thus must derive all of their water either from the food they eat (preformed water) or from metabolism. This necessitates a variety of water conservation mechanisms, such as the excretion of a highly concentrated urine, a thick water impervious skin, and a lack of thermoregulatory sweating. I have here provided evidence of yet another important adaptation that enables manatees to exist without ever needing to drink fresh or salt water.

INTRODUCTION

RATIONALE

Boater compliance with posted manatee speed zones is not optimum, and results in continued unacceptable levels of boat strikes that seriously injure or kill manatees. It is assumed 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. The purpose of this investigation was to test the feasibility of using infrared (IR) imaging technology to detect manatees as part of a boater manatee awareness system.

This system will have three-parts; 1) an imaging system that will determine the number of manatees in a semi-enclosed area, 2) a lighted sign that will alert boaters of the number of manatees in the area, and 3) a system that will monitor boater compliance with the posted speed zones. It is proposed to develop and install such a system in and around the effluent canal from the FPL Port Everglades power plant, in Ft. Lauderdale, FL. This plant discharges large volumes of warm water on a continuous basis, and the effluent canal provides a warm water refuge for manatees during the cold weather months. This system will detect the manatees as they enter this canal and record their numbers. This information will then be displayed on a lighted sign in the intracoastal waterway near the mouth of the effluent canal to alert boaters to the number of manatees present in the area. Their compliance with the posted manatee speed zones will be monitored by a wave-staff system that has already been developed at the NSU Oceanographic Center. Initial funding under this project was used to test the technology necessary to accomplish objective 1) above using thermal imaging cameras to detect and count the number of manatees. The technology to accomplish objectives 2) and 3) of this system already exists and will be described further in the discussion section of this report.

REGULATORY BACKGROUND

The Marine Mammal Protection Act (MMPA) forbids the ‘take’ of any marine mammal. The meaning of a ‘take’ as defined by the MMPA is “to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal” (Title 16, Chapter 31 UC Code; 50CFR216). Most survey techniques in use today require some level of harassment. In response to this harassment, marine mammals exhibit alterations in natural behavior. Behaviors indicative of harassment include avoidance strategies such as alterations of course, increased dive time, and dispersal of groups (Richardson *et al.* 1995). A need exists for a method of passively detecting the presence of marine mammals in their natural environment, while avoiding any harassment of the animals as a result of detection activities. Addtionally, the Endangered Species Act of 1973 (Title 16, Chapter 35 US Code; 50CFR18) gave the Fish and Wildlife Service, which is in the Department of the Interior, jurisdiction for the protection and conservation of the manatee.

THERMAL INFRARED IMAGING TECHNOLOGY

The primary source of infrared radiation is heat or thermal radiation. Any object that has a temperature above absolute zero (-273.15°C) emits heat in the infrared range. Infrared radiation lies between the visible and microwave portions of the electromagnetic spectrum. Infrared energy is emitted proportionately to the temperature of an object. Therefore, infrared detectors can “see” objects in the dark that cannot be seen in visible light because such objects emit thermal energy within the infrared wavelength range. Infrared energy is emitted proportionately to the temperature of an object. Thermal infrared cameras are comprised of four necessary components: optics, infrared detectors, image processing electronics, and image translation circuitry. With the recent advances in thermal infrared technologies, objects of different temperature gradients can now be detected within the same view. The application of this type of technology would allow for a completely passive, harassment-free, method for the surveying and detection of marine mammals.

ADVANTAGES OF AN INFRARED SYSTEM FOR MARINE MAMMAL DETECTION

There are several advantages to using a thermal infrared system for the detection of marine mammals. Thermal infrared imaging may be used regardless of the time of day or night. Thermal infrared imaging provides a completely passive, non-invasive, and harassment-free method of surveying and detecting marine mammals. This type of system has the potential to be fully automated. Compatible software has already been in development for the integration of infrared sensors, cameras, and computers into a system that can monitor, detect, and record heat emissions within a pre-determined wavelength and temperature range. Many infrared cameras are designed to be lightweight, compact and portable in construction. The portable models used in this project were all designed to weigh less than five pounds. Many infrared camera models also come with option of a rugged, weather-proof housing; thus allowing operation during inclement weather.

APPLICATIONS OF THERMAL IMAGING TECHNOLOGY

At this time, infrared imaging systems are being utilized in population studies, animal behavior studies, heat regulation studies in terrestrial warm-blooded animals (including insulation from heat loss by means of feathers, fur, and blubber), and veterinary diagnoses of animal disease and soft tissue injuries including general health assessments, soundness/lameness, wound management, dental care, localized inflammation, and reproduction. Infrared imaging is becoming increasingly popular due to its non-invasive nature.

The utilization of infrared technology to detect the presence of marine mammals is not a new technological development. In a personal communication described in Greene and Chase (1987), Steve Riley (SWFC) and Alan Wolman (NMML) discussed their experiments using infrared devices (at that time only available to the Army) to determine the migration of gray whales at night. It is thought that the experiment failed because the equipment lacked the sensitivity necessary to detect whale spouts and did not operate at the proper infrared wavelengths.

An 'accidental' experiment was conducted by Hughes Aircraft Company when an airborne infrared sensor was used in anti-submarine exercises. The sensor wavelengths were in the 8-12 μm region. The sensor readily detected spouts from gray whales, which obscured the desired [submarine] signals (Greene and Chase 1987). Other experimental thermal imaging studies have included diel variation in migration rates of gray whales (Perryman *et al*. 1999), thermographic measurements of the surface temperatures of animals and detection of infrared radiation from free living whales (Cuyler *et al.* 1992).

DETERMINING FACTORS FOR MARINE MAMMAL DETECTION

The use of infrared imagery for marine mammal detection is dependent upon several factors. These factors include, but are not restricted to, core body and skin temperature, sea state, differences between animal temperature and ambient environment (including water and air), amount of time an animal may be detectable (on the surface or surfacing), and the proximity of the animal to the sensor

The core body temperature for the manatee ranges between 35.6-36.4°C (Irvine 1983, Costa and Williams 1999). Adult Florida manatees have an average lung volume of 10 liters (Pabst *et al.* 1999). The length of the exhalation and inhalation cycle (for moderate activity in adults) approximates 3.3 seconds. Their average dive time is 4 minutes with an average dive depth of no greater than 3 meters (Reeves *et al.* 1992, Wynne and Schwartz 1999). This is a good indication of the amount of time an animal will spend at the surface of the water and thus the time available for detection. Manatees dive with lungs full of air (Pabst *et al.* 1999). The assumption is that, upon exhalation, released air will be at or near core body temperature. This exhalation should be clearly visible on thermal imaging detection system (Greene and Chase 1987) due to the contrast with the ambient environment.

The primary objective of this study was to demonstrate that manatees can be detected passively through the use of infrared cameras. This objective was be further subdivided four focal hypotheses:

$H_o(1)$: Manatees in aquatic habitats can be detected passively through the use of infrared cameras and computer image analysis software.

$H_o(2)$: The temperature of manatee exhalations is sufficiently different from that of ambient air to be detected by thermally sensitive infrared imaging systems.

$H_o(3)$: Manatee exhalations can be better discriminated at night than during the day when detected passively through the use of infrared cameras.

$H_o(4)$: The presence of manatees can be better determined during the winter months as opposed to the summer months through the use of infrared cameras.

Early results using only the thermal infrared imaging technology, during the summer season, were only marginally successful. Manatee exhalations were not clearly visible, either due to warm ambient air conditions, or because the manatees were not exhaling air at core body temperature (see discussion), or both. Therefore it was decided to broaden the scope of the project to include a “night vision” scope that emits infrared radiation, and then captures reflections of this radiation to create an image, as well as a video camera with “night-shot” capability (see below). Subsequent observations later in the fall, indicated that all three technologies were capable of detecting the thermal signatures of manatees, with varying degrees of success and quality of images obtained.

MATERIALS AND METHODS

The Miami SeaQuarium graciously provided access to their facilities where the manatees were maintained. Manatees were observed and imaged during daylight hours, at dusk, and after dark. These observations occurred in both the summer season and the fall season. The manatee environment consisted of two pools connected by dividing gate and surrounded by an observation deck. There were multiple animals living together in this environment. Behaviors exhibited included socializing, eating, resting, with normal breathing patterns. Generally, each infrared observation started with a visual localization of the subject animal. Then, an attempt was made to “sight” the same animal with the infrared camera. Once contact was made with the infrared camera, recording was begun. Digital still frames were also taken to capture the environment of observation (number of observers, weather, activity state of subject animals, approximate time of day, etc.).

For the summer observations two types of infrared cameras were utilized, the PalmIR 250® and PalmIR Pro®, both made by Raytheon (Raytheon Company, Lexington, MA, USA). Thermal infrared cameras observe subjects in the infrared spectrum by means of radiated body heat. Each infrared camera was connected to a Sony (Sony Electronics, Inc., Oradell, NJ, USA) DV cam digital videocassette recorder (DSR-V10) to record video input. Infrared image recordings were made on Panasonic (Matushita Electrical Corporation of America, Secaucus, NJ, USA) 07094DVC Linear Plus 120 minute cassettes (AY-DVM80EJ). Images were also recorded in the visible spectrum for analytical comparison to infrared images of the same subject using Sony Hi-8 XR Steady Shot (72x digital zoom) Video Camera Recorder with Handy cam Vision (CCD-TRV65 NTSC). For further analysis, the Kodak (Eastman Kodak, Co., Rochester, NY, USA) digital science megapixel zoom camera (DC210) was used to record digital still frame images during each observation.

The fall observations utilized the PalmIR Pro thermal infrared camera; a Night Owl Explorer Pro™ NOCX5 night-vision camera made by Night Owl Optics (Night Owl Optics, New York, NY, USA) with a camera adapter allowing still black-and-white image capture using a Canon (Canon U.S.A., Inc., Lake Success, NY, USA) 35 mm SLR camera; and a Sony TRV 608® Hi-8 video camera with night-shot capability and digital image transfer to a laptop computer.

The infrared cameras used in this project are manufactured by Raytheon Company. Ms. Rosita Federico, with CMI Tech, in Miami, FL, generously provided use of these cameras on a demonstration basis. Their specifications are listed in Table 1. The specifications for the Night

Owl Explorer Pro are listed in Table 2. This device attaches to a 35 mm camera with an adaptor. Specifications for the Sony video camera are listed in Table 3.

Table 1. Specifications for the two Raytheon infrared cameras.

Performance Parameters	PalmIR PRO (color gradient)	PalmIR 250 (b/w gradient)
Spectral Response	7-14 microns	7-14 microns
Thermal Stabilization	None	Thermoelectric cooler
Video Update Rate	Standard 30 Hz	Standard 30 Hz
Time to Operation	<25 seconds at 25ºC	<25 seconds at 25ºC
Battery Operating Time	>2 hours	>4 hours
Operating Temperature Range	-20ºC to 50ºC (Camera); 0ºC to 50ºC (LCD display)	-20°C to 49°C
Standard Lens	25mm; *f*1	75mm; *f*1
Field of View	36ºH x 27ºV	12ºH x 9ºV
Focus Range	6 in - 8	8 ft - 8

Table 2. Specifications for the Night Owl Explorer Pro night vision monocular scope.

Infrared Imaging Technology Generation	1
Magnification	5.0x
Range of View	200 m
Focal Length	80 mm
Aperture	*f*1:1.7
Field of View (@1000 yds)	524 ft
Focusing Range	3.0 m - 8

Table 3. Specifications of the Sony video camera with “night-shot” capability.

Video Signal	NTSC Color, RIA standards
Image Device	CCD- 4.5 mm; ~320,000 pixels
Lens	37 mm diameter, 20x optical, 500x digital zoom
Focal Length	41-820 mm
Minimum Illumination	0.1 Lux in night-shot mode

NECESSARY PERMITS

On 15 May 2002 I received a letter from Linda D. Walker, who is the assistant field supervisor for the Fish and Wildlife Service in Jacksonville, FL. In the letter she states that because the work I was doing under our award (FWC PO No. 7701-617577) was noninvasive and did not entail harassment of captive manatees, the work did not require a permit. She went on to say that should the methods change, or be transferred to the field, that we should contact them again to ensure that any permitting needs are addressed.

RESULTS

THERMAL INFRARED IMAGING

Preliminary testing of the infrared cameras indicated that they can detect the exhalations of a killer whale (*Orcinus orca*) (Figure 1). Manatee observations were conducted at the Miami SeaQuarium in Miami, Florida, in a captive environment as described above. Several hours of observation were accomplished during the summer and fall seasons. Manatees and their

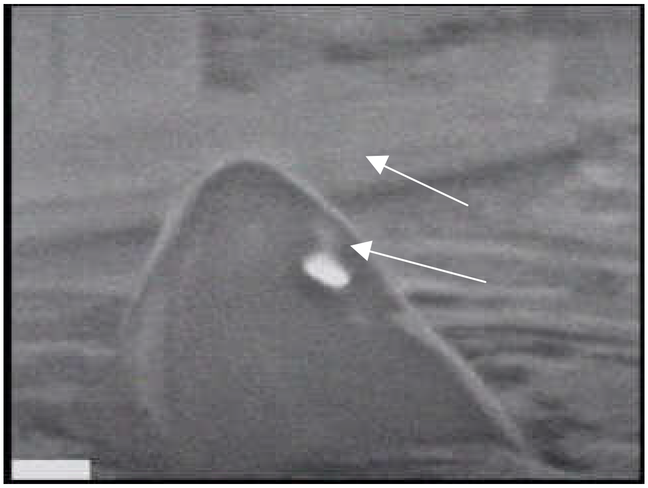

Figure 1. IR camera view of a killer whale exhalation. The exhalation extends from the blowhole up to and beyond the upper arrow, in a vertical direction slightly skewed to the right.

exhalations were observed and imaged during daylight hours and at dusk. Infrared images were digitally recorded at varying times of day and activity states. Results were highly dependent on the type of camera used due to differences in spectral response, sensitivity, image resolution, and lens configurations. Both color and monochrome infrared images were obtained, with black-and-white images providing better detection of manatees (Figures 2 and 3).

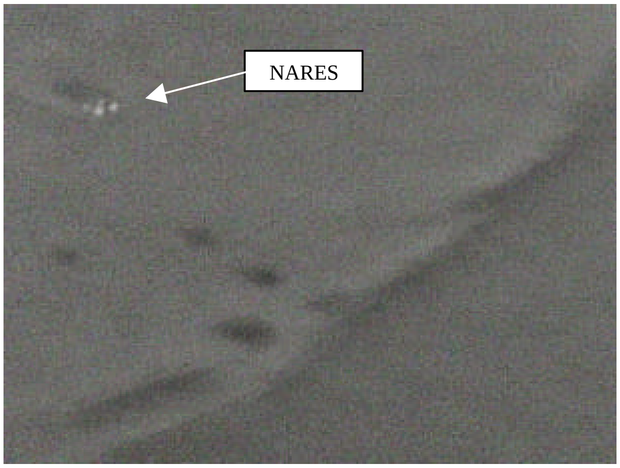

Figure 2. Summer season image of manatee respiring at surface.

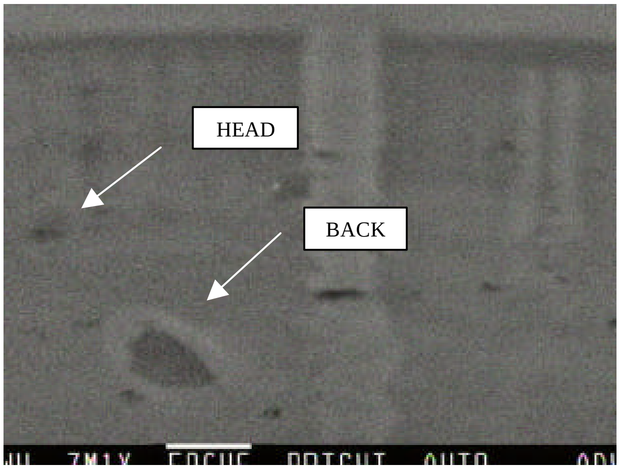

Figure 3. Summer image of the back of a manatee. The head of the animal is to the upper left of the back, visible above the surface.

Images were also affected by length of surface interval, time of dive, and amount of body surface exposed. The near infrared energy portion of the visible spectrum also impacted images due to heat "reflections" of surface ripples. In general terms, detection of exhalations was more successful in cetaceans than in sirenians or pinnipeds. Thermal energy in cetacean exhalations was most often captured as a bright white image on a gray background. For the most part, pinnipeds exhalations radiated poorly detectable heat signatures. The sirenian exhalations did not emit any detectable thermal radiation. However, the infrared cameras were able to detect the heat signature of the nasal openings of the manatees while they were respiring at the surface. These images resembled two white circles, fairly close together, near the top and front of the rostrum (Figures 4 and 5). These heat signatures were visible from a variety of viewing aspects, from the front, side, and rear of the animal.

Although the infrared camera systems were designed to detect temperature or heat gradients, they also detected non-heat sources, such as light reflections and ripples on the surface of the water, as well as remnants of the lettuce which is the primary food provided to the

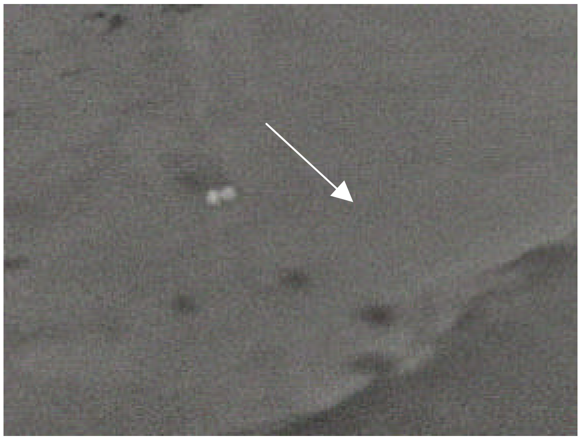

Figure 4. Fall season image of manatee exhaling at the surface. The animal is moving towards the camera to the lower right (arrow).

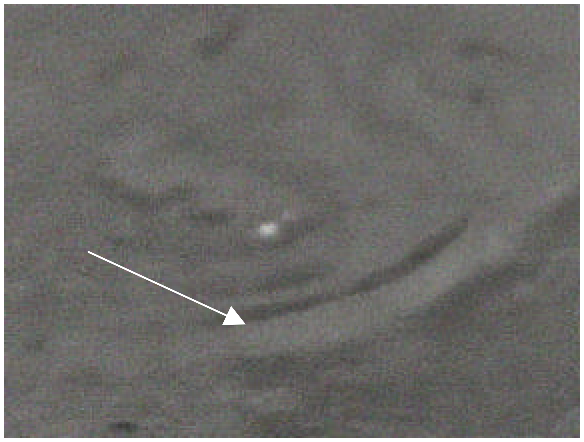

Figure 5. Fall season image of manatee exhaling at the surface. The animal is moving towards the lower right corner of the image (arrow).

manatees. While this phenomenon was noted throughout each trial, it was especially evident in the manatee habitat where the light reflections from the surrounding structures were clearly visible on the image both during the day and at night, although this interference was less after dark.

Despite my earlier expectations, the infrared cameras were not able to detect the exhalations of the manatees directly. The veterinarian at Miami SeaQuarium, Dr. Maya Menchaca, could offer no possible explanation for why manatee exhalations are so difficult to detect, as compared to the exhalations of a killer whale or sea lion. However, there may be a reason for this, based on the differences in the anatomy of the terminal airways of cetaceans, pinnipeds, and sirenians, and the physiology of respiration in these groups. Dolphins exhale through a single blowhole on the top of the head. This blowhole is a relatively large diameter structure, closed by a muscular plug when the animal is submerged. Upon surfacing, the cetacean exhales strenuously, forcing air from the lungs and respiratory passages at high velocity. Pinnipeds and manatees, in contrast, have a system of nasal turbinate bones over which the air flows as it is being exhaled. These turbinates cool and dehumidify the exhaled air by employing a counter-current heat exchange system. The turbinate system of pinnipeds is generally less well developed than that of sirenians, and our results indicate that the degree of cooling of the exhaled air should be less in pinnipeds than it is in sirenians. Similar systems are well known in terrestrial mammals, especially ungulates, and acts as a water conservation mechanism in these species. It may be that a similar mechanism may be utilized by the manatees, and may provide the same water conservation benefit to manatees. As manatees are the evolutionary descendants of ungulates, this explanation seems plausible (See discussion).

NIGHT VISION IMAGING

The Night Owl night vision system appeared to be able to penetrate the water to a depth of 0.5-1.0 m, which the infrared cameras (above) were not able to do. Images obtained with the Night Owl monocular scope and captured with the 35 mm SLR camera were of equivalent quality to those of the infrared cameras (above). The system as configured for this investigation was cumbersome in use, due to the need to focus both ends of the night vision scope, i.e. the aperture end and the objective end. In addition, the 35 mm SLR camera adaptor allowed free rotation between the night vision scope and the camera, necessitating a significant degree of manual dexterity to both control this rotation, and focus the image. Should this technology be investigated further, modifications of this system would be essential to permit increased image quality and rapidity of image capture.

Figure 6 depicts a manatee near the surface, with only the nostrils emerging from the water. The submerged head, eyes, and neck area are clearly visible below the surface. Figure 7 shows a different respiration cycle, with the manatee in a different orientation. In this image it is possile to again see a portion of the manatee below the surface of the water. Figure 8 shows a

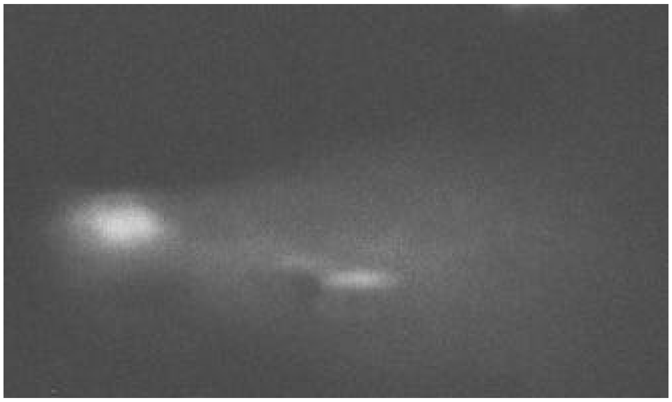

Figure 6. Manatee respiring at the surface, captured with the Night Vision scope.

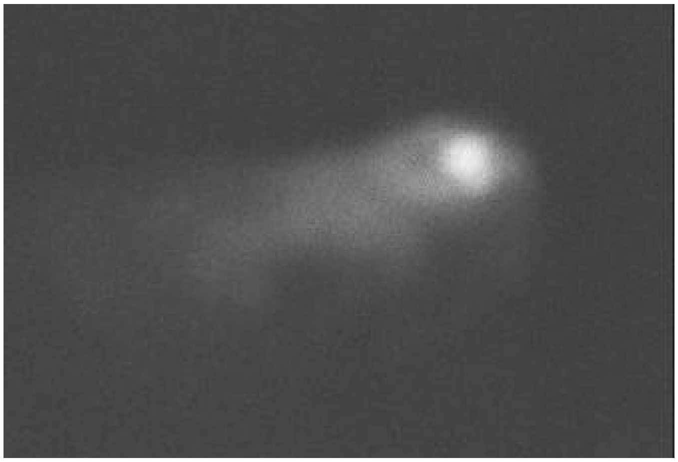

Figure 7. Night Owl image of a manatee at the surface.

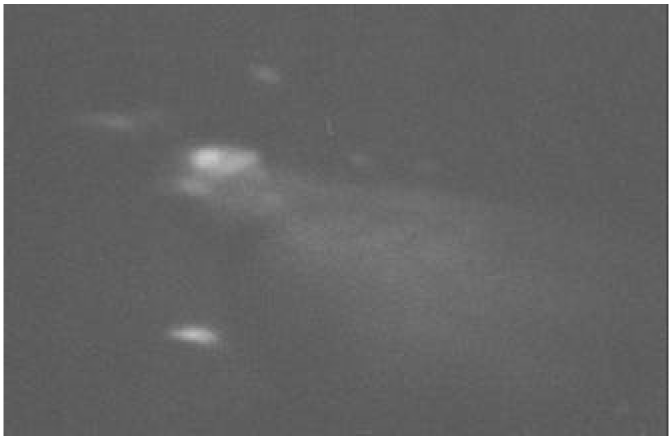

Figure 8. Night Owl image showing manatee at the surface. The nostrils and head are not in focus, but a large portion of the animal is visible below the surface.

body of the animal is clearly visible below the surface. The final image in this series shows the tail of a manatee below the surface of the water (Figure 9).

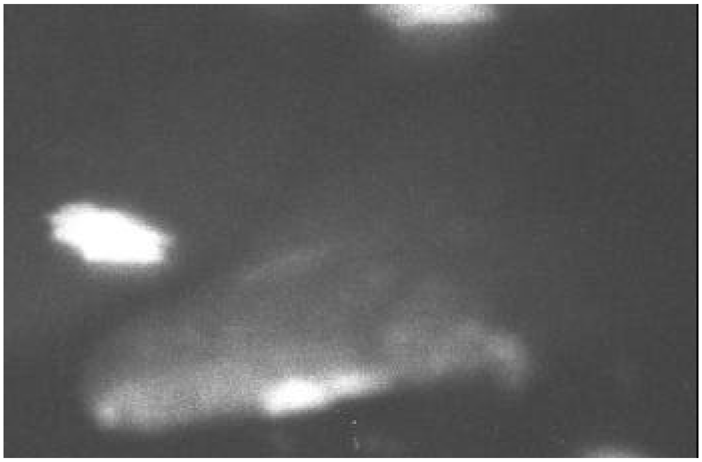

Figure 9. Night vision image of the scarred tail of a manatee below the surface of the water. This animals tail is truncated and deformed from an accident. She is a captive resident of the Miami SeaQuarium.

NIGHT-SHOT VIDEO IMAGING

Images captured with the night-shot video capability of the Sony handy-cam video camera were of the poorest quality of the three imaging technologies examined. The camera was very sensitive to extraneous light sources, and did not penetrate the surface of the water to any appreciable degree. However, the ability to use this system to capture images during both daytime and nighttime hours might confer a distinct advantage, if these image quality issues could be overcome.

Figure 10 depicts a typical night-shot image of a manatee at the surface, indicating the general low resolution yielded by this imaging technology. Only the time of the animal's rostrum is visible, and only a slight ripple on the water surface is showing in front of the animal. Figure 11 shows a better night-shot image of two manatees at the surface, heading in opposite

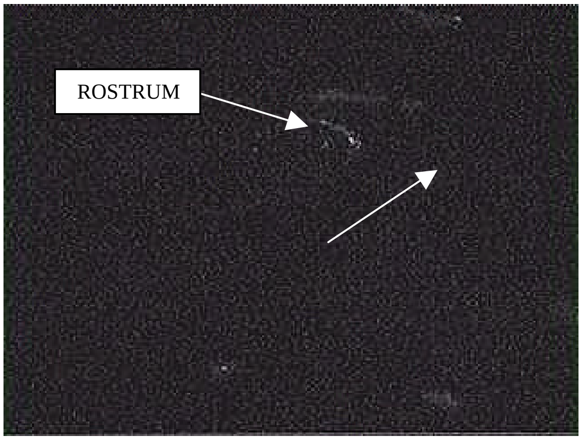

Figure 10. Night shot image of a manatee at the surface.
The white arrow indicates the direction of animal movement.

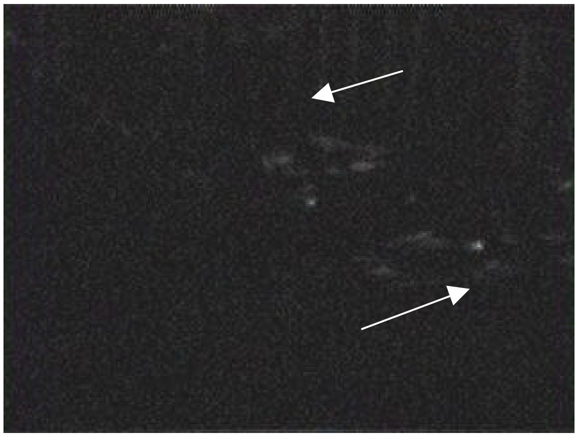

Figure 11. Two manatees respiring at the surface, captured with the night-shot video camera.
The white arrows indicate the direction of animal movement.

directions. The vertical striping visible in this image is a reflection of the fence surrounding the manatee habitat at the Miami SeaQuarium. Although this imaging system did not penetrate the surface of the water to any appreciable degree, Figure 12 depicts a manatee below the surface, at just the very limit of visibility. The final image in this series, Figure 13, raises the enigmatic possibility that this imaging technology might be the only one examined here that can actually see a manatee exhalation. The only prominent feature in this image is a vertical white streak, against an almost uniformly black background. This image was captured just as the manatee

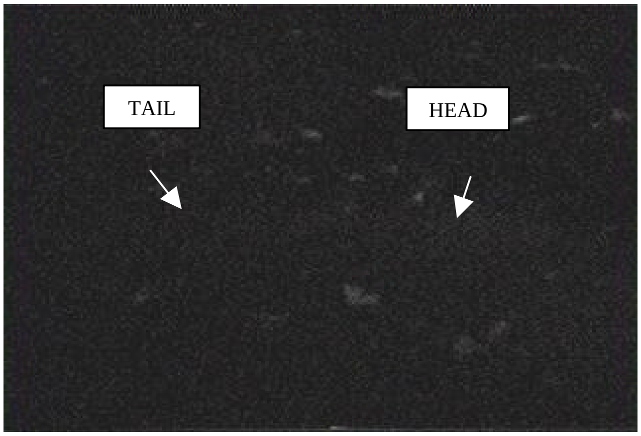

Figure 12. Poor quality image of subsurface manatee captured by the night-shot video camera.

Figure 13. Putative heat signature of manatee exhalation.

reached the surface to exhale, and the white streak may be the heat signature of that respiration. The question of why this particular imaging technology might capture such a heat signature, where the other, more sensitive, technologies did not can perhaps be answered by suggesting that the infrared radiation emitted by the camera added to the infrared radiation emitted by the, only slightly, warmer exhalation of the animal to create this image. It may also be that this animal exhaled in a way that either bypassed the counter-current heat exchange system in the nasal turbinates, or minimized its effect. Finally, is possible that this image captured some other feature than the exhalation, reducing all of this to mere speculation.

SUMMARY OF RESULTS

With respect to the four focal hypotheses posited in the introduction, this investigation has conclusively shown that manatees in aquatic habitats can be detected passively through the use of thermal imaging technology and other infrared imaging systems ($H_0(1)$). Although the temperature of manatee exhalations was not sufficiently different from that of ambient air to be detected by thermally sensitive infrared imaging systems ($H_0(2)$), the nostrils themselves emitted a heat signature that was able to be visualized. The other technologies examined, both of which utilizing reflected infrared radiation, were able to penetrate the surface of the water, to variable degrees, and detect manatees.

During the course of these investigations, manatees were better discriminated at night than during the day when detected by all technologies examined here ($H_0(3)$). This is perhaps not so much due to a reduced ambient temperature, especially during the summer months, but rather due to decreased ambient light interference with the imaging processes examined.

Finally, these investigations revealed that manatees can be better detected during the cooler months as opposed to the warmer months by the thermal imaging technology, probably due to a reduced ambient and water temperatures, and therefore an increased thermal gradient ($H_0(4)$).

DISCUSSION

All of the technologies examined herein, thermal infrared imaging, night-vision infrared imaging, and night-shot video infrared imaging, were able to detect manatees in an aquatic environment. Additionally, two of them, the night-vision and night-shot video systems, were able to detect manatees beneath the surface of the water. The thermal infrared imaging camera yielded the best images of manatees at the surface, because the heat signature of the nares could be visualized as a pair of bright white circles that resembled “snake-eyes’ on a pair of dice, or a pair of brightly lit quarters resting on the rostrum of the animal. This characteristic visual signature of a manatee at the surface could probably be detected by computerized image analysis software, which would be a prerequisite for the boater awareness system envisioned here, which would require that real-time imaging of manatees moving into a restricted refuge be analyzed, the animals detected and counted, and the results be transferred to a lighted signage system to alert boaters, all on a continuous 24 hours a day, seven days a week, basis. The drawback of the thermal infrared imaging system is its cost.

The other imaging systems explored in this study have the advantage of lower cost, but the disadvantage of poorer image quality, and a reduced probability of automated image analysis. In order to incorporate these systems into the boater awareness system, further study of their potential, and reconfiguration of their image capture and analysis methodologies would be required. Should these hurdles be surmountable, the advantage of water penetration further enhances the attraction of these technologies.

PHYSIOLOGICAL IMPLICATIONS

The distribution patterns of manatees suggest that they possess a number of physiological adaptations related to water balance and osmoregulation. The anatomy of manatee kidneys suggests that these animals might be able to concentrate their urine beyond the osmolality of sea water, a prerequisite for the drinking of sea water, or mariposia (Hill and Reynolds 1989). Irvine et al. (1980) suggested that manatees were able to drink sea water because urine osmolality varied with the salinity of their environment. Ortiz, *et al.* (1999) examined the water turnover rates of manatees under four different environmental and food situations. Animals kept in fresh water had the highest water turnover rates. Upon acute exposure to salt water, manatees decreased their water turnover rate significantly, indicating water conservation. Animals kept in salt water, and fed lettuce, had significantly lower water turnover rates than animals kept in salt water and fed sea grasses, again indicating water conservation. These data suggest that manatees do not engage in mariposia (Ortiz, *et al*. 1999).

The endocrine mechanisms by which manatees conserve water were examined by Ortiz et al. (1998). They found that acute exposure to salt water increased plasma osmolality, and sodium and chloride levels in the plasma, and decreased aldosterone in the plasma. Animals held in salt water, and deprived of fresh water, increased their aldosterone levels by almost two-fold, and then decreased aldosterone by almost four-fold when provided with fresh water. However, plasma electrolyte levels did not change after this transition. Plasma renin levels were significantly correlated throughout the study. (Ortiz, *et al*. 1998). These data indicate that manatees are good osmoregulators through a wide range of aquatic salinities, regulating their sodium balance via the renin-angiotensin-aldosterone axis, and their osmotic balance via aldosterone.

The authors of both of the above studies suggest that a significant source of water to manatees comes through their food. The lettuce fed captive animals contains a large amount of water that becomes available upon ingestion. A second source of water is that ingested incidental to feeding, which when the animals are feeding in salt water is probably a very small contribution to overall water balance (~ 5.0 ml/kg/day- Ortiz, *et al.* 1999). A third source of water comes from the oxidation of the food, or of fat when the animal is fasting. The complete oxidation of one gram of fat will actually yield 1.03 grams of water. It may be that manatees use their fat as a ‘water storage depot’ as suggested by Ortiz, *et al.* (1999) to prolong their ability to inhabit saline environments without resorting to mariposia.

A final mechanism for water conservation has been suggested by this study. The fact that the manatee exhalations were not able to be imaged by the thermal infrared system indicates that manatees exhale air at near ambient temperature. During the cold weather months this could provide a means of water conservation, though a mechanism previously described by terrestrial vertebrate desert inhabitants. The Cape eland (*Taurotragus oryx*) and the oryx (*Oryx gazella*) can survive indefinitely without drinking water (Taylor 1969). They conserve water in many ways, among them by allowing their body temperature to increase, thus saving water that would otherwise be lost to evaporative cooling. Another is through a counter-current heat exchange system in the nasal turbinate bones that cools the exhaled air to the ambient temperature. Exhaled air is saturated with water, and warmer air can hold more water than cooler air. Thus, by cooling the air as it is exhaled, these animals conserve valuable water (Taylor 1969).

It may be that manatees also utilize both of these mechanisms, the first one at least in part, and the second one fully, as suggested by our results. Manatee skin lacks sweat glands, and is heavily keratinized to minimize osmotic water loss when the animal is in a hypertonic environment. This minimizes water loss through the skin. Manatees also possess an elaborate nasal turbinate system, and may utilize this system as do many terrestrial vertebrates to conserve water. Manatees have been shown to have counter-current blood flow systems in other parts of their bodies, which they utilize to maintain reproductive tissues at temperatures different from core body temperature (Rommel, *et al.* 2001). My inability to detect a thermal signature from manatee exhalations strongly suggests that manatees exhale air at ambient temperature, which may result in significant water conservation, especially during the cold weather months. This mechanism has been found to significantly reduce expiratory water loss in the northern elephant seal, which fasts completely from food and water for 1-3 months during terrestrial breeding (Huntley, *et al*. 1984). Temporal countercurrent heat exchange in the nasal passages reduces expired air temperature to below body temperature, which at mean ambient temperatures results in the recovery of 71% of the water added to inspired air during inhalation. The percentage of water recovery varies inversely with ambient temperature in these animals, however, such nasal temporal countercurrent heat exchange reduces total water loss sufficiently to allow maintenance of water balance using metabolic water production alone (Huntley, *et al.* 1984).

BOATER MANATEE AWARENESS SYSTEM

This boater manatee awareness system envisioned here will have three-parts; 1) an imaging system utilizing one of the technologies examined in this study that will be used to monitor the number of manatees in a semi-enclosed area, 2) a lighted sign that will alert boaters of the number of manatees in the area on a real-time basis, and 3) a mechanism to monitor boater compliance with the posted manatee speed zones.

Initial funding under this project was used to test the technology necessary to accomplish objective 1) above using thermal imaging cameras to detect and count the number of manatees, and was found to be successful. Computer operated lighted signage to accomplish objective 2) is commercially available, and familiar as the warning signs seen on Florida roadways under construction. The technology to accomplish objective 3) has already been field tested. This testing was funded by two Special Waterways Projects grants from the Florida Department of Environmental Protection. The projects, entitled Waterway Expert Traffic System (WETS), demonstrated a new and innovative method of obtaining information on waterway use in an urban canal. The WETS automated system counted every boat passing the test site, and determined its speed and heading. Both instantaneous measurements and an Internet searchable database of boating activities were realized. A summary of this work may be viewed at the Waterway Expert Traffic System Gateway Internet site (http://www.wets.net/wets_gateway.htm). A computerized data acquisition and control system would integrate the three components of the system, and provide summaries and analyses of the data. Regarding the entire boater awareness system, all other components exist and their functionality has been adequately demonstrated. This project involves incorporating existing validated technology into a novel manatee awareness system.

Further future development of the entire manatee awareness system will probably require a permit to modify one of the existing manatee speed zone signs in the vicinity of the FPL effluent canal in Port Everglades. It is expected that such permission will not be difficult to obtain, given 1) the relatively minor change from a static unlighted sign to a dynamic lighted sign, and 2) the potential benefits of this system to the manatees.

NEGATIVE IMPACTS

Because this system will passively monitor the manatees from a terrestrial location, it will have absolutely no effect upon them. Placement of the real-time lighted sign, and the compliance monitoring wave-staff near the Intracoastal Waterway will in no way affect the behavior or the movements of manatees. It will likewise not create a hazard to navigation. A permit may be required in order to install the wave-staff boat detection system next to the Intracoastal Waterway. However, again, it is expected that if this is required, it will not be difficult to obtain for the two reasons given above.

FUTURE POTENTIAL

Once developed, such manatee awareness systems could be installed in many locations where manatees congregate, and enable boaters, managers, and even the general public to become more aware of the presence of manatees, their numbers at any particular time, and how well boaters are complying with posted speed zones. By reducing the speed of boats in posted manatee speed zones, this technology could reduce manatee mortality, essential for the recovery of this endangered species, while at the same time informing boaters, and others, about the seasonal movements of manatees and the status of their population. Proper use of this technology might also result in the flexible application of manatee speed zones on a short-term basis, such that speed restrictions could be lifted when manatees are not present. By making boaters partners in the conservation efforts directed towards manatees, their cooperation and compliance will be increased.

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