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METHODS USED DURING GROSS NECROPSY TO DETERMINE WATERCRAFT-RELATED MORTALITY IN THE FLORIDA MANATEE (*TRICHECHUS MANATUS LATIROSTRIS*)

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Abstract: Between 1993 and 2003, 713 (24%) of 2,940 dead Florida manatees (*Trichechus manatus latirostris*) recovered from Florida waters and examined were killed by watercraft-induced trauma. It was determined that this mortality was the result of watercraft trauma because the external wound patterns and the internal lesions seen during gross necropsy are recognizable and diagnostic. This study documents the methods used in determining watercraft-related mortality during gross necropsy and explains why these findings are diagnostic. Watercraft can inflict sharp- and blunt-force trauma to manatees, and both types of trauma can lead to mortality. This mortality may be a direct result of the sharp and blunt forces or from the chronic effects resulting from either force. In cases in which death is caused by a chronic wound-related complication, the original incident is usually considered to be the cause of death. Once a cause of death is determined, it is recorded in an extensive database and is used by Federal and state managers in developing strategies for the conservation of the manatee. Common sequelae to watercraft-induced trauma include skin lesions, torn muscles, fractured and luxated bones, lacerated internal organs, hemothorax, pneumothorax, pyothorax, hydrothorax, abdominal hemorrhage and ascites, and pyoperitoneum.

Key words: Florida manatee, mortality, *Trichechus manatus latirostris*, watercraft trauma.

INTRODUCTION

The Florida manatee, *Trichechus manatus latirostris*, is a subspecies of the West Indian manatee (*Trichechus manatus*).[5] Florida manatees are found in coastal and inland waters throughout the southeastern United States during the summer. During winter, the range is much smaller, with manatees aggregating mostly at natural and man-made warm water sources throughout Florida.[13] Manatees share the waterways with watercraft and have historically sustained injuries due to interactions with these vessels (Fig. 1).[3,14,25] Of the 2,940 manatee necropsies performed at The Marine Mammal Pathobiology Laboratory, Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission between 1993 and 2003, 713 fatalities (24%) were the result of watercraft. Watercraft-related mortality is therefore the most commonly identified cause of death of the Florida manatee. Other causes of mortality include perinatal and natural causes, death due to other types of human interactions, and undetermined causes of death. This article will describe the lesions associated with watercraft-related injuries and the methods used in classifying a carcass as a watercraft-related mortality.

It is important to have a basic understanding of the manatee's unique anatomy when interpreting watercraft-induced lesions. The skin of the Florida manatee is four times thicker than would be predicted for a terrestrial mammal with similar body mass.[8] The epidermis is thin and keratinous and interdigitates with the dermis, which is an organized three-dimensional weave that is reinforced with two sets of collagen fibers: radial and helical. The radial collagen fibers reinforce the skin against shear forces in nearly all directions, whereas helically wound fibers reinforce the circumference.[9] Partly because of the skin's structure and composition, watercraft-induced wounds in manatees are often sublethal, with the protective dermis and underlying fat and muscle absorbing much of the impact, whether this impact is from blunt structures like hulls and keels or from sharp structures like propellers, skegs, and rudders.

The manatee's skeleton supports the large body. Its ribs are massive, extremely dense, pachyostotic, osteosclerotic, and amedullary.[4,6] The manatee's cervical and lumbar regions are short, whereas the thoracic and caudal regions are elongated.[20] The vertebral formula is C6:T16–19:L1–3:S0:Ca23–27.

Another unique feature of the manatee's anatomy is the orientation of the diaphragm, which is attached laterally near the distal rib tips and medially to the ventral aspect of the vertebral column. The diaphragm is divided along the vertebral column

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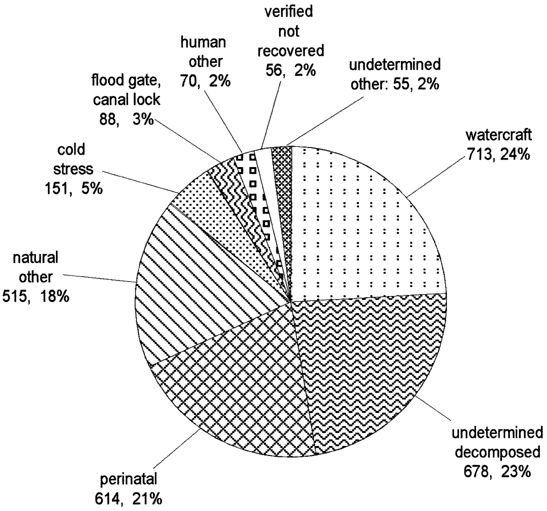

Figure 1. Death categories for the Florida manatees necropsied between 1993 and 2003.

into two hemidiaphragms, which serve to structurally and functionally isolate the two pleural cavities from each other and to keep the lungs in a horizontal position. The manatee's diaphragm extends dorsally over the heart and attaches to the first two ribs, not to the sternum, as is common in most mammals. The transverse septum provides the barrier between the heart and abdominal organs, a function typical of the diaphragm in other mammals (Fig. 2).[19] The lungs are located directly beneath the arch of the ribs and extend almost the entire length of the thorax; they are susceptible to damage from impacts to the dorsal and lateral aspects of the body—where most watercraft strikes occur.[25]

The kidneys are lobular and highly vascularized, with numerous ancillary blood vessels perforating the cortex, making them prone to fracture. The cortex thickness ranges from 5 to 11 mm in the adult (57.3% of renal mass) and is 3.6 mm thick in the calf (68.5% of the renal mass).[10] The kidneys are found in the caudal abdomen and lie against the diaphragm at or near its midline attachment (Fig. 3).[17] This position, like that of the lung, makes the kidneys more susceptible to injury as a consequence of watercraft strikes on the caudal dorsum.

The Florida manatee is a hindgut fermenter, with an extensive gastrointestinal (GI) tract that occupies the greater part of the abdominal cavity. The complete tract, including contents, can account for up to 23% of the total body weight.[16,18,21] The locations of other abdominal organs can be seen in Figure 3.

The Florida manatee is listed as a Convention of International Trade in Endangered Species of Wild Flora and Fauna Appendix I species. The World Conservation Union lists the species as vulnerable, and the United States Endangered Species Act (USESA) of 1973 list the Florida manatee as endangered. The Florida manatee is protected under Florida statutes, the U.S. Marine Mammal Protection Act of 1972, and the USESA and its subsequent amendments. In 1985, the Florida Fish and Wildlife Conservation Commission's Marine Mammal Pathobiology Laboratory (MMPL) assumed responsibility for the manatee carcass salvage program in Florida and has since performed necropsies, when possible, on all recovered dead manatees. Federal and state managers of Florida manatee conservation strategies use these data extensively. This information emphasizes the importance of reporting causes of death and loss of endangered wildlife.

MATERIALS AND METHODS

Every manatee carcass that is brought to the MMPL undergoes a full necropsy and a comprehensive report is completed. The animal is weighed and scanned for the presence of a passive integrated transponder tag, external measurements are taken, and a genetics sample is collected from the fluke for a genetics tissue bank. The dorsal, ventral, and lateral aspects of the carcass are examined and photographed.

Wounds and scars caused by trauma are identified by careful inspection of the skin and subcutaneous tissues. Lesions caused by blunt-force trauma may or may not be visible externally, but on cut surfaces contusions are typically evident in the epidermis, dermis, blubber, and/or muscle. Externally visible blunt-force trauma lesions may be identified by a depression from the impact or a region of abraded epidermis revealing hemorrhage and/or contusion in the dermis. Acute wounds can be superficial or deep skin lacerations. Fresh lacerations are open, with few signs of healing, and they may be associated with hemorrhage, hematomas, blood clots, and/or ecchymoses in the underlying dermis, blubber, and muscle. Because of their persistent nature, hemorrhage, hematomas, blood clots, and/or ecchymoses may also be associated with chronic, healing lacerations. If the wound is healing, it is typically smoother than the surrounding skin but has rough margins. Healed scars can be completely covered by smooth epidermis or may be hypopigmented.

Scars are highlighted with a waterproof cattle marker and rephotographed. Fresh wounds and scars are sketched within manatee outlines on a data sheet kept with the necropsy report. Each fresh wound is given a reference number, and multiple measurements are collected. The length of each

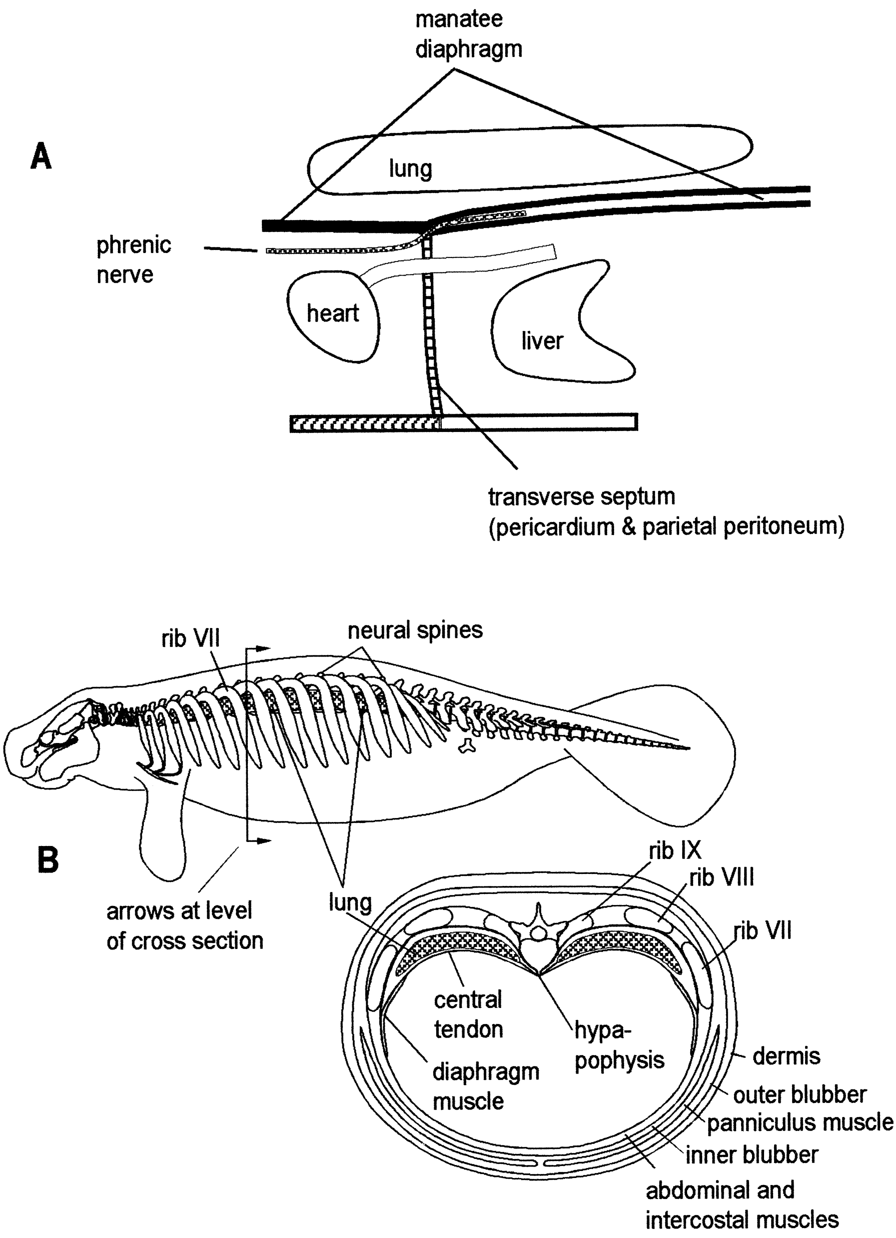

Figure 2. **A.** A left lateral sketch illustrates the manatee diaphragm extending dorsally over the heart and the transverse septum providing the barrier between the heart and the abdominal organs. **B.** The left lateral view of the Florida manatee illustrates the position of the elongated lung. On transverse section, the diaphragm attachments are evident—the hypapophyses at the midline and ribs at mid-shaft.[19]

wound within a pattern is measured using calipers. Length, width, and maximum depth of each penetrating wound are also recorded. Cut-spans, the distances along the wound axis between successive lesions in a single pattern, are each measured from leading edge to leading edge or trailing edge to trailing edge of the wound (Fig. 4).[15]

After a detailed external examination, the carcass is positioned in dorsal recumbency, and a full necropsy is performed. Initially, the flippers are removed and the scapulo-humeral joint and bones are examined. Muscle, fat, and organs are examined for evidence of trauma, as described in the following paragraphs.

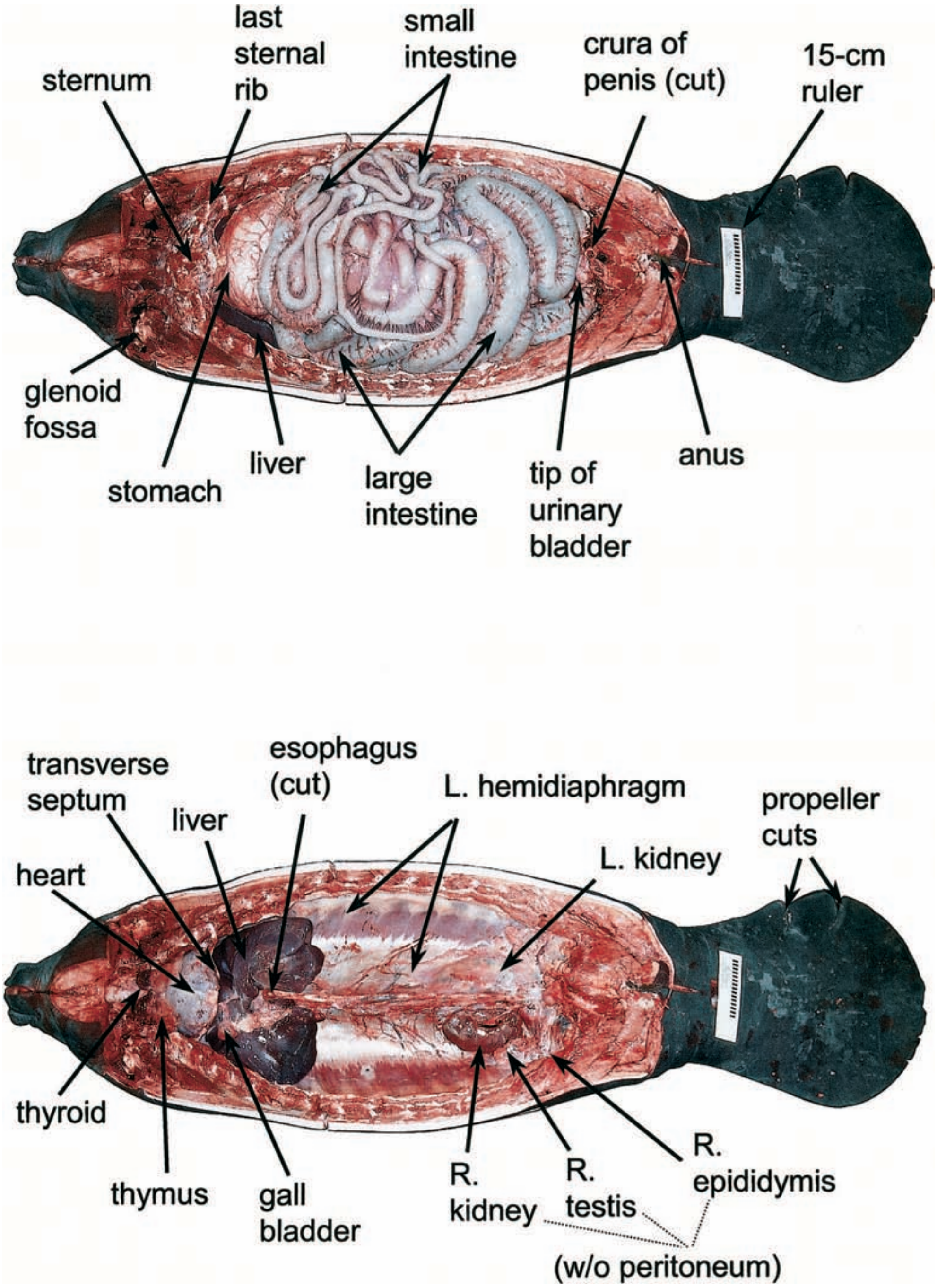

Figure 3. Florida manatee internal anatomy. **A.** A dorsally recumbent, freshly dead male manatee. The skin, blubber, and superficial musculature have been removed. **B.** The same manatee as in A with the gastrointestinal tract and sternum removed.[19]

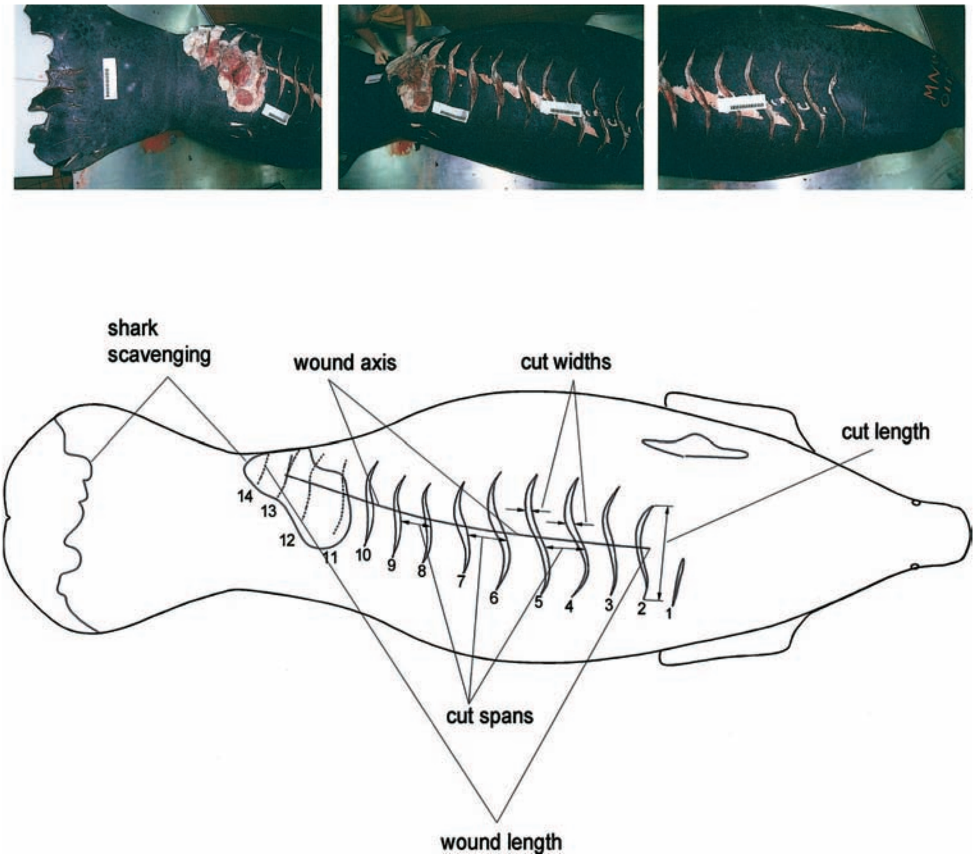

Figure 4. Characterizing watercraft traumatic injury. Dorsal photographs of a watercraft-related wound pattern illustrate a single linear lesion consistent with skeg trauma and repeating, almost evenly spaced lesions consistent with propeller trauma. Sharks scavenged the fluke and parts of the watercraft-related wound pattern (sketched). The wound axis is a line drawn through the center of each cut in the pattern. It is parallel to the direction of travel of the watercraft. The cut span is the distance along the wound axis from leading edge to leading edge of the wound or from trailing edge to trailing edge of the wound. The length of the wound pattern is measured using calipers. The length, width, and depth of each single lesion are also measured.[15]

Muscle and fat

The carcass is skinned deep to each wound and scar in order to look for signs of bruising and hemorrhage in the muscle and fat. Next, the entire ventral skin is removed, exposing the ventral musculature. Muscle pallor can be apparent in manatees that have sustained blood loss due to trauma and are thus anemic. Fat depletion (i.e., emaciation, serous atrophy) can occur in chronic watercraft trauma cases when the animal's body condition has worsened as a result of its injuries. A postmortem blood shift can be evident in the dermis, muscle, and fat in the cranial aspects of the carcass as a result of build-up of decompositional gasses. This should not be misinterpreted as evidence of trauma, and a cut through the dermis at the level of the bruise can distinguish between antemortem and postmortem trauma. The presence of granulation or scar tissue, purulent inflammation, proliferation of fibrous tissue, and reddening of wound margins are signs that indicate antemortem trauma.[15]

The abdominal cavity

The ventral muscles are removed, exposing the abdominal cavity. The abdominal cavity and all abdominal organs are examined in situ (Fig. 3). The in situ examination is extremely important in order to investigate the relationship between internal and external lesions. For example, a laceration in the stomach may be consistent with a propeller pattern in the adjacent body wall. Typically, the abdominal cavity contains 50–100 ml of clear yellow (serous) fluid. Normally, the serosal surfaces of the intestines and parietal peritoneum are light tan to pink and the visceral peritoneum is smooth. Fats are firm and are light tan to pink in color. Blood clots and frank blood in the abdominal cavity are abnormal and can be indicative of trauma. The amount of blood present is quantified, and the surrounding regions are examined thoroughly for signs of trauma that would lead to blood loss (i.e., fractured bones that puncture the abdominal cavity, tears to abdominal organs, or lacerated vascular structures). Scar tissue and/or fibrous adhesions can form in cases of chronic irritation and inflammation secondary to trauma. GI tract contents may be found free in the abdomen if the GI tract has been torn. After a thorough examination has been made of the intact abdominal cavity, the organs are removed and examined separately.

The effects of watercraft-related trauma in most abdominal organs are similar, and each organ is examined for grossly apparent lesions. Organs that have sustained traumatic injury may be lacerated from propeller trauma and/or from broken and luxated bones. There may be blood clots and hemorrhage in and around the organ. Hematomas may be evident on or within the capsule of the liver or kidney or ovaries. Organs may display pallor due to exsanguination. Adhesions may be present, and scar tissue from healed wounds can be apparent. In cases of trauma to the head, the manatee will often swallow blood, so the stomach contents should also be examined.

The thoracic cavity

After all abdominal organs are removed, the hemidiaphragms are examined for lacerations, adhesions, and loss of integrity. The hemidiaphragms are then removed and the lungs are inspected. Lacerations of the lung from propellers, fractured and luxated ribs, and vertebral separations are common. Grossly, hemorrhage or blood clots may be seen around the lesion, in the pleural cavity, and in the primary and secondary airways. Fibrin tags and adhesions may be found in more chronic cases. The primary and secondary airways of the lung are dissected in order to note any blood, mucus, froth, or grit that could be consistent with drowning secondary to trauma. The pleural cavity can contain frank or clotted blood, purulent exudate, or effusion as a consequence of organ damage from trauma. This material is quantified, described, and, depending on the decomposition stage of the manatee, may be collected for further analysis.

The heart

The sternum is carefully inspected and removed so that the integrity of the pericardium and transverse septum can be examined (Fig. 2). The pericardium is opened, the volume of fluid (normal is about 100 ml) is estimated, and the color of the fluid (normally a clear yellowish-pink) is recorded. The epicardial fat is inspected, and the amount of fat, consistency of the fat, any associated hemorrhage, and the presence or absence of blood clots are described. The myocardium, valves, and great vessels are inspected for lacerations, pallor, hemorrhage, blood clots, and thromboses.

The postcranial skeleton

Skeletal damage is the most common internal consequence of watercraft-induced injury. The postcranial skeleton is exposed and examined for evidence of fracture, luxation, and/or vertebral separation. Fractures of the scapulae, sternum, humeri, radii, ulnae, vertebrae, and ribs have been documented, as have luxations and subluxations of the ribs and vertebral separations.

Manatees have a remarkable ability to repair damage to their bones. This is most often seen in the remodeling of the ribs in chronic watercraft injuries. Proliferative bone formation can occur as a sequel to fracture and luxation. In a few animals, dramatic exostoses form (Fig. 5). Regions of proliferative bone growth are documented during necropsy. Bruised and reactive periosteum can also be a consequence of trauma and is documented.

Head and neck regions, including cranial skeleton

The soft tissues of the head region are examined for ecchymoses, bruises, blood clots, hemorrhage, and pallor. The head is stripped of flesh and the cranium is carefully inspected. The periotic bone is extracted and used later in determining the age of the animal. Head trauma can result in decapitation, fractured skull bones, separation of the sutures of the skull bones, subdermal bruising, hemorrhage, hematomas and blood clots, and hemorrhage and blood clots in the brain and brain case. The ear bones are often affected. Tympano-periotic bones are brittle and can be fractured. Consequently, associated blood clots can be found in the middle ear cavity and pterygoid sinuses.

All findings and observations from the gross necropsy of the carcass are recorded immediately in the necropsy report, and a probable cause of death is determined.

RESULTS AND DISCUSSION

Watercraft-related injuries were observed during gross necropsies of 713 of the 2,940 carcasses examined (24%; Fig. 1). It is apparent from the gross

Figure 5. Proliferative new bone growth secondary to remodeling in the ribs and vertebrae of the Florida manatee.

necropsies that manatees are killed by both sharp- and blunt-force traumatic collisions with watercraft. Sharp-force trauma includes lacerations from propeller blades and scrapes from skegs, whereas blunt-force trauma includes nonpenetrating injuries from hulls, keels, rudders, propeller blades, and skegs. Individual, linear wounds are considered to be caused by skegs, keels, rudders, or other submerged, nonrotating features of the vessel. Externally these lesions are superficial, but they are typically accompanied by deep tissue trauma.

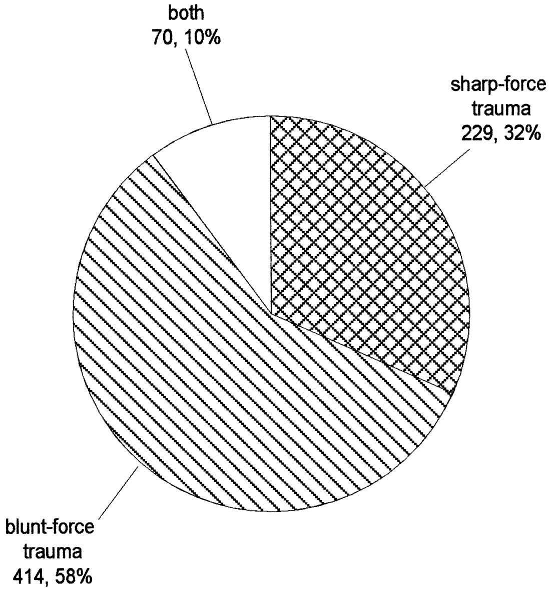

Figure 6. Types of watercraft-related mortality from 1993 to 2003. Two hundred and twenty-nine animals (32%) died as a direct result of sharp-force trauma. Propellers and skegs were the most common causal agents of sharp-force trauma. Four hundred and fourteen animals (58%) died as a result of blunt-force, or impact, trauma. Hulls, keels, rudders, propellers, skegs, and other submerged features of a watercraft can cause blunt-force trauma. The remaining 70 manatees (10%) died as a result of a combination of sharp- and blunt-force traumatic injuries.

Propeller wounds are usually observed in a roughly parallel series and may vary in appearance depending on the diameter and the pitch (the distance that a propeller travels in one revolution through a soft solid) of the propeller.[15] Thirty-two percent of all watercraft-related mortalities in this study were determined to be a consequence of sharp-force trauma, including propeller trauma (Fig. 6).

Because manatee skin is thick and tough, a sharp object is also capable of causing blunt-force, or impact, trauma. For example, a propeller blade or skeg may only deform the skin yet cause considerable internal damage (Fig. 7, 8). Fifty-eight percent of watercraft-related mortalities in this study were determined to be from blunt-force impacts resulting in wounds that did not penetrate the skin (Fig. 6). More manatees in this survey died as a result of blunt-force trauma (58%) than as a result of sharp-force trauma (32%). The remaining 10% of watercraft-related mortalities were attributed to a combination of blunt- and sharp-force trauma (Fig. 6).

Mortality from blunt- and/or sharp-force trauma may be a direct and immediate result of these forces (acute mortality). An animal's death is termed an acute mortality if it is estimated that death occurred within approximately 24 hr after the watercraft impact.[2] Chronic effects of trauma can also cause mortality. Chronic mortality is defined as that

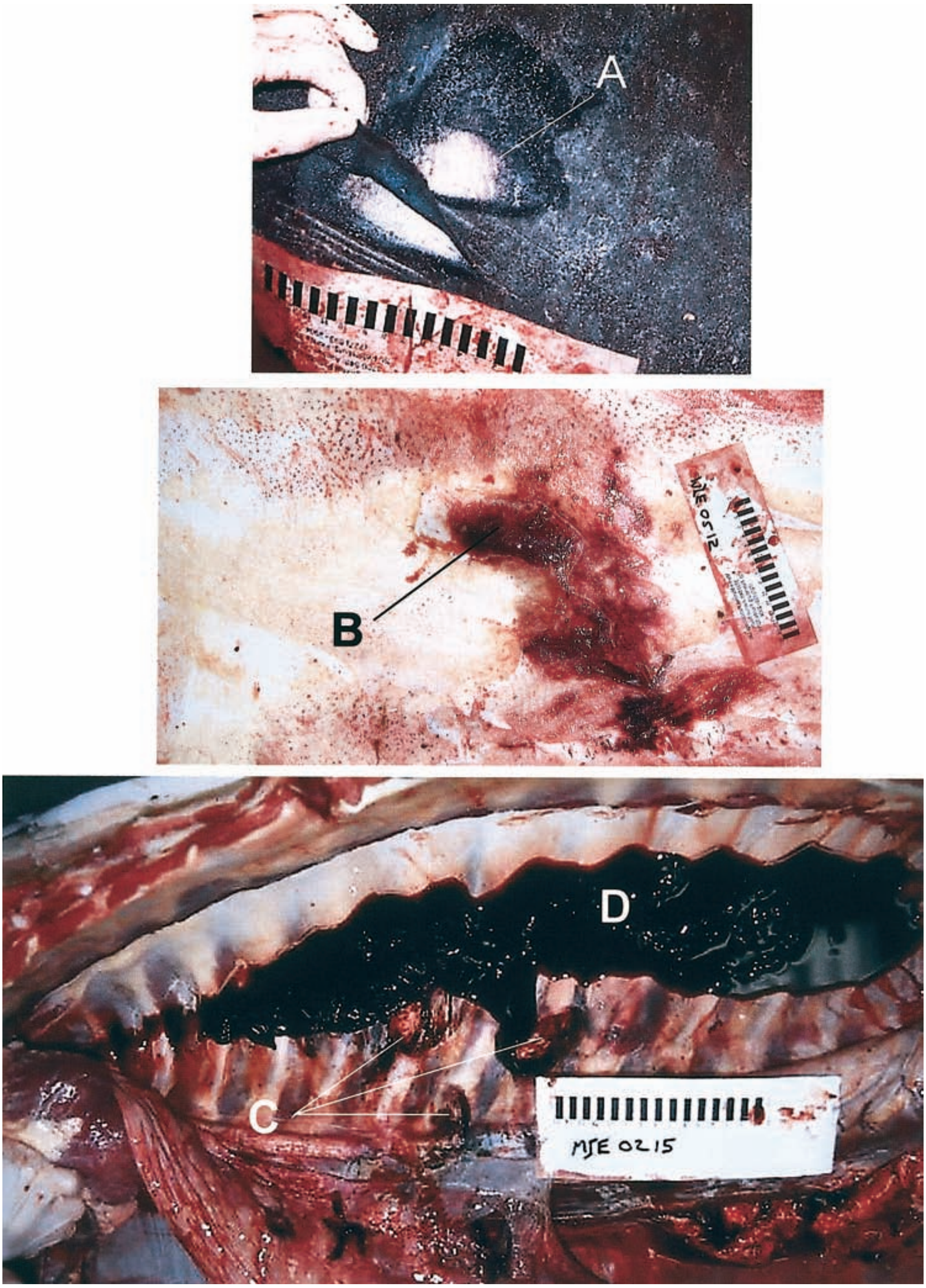

Figure 7. This manatee was a known boat-strike mortality. The owner of the vessel notified authorities shortly after he hit and killed the manatee. All of the epidermis was present at necropsy. **A.** There was only a single epidermal abrasion grossly visible on the carcass. **B.** When the carcass was skinned, dermal ecchymoses and hemorrhage were evident. **C.** Upon investigation of the thorax, fractured and luxated ribs, a torn hemidiaphragm, punctured lung, shredded muscle, and, **D,** extensive hemorrhage were found. A blunt-trauma injury that looked very superficial on first inspection had consequences that resulted in this animal's immediate mortality.

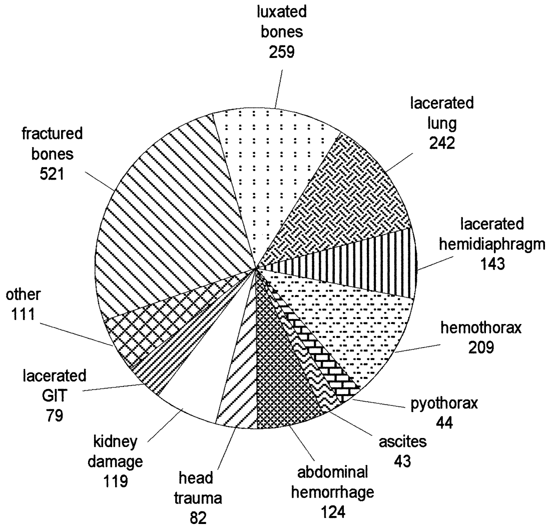

Figure 8. Internal sequelae to watercraft trauma. Note that the total number of lesions add up to more than 713 mortalities because one animal may have multiple sequelae to trauma. The "other" category comprises animals with hydrothorax, pneumothorax, heart damage, reproductive tract damage, pyoperitoneum, or liver damage.

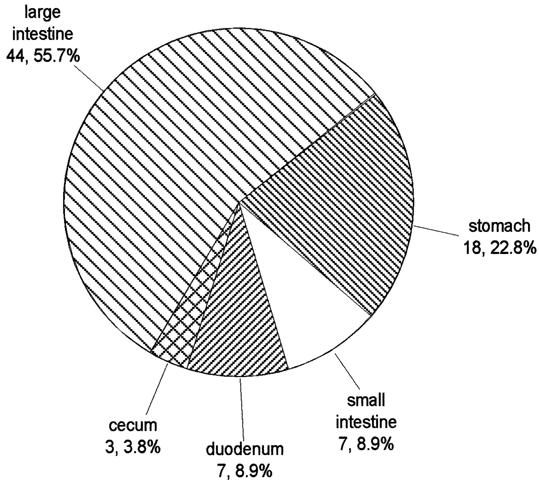

Figure 9. Lacerations are the most common GI tract consequence of watercraft trauma (*n* = 79/713, 11%) and have been found in the stomach (*n* = 18, 22.8%), duodenum (*n* = 7, 8.9%), ileum and jejunum (*n* = 7, 8.9%), cecum (*n* = 3, 3.8%), and large intestine (*n* = 44, 55.7%). Lacerations can occur in more than one part of the GI tract of the same animal.

which is not immediately fatal but eventually leads to the animal's death.

The abdominal cavity

Lacerations are the most common GI tract consequence of watercraft trauma (*n* = 79, 11%) and were found on the stomach (*n* = 18), duodenum (*n* = 7), small intestine (*n* = 7), cecum (*n* = 3), and large intestine (*n* = 44; Fig. 9). Note that lacerations occurred in more than one part of the GI tract of the same animal. The location of the laceration was often directly correlated with the overlying skin lesions. Consequences of GI tract laceration included spillage of contents into the abdominal cavity (with subsequent formation of adhesions), peritonitis, hemorrhage, and blood clots.

The kidneys are especially vulnerable to watercraft-related trauma because of their anatomical position (Fig. 3), their ancillary surface vessels, and their tendency to fracture. One hundred and nineteen manatees (16.7%) had some type of grossly evident kidney trauma (Fig. 8). We hypothesize that shear-wave motion, impact forces (including acceleration and deceleration), and pressure applied during impact also cause kidney damage. These forces are documented causes of abdominal injury in human impact injuries but have not been previously described in the Florida manatee.[22]

Liver trauma (*n* = 24, 3.4%) is not as common as kidney trauma, but lacerations, pallor, hemorrhage, hematomas, and blood clots associated with trauma have been described (Fig. 8). No injuries to the gallbladder were observed in this study.

In cases of watercraft-related trauma in this survey, the uterus and ovaries were infrequently affected (*n* = 7). Four animals of the affected seven sustained damage to the ovaries, and the remaining three had damaged uterine bodies or horns. Interestingly, two of the seven females with damaged reproductive tracts were pregnant; one sustained uterine trauma and the other had damaged ovaries. Since 1993, at least 40 pregnant females were killed as a result of watercraft interactions. Fetal mortality and necropsy findings were documented only in the cow's necropsy report. Separate recordings would increase the total number of watercraft-associated deaths described from 1993 to 2003 from 713 to 753. There are only three reports of trauma to the male reproductive tract: three animals had damaged testes, and one of these animals also had a severed penis.

The thoracic cavity

Of the manatees killed by watercraft interaction, 20% (*n* = 143) had a torn hemidiaphragm (Fig. 8). Because of the unique structural and physical isolation of the two lungs (Fig. 2), a laceration to the right or left side alone can allow the manatee to survive by relying on a single viable lung for res-

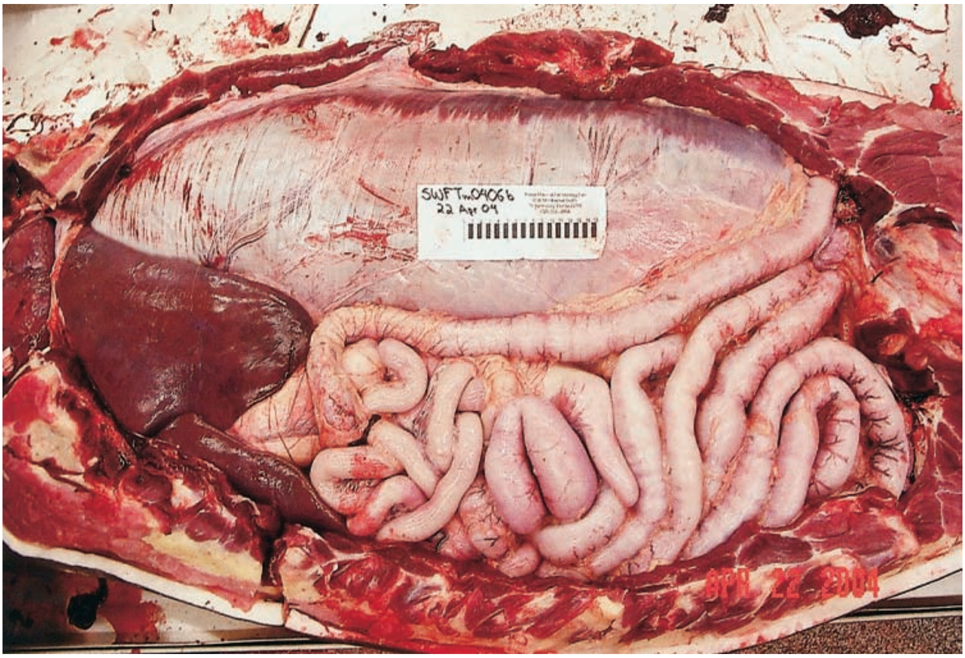

Figure 10. Pneumothorax. Photograph of the ventral surface with head to the left. This animal's left hemidiaphragm was severely distended with gas, forcing the abdominal organs to lie entirely on the right side of the abdominal cavity. The left lung had severe caseous adhesions along the entire serosal surface. There were multiple broken and subluxated ribs on the left side of the body, and left ribs 11–14 were exposed through a dorsal wound. The most probable cause of death on gross necropsy was watercraft impact trauma.

piration.[19] Broken or luxated ribs often puncture the lung and subsequently lacerate the hemidiaphragms deep to the lung. Hemidiaphragms can also be torn as a consequence of vertebral separations. When a hemidiaphragm is torn, abdominal organs can move into the pleural cavity. Additionally, there can be associated pleural effusion, clotted blood and hemorrhage, fibrinous adhesions, infection, and inflammation.

Possibly because they are more proximal to the ribs, the lungs were more commonly lacerated than the hemidiaphragms (n = 242, 34%) (Fig. 8). As with other organs, this was due to a primary laceration from the watercraft or secondary lacerations from rib and vertebral fractures, luxations, or vertebral separations.

Pneumothorax (n = 11, 1.5%), pyothorax (n = 44, 6%), and hemothorax (n = 209, 29%) were observed (Fig. 8). Both an open pneumothorax (with free communication between the pleural surface and the environment) and a closed pneumothorax (where air accumulates as a result of leakage from the pulmonary parenchyma or bronchial tree) were observed. Live manatees with a pneumothorax may list to one side because there is a more positive buoyant force on the side of the body with the pneumothorax. The condition may resolve with time or may contribute to the animal's mortality.[12] At necropsy, there is a distended hemidiaphragm because of the positive pressure of gas in the pleural cavity and the displacement of the abdominal viscera to the opposite side of the abdomen (Fig. 10). Manatees with a pyothorax display similar clinical signs. The animals will list, but the purulent material makes the affected pleural cavity more negatively buoyant than the contralateral one, so the manatee will swim with the affected side down. The hemidiaphragms and the abdominal viscera can also be displaced. Upon incision of the affected pleural cavity, pus is evident (Fig. 11). This purulent exudate can vary in consistency from a thick, milky liquid to firm, caseous material. Coloration ranges from white to yellow to green. The purulent exudate can be quite odiferous, and many liters are often collected from just one pleural cavity. For example, a manatee with a known history, MSW0428, had confirmed negative buoyancy problems from 22 January 1994 until its death on 15 March 2004. In life, it tended to lie in very shallow locations where it could surface by pushing off the substrate with its flippers. At necropsy, the right pleural cavity was filled with thick, caseous, purulent material

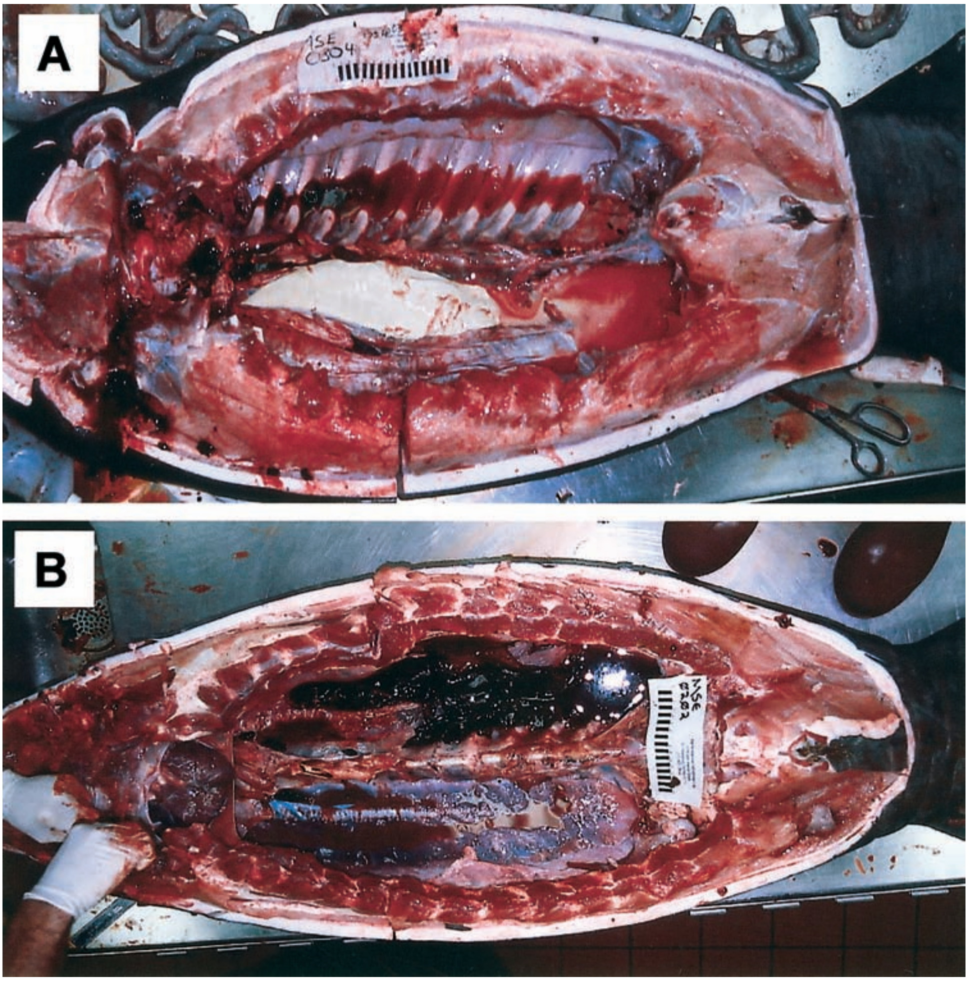

Figure 11. **A.** Pyothorax. Photograph of the ventral surface with the head to the left. The manatee's right pleural cavity was filled with a thick, viscous, yellow-white purulent fluid. The cranial half of the lung was compressed by this purulent material. Externally, there were healing, nonpenetrating propeller wounds on the right dorsum. The most probable cause of death on gross necropsy was watercraft impact trauma. **B.** Hemothorax. The left pleural cavity contained a well-formed blood clot that adhered to the serosal surface of the lung. The dorsal aspect of the lung was torn in several locations, and the tears were directly associated with three broken ribs. Most probable cause of death on gross necropsy was watercraft impact trauma. This diagnosis was supported by histopathology.

and flat, chalk-like pieces of hard, consolidated pus. The right hemidiaphragm projected into the body cavity and was hardened by a chronic investment of inorganic material. The right lung was collapsed and not likely to be functional. MSW0428 had a healed propeller scar pattern on its right dorsolateral aspect.

Hemothorax was observed in 29% (n = 209) of the animals killed by watercraft-induced trauma between 1993 and 2003 (Fig. 8). In these cases, one or both of the pleural cavities were filled with adherent, clotted, or frank blood. When a hemothorax is present, clotted and frank blood may be found in the primary, secondary, and tertiary airways and the trachea and nares (Fig. 11).

The heart

The heart can be directly affected as a consequence of watercraft-related trauma (Fig. 8). In this study, there were 15 cases of traumatic laceration to the heart (2.1%). Manatees with lacerated or ruptured hearts also had penetrating dorsal or dorsolateral propeller wounds or scrapes at the level of the heart, luxated or broken ribs directly dorsal to the heart, skull damage, and broken or dislocated humeri, scapulae, or radii. For example, manatee

MEC0145 had a propeller cut on the left lateral aspect of the body, just cranial to the flipper, resulting in the shredding of the heart, broken ribs and left scapula, lacerated muscles, severed bronchi and trachea, and a shattered sternum.

The postcranial skeleton

Skeletal damage is the most common internal consequence of watercraft-induced injury. Five hundred and twenty-one manatees (73%), of 713 animals killed by watercraft, had at least one fractured bone (Fig. 8). Two hundred and fifty-nine manatees (36%) had at least one luxated bone. Ribs were by far the most commonly fractured bones. Because of the mass and location of the ribs, there were many consequences of rib damage. Broken or luxated ribs caused severe trauma to internal organs. Muscle, gastrointestinal tract, uterus, ovaries, kidneys, heart, lungs, liver, and hemidiaphragms were each affected by rib trauma.

Fractured vertebrae and vertebral separations were also a possible consequence of watercraft-related trauma. Osteomyelitis, periostitis, osteitis, and proliferative bone formation were apparent in the vertebrae as well (Fig. 5).

The head and neck regions, including cranial skeleton

Bruising, hemorrhage, and blood clots were consequences of head and neck trauma. Fractured skull bones were common sequelae. The result of trauma to the head was acute or chronic. In one case, LPZ101445, the manatee survived for at least 32 hr after a propeller strike to the head. Upon necropsy, skin margins surrounding the propeller wound appeared to be healing, but when the skin was reflected, there was a large region of muscle necrosis and infection directly underneath the propeller wound. The upper lip was enlarged and there was cellulitis over the dorsal aspect of the neck. Deep dissection revealed that the strike penetrated into the masseter muscles. The left side of the skull of this animal was shattered. There were multiple fractures to the left zygomatic arch, the orbital bones, and the temporo-mandibular joint. The left nasal cavity had collapsed as a result of the fractures. This manatee also had at least 17 other distinct healed propeller patterns on its dorsum.

Other findings

Since 1993, the MMPL has necropsied nine animals from self-reported vessel strikes. These were known boat-killed manatees, and a detailed history (including specifics of the vessel, speed, and direction of travel) had been obtained from the vessel operator. The information gained from these self-reported strikes was valuable in strengthening and supporting the results of the necropsies of suspected watercraft-related manatee mortality. This type of interpretive information is used in human forensic pathology and is acceptable evidence in a court of law (Pellan, pers. comm.).

When carcasses were fresh enough for samples to be taken for histopathology, gross diagnostic necropsy findings in the majority of cases (20 of 23, 87%) were supported by histopathologic determination of death. In no cases did the histopathologic determination of death refute the gross diagnosis. In human medicine, gross autopsy alone provides an accurate diagnosis in 90% of cases; the remaining 10% are close to the correct diagnosis.[23]

Many of the carcasses brought to the MMPL were moderately to badly decomposed (n = 2,388 of 2,940, 81%). Nevertheless, a cause of death was determined from these carcasses, especially in cases of watercraft-induced trauma. When examining external wounds, one can look for signs of wound resolution, such as inflammation, bruising, necrosis, proliferation of fibrous tissue, rounded margins, and/or granulation. Also, the margins of antemortem cut muscle contract and may appear curled, whereas postmortem cuts do not. An absence of such resolution indicates a postmortem strike. Additionally, the location of cuts will typically differ. Live manatees rarely spend time floating ventrum up, so animals with ventral cuts alone are typically considered to have been postmortem watercraft strikes, unless otherwise indicated. Postmortem blood clots can be differentiated from antemortem clots: postmortem blood clots are nonadherent to the lining of the blood vessels and the heart, and the clots are more jelly-like, red, and elastic than are antemortem clots. Agonal clots may stratify, resulting in a layered clot.[24] Antemortem clots tend to be dull and irregularly rough and are more likely to be attached to the wall of a vessel than are postmortem clots.[24] Antemortem clots may be adherent to the source (i.e., kidney fracture, lung laceration, or torn muscle). Well-formed blood clots take on the shape of their immediate surroundings, so clots that are similar in size, shape, or position to large vascular structures (i.e., veins, sinuses, plexuses) are not used as evidence of antemortem trauma. Well-formed clots that are different in size, shape, and position from the adjacent vascular structures are considered antemortem (i.e., epidural clots, loose clots in the abdomen, subcapsular renal clots, subdural clots).

CONCLUSIONS

Watercraft-related trauma is a significant contributor to Florida manatee mortality. It was the most commonly determined cause of death of the manatees in this study, conducted between 1993 and 2003; 713 carcasses of the 2,940 recovered and necropsied were determined to be watercraft-related mortalities. In most cases, we were able to determine when the cause of death of a Florida manatee was a result of watercraft trauma by gross necropsy findings alone, even in the case of decayed carcasses. We were able to determine this because many watercraft-induced lesions are diagnostic and persist through autolysis. Veterinarians and biologists can be trained to detect these grossly apparent lesions, and Federal and state managers can use this information in formulating effective conservation strategies for the species.

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