EcoHealth 1, 255–262, 2004
DOI: 10.1007/s10393-004-0095-5

ECOHEALTH

Manatees as Sentinels of Marine Ecosystem Health: Are They the 2000-pound Canaries?

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Abstract: The order Sirenia is represented by three species of manatees and one species of dugong distributed in tropical and subtropical regions of the world and considered vulnerable to extinction. The sentinel species concept is useful to identify indicators of the environment and may reflect the quality of health in marine ecosystems. The single species approach to evaluate ecological health may provide a series of "snap shots" of environmental changes to determine if animal, human, or ecosystem health may be affected. Under this concept, marine vertebrates may be good integrators of changes over space and time, and excellent sentinels of ecosystem health. Based on their life history, manatees may or may not be ideal sentinels, as they are robust, long-lived species and appear remarkably resilient to natural disease and the effects of human-related injury and trauma. These characteristics might be the result of an efficient and responsive immune system compared to other marine mammals. Although relatively immune to infectious agents, manatees face other potentially serious threats, including epizootic diseases and pollution while in large aggregations. Manatees can serve as excellent sentinels of harmful algal blooms due to their high sensitivity, specifically to brevetoxicosis, which has caused at least two major die-offs in recent times. Threats to manatees worldwide, such as illegal hunting and boat collisions, are increasing. Habitat is being lost at an alarming rate and the full effects of uncontrolled human population growth on the species are unknown. The manatee may serve as a sentinel species, prognosticating the deleterious effects of unhealthy marine and aquatic ecosystems on humans. We have identified a number of critical research needs and opportunities for transdisciplinary collaboration that could help advance the use of the sentinel species concept in marine ecosystem health and monitoring of disease emergence using our knowledge on these magnificent sirenians.

Key words: brevetoxin, ecosystem health, harmful algal blooms, manatees, sentinel species, *Trichechus manatus*

INTRODUCTION

The order Sirenia is represented by three species of manatees and one species of dugong distributed in tropical and subtropical regions of the world. All Sirenia are listed as vulnerable to extinction by the World Conservation Union (IUCN) (Marsh and Lefebvre, 1994). The family Trichechidae is comprised of the three species of manatee: the Amazonian manatee (*Trichechus inunguis*) inhabits the Amazon river, the West African manatee (*T. senegalensis*) is found along the coast of western Africa, and the West In-

Published online: May 13, 2004
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dian manatee (*T. manatus*) resides in the tropics of the Americas. The West Indian manatee includes two subspecies: the Antillean manatee (*T. m. manatus*) is distributed in the Caribbean, Mexico, Central and northern South America, while the Florida manatee (*T. m. latirostris*) is restricted to southeastern United States and the Gulf of Mexico. The dugong (*Dugong dugon*) is the only extant species of the family Dugongidae and is distributed primarily in the Indopacific, including eastern Africa (Reynolds and Odell, 1991).

Manatees are typically located in coastal areas, inhabiting rivers, estuaries, marshes, and inlets; occasionally they are observed in the sea. The species are intolerant of cold water. Winter temperatures restrict the Florida manatee to 1 of 25 warm-water refugia, 16 of which are artificial (Bell, 2000). In warmer months, many animals travel further north and are routinely sighted in Georgia and South Carolina on the east coast, and in Mississippi and Louisiana on the gulf coast. Extralimital sightings have increased over the last few years as evidenced by recent sightings at Chesapeake Bay in Maryland, Long Island in New York, and Galveston Bay in Texas (Bonde and Lefebvre, 2001).

The use of the sentinel species concept to monitor the health of marine ecosystems is not clear for the manatee. Sentinel, from the Latin *sentire*, means to perceive or feel. According to the Oxford English Dictionary, a sentinel is defined as one who "stand[s] guard over." A sentinel species is thus one that is "on guard" or "vigilant" of changes occurring in its environment. Sentinel species provide knowledge in order to facilitate early responses to potentially hazardous conditions and permit more effective resource management. We hope that sentinel species will detect changes prior to their effects becoming irreversible (Reddy et al., 2001). In some circumstances, manatees may serve as ideal sentinels of ecosystem health; however, in other instances they may not qualify as a species to answer specific questions about the environment due to their unique characteristics. The purpose of this article is to briefly review the anthropogenic and natural threats affecting manatees, and to discuss the qualities of the species that make it a potential sentinel of marine ecosystem health.

Unique Marine Mammal Species

Manatees are obligate herbivores that are low on the food chain, contrary to other potential marine vertebrate sentinel species. They feed on a wide variety of both freshwater and saltwater plants, consuming up to 10% of their body weight per day. Except for Florida, insufficient data exist on population size, birth rates, causes of mortality, seasonal distribution, and habitat requirements for the species worldwide (Reynolds and Odell, 1991). Despite reaching the massive size of 1200 kg in weight and 3.5 m in length (Walsh and Bossart, 1999), manatees are gentle, inconspicuous, and shy creatures. They reach sexual maturity between 6 and 10 years of age, have a 20-month gestation period, and calve every 2–5 years (Reynolds and Odell, 1991). Consequently, the slightest changes to either morbidity or fecundity will have dramatic effects on the long-term survival of the population (Marmontel et al., 1997). Additionally, impacts due to human-related mortality are extremely high in some regions, resulting in a low reproduction rate (Rathbun et al., 1995). If current reproductive rate and survival estimates are correct for some areas, then the prognosis for a healthy, sustainable population is poor (Langtimm et al., 1998; O'Shea et al., 2001).

The species is vigorously studied in Florida, with research concentrating on distribution and movement patterns, feeding, habitat status, physiology and functional morphology, and captive husbandry. Throughout all of this work is the superseding concern for the survival of the species. Causes of manatee deaths have been well documented (Buergelt et al., 1984; O'Shea et al., 1985), with recent records indicating an alarming increase in mortality numbers, although actual rates are unknown (Ackerman et al., 1995). In 2000, 273 manatees died in Florida's waterways (Fig. 1). Mortality has occurred on several fronts: direct human-related causes primarily result from collisions with water vessels. Human and natural causes of mortality for the Florida manatee are summarized in Figure 2. Natural causes include exposure to low temperatures in winter, resulting in metabolic drain and hypothermia; harmful algal blooms due to lethal red tide outbreaks; and anthropogenic maladies, such as possible exposure to environmental contaminants (O'Shea et al., 1991; Bossart et al., 1998; FFWCC, 2003, Wright et al., 2002).

Canaries in the Mineshaft?

Manatees may not be ideal sentinels, as they are robust, long-lived species, and appear remarkably resilient to natural disease and the effects of human-related injury and trauma. These characteristics may be the result of an efficient and responsive immune system compared to other

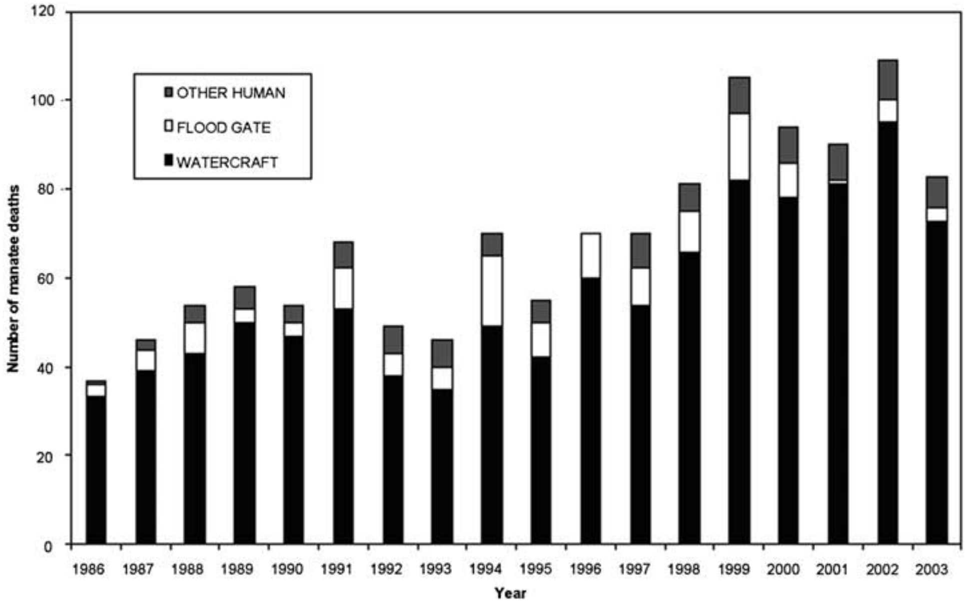

Figure 1. Number of human-related Florida manatee (*Trichechus manatus latirostris*) deaths per year (total 1239), 1986–2003 (source: Florida Marine Research Institute).

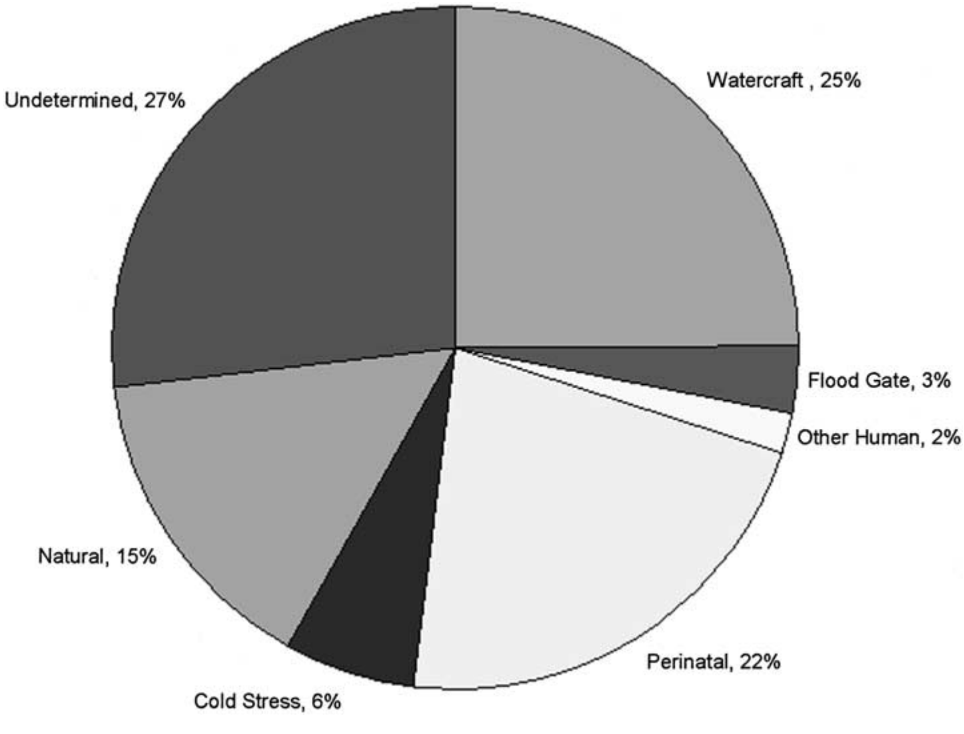

Figure 2. Causes of mortality of the Florida manatee (*Trichechus manatus latirostris*) based on 4058 necropsies, 1986–2003 (source: Florida Marine Research Institute).

marine mammals (Bossart, 1999). Investigations of the infectious disease of manatees are relatively recent. Antibodies to some infectious agents have been found in wild and captive Florida manatees, including porpoise and dolphin morbilliviruses, pseudorabies virus, San Miguel sea lion virus type 1, and several equine encephalitis viruses (Duignan et al., 1995; Geraci et al., 1999). No evidence of clinical disease to any of these agents has been demonstrated.

Although relatively immune to infectious agents, manatees face other potentially serious threats, including epizootic diseases and pollution while in large aggregations (O'Shea et al., 1991; Bossart et al., 1998). Three organochlorines, six metals, 48 species of bacteria, 2 fungi, 3 protozoans, 4 trematodes, 2 nematodes, 1 cestode, and 15 ectoparasites, copepods, barnacles, and assocites have been documented in the Florida manatee, and some have been directly associated with morbidity and mortality (Forrester, 1992). Manatees often aggregate in warm water or feed together in large, massive sea grass beds where contagious disease can spread rapidly, potentially devastating a population. Manatees that are environmentally stressed are known to be immunologically suppressed and susceptible to pathogens, as was recently reported with an outbreak involving papillomavirus in Florida (Bossart et al., 2002b).

Sentinels of Harmful Algal Blooms

Manatees can serve as excellent sentinels of harmful algal blooms due to their high sensitivity (Trainer and Baden, 1999). Manatees succumb relatively quickly to marine toxic algal blooms. Brevetoxin toxicosis, a condition produced by the dinoflagellate *Karenia brevis*, has been identified as an important cause of mortality in Florida manatees (O'Shea et al., 1991; Bossart et al., 1998, 2002a). At least two die-offs of Florida manatees have been attributed to this toxin. In 1982, almost 40 manatees were found dead and many moribund animals were found with neurological signs. In 1996, approximately 150 manatees died in an epizootic along the southwest coast of Florida. Severe nasopharyngeal and pulmonary lesions were present in all cases, suggesting inhalation as the primary route of exposure (Bossart et al., 1998, 2002a).

An immunohistochemical technique to test for dinoflagellate toxins has recently been developed (Bossart et al., 1998), thus increasing the utility of the manatee as a sentinel of toxic algal blooms. This test, along with the manatee's high sensitivity to algal toxins, made possible for the first time the determination of the presence, abundance, and distribution of brevetoxin in animal tissues. Also, the utilization of this technology confirmed a type of consumption coagulopathy during the 1996 unusual mortality event and during a smaller die-off that occurred in 2000 (Bossart, 2001). The manatee may be a good sentinel species for coastal ecosystems during red tide events. Scientists, however, must determine if the manatee is the most accurate sentinel to systematically alert professionals to these threats that may affect both wildlife and human populations.

Sentinels of Environmental Contaminants

Due to their benthic habits, manatees come in direct contact with sediments that could be laced with contaminants. Specifically, copper-based herbicides used to control aquatic vegetation as well as run-off from agricultural fertilizers and pesticides may contaminate manatee feeding habitats. Florida currently has large expanses of agricultural land near wetlands and rivers where contamination of waterways is highly probable. Pollution can also indirectly affect manatees by reducing their food source and thereby reducing reproduction, causing nutritional stress, and promoting shifts in population distribution. A decrease of seagrasses by 80% in Tampa Bay, for example, has reduced the carrying capacity of manatees in the region. Only during the past few years have seagrasses begun to increase their coverage of the bay, resulting from a clean up and an improvement in water clarity. Additionally, manatee numbers in the area appear to be increasing (Wright et al., 2002). Changes in water quality and the health of seagrass beds may affect a manatee population, as well as the populations of organisms coexisting in the habitat. It is therefore evident that pollution and development that can adversely affect seagrass beds or freshwater vegetation will also have an impact on manatee populations. Declines in their food source are apparent within a season and may alert conservationists to possible effects on other species that are also dependent on these rich stands of vegetation.

Other sources of pollution in the marine ecosystem can be generally attributed to marine vessels and associated cargo, fuel spillage, bottom paint, boat sewage, coastal industrial facilities, and municipal waste. Marine vessels discharge many types of waste into the waterways, including fuels and solvents. The bottom paints used on some vessels contain chemical constituents that are toxic to many marine organisms, and manatees are often seen rubbing or even mouthing the bottom of boats. Discarded trash is also the source of manatee entanglements, or may induce ingestion of foreign objects that cause digestive blockages (Beck and Barros, 1991).

Attracted to industrial effluents by the increased water temperature, manatees are potentially exposed to numerous toxins (O'Shea et al., 1984). Municipal outfalls can also contain endocrine disruptive agents, coliforms, and a variety of potential pathogens. Analyses of manatee tissues have already established baseline levels for a broad series of contaminants. Tests were performed on 45 tissues recovered from stranded carcasses using combined gas chromatography-mass spectrometry for a variety of chlorinated hydrocarbons (Ames and Van Vleet, 1996). Pesticides including o,p-DDT, o,p-DDD, hexachlorobenzene, and lindane were detected in liver, kidney, and blubber. However, due to their low frequency, concentrations could not be related to age, sex, length, or geographical location.

Although the risk of exposure to heavy metals and organochlorines is high in some urban or intensively agricultural areas, manatees occupy a position low on the food chain and current known exposure to the most prevalent contaminants is rather low. However, in one case, contaminated water was thought to be the route of exposure for the infection of a manatee with *Toxoplasma gondii*, resulting in meningoencephalitis (Buergelt and Bonde, 1983).

Manatees in Other Countries

The most pressing problem in the effective management and conservation of the West Indian manatee is perhaps mortality due to human activities. For example, 90 manatee strandings in Puerto Rico were recovered from 1990 through 1995. Patterns of mortality, including type of event, condition of carcasses, spatial and temporal distribution, gender, size/age class, and the cause of death were determined. Most identified causes of death were due to human interaction, especially captures and watercraft collisions. Natural causes usually involved dependent calves. A reduction in anthropogenic mortality of this endangered species in Florida and other countries can be accomplished only through education, proactive management, and a regional conservation plan that includes law enforcement, mortality assessment, scientific research, rescue and rehabilitation, and interagency cooperation (Mignucci-Giannoni et al., 2000).

Data indicate that manatees are threatened by hunting, an increase in boat traffic, associated in part to an increase in ecotourism, and environmental degradation associated with the clearing of tropical forest for commercial banana plantations, logging, and cattle ranching in Costa Rica (Smethurst and Nietschmann, 1999). The Amazonian manatee faces an even grimmer future. For example, in Peru, the species has been legally protected since 1973; however, exploitation for local consumption of meat has continued without any restrictions (Reeves et al., 1996). Surveys in Ecuador identified manatees only from blackwater habitats in undisturbed, primary, lowland rainforest. Manatees were abundant only at one locality, Laguna Lagarto Cocha. However, this population was actively hunted and the meat sold to the local military outposts. It was estimated that if that level of harvest continued unabated, Amazonian manatees would be extinct within a few years in Ecuador (Timm et al., 1986). If human activities are not managed to reduce their impact on manatees, the species will be extirpated throughout an ever-greater percentage of its range.

Manatees as a Sentinel Species

The current minimum estimate of the Florida manatee population is about 3300, based on an aerial survey conducted in January 2001 when 3276 manatees were counted (FFWCC, 2002). However, there is not sufficient information to quantify historical population trends and overall population dynamics. Genetic data using microsatellites suggest that manatees in Florida have gone through a recent bottleneck event (Garcia-Rodriguez, 2000). The lack of heterozygosity may result in animals displaying immunological depression or lower reproductive success. This endangered species is subject to continually increasing threats as it grapples to compete with a rapidly growing human population. Habitat is being lost at an alarming rate and the full effects of uncontrolled human population growth on this species are unknown. The manatee may serve as a sentinel species, prognosticating deleterious effects to humans of unhealthy marine and aquatic ecosystems.

Tourism in Florida is a major industry continuing to be a threat to manatees (O'Shea, 1995). Coupled with this increase in tourism is greater waterborne recreation, more boats occupying fragile habitat, and the associated pollution (O'Shea et al., 2001). As an example, last year in Crystal River in northwest Florida, more than 70,000 people came to swim with manatees (Sorice, 2001). Large numbers of humans donning masks, fins, and snorkels converged onto the winter aggregation areas in hope of connecting with wild manatees on a one-to-one basis. However, little is known about the potential impact of this form of wildlife observation on the population. In this case, swimming with wild manatees is viewed as a resource to educate the public about manatees and the unique regional habitat and ample biodiversity that enriches the Gulf Coast of Florida. Possible water pollution and destruction of seagrass beds may inevitably outweigh the benefits of ecotourism.

There is a concerted effort to recover and examine all reported manatee carcasses throughout the State of Florida. Florida Fish and Wildlife Conservation Commission (FFWCC) researchers following a standardized and detailed necropsy protocol (Bonde et al., 1983) examine each carcass. Thousands of tissue samples have been collected and archived for more than two decades. Therefore, there currently exists a wealth of historical data and samples available from federal and state wildlife agencies that can be used retrospectively for comparative analyses. The vast knowledge about distribution and movement of manatees is the foundation for a well-based sentinel species program.

Monitoring and Health Assessment

Long-term monitoring and health assessment studies are key factors to characterize a species as a sentinel of marine ecosystem health. Radio-telemetry studies of manatees in Florida have been ongoing for over 25 years, thus making the manatee the most successfully tracked marine mammal to date (Deutsch et al., 1998). Scientists have learned that most individuals have specific seasonal site fidelity. Some have home ranges within a few miles of their over-wintering site, whereas others travel the entire coastline, migrating in excess of 500 miles. These movements are often made in response to changes in water temperature, as well as food preferences, freshwater availability, and social behavior.

A computerized catalog of photographs of manatees with unique scars and features has enabled scientists to monitor the movements and site fidelity of individuals throughout their range (Beck and Reid, 1995). Over 2,000 individual manatees are recognized and monitored with this system. Work initiated more than 30 years ago is included in the database. Additionally, all manatees captured in the wild are now fitted with passive integrated transponder (PIT) chips and freeze-branded for future identification if scars are not present. Development and application of these technologies for mark recapture assessment, coupled with recent advances in molecular genetics work, are providing information on current population status and trends (Langtimm et al., 1998; Garcia-Rodriguez et al., 1998; O'Shea et al., 2001).

Complete health assessments are also conducted on Florida manatees whenever possible (Walsh and Bossart, 1999). Also, relatively pristine populations are being monitored on a long-term basis. Manatees in Southern Lagoon, Belize have been monitored for several years (Aguirre et al., 2002a; Bonde et al., 2001, 2002; Powell et al., 2001). Multiple recaptures have provided the basis for obtaining a series of "snapshots" of individuals, which in turn will furnish the epidemiological information to make inferences at the population level. Researchers have been able to determine condition, health, seasonality, and environmental changes over time. Manatee population data can then be compared to data regarding water temperature and seagrass bed cover changes to determine how this species can signal a decrease in ecosystem health (Axis-Arroyo et al., 1998). If several populations or species are monitored with this intensity, then researchers will obtain a picture of the health of an ecosystem or region. This proactive approach may also provide a basis for monitoring emerging diseases, new pollutants, or other anthropogenic influences in an ecosystem (Aguirre et al., 2002b).

Conclusions

The single species approach may provide a series of "snap shots" of environmental changes to determine if animal, human, or ecosystem health may be affected. Manatees are good integrators of changes over space and time and could serve as sentinels of ecosystem health. By moving in and out of infected or polluted areas, or both, they can spread pathogens and contaminants geographically as well as throughout the food chain. The sentinel species concept can be useful for providing an "early warning" system of emerging diseases or for monitoring the course of disease-related activities requiring prevention, remediation, or control. We have identified a number of critical research needs and opportunities for transdisciplinary collaboration that could help advance the use of sentinel species in ecosystem health, and the monitoring of disease emergence, using our knowledge of these magnificent sirenians.

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