Aquatic Mammals 2016, *42*(3), 376-391, DOI 10.1578/AM.42.3.2016.376

Twenty-Six Years of Post-Release Monitoring of Florida Manatees (*Trichechus manatus latirostris*): Evaluation of a Cooperative Rehabilitation Program

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Abstract

The rescue, rehabilitation, and release of Florida manatees (*Trichechus manatus latirostris*) into the wild has occurred since 1974; however, a comprehensive evaluation of the outcomes of the releases has never been conducted. Herein, we examined data for 136 Florida manatees that were rehabilitated and released with telemetry tags between 1988 and 2013 to determine release outcome of each individual as either success (acclimation) or failure after at least 1 y. Ten predictor variables were statistically evaluated for potential relationships to release outcome. To assess the contribution of each predictor variable to release outcome, each variable was tested for significance in univariate analyses. Manatees born in captivity experienced poor success after release (14%), whereas the overall success of wild-born individuals was higher (72%). When compared with other variables in our dataset, number of days in captivity was the strongest predictor for determining success. Manatees rescued as calves and held in captivity for more than 5 y had a high likelihood of failure, while subadults and adults had a high likelihood of success, regardless of the amount of time spent in captivity. Ensuring the success of individual manatees after release is critical for evaluating the contribution of the manatee rehabilitation program to the growth of the wild population.

Key Words: rehabilitation, manatee, *Trichechus manatus latirostris,* monitoring, captive, post-release, telemetry

Introduction

Beginning in the 1960s with the rise of environmental awareness and the increase in human impacts on ecosystems, many wildlife rescue, rehabilitation, and release programs were established for aquatic, terrestrial, and avian species with high conservation interest (International Union for Conservation of Nature [IUCN], 1998; Measures, 2004; Quakenbush et al., 2009; Whaley & Brokowski, 2009). Several of these rehabilitation/release programs have made significant contributions in species biology, veterinary medicine, habitat use, behavior, and management (e.g., Odell, 1983, 1984; Ludwig & Mikolajczak, 1984; Clumpner & Wasserman, 1991; Reijnders et al., 1996; Convy & Zaremba, 1998; Moore et al., 2007; Norris et al., 2011). The word *rehabilitation*, though broad in nature, may be defined as an attempt to return an animal to full health or to an independent functional condition for survival in the wild, where it may biologically contribute to the wild population after release (Measures, 2004; Moore et al., 2007). Despite efforts to ensure the greatest chance of adaptation and survival after release, without post-release monitoring, the fate of a released animal is usually unknown (Hohn & Wilkinson, 1996).

In the United States, marine mammal rehabilitation programs have been underway and regulated through legislation for more than 40 y (Moore et al., 2007; Whaley & Brokowski, 2009). Although these programs are highly visible and contribute significantly to public outreach and education, their operation is time-consuming and often involves the expenditure of significant resources to obtain information on an individual animal level, with limited insight for the species at a population level. Further, some marine mammal rehabilitation programs have been critically reviewed as to success, efficacy, and overall benefit to wild populations given their limited resources (Reynolds & Odell, 1991; Le Boeuf, 1996; St. Aubin et al., 1996; Malakoff, 2001; Perrin & Geraci, 2002). For more than 20 y, such scrutiny has encouraged scientists and managers to increase efforts for post-release monitoring through the use of various marking or tracking techniques, including the use of flipper tags, color markings, head tags, photo-identification, microchip identification, conventional and satellite-linked radio-tags, and periodic observations to evaluate animal survival, body condition, and overall program success (e.g., Irvine & Scott, 1984; Mate et al., 1994; Deutsch et al., 1998; Wells et al., 1998; Wells, 1999; Lander et al., 2001; Vincent et al., 2002).

The West Indian manatee (*Trichechus manatus*) is listed as endangered in the U.S. and is federally protected under the Endangered Species Act of 1973 and the Marine Mammal Protection Act of 1972, as amended. The U.S. Fish and Wildlife Service (USFWS) has the federal management authority for this species, including the responsibility for recovery. Beginning in 1973, injured and distressed manatees were rescued or provided assistance within Florida. Eventually, the program was formalized into the Manatee Rescue, Rehabilitation, and Release Program, with the participation of U.S. local, state, and federal governmental agencies; nonprofit organizations; academic institutions; and oceanaria, with all activities closely managed by the USFWS. In 2012, the program became the Manatee Rescue/Rehabilitation Partnership (MRP) and is self-governed by member agencies and organizations, with permitting and oversight by the USFWS. With an increase in the Florida manatee population in recent decades (Craig & Reynolds, 2004), there has been an increase in the number of rescues in the southeastern U.S. (USFWS, 2014). Rescue techniques, captive care information, and tagging/monitoring methodologies used by the MRP have helped to establish similar programs for West Indian and Amazonian manatees (*T. inunguis*) in other countries, primarily in Central and South America (Adimey et al., 2012).

Manatees are rescued for many reasons, including injury from collisions with watercraft, entanglement in or ingestion of fishing gear, illness resulting from respiratory and gastric tract complications, active disease processes, exposure to red tide toxins, cold stress syndrome, entrapment in water control structures, displacement from their traditional range, and becoming orphaned (Buergelt et al., 1984; O'Shea et al., 1985; Bossart et al., 1998, 2002, 2004; Lightsey et al., 2006; Bonde et al., 2012a; Adimey et al., 2014). As the number of rescues per year surpassed 50, pressure to release manatees back into the wild greatly increased. Advances in medical care, facility-assisted husbandry techniques, and provision of nutritional needs resulted in improved prognosis and treatment of captive individuals. Critical care facilities often reach capacity, increasing pressure on the system to release healthy manatees back into the environment as soon as practicable and safe for the animal.

The Florida manatee (*T. m. latirostris*) is an excellent example of a marine mammal with a sustained rehabilitation program. From 1973 through 2014, with extensive management and partner coordination, this program rescued 1,619 manatees, which included those individuals brought into captivity as well as those assisted and released on site (USFWS, 2014). After successful rehabilitation through the program, 526 Florida manatees have been released (USFWS, 2014). However, there have been very few published findings on the rescue, rehabilitation, and release of manatees worldwide (e.g., Lima et al., 2005; Reep & Bonde, 2006; Adimey et al., 2012; Luna et al., 2012; Lima & Passavante, 2013; Normande et al., 2015). In this paper, we compile and review data for 136 Florida manatees that were born in captivity or rescued in the wild. After rehabilitation, many of these individuals were suspected to have difficulty responding to challenges faced in the wild and, therefore, were selected to be monitored upon release with telemetry tags. These tagged manatees were released and monitored between 1988 and 2013. For all tagged individuals, we determined survival probability based on at least 1 y of monitoring. Statistical evidence is presented to identify potential relationships between predictor variables and the probability of a manatee being successful after release.

Methods

Release Planning

In an effort to release Florida manatees as soon as feasible, the MRP developed individual manatee release plans that include specific criteria for medical clearance, site selection of release, and logistics. In addition, a detailed monitoring schedule was prepared for those manatees released with telemetry devices. Initial post-release monitoring efforts were focused on individuals believed to have a high chance for acclimation to the wild (i.e., rescued adults held in captivity for short periods of time) and in areas where telemetry studies of wild manatees were already being conducted (Bonde, 1998; Weigle et al., 2001; Deutsch et al., 2003; U.S. Geological Survey [USGS], 2014). As a result, rehabilitated manatees were released near their rescue location, likely former range, or assumed genetic subpopulation during warmer periods of the year when exposure to cold was not a threat. Post-release, out-of-water health assessments performed at standardized intervals were not implemented until 1996; however, field researchers visually monitored each manatee at least weekly.

As biologists gained a greater understanding of habitat use and the acclimation of released manatees, more challenging cases, such as naïve individuals (i.e., manatees known or thought to have little experience in the wild) and those that had been held in captivity for long periods, were released and monitored through telemetry efforts. Survival (especially through winter), local movements and seasonal migration patterns, consumption of fresh water and appropriate food, interactions with conspecifics, and, ultimately, reproductive contributions to the wild population were of particular interest for the study. In 2000, to help imprint naïve manatees to a reliable over-wintering site, the timing of release was adjusted from the warmer months to the middle or end of winter at known warm-water aggregation sites, preferably non-industrial sites such as springs or passive thermal refugia (i.e., artificial canals, basins, and natural deep water sites with no major source of warm-water influx that provide water warmer than that of ambient temperature; Stith et al., 2011).

Marking and Tagging Individuals

To assist with future identification, individuals with scars and natural markings were photographed before release to document their identifiable features for inclusion in the *Manatee Individual Photo-identification System* (MIPS), a cataloging system for individual Florida manatees that includes their sighting histories (Beck & Reid, 1995; Langtimm et al., 2004; Beck & Clark, 2012). In some cases, a freeze brand was applied to individuals that did not have unique scars or markings to facilitate re-identification (Irvine & Scott, 1984). Beginning in 1993, all rehabilitated manatees were implanted with two passive integrated transponder (PIT) tags prior to release in order to enable future identification when recaptured or recovered dead (Wright et al., 1998).

At release, selected individuals were equipped with tracking gear that conformed to standard construction and deployment protocols developed by the U.S. Geological Survey (USGS) Sirenia Project and the Florida Fish and Wildlife Conservation Commission (FWC) (Reid et al., 1995; Deutsch et al., 1998; Weigle et al., 2001). The tracking gear consisted of a padded belt fit snuggly around the manatee's peduncle at the base of the tail (Figure 1). A buckle on the belt enabled a variable fit within different belt size classes and provided an attachment point for the floating tethered tag. The belt also included an ultrasonic beacon to assist with field tracking. A buoyant tag was attached to the belt via a 1.2- to 1.5-m-long flexible nylon tether, allowing the transmission and reception of radio signals when the manatee was at depths less than 1.5 m (Deutsch et al., 1998; Lander et al., 2001; Weigle et al., 2001). A variety of telemetry tags were used over the years, including VHF-only tags that required extensive field monitoring, satellite-linked PTTs (platform transmitter terminals) that provided Argos locations day and night, and satellite-linked GPS tags that allowed for greater location accuracy and environmental data collection (Deutsch et al., 1998; Marmontel et al., 2012).

Since 2002, with the exception of three individuals (included in our analyses) with atypical case histories, all manatees chosen for post-release tracking were considered "high risk" based upon one or more criteria: small size at rescue, birth in captivity, and/or held in captivity for a long length of time. Manatees rescued at a small size or born in captivity were considered naïve and were fitted with telemetry tags upon release due to concerns about their limited or lack of experience in the wild. Manatees held in captivity for > 5 y, regardless of size at rescue, were also tagged at release due to concerns regarding their ability to adapt to the wild after such a lengthy period in captivity.

The loss of telemetry tags during the monitoring period often hampered determination of release outcome. In circumstances in which only the tethered tag was lost, a belt-mounted VHF transmitter (in freshwater systems only) or ultrasonic beacon allowed for relocation and subsequent retagging of some individuals. Uniquely scarred individuals and those with freeze brands were occasionally identified in the field and retagged, if possible. Aerial reconnaissance, boat searches, and media advisories were used to assist with relocating "missing" individuals. Efforts were made to monitor tagged individuals for a minimum of 1 y after release; if after that time a manatee was deemed to have acclimated to the wild, the telemetry gear

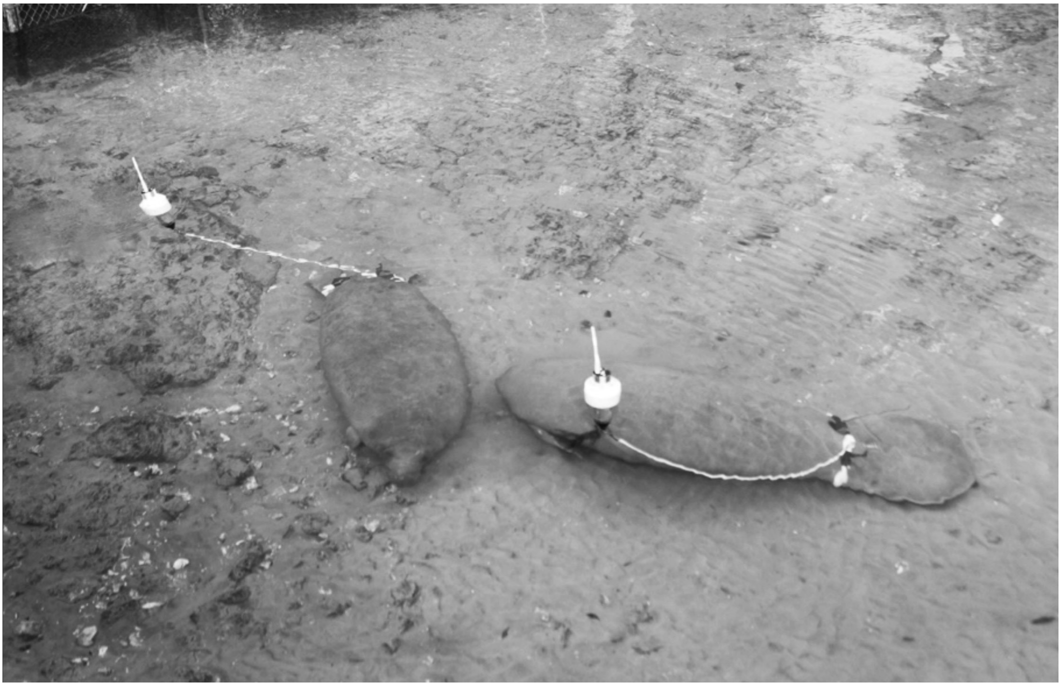

Figure 1. Two Florida manatees (*Trichechus manatus latirostris*) tagged with satellite-linked GPS tracking devices tethered to a padded belt secured around the individual's peduncle (Monica Ross, Sea to Shore Alliance, USFWS Permit #MA37808A-0)

was removed. If acclimation concerns were noted, tags remained on the manatee, and a new monitoring schedule was implemented.

Field Monitoring

Methodologies for behavioral monitoring of released manatees were initially developed based on wild manatee studies (Reid et al., 1995; Deutsch et al., 1998, 2003; Weigle et al., 2001). Manatees were observed in the field, generally from a boat, at a distance so that the target animal did not alter its behavior due to the presence of the observer. Abnormal behaviors, inappropriate habitat use, excessive interactions with humans, and/or poor body condition were indicators used to determine if intervention (relocation to a more appropriate habitat) or rescue was necessary. Visual observations ranged from 30 min per week to 90 min twice a week.

From 1996 to 2008, routine out-of-water assessments were conducted three times within 13 mo of release of the individual to assist in monitoring the health of the tagged manatees. Manatees were captured either by a land- or boat-based net set, and a detailed health assessment was conducted on site (Weigle et al., 2001; Bonde et al., 2012b; Stamper & Bonde, 2012). These examinations typically included the measurement of total body weight, morphometrics, dorsal blubber thicknesses (via ultrasound), heart and respiration rates, and oral temperature; the collection of blood samples; and an overall body condition assessment (Stamper & Bonde, 2012; Wong et al., 2012). Individuals appearing in good physical condition and receiving a passing health exam were returned to the wild for continued monitoring. Individuals with health/acclimation concerns were returned to captivity for supportive care and preparation for subsequent rerelease. As monitoring experience increased and information was garnered from examinations, it became clear that routine health assessments were not always necessary (Ross et al., 2009). By 2009, health assessments were conducted only as necessary (e.g., poor body condition as described below, abnormal behavior, or poor use of quality habitat). To ensure that changes in body condition were documented over time, monthly in-water body condition assessments for each tagged manatee were conducted to assign a body condition score. The manatee body condition scoring system was based on clinical observations related to concavity of ventrum, roundness of dorsum, presence or absence of fat rolls and skin folds along the body, and overall body shape. Based on key points of comparison and using an assigned rating system of 1 to 5

(1 = emaciated to 5 = fat), an estimated value was assigned to rank overall appearance of the body condition of an individual manatee. Veterinarians use similar systems to assess livestock, dogs, and cats (Baldwin et al., 2010).

Data Categories

The initial analysis included 136 manatees released in Florida between 1988 and 2013 that were fitted with telemetry tags. Cause of rescue was divided into four categories: (1) human, (2) calf, (3) environmental, and (4) born in captivity (Table 1). The limited wild experience of manatees < 235 cm in length, including time spent learning from their mothers, was considered to be a contributing factor as to why young manatees in the calf category were rescued; however, other categories took precedence for individuals rescued at < 235 cm for human-related or environmental reasons, and they were placed into the applicable cause of rescue category. Manatees rescued as calves were further evaluated by comparing release outcome for those rescued at > 185 cm and < 185 cm. This length value was chosen based on discussions within the MRP where it was speculated that calves of a larger size (i.e., longer length) had survived at least one winter season in the wild while their smaller counterparts likely had not and, therefore, would have some wild experience upon their return to the wild. In addition, release outcome for calves rescued at > 175 cm and those < 175 cm were also compared based on previous work from O'Shea et al. (1985) in which manatees < 175 cm were considered still nutritionally dependent on their mothers.

Total body straight-line length (cm) was used to reflect life stage at rescue and release: calf (CA), < 235 cm; subadult (SU), 235 to 265 cm; and adult (AD), > 265 cm (Harvey et al., 2007, 2009; Bonde et al., 2012b). The length of time an individual was in captivity (i.e., *period in captivity*) was separated into four categories and calculated as the difference between the initial rescue and release dates, tabulated as the total number of days in captivity, and then converted to number of years. *Period in captivity* categories included < 1 y, 1 to 5 y, > 5 to 10 y, and > 10 y. In addition, the total number of days in captivity was log transformed to normalize the distribution for the predictor variable *log days in captivity*.

Six regions were identified to evaluate where manatees were released throughout the State of Florida (Table 1). Rescue and release locations were further assessed by county to determine whether those individuals rescued and released in the same county had a greater chance of success than those released in a different county from the one in which they were rescued.

Statistical Evaluation

Data from manatees released with telemetry tags were evaluated to determine which predictor variables correlated with the post-release fate of manatees as defined by three outcomes: (1) success, (2) failure, and (3) incomplete. After the initial release from captivity, some manatees needed further assistance either in the field (e.g., disentanglement) or additional medical attention (e.g., exposure to cold) requiring a return to captivity. Reasons for subsequent rescues included emaciation, entrapment in water control structures, exposure to cold, entanglement in fishing gear, and relocation from poor quality habitat. For those individuals rescued multiple times, only the first rescue event and release outcome were used for the regression analyses. Manatees were considered a success if they survived to 1 y post-release, occupied appropriate habitats, did not require additional rescue, and their physical body condition after 1 y did not warrant medical concerns upon visual sighting or after a health assessment. Those individuals that were lost within the first year of monitoring (e.g., tag loss or malfunction) but were sighted in appropriate habitat and in good physical condition after one or more years post-release were also considered a success. Individuals that lost their telemetry tags or had tag malfunctions and were never re-sighted were deemed an incomplete outcome. Animals that died during the first year due to causes other than acclimation (e.g., boat strike, red tide exposure) were also considered an incomplete outcome. Individuals were deemed a failure if they died within the first year due to maladaptive behavior (i.e., behaviors that caused emaciation, dehydration, or cold stress), did not receive a passing final health exam and required an additional monitoring period, and/or required intervention within the first year following release (e.g., the manatee was in unsuitable habitat for a period of time that resulted in reduced overall body condition, requiring a relocation or rescue).

The initial dataset contained 14 predictor variables; however, four variables were eliminated (i.e., *sex*, *receiving facility*, *longest holding facility*, and *total number rescues per individual*), resulting in ten that were used for the final dataset (Table 1). The variables tested in the regression analyses were (1) *days in captivity* (log_{10}), (2) *rescue year*, (3) *rescue length*, (4) *cause of rescue*, (5) *prior exposure to salinity of water at release site*, (6) *release year*, (7) *release length*, (8) *release region*, (9) *salinity of water at release site*, and (10) *same rescue and release county*. Based on the straight-line length of the individual, the *rescue* and *release length* predictor variables were initially put into one of the three

Table 1. The ten predictor variables tested in univariate analyses, including the parameter descriptions, category levels (for categorical variables), minimum to maximum ranges (for continuous variables), and p value results for individuals with complete outcomes ($n = 91$). Bold p values are significant.

Predictor variable	Parameter description	Category levels/ Min-max ranges	p value
Days in captivity (Log10)	Log transformed days in captivity from initial rescue until first release	1.46 to 4.04 (29 d to 30 y)	**0.0021**
Rescue length	Straight-line length of manatee at rescue	104 to 338 cm	**0.0069**
Cause of rescue	*Human-related:* Individuals rescued due to watercraft, entrapment, or entanglement injuries; *Calf:* Individuals < 235 cm in straight-line length rescued alone (orphaned) or with their mother; *Environmental:* Individuals rescued for exposure to red tide toxins or severe cold weather resulting in illness; and *Captive born:* Individuals born in captivity	Human-related ($n = 24$) Calf ($n = 40$) Environmental ($n = 27$) ——— Captive born ($n = 14$, not included in analysis)	0.0508
Prior exposure to type of water at release site	Was the manatee exposed in captivity to the same water type in which it was later released? *Types: Fresh:* < 5 parts per thousand (ppt); *Brackish 1:* 5 to 20 ppt; *Brackish 2:* 20 to 30 ppt; and *Salt:* > 30 ppt	Yes ($n = 73$) No ($n = 18$)	0.2793
Release length	Straight-line length of a manatee at release	228 to 360 cm	0.8461
Release region	*North Atlantic:* North of Stuart, including the St. Johns River north of Palatka; *South Atlantic:* South of Stuart, including the Florida Bay side of Everglades National Park and the Florida Keys; *Everglades:* Ten Thousand Islands south through Whitewater Bay; *Southwest:* Pasco County south to Marco Island and western Collier County; *Northwest:* Hernando County north through the panhandle to the Florida-Alabama line; and *Upper St. Johns River:* South of Palatka	North Atlantic (n =14) South Atlantic ($n = 12$) Everglades ($n = 11$) Southwest ($n = 22$) Northwest ($n = 12$) Upper St. Johns River ($n = 20$)	0.2829
Salinity of water at release site	What was the salinity category in which the manatee was released? *Types: Fresh:* < 5 ppt; *Brackish 1:* 5 to 20 ppt; *Brackish 2:* 20 to 30 ppt; and *Salt:* > 30 ppt	Fresh ($n = 36$) Brackish 1 ($n = 14$) Brackish 2 ($n = 31$) Salt ($n = 10$)	0.2723
Same rescue/ Release county	Was the manatee released in the same county in which it was rescued? Possible counties for rescue and release: Brevard, Broward, Charlotte, Citrus, Clay, Collier, Dade, Duval, Glades, Glynn (GA), Hillsborough, Lee, Manatee, Martin, Miami-Dade, Monroe, Nassau, Palm Beach, Pinellas, Sarasota, St. Lucie, and Volusia	Yes ($n = 38$) No ($n = 53$)	0.3822
Rescue year	The year in which the manatee was rescued for rehabilitation	1977-2011	0.5959
Release year	The year in which the rehabilitated manatee was released	1990-2013	0.3165

life stage categories: (1) CA, (2) SU, or (3) AD. Each life stage was evaluated for release outcome. Additional analyses of life stages were completed for each *period in captivity* to determine the percentage of manatees that successfully acclimated in the wild (Table 2).

Due to their naïveté, captive-born manatees face a different suite of challenges than wild-born manatees and, therefore, were evaluated separately. A Fisher's exact test was used to determine if the proportion of successful individuals was different in captive- vs wild-born manatees. Wild-born individuals with known post-release outcomes of success or failure were analyzed using *JMP*, Version 11 Pro, from Statistical Analysis System (SAS) Institute (2003).

Logistic regression was used to determine whether relationships existed between the suite of previously described predictor variables and release outcome. To assess the contribution of each

Table 2. The percentage of those manatees (*Trichechus manatus latirostris*) deemed to have successfully acclimated after release based on life stage at rescue and period in captivity. Results for calves are divided into captive-born (CB) and wild-born (WB) individuals. Number of individuals included in each period in captivity is shown in parentheses.

	Period in captivity				
Life stage at rescue	< 1 y	1 to 5 y	> 5 to 10 y	> 10 y	Total
Calf–CB (n = 14)	0% (1)	17% (6)	100% (1)	17% (6)	14%
Calf–WB (n = 66)	67% (3)	73% (49)	30% (10)	50% (4)	65%
SU (n = 7) + AD (n = 18) combined	90% (20)	100% (4)	0	100% (1)	92%
Total (excluding CB)	87% (23)	75% (53)	30% (10)	60% (5)	72%
Total (including CB)	83% (24)	69% (59)	36% (11)	25% (16)	65%

predictor variable to release outcome, each variable was first tested for significance in univariate analyses. Variables significant in univariate analyses ($p \leq 0.05$, Pearson's correlation for continuous variables and Pearson's X^2 test for categorical variables) were tested against each other for collinearity. Variables found to be significantly collinear ($p \leq 0.05$) were not included in the final model. Additionally, interaction terms between variables were tested for significant contributions to our model. Lastly, all noncorrelated variables in the dataset were added individually to our most significant model to test for an improved fit. Model selection was based on minimum corrected Akaike information criterion (AICc) values (Akaike, 1974; Hurvich & Tsai, 1989), where the final model had the smallest AICc value and parameter estimates were significant ($p \leq 0.05$) for every variable in the model. Positive coefficients represented a correlation between increases in a predictor variable and post-release rehabilitation failure, whereas negative coefficients represented a correlation between increases in a predictor variable and post-rehabilitation success. Receiver operating characteristic (ROC) curves were generated in *JMP* to measure the predictive ability of our model, and inverse predictions were generated for several probabilities.

Results

Descriptive Statistics

Data were compiled for 136 telemetry tagged manatees: 64 (47%) were female, and 72 (53%) were male. The minimum number of days held in captivity before initial release with a tag was 6 d, while the maximum number of days in captivity for an individual was 10,961 d (30 y). The minimum length at release was a 228-cm male, while the maximum length at release was a 360-cm female. The maximum number of consecutive tracking days for one individual was 1,192, and the minimum was 2 d before the telemetry tag detached and the manatee was missing.

In this study, 17 individuals were captive-born and 119 were wild-born. Three captive-born and 25 wild-born individuals had incomplete monitoring outcomes and were eliminated from the dataset. For individuals with known release outcomes (n = 108), captive-born (n = 14) manatees had a higher failure rate (0.857) than wild-born (n = 94) manatees (0.277). Results from a contingency analysis using a Fisher's exact test revealed a significant difference in failure rates ($p < 0.0001$). Due to this striking difference, captive-born individuals were not included in the regression analyses. Additionally, the distribution and 95% confidence intervals (CIs) of the *days in captivity* data revealed two individuals determined to be outliers based on their very short time in captivity (i.e., < 10 d); these individuals were then removed from the dataset (Figure 2). A manatee calf rescued and released with its mother was also eliminated from the dataset to avoid pseudoreplication. As a result, 91 manatees were included in the regression analyses of which 43 (47%) were females and 48 (53%) were males. Release outcomes were similar for both sexes, with females having 30 (70%) successes and males having 35 (73%). Based on straight-line body length, life stage at rescue for the dataset included 66 CA (72%), 7 SU (8%), and 18 AD (20%). The CA individuals were 39% female and 61% male, SU individuals were 86% female and 14% male, and the 18 AD individuals were 61% female and 39% male.

There were 137 independent rescue events for the 91 manatees included in the analyses. Although 22 (24%) of the 91 individuals required more than one rescue, only the initial rescue and release events were included in the logistic regression analyses. Twenty (91%) of the manatees needing additional rescues were initially rescued as calves. Ten manatees needed one additional rescue after their first release;

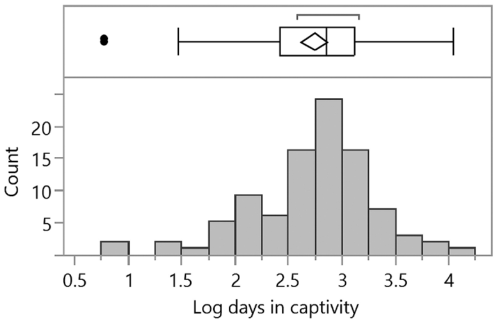

Figure 2. Distribution of the *log days in captivity* (DiC) parameter for wild-born tagged manatees (n = 94) with a Tukey outlier box plot revealing two individual manatee outliers (as shown by black points) at 0.78 DiC (or 6 d in captivity). As a result, the outlying individuals were removed from the sample prior to regression analyses. The vertical line within the box represents the overall median sample value (2.862 DiC), the confidence diamond within the box represents the mean (2.733 DiC) and the upper and lower 95% CI of the mean, the box represents the interquartile range between the 1st and 3rd quartiles (2.423 to 3.109 DiC), the whiskers extending off the box plot represent the maximum and minimum observations (not including the outliers), and the bracket above the box plot represents the shortest half or the most dense 50% of the observations.

three of these were deemed a success after 1 y of monitoring but required additional assistance after that mark. None of those individuals requiring two additional rescues (n = 6), three additional rescues (n = 4), and five additional rescues (n = 2) were determined to successfully acclimate to the wild within 1 y of their initial release. Sixty percent of the manatees held in captivity for > 5 y (n = 15) were rescued more than once after their initial release, whereas only 17% of those individuals in captivity < 5 y (n = 76) were rescued more than once.

The predictor variable *cause of rescue* had three categories: (1) calf (n = 40, 44%), (2) environmental (n = 25, 28%), and (3) human-related (n = 26, 28%). Sixty percent of the manatees in the calf category were categorized a success (n = 24). Manatees rescued for environmental reasons had an 88% success rate (n = 22), whereas human-related rescues had a 73% success rate (n = 19). The analysis for manatees rescued as CA (n = 66) found that individuals rescued at lengths of both < 185 (n = 43) and > 185 cm (n = 23) had a 65% success rate (p = 0.9934; Pearson's X^2 test). Further analysis of manatee calves rescued at lengths of < 175 cm (n = 41) reported a 63% successful outcome, and those rescued at lengths of >175 cm (n = 25) had a 68% successful outcome, with no significant difference in success rates (p = 0.7045; Pearson's X^2 test). Thirty-eight of 66 manatees in rehabilitation rescued as CA (58%) reached the size of an SU (> 235 to 265 cm), and 19 (29%) grew to AD size (> 265 cm) before being released back into the wild.

Evaluating *period in captivity* indicated that, overall, manatees held in captivity for < 5 y were mostly successful after release (n = 76, 79%). Of those manatees held in captivity for < 5 y and rescued as CA (n = 52), only 38 (73%) were a success as compared to those rescued as SU or AD (n = 24, 22 success, 92%); however, no significant difference was observed (p = 0.0646; Pearson's X^2 test). Of the manatees held in captivity for < 1 y (n = 23), 87% were deemed a success; however, the vast majority of these individuals were rescued as SU and AD (n = 20, 87%). Two of the three individuals rescued as CA and held in captivity for < 1 y were successful (Table 2). Seventy-five percent of those manatees with a *period in captivity* of 1 to 5 y (n = 53) had a successful outcome; the majority of these individuals were rescued in the CA life stage (n = 49, 92%). For individuals with a *period in captivity* > 5 y (n = 15), only 40% had successful outcomes; all but one of these individuals were rescued as a CA.

Logistic Regression

Two of the ten predictor variables were significant in univariate analyses: (1) *rescue length* (continuous, p = 0.0069, AICc = 105.7) and (2) *log days in captivity* (continuous, p < 0.0021, AICc = 103.6). These two significant predictor variables showed collinearity with one another: *rescue length* was negatively correlated with *log days in captivity* (R^2 = 0.50; p < 0.0001). Because of the collinearity between the two significant variables and lack of significant interactions, only one parameter was used in our regression model. The variable *log days in captivity* was selected based on the lower AICc value. There were no significant first-order interactions between the predictor variable for the logistic regression, *log days in captivity*, and the nine other variables (*rescue length*, *cause of rescue*, *rescue year*, *release year*, *release length*, *release region*, *same rescue and release county*, *salinity of water at release site*, and *prior exposure to salinity of water at release site*).

Each of the eight variables that were nonsignificant in univariate analyses were added to the model with *log days in captivity*, and AICc values were compared. None of the generated models had a lower AICc value than *log days in captivity*. Therefore, the logistic function of our final model was

$$\text{Logit}\ (P_F) = -5.40 + 1.55\ \text{DiC}$$

where P_F is the probability of post-release failure and *log days in captivity* (DiC) is $\log_{10}$ transformed days in captivity (Figure 3).

We tested the predictive ability of this model by generating an ROC curve and measuring the *area underneath the curve* (AUC). The ROC curve demonstrates the trade-off between sensitivity and specificity of the model or the relationship between true-positive and true-negative prediction rates. Values of AUC range from 0 to 1 where 1 indicates a perfectly predictive model, whereas an AUC of 0.5 indicates no predictive ability and generates a line that follows the diagonal of the grid (DeLong et al., 1988; Swets, 1988). The AUC for this model was 0.6962, indicating a good, predictive model (Figure 4).

Inverse prediction calculations estimate values of the independent variable (*log days in captivity*) using values of the response variable (P_F). Inverse prediction values of probability of failure after release (P_F) at 0.25, 0.50, and 0.75, along with 95% CI, were calculated for all manatees in our final dataset. Inverse predictions at the same probabilities (P_F = 0.25, 0.50, and 0.75) were calculated for calves and for subadults combined with adults (Table 3). The inverse prediction for the probability of 25% failure (P_F = 0.25) for all manatees (*n* = 91) was 1.54 y in captivity. For a 50% failure rate (P_F = 0.50), there was an increase to 7.9 y in captivity, while a 75% failure rate (P_F = 0.75) was calculated at 40.5 y in captivity (Figure 5).

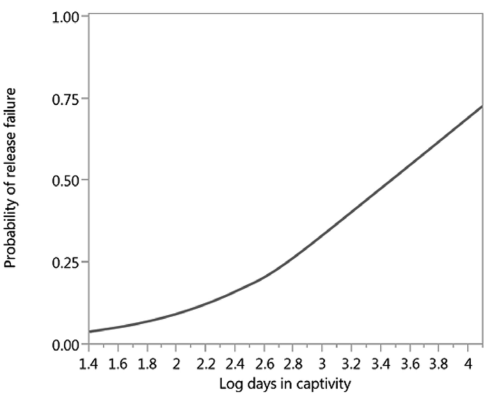

Figure 3. Results from the logistic regression of *log days in captivity* (DiC) and the probability of failure after release ($p < 0.0021$)

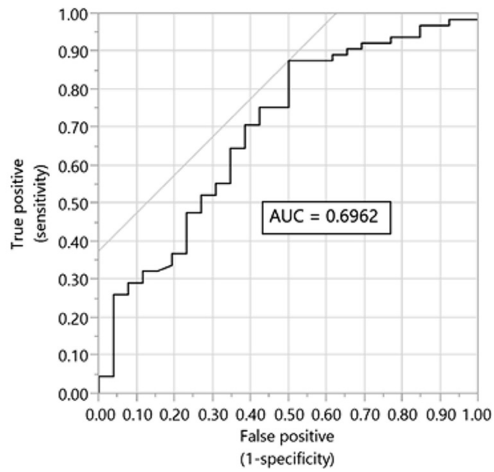

Figure 4. Receiver operating characteristic (ROC) plot, displaying the relationship between true positive (sensitivity) and false positive (1 – specificity) prediction rates for our logistic regression model (AUC = 0.6962). The optimal cut point is depicted by the light gray line, which lies tangential to the point in the ROC graph where the false positive rate is 0.50.

Table 3. Inverse prediction values and associated 95% confidence intervals (CI) of log days in captivity for three probabilities (0.25, 0.50, and 0.75) of failure (P_F); the predicted years in captivity are listed in parentheses. Inverse predictions were made for all manatees in the dataset for calves at rescue, and for subadults and adults at rescue.

	All manatees (*n* = 91)			Calves only (*n* = 66)	Subadults + adults only (*n* = 25)
Specified probability of failure (P_F)	Predicted log days in captivity (y)	Lower 95%	Upper 95%	Predicted log days in captivity (y)	Predicted log days in captivity (y)
0.25	2.75 (1.5)	2.05	3.08	2.36 (0.6)	2.66 (1.3)
0.50	3.46 (7.9)	3.12	4.86	3.86 (19.9)	2.95 (2.4)
0.75	4.17 (40.5)	3.60	7.23	5.35 (613.4)	3.24 (4.8)

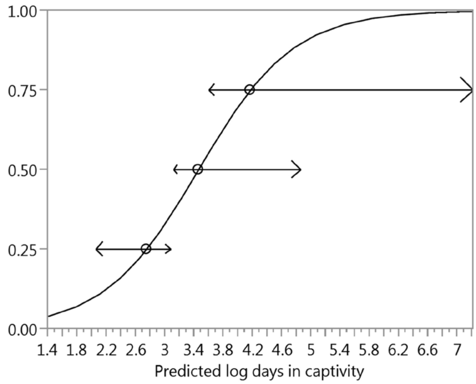

Figure 5. Inverse prediction plot for the probability of failure (P_F) after release at 25%, 50%, and 75% for all manatees in the dataset (n = 91); arrows represent 95% CI for predicted *log days in captivity* (DiC).

Discussion

Ten variables believed to have the greatest likelihood of predicting the outcome of acclimation for a released rehabilitated Florida manatee were analyzed. This analysis revealed that the length of time a manatee spent in captivity (as represented by *log days in captivity*) appears to be the strongest predictor for determining success. *Rescue length* also showed significant impacts on release outcome when modeled individually, with larger rescued animals experiencing higher success rates after rehabilitation and release. *Rescue length* and *days in captivity* were collinear; the smaller the manatee at rescue, the longer the period in captivity. As a result, long periods in captivity and lack of experience in the wild both play key roles in determining the likelihood of successful acclimation of released Florida manatees. These findings can assist facilities and managers with decisions regarding managed care and timing of releases.

In Florida, a manatee's early experience in the wild with its mother is crucial to successful adaptation after release from captivity. Only 14% of initially released captive-born manatees successfully adapt to wild conditions. Likewise, individuals that were orphaned (CA rescue category) also had greater difficulty successfully adapting after release (60% success) than individuals rescued for environmental or human-related causes (88% and 73% success, respectively). All of the failed releases in the environmental category and the majority of those in the human-related category were in the CA life stage at rescue (< 235 cm long). Limited wild experience is likely an additional factor influencing the rescue and release outcome for these individuals. Although there was no difference in either acclimation outcome for calves rescued at < 175 cm or > 175 cm or < 185 cm or > 185 cm regardless of the cause of the rescue, the data indicate that individuals rescued at smaller sizes (< 235 cm) will have more difficulty acclimating to the wild. This small size at rescue indicates that a limited amount or lack of time the manatee spent with its mother influences successful acclimation disproportionally. When manatees are small, important survival strategies, such as finding warm water, food, and fresh water for drinking are learned. Many of the manatees rescued in the CA life stage required multiple rescue events, also supporting the importance of previous wild experience on release outcome. While manatees needing multiple post-release rescues may not be deemed successful upon their initial release, the MRP continues to support these individuals with medical treatment and assistance until they are eventually successfully acclimated to life in the wild.

The amount of time a Florida manatee is held in captivity is also critical to a successful release. For manatees held < 5 y, 79% successfully acclimated after release (n = 76); while only 40% of manatees held > 5 y were similarly successful (n = 15). In addition to the difference in sample size, two factors need to be addressed. First, because every effort is made within the MRP to release manatees as soon as is feasible, there were few individuals held > 5 y in captivity for analysis in this study. Second, manatees must meet specific length and weight requirements prior to being eligible for release. As a result, only three individuals rescued as calves were released after being held in captivity for < 1 y. Florida manatees rescued as calves were the largest age class fitted with telemetry tags. This group biased the dataset due to the fact that later tagging efforts within the MRP focused on assessing the outcome of these individuals. All but one of the individuals held for > 5 y were rescued as a CA.

Despite these limitations, the overall success of individuals rescued as subadults and adults, regardless of the amount of time spent in captivity (92% were successful), further supports the difficulty individuals rescued as calves face when acclimating after release. The amount of time these inexperienced calves spend in captivity can further complicate that adaptation. Nearly three-quarters of the manatees rescued as calves that were held for < 5 y were successful, while nearly two-thirds of their cohorts held for > 5 y were unsuccessful. Of the four individuals that were held for > 10 y, the two that failed were very small (< 120 cm) at rescue, while the two that succeeded were somewhat larger (> 180 cm) and likely had some amount of time in the wild with their mothers. Small sample sizes for these size classes limit confidence in some categorical conclusions.

Determining an acceptable level of failure for a rehabilitation program is difficult. As reported herein, the inverse prediction probabilities of 25% failure after release (P_F) is approximately 1.5 y in captivity for all Florida manatees regardless of age class at rescue. Furthermore, the data clearly demonstrate that manatees have an increasing chance of failure to acclimate in the wild as their time in captivity increases past 2 y. As a result, manatees in captivity for less than 2 y appear to have a greater chance of success and a more acceptable failure rate (25%). Current practice within the MRP is to release manatees within 2 to 3 y of their rescue. MRP Release Guidelines (USFWS, 2010) for captive manatees require all individuals (with the exception of dependent calves released with their mothers) obtain a minimum weight (273 kg) and length (> 200 cm) prior to release. This was reflected in the data for which just over one quarter of those manatees rescued as calves remained in captivity until reaching adulthood (> 265 cm), while over half reached the size of a subadult (> 235 cm) before being released back into the wild.

The rationale for a minimum size at release is to ensure that the manatee can physically handle the tracking apparatus. Additionally, as is very important in Florida manatees, an increase in body mass will assist in the thermoregulatory heat conservation necessary for exposure to colder waters and ensure sufficient nutritional reserves (Worthy et al., 2000). These guidelines generally equate to 2 y that a manatee will be in captivity; however, manatees rescued at smaller sizes needing additional time to achieve the length and weight requirements and those individuals needing extended medical treatment may stay in captivity for longer periods of time.

Understanding the implications of holding manatees in captivity for longer periods of time and how that adversely impacts their outcome for success upon release is important when weighing factors that contribute to release plans for individuals. Florida manatees held in captivity for longer periods may need additional time and multiple opportunities to acclimate to life in the wild as suggested by previous assessments (Adimey et al., 2009; Normande et al., 2015). Other studies involving carnivores and hedgehogs have also shown that extended time in captivity can promote the suppression of instinctual behaviors (Brill & Friedl, 1993; Sainsbury et al., 1996; Molony et al., 2006; Jule et al., 2008) and increase susceptibility to stress-related medical issues, resulting in a reduced fertility and reproductive lifespan (Hermes et al., 2004; Jule et al., 2008). The data reported herein show the high percentage of successful outcomes for manatees held in captivity for < 5 y vs those held in captivity for > 5 y. Inverse prediction probabilities of the model further support holding manatees in captivity for < 2 y. Therefore, minimizing the length of time individuals remain in captivity, particularly those < 235 cm at rescue that are less experienced in the wild, should be strongly considered when weighing factors that may influence their potential for success.

Captive-born Florida manatees were excluded from the regression analyses because they biased the data toward failure, likely due to a complete lack of knowledge of the wild. All but two of the released captive-born manatees required intervention or died within the first year. Additionally, nearly half had been held in captivity for > 5 y. As shown with their wild-born cohorts, the naïve nature of these manatees, along with extended periods of time in captivity, likely contributed to the failed outcomes and suggests the difficulty of releasing this group of individuals without knowledge from their wild-experienced mothers.

Although the study results indicate more successful acclimation outcomes than those that failed, the proportion of successes, in reality, could have been calculated as higher or lower when considering that all manatees with incomplete outcomes were excluded from the analysis (n = 28; 25 wild-born and 3 captive-born). This approach is different from the recent tagging analysis of Antillean manatee (*T. m. manatus*) releases (Normande et al., 2015). While both studies were ultimately biased toward manatees that researchers suspected would have a greater challenge acclimating to life in the wild (e.g., individuals with limited wild experience), missing Antillean manatees (those not re-sighted after release) were considered successful if the carcasses were not recovered. In our study, however, these individuals were classified as incomplete and excluded from analyses. Regardless, both studies agree that the amount of time a manatee spends in captivity plays an important role in their release outcome.

Rehabilitation efforts will continue to grow as Florida manatee populations recover, putting more pressure on the limited resources of the captive care system and requiring release of manatees back into the wild in a timely manner. The intent of this study was to inform decision makers in the captive care program to improve selection of releasable manatees. This will provide the greatest opportunity for the long-term survival of released manatees and allow them to contribute to the overall population and recovery of the Florida manatee. Within the MRP, every effort is made to release a manatee as soon as feasible, which is usually within 2 to 3 y of rescue. We recommend this practice continue to avoid extended periods of time spent in captivity, except with those individuals possessing debilitating medical or physical conditions that preclude independent survival or for those that may negatively impact the wild population (e.g., active papilloma virus lesions). Based on our findings, manatees held in captivity for < 5 y have a high probability of successful acclimation into the wild without requiring subsequent intervention. Those held in captivity for > 5 y may require additional time, resources, and assistance to ensure successful acclimation after release. Furthermore, experience within the MRP has shown that those manatees rescued as orphans (< 235 cm) and those held in captivity for extended periods of time often require intervention or returns to captivity, in some cases multiple times, before their wild behavioral skills fully develop. This can only be achieved with an active monitoring program ensuring there are the necessary resources for success. Therefore, we suggest continuing the monitoring of "high risk" manatees for at least the first year as a prudent way to assess their adaptation to the wild. In addition, the two collinear predictor variables assessed in this study—*rescue length* and length of time spent in captivity (represented by *log days in captivity*)—should be evaluated when creating individual release plans for manatees that have been in captivity for > 2 y.

The MRP continues to evolve as a result of the number of manatees handled and knowledge gained from prior releases, which influence such program areas as rescue techniques, clinical practice, managed care and husbandry, prerelease preparation, development of release guidelines, and monitoring. This adaptive approach has enabled the MRP to refine operational protocols and guidelines, develop future initiatives and goals, and quantify the overall contribution of released manatees to the wild population (Sanders-Reed, 2005; Runge et al., 2007; Runge, 2013). Although the Florida manatees' chances for success may be slighter than for other manatees in warmer environments, the results and contributions of the MRP will continue to help guide manatee rescue and release programs in other countries. For example, in Guadeloupe, efforts are underway to reintroduce manatees back into the regional coastal waters where they were hunted to local extinction. Knowledge from the long-standing MRP in Florida has already assisted in the planning efforts for the Guadeloupe reintroduction initiative and will be valuable for its implementation.

Decisions regarding the release of captive manatees are complex. Many compounding variables come into play, and even the most well-intended recommendations may not be possible solutions for building a strong release program (Runge, 2013). Data generated from release programs are essential for assisting with complex management decisions (Sarrazin & Legendre, 2000). Ensuring the success of individual manatees after release, therefore, is critical for evaluating the contribution of the captive program to the growth of the wild population. Long-term monitoring is a way to assess survival of manatees after release and potentially determine their reproductive contribution to the population. In the broader context, if a manatee is unable to reproduce in the wild, it essentially serves no benefit to the population. Since the inception of MRP, hundreds of manatees have been rescued and released that might have died had intervention and care not been provided. Programs like the MRP are often high-profile, expensive, and scrutinized by research and conservation communities (Moore et al., 2007); however, if managed correctly and evaluated regularly, they can be effective at contributing to the wild population. Future studies assessing the reproductive contribution of those manatees released from captivity using genetics and field observations through MIPS may further support the continuation of the MRP to assist in manatee recovery efforts.

Acknowledgments

The authors would like to thank all the oceanaria facilities; local, state, and federal governmental agencies; not-for-profit organizations; academic institutions; and volunteers who have collaboratively worked to meet the goals of the Manatee Rehabilitation Program. Special thanks to the USGS Sirenia Project, the FWC Marine Mammal Program, and Sea to Shore Alliance for their stalwart dedication over the years to providing reliable and consistent data for assisting with manatee recovery objectives and ensuring a legacy that will help guide future efforts. We appreciate the critical reviews of this manuscript from Graham Worthy, Daniel Slone, Bland Crowder, Charles (Chip) Deutsch, Tom O'Shea, and Cathy Beck. Participants in the program were issued a Letter of Authorization for their work conducted under a federal wildlife research permit (MA-770191) issued to the USFWS Jacksonville Field Office. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government. The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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