

Understanding impacts of mitigation in waterway control systems on manatee deaths in Florida

Abstract

Marine conservation management faces constraints of time, funding and resources. Traditionally management has used expert opinion to guide actions, especially where empirical data is patchy or non-existent. Systems Behavior Charts (SBC) are presented as an alternative method for evaluating data to support decision making and test efficacy of actions. Florida manatees (*Trichechus manatus latirostris*) range over dispersed waterways, estuaries and coastlines in southeastern USA and suffer unnecessary deaths in manmade waterway controls such as floodgates and locks. The Manatee Pass Gates project aims to alleviate such deaths. Annual mortality data relating to floodgates and locks is analyzed using SBCs including standard deviation (SD) limits and moving range ($\bar{X}mR$) limits. $\bar{X}mR$ charts are shown to provide more stringent limits for detecting changes in heterogenous data commonly encountered in environmental systems. Systemic improvement achieved by the Manatee Pass Gates project is presented and an exceptional one-off bad year for manatee deaths is explored. Management responses to both situations are discussed and the power of the SBC method to diagnose and predict system behavior is demonstrated. SBC is also used to demonstrate the capability of a management system to improve ecological health or to improve the status relative to a specific threat. The study also demonstrates how SBC data can describe underlying improvements achieved by an intervention in measurable terms. The management thinking required to consider SBC insights and to test and improve interventions is a new skill set that is relevant to both conservation managers and scientists.

Keywords: conservation, decision-making, impact evaluation, lake Okeechobee, statistical process control

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Abbreviations: SBC, systems behavior chart; WWAA, warm water aggregation area; IMA, important manatee area; AIP, area of inadequate protection; SD, standard deviation; $\bar{X}mR$, Average Moving Range; mR , moving range; UL, upper limit; LL, lower limit; UNL, upper natural limit; LNL, lower natural limit; UWL, upper warning limit; LWL, lower warning limit; URL, upper range limit

Introduction

The wildlife conservation sector operates under time, financial and resource constraints and often in operationally challenging geographic settings. The prioritization of decisions and action is therefore crucial.¹ Practitioners tend to rely on either 'expert opinions',² or best-informed decisions in 'good faith' if data is patchy or absent.³ As an alternative to this, System Behavior Charts (SBC) offer a better way to understand even small, patchy datasets to manage threats effectively.^{4,5}

SBCs are visual statistical tools derived from industrial Shewhart control charts⁶ to examine the behavior of ecosystems from longitudinal representation of data. SBCs have the advantage of differentiating changes due the 'noise' of a system (i.e. predictable variation in data) from exceptional 'signals' due to assignable causes.⁷ Failure to identify the difference leads to ineffective misappropriation of resources leading to, at best, ineffective interventions or, at worst, exacerbating the problem. SBCs allow detection of signals that may otherwise be missed in data tables, plots or histograms.⁸ SBCs prompt questions to improve decision-making.⁷ Human-wildlife conflict scenarios involve many different variables,⁹ but analysis of data variation using SBCs enables practitioners to identify and rationalize

unknown influences on the system.¹⁰ SBCs offer the opportunity to evaluate one or more of these variables as a surrogate for overall system performance and decide upon timely operational changes, which can be studied, modified and improved.⁸

The Florida manatee (*Trichechus manatus latirostris*) inhabits coastal waters, estuaries and waterways of southwestern United States and the Caribbean.¹¹ Despite human development along these waterways, the manatee population has grown since the 1970s.¹² The US Federal government listed the manatee as an endangered species in 1967, and active protection followed with the passing of the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973.¹³ Some waterways and coastal localities provide critical habitats significant to the species, especially designated 'Warm Water Aggregation Areas' (WWAA) where artificial or natural warm water discharges attract increased densities of manatees, and 'Important Manatee Areas' (IMA) which are heavily utilized for feeding, transiting, mating, calving, nursing or resting.¹⁴ WWAAs and IMAs may include federally-designated manatee sanctuaries or seasonal protection zones.¹⁴

Causes of manatee mortality in USFWS data from 1974-2012 include watercraft collision (22.5%), perinatal-related (20.1%), other natural (13.5%), cold stress (9.8%) and deaths in canals/locks (2.4%), with the remaining 26% of deaths unascertained or undeterminable.¹⁵ Previous studies have examined watercraft collisions,^{4,8} however deaths in floodgates/locks remains the second most significant human-induced factor, and therefore important for further examination. Manatees follow boats through canal locks and floodgates during

normal transit around inland waterways¹⁵ and their slow swim speed means they risk being caught in closing barriers and subsequently being crushed or drowned. Causal classification is based on proximity to a floodgate/lock, signs of crushing (broken ribs, hemorrhaging, injury) and impressions of floodgates on the animal's body.¹⁶

To prevent canal locks and floodgates from killing manatees, technology has been developed to detect the animals as they enter these structures. The Manatee Pass Gates project was initiated in 1994,¹⁷ authorized under the Energy and Water Development Appropriation Act, with the goal of zero structure-caused manatee deaths, by installing modifications to water control structures.¹⁸ The controls involve acoustic transmitters and sensors which are activated when the moving gates are 15% from their fully-closed position. If a manatee interrupts the signal, the gates automatically stop, allowing the animal to swim through unimpeded.¹⁹ After a programmed delay, the gates attempt to close again, repeating the cycle if the obstruction remains, or finally closing when free.

This study examines the mortality in manatees in floodgates and canal locks to establish whether SBCs can identify the impact of the manatee protection system. The analysis examines whether (i) systemic change occurs as a result of the new system, and (ii) whether exceptional occurrences are detected and if they signal issues for future consideration in management of the waterways.

Materials and methods

The data covering death of manatees due to drowning or collision from entrapment in locks and floodgates in Florida is routinely collated on a regional, monthly basis for statutory public reporting and is available for the years 1974-2016.²⁰ In a Systems Behavior Chart (SBC) this data is organized longitudinally (e.g. daily, weekly, monthly or by incident in order). The dataset is used to calculate additional reference lines ('limits') which are plotted on the chart adjacent to data. In limited datasets, such as the annual mortality of manatees in this case, it is appropriate to plot single points (i.e. yearly total) and use those to calculate limits.^{8,21} In SBCs, 20 or more data points usually provide useful insight when plotted alongside calculated limits,⁸ although fewer data points may still yield useful observations.⁷ In this study data was analyzed using two SBC methods, namely the SD chart and *XmR* charts (the latter involving two plots, an *X* chart and an *mR* chart). In both SD and *XmR* charts the data points are plotted alongside the mean (represented on the plot as a Centre Line = \bar{x}) but differ on the calculation of limit lines.

In the SD chart²¹ the limit lines are calculated using mean (\bar{x}) and standard deviation (SD) for the data,^{4,8} namely: Upper Limit: $UL = \bar{x} + 3SD$; Lower Limit: $LL = \bar{x} - 3SD$; Upper Warning Limit: $UWL = \bar{x} + 2SD$; Lower Warning Limit: $LWL = \bar{x} - 2SD$.

In *XmR* charts⁷ the limits are derived using the two-point moving range between adjacent data points and calculated from the mean of those moving ranges (\overline{mR}). These limits are considered more sensitive in heterogeneous data sets and less likely to miss signals in the data.^{5,7}

The *X* chart Upper Natural Limit = $\bar{x} + 2.66(\overline{mR})$ and Lower Natural Limit = $\bar{x} - 2.66(\overline{mR})$.

The moving range (*mR*) chart is often presented alongside the *X* chart to show moving ranges between data points⁷ with a limit calculated as Upper Range Limit = $3.27(\overline{mR})$.

This study examines mortality occurrences from 1974-2016 using a single chart presenting both SD chart and *X* chart limits for comparison, plus an *mR* chart to support *X* chart observations. Later a specific focus on years 2000-2016 used a pair of *X* and *mR* charts to understand the current manatee protection system. Analysis was directed upon (i) whether the mortality changes at any points in time as indicated by SBC rules;⁸ (ii) whether SBC limits are sufficiently sensitive to identify critical points for mitigating mortality; (iii) identifying any exceptional instances worthy of investigation.

Results and discussion

Both the SD limits and *XmR* limits in Figure 1 identify three different mortality 'systems', namely the periods; A) 1974-1993, B) 1994-2000 and C) 2001-2016. Each change is indicated by datapoints remaining one side of the calculated mean in the preceding steady system [8]. The manatee population grew significantly from 1267 in 1991, up to 3300 by 2001 [20], so greater presence of the animals may have increased risk of accidental mortality during that period when installation of mitigation technology was still incomplete. Infrastructure improvements in the mid-1990s were likely masked by increased incident probability due to higher densities of animals. The recent 'C' system (2000-2016) shows one exceptional point in 2012 which sits above the upper limits (Figure 1&2).

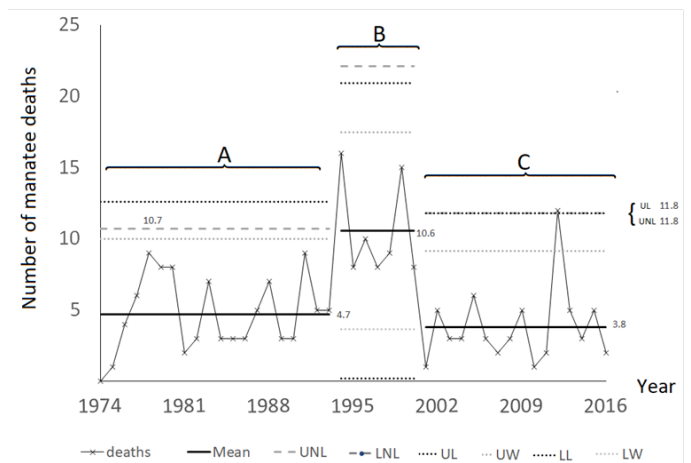


Figure 1 SBC chart for manatee deaths²⁰ in canal locks/floodgates in Florida (1974-2016), showing both SD and *XmR* limits. Note: most lower limits sit below 'zero deaths' so are not plotted. Three systems of mortality are identified: A) years 1974-1993, B) 1994-2000 and C) 2001-2016.

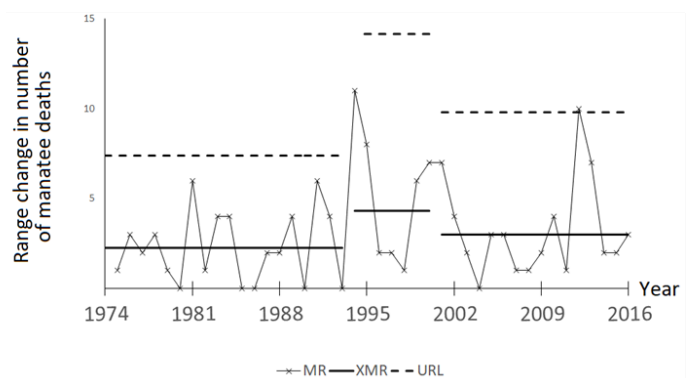


Figure 2 *mR* (moving range) of manatee deaths²⁰ in floodgate/locks shows an exception in 2012.

Effectiveness of the Manatee Pass Gates system

The current system ‘C’ (2001-2016) is re-plotted as an *X* chart in Figure 3 and a supporting *mR* chart in Figure 4. The exceptional 2012 data point was excluded from the calculation of revised limits. Under this revision, in addition, the *mR* indicated that the initial 2001 data point was also an exception (i.e. outside the URL), so that data point was also excluded from calculation of limits. This shows the added analytical value of using *XmR* plots instead of SD plots. The revised charts give a clearer prediction of future performance, based on \bar{x} , UNL, \overline{mR} and URL, with the lower natural limit LNL in this case being below zero.

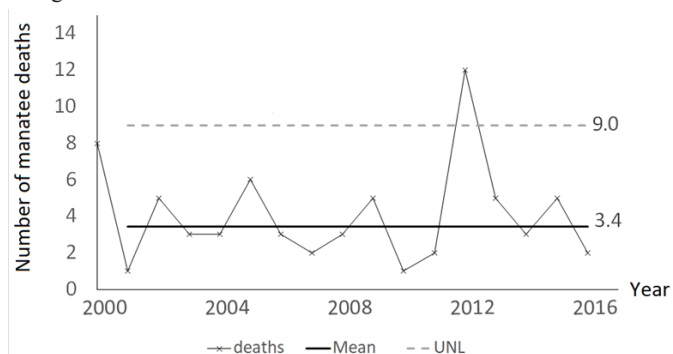


Figure 3 X chart for recorded manatee deaths²⁰ in canal locks/floodgates in Florida (2000-2016), showing a mean (\bar{x}) of 3.4 and UNL of 9.0 deaths. The LNL sits below ‘zero deaths’ so is not plotted. Note that exceptions for 2001 (Figure 4) and 2012 are not included in calculation of (\bar{x}) and the UNL.

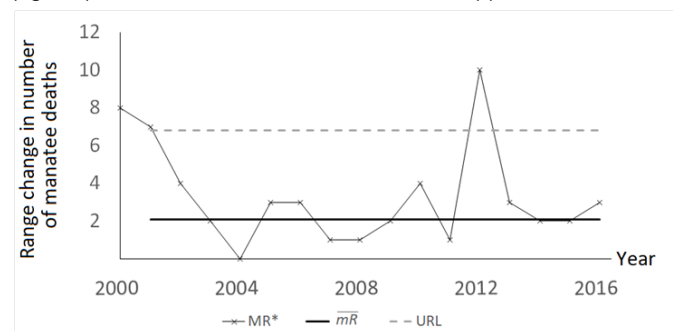


Figure 4 *mR* chart of manatee deaths in floodgate/locks (2000 – 2016). Year 2002-2008 indicate the change in the system (7 points below previous *mR*) but 2001 and 2012 are exceptions above URL.

The *X* chart in Figure 3 illustrates the improved system established after year 2001 under the Manatee Pass Project initiative. The Lower Natural limit (LNL) sits below zero suggesting the desirable ‘ideal’ threat status (e.g. deaths reduced to zero) could be achieved by the system in any one year^{8,22} although this has not been achieved to date. Mean mortality (\bar{x}) has improved from 10.6 deaths per annum in the 1990s to 3.4 per annum in the 21st century.

Detecting ‘exceptional’ occurrences versus systemic changes

The SBCs identify 2012 as an exceptional occurrence above the UNL (Figure 1&3). Similarly, the *X* chart’s sister plot of Moving Range (*mR*) also identifies this exception (Figure 2&4). Mortality in 2012 was influenced by six incidents in Glades county.²⁰ Glades County is to the west of Okeechobee Lake, but has no designated Important Manatee Areas (IMAs), Warm Water Aggregation Areas (WWAAs) or Areas of Inadequate Protection (AIPs), so would not ordinarily be of concern.¹⁴ However, Lake Okeechobee is the largest freshwater lake in Florida²³ and Moore Haven Lock, one of the most significant

man-made structures on the waterway resides in Glades County.²⁴ Moore Haven Lock was closed from early April through May 2012²⁴ for installation of its manatee protection system, finally completed on July 14, 2012.¹⁷ Whether mortality incidents occurred around Moore Haven Lock itself, or whether manatees avoided Moore Haven and congregated at exceptional levels in other nearby locks in the county is unknown. Separate to this, water levels in Okeechobee lake from 1st May 2011 to 30th April 2012 (Water Year 2012) were extremely low (10.26 ft or 3.13m at sampling point NGVD29) providing unusual light conditions for proliferation of *Chara*, a genus of macro algae that have stems and leaves.^{23,24} This type of information (and other possibilities) should generate hypotheses potentially worthy of further investigation such as:

- i. Building activity around the locks causes disruption and increases mortality events
- ii. Building activity around Moore Haven forces manatees away, to congregate at higher densities near other waterway structures, increasing mortality risk in those locations
- iii. Low water levels force manatees to clearer water at man-made structures, raising mortality
- iv. Macro-algal bloom forces manatees to clearer water at man-made structures, raising mortality
- v. Macro algal bloom changes manatee feeding aggregations and presence in man-made structures, raising mortality.
- vi. There is some affective combination of the above factors.
- vii. Mortality is caused by an unknown, one-off factor which is unlikely to arise again in the future.

Hypotheses relating to exceptions (in this case, unexpected mortality) could be worth investigating, or be completely ignored. If manatees are occasionally affected by such factors, future waterways management and risk assessment could consider temporary mitigation during similar occurrences of building works, low water levels or macro algal blooms.

Understanding the sustainability of improvements and future challenges

The manatee population in Florida has continued to increase since 2001 with noticeable increases since 2007 to over 6000 animals.¹² Despite this increase, the *X* chart for system C (Figure 3) shows that the mortality occurrences in floodgates/locks has successfully remained in a steady state of mean (\bar{x}) of 3.4 annual deaths and Upper Natural Limit (i.e. practical predicted maximum) of approximately 9 deaths per annum. In other words, the modified manatee protection system has improved the situation so that any year should predictably perform below the previous 1990s mean (\bar{x} = 10.6 deaths per annum). At very least the system now prevents the deaths of between seven and 13 manatees per year, and taking population increases into account, can claim to prevent perhaps 15 to 30 unnecessary deaths, or between 0.25% and 0.5 % of the total Florida population year on year.

Data from synoptic surveys of Florida manatee populations¹² and the floodgate/lock deaths²⁰ allows calculation of percentage mortality for an SBC with *XmR* limits for mortality rate (Figure 5). This chart reveals that mortality rate has been fundamentally improved since 2001 (subsequent data points consistently falling below the mean). This is an area that traditional methods for examining manatee mortality and the impact of interventions have in the past found difficult to measure.²⁵ Future improvements will be less about removing exceptional death events and instead must be systemic. The conservation challenge is to

identify what changes might enable improvement towards the goal of ‘zero deaths’.¹⁸ This requires detailed examination of potential causes of death in locks. For example, if a manatee has safely entered a lock alongside a boat, the risk of accidental crushing or drowning on a recurring basis due to boat handling practices. Simple signage or an awareness campaign may have sufficient effect, and these approaches or other specific mitigation actions should be tested for potential impact using SBC analysis.

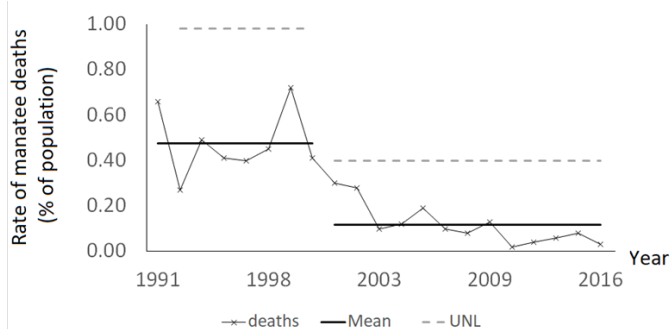


Figure 5 X chart of manatee mortality rate for deaths in floodgate/locks (1991–2016) against overall manatee population from synoptic surveys.¹² Note the change after 2001 (7 points below previous mean) with the lower mortality system maintained at improved levels to the present.

Conclusion

Despite the continuing increase in the Florida manatee population, annual mortality occurrences in floodgates/locks has remained steady. The Manatee Pass Gates project has delivered a manatee protection system which predictably performs below the previous 1990s mean rate of 10.6 deaths per annum when the project was initiated. SBC analysis also demonstrates how manatee protection systems on Florida floodgates and locks have systematically reduced death rates in manatees. This indicates a considerable achievement in risk mitigation, however further improvement of the system is still possible, and the SBC method can be used to detect whether future initiatives progress towards zero manatee deaths. If an SBC-based understanding of performance is utilized it will prompt a different approach to intervention management. If the ‘goal’ is to achieve zero deaths in locks or floodgates, then a fundamental review of the overall system, including consideration of aspects other than physical structures is necessary. As it stands currently, the system itself can do no better than sustain annual mortality between nine and zero per year. Essentially a ‘good’ year (zero deaths) is as likely as a ‘bad’ year (nine deaths). Systematic reduction in variation requires experimentation with various methods to determine sustainable improvements.

SBCs are diagnostic in being able to detect changes in performance of a system relative to the intended improvement actions that have been applied, distinguishing fundamental changes in performance of a system. SBCs are also able to identify exceptional ‘one-off’ occurrences which may be worthy of a different type of management attention. Exceptions highlight possibilities that lie outside the normal system. Practitioners need to identify if the exception is positive and should in some way be replicated (e.g. exceptionally low deaths) or, as in the high manatee floodgate/lock mortality in 2012, is an exception to avoid in future. This may be important if, as hypothesized in this manatee case, some factors may be considered for temporary mitigation in the future. Many exceptions, however, are driven by causes which cannot be influenced by management or will likely never occur again. In those cases it is wrong to take action on the existing system since

the response would be disruptive and counter-productive. Exceptions are only of interest if they affect the system with factors which can later be managed, or they generate fundamental insights relating to the species or ecosystems of concern.

Both the SD chart and the XmR charts can be practically applied, but the latter with X chart limits alongside an mR chart are shown to be more sensitive to signals in the data. This corresponds with previous suggestions about the preferred use of XmR limits since whilst in homogenous data SD limits appear tighter, in heterogenous data sets of the type often found in ecological systems, XmR limits will be better suited for detection of fundamental signals. Furthermore, using the mR chart in tandem can identify additional signals. Through this analysis of tangible Florida Manatee mortality data and specific mitigation efforts on waterways, this study demonstrates the diagnostic and predictive power of Systems Behavior Charts for managing improvement in ecological systems.

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Conflict of interest

The authors declare no conflicts of interest in relation to this research.

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