Systems Behaviour Charts for Longitudinal Data Inform Marine Conservation Management

Abstract

Conservation practitioners need to predict changes in ecological performance, such as species population levels, and the status of threats. Whilst an assessment of ecosystem status can be achieved from complex data analyses, this is less helpful for practical decision-making on the ground where a straightforward, reliable decision-framework is required. Systems Behaviour Charts offer a simpler method for reviewing the state of the system. The methods for developing and analyzing System Behaviour Charts are applied to two longitudinal datasets from coastal, estuary and freshwater conservation; threatened species head-starting (sea turtles), and mortality of aquatic mammals (manatees) due to human waterway traffic (watercraft collisions). Inferences from observations are made using a series of empirical rules. Results illustrate how Systems Behaviour Charts identify changes, declines, recoveries and steady state systems. This insight enables early intervention and identification of actual improvements in ecosystem performance. These insights illustrate how Systems Behaviour Charts offer an improved approach to analyzing data sets to support marine and aquatic conservation.

Keywords: Ecosystem; Management; Recovery; Systems Theory; Manatee; Turtle; Variation

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Abbreviations: SBC: Systems Behaviour Chart; UNL: Upper Natural Limit; LNL: Lower Natural Limit; UWL: Upper Warning Limit; LWL: Lower Warning Limit

Introduction

The effectiveness of managing marine and aquatic conservation encompasses complexities of species decline, threat status and habitat degradation. Judgments of destabilization, decline and improvement relate to choices of relevant indicators and understanding the state of systems [1], both being important areas of competence in conservation management [2]. The Systems Behaviour Chart (SBC) indicates decline, improvement, stability or instability using the theory of variation to identify signals in data [3-5]. SBCs enable a degree of statistical rigor in decisions made by managers with little background in formal statistics [5,6] as illustrated in the following examples.

Approaches in sea turtle head-starting hatcheries

Sea turtles are threatened by hunting, pollution, loss or degradation of nesting grounds and disruptive fishing practices, impacting both population status and reproductive success [7-9]. A common practice in sea turtle conservation is the relocation of entire clutches of eggs into protected 'hatchery' reserves to increase hatchling numbers released into the ocean [10]. Human skills in transferring eggs and managing re-buried nests can affect hatchery success [7].

Managing manatee habitats impacted by human activity on waterways

The Florida manatee (*Trichechus manatus latirostris*) inhabits the coastal waters and estuaries of southwestern United States and the Caribbean [11]. The manatee population has grown since the 1970s, but increases in manatee deaths due to watercraft collisions is of primary concern, representing up to a fifth of annual mortality whilst the number of registered boats in the region has also increased [12, 13].

Materials and Methods

In a Systems Behaviour Chart (SBC) the run of ecological or socio-ecological data (organized longitudinally, e.g. daily, weekly, monthly) is used to calculate five reference lines ('limits') which are plotted adjacent to the data. In a limited dataset it is appropriate to plot single points and use those to calculate limits, whilst in large datasets a rolling mean derived from the last 4 or more data points provides a more realistic representation according to Central Limit Theorem [6].

The five limits are based upon the mean ($\bar{x}$) and standard deviation (σ) for the data [3], namely: Centre Line = $\bar{x}$; Upper Natural Limits: NL = $\bar{x} + 3\sigma$; Lower Natural Limits: NL = $\bar{x} - 3\sigma$; Upper Warning Limits: NL = $\bar{x} + 2\sigma$; Lower Warning Limits: NL = $\bar{x} - 2\sigma$. In some situations, the position of lower limits (LNL or LWL) may fall below zero [5,14] suggesting the system is tending towards either a desirable ideal (e.g. collision incidents reduced to zero), or a worst-case scenario (e.g. hatchling success reduced to zero).

Operational measures and sampling in Marine and Waterways conservation

To examine alternative methods for head-starting in sea turtle hatcheries, counts of eggs recovered and re-buried in a safe location, plus the number of turtle hatchlings successfully emerging from re-buried nests provide a measure of productivity of each nest (as a %). This generates a large dataset of hatchling success per nest, so a rolling mean of five consecutive weekly hatchling rates is used for each hatchery site. To examine intervention impacts on Florida manatee boat-collision mortality, measurements of logged boat-collision incidents involves a relatively small number of data points (annual totals across the years 1974-2015). This information is routinely collated on a regional, monthly basis and collated for statutory public reporting [15].

Rules for detecting changes within Systems Behavior Charts

Typical patterns of a system can be observed based upon statistical expectations of the data as depicted in a Systems Behaviour Chart. Criteria for identifying non-random changes in a run of longitudinal data are summarized by various authors [4-6]. If the data shows specific patterns or trends reflecting one or more of these rules it indicates that the system has changed in a non-random fashion and this is therefore worthy of investigation. Any repeating patterns suggest that more than one system is operating (such as seasonal fluctuations), which would require dividing the data into different datasets, for example by season, geographical region or some other phenomenon.

Results and Discussion

Systems Behaviour Chart analysis of longitudinal datasets for the examined marine and waterway cases enables the identification of the following phenomena.

Efficacy of human conservation intervention: turtle head starting

The Systems Behavior Chart in Figure 1 represents the percentage hatchling success rate for a sample population incubated in the *ex-situ* hatchery over time. Using the 5-point moving average, the SBC shows hatchling success rates in both 2013 and 2014 in a steady state shown by data sitting within natural limits for their respective years. The run of data across the two years breaks three of the SBC rules; first showing two consecutive points outside the UWL (± 2σ), secondly, a sequence of points closer to limits than the mean, and thirdly a sequence above the mean or below the mean. These all suggest a systemic change between the years 2013 and 2014. The mean hatchling success rate reduced from 77.3% in 2013 to 52.6% in 2014.

The SBC identified a non-random change in the hatchling system with a decline of the performance of the system in 2014 compared to 2013 (Figure 1). This follows a change in nest burial method in 2014, increasing the density of nests in the protected hatchery. Whilst 2014 was considered initially 'in-control' (points remaining inside recalculated natural limits) it represents a lower-performing system than 2013. Furthermore, the last data points in August 2014 drop below first the LWL line then the LNL, indicating at that point in time that the hatchling rate has dropped 'out of control' [5]. The SBC indicates to hatchery managers by July 2014 that the system is under-performing, and August data confirms the case, and finally the last data points highlight the error of the approach. From an operational perspective, alternatives which the managers can take include either to increase the clutch sizes by combining several into single nests within a 1 m^2 area. Another alternative is to enlarge the protected hatchery itself to accommodate more nests, subject to available space. Since both 2013 and 2014 systems are essentially stable, human error appears not to be major factor affecting hatchling success. The fundamental improvement in nest success arises from adjusting the method (e.g. the size of egg burial areas and space between adjacent nests).

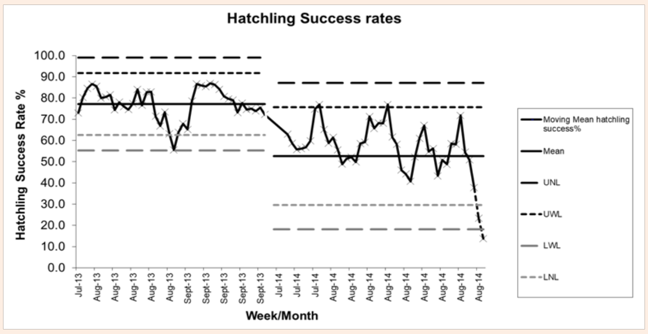

Figure 1: Success rate of turtle nest hatchlings from July-September for years 2013 and 2014. Showing a 5-point moving average, the mean and natural limits, (UNL and UWL), and warning limits (UWL, LWL) as calculated from the 5-point moving average when entirely infertile nests were removed from the data set. The 2014 system performs at a lower percentage hatchling rate overall. Note the dashed line between the last three points in the data indicate that the 2014 system falls out of control. The last two points which sit outside the LWL and LNL should be treated as exceptions worthy of further investigation.

Identifying system status under human pressures: Florida Manatee mortality

The Systems Behavior Chart for manatee collision fatalities (Figure 2) reveals that collision mortality occurrence is split into three systems over the period 1974-2015. The first system appears from 1978, the second from 1984, and the third from 1998 through to 2015. The number of registered boats accelerated from 1984 to 1990 and again from 1994 to 1999 [12] which indicates a reason for the "jumps" in the data.

Conservation managers and policy officers in Florida can, however, take satisfaction that waterway speed controls have had a stabilizing influence on manatee collision deaths. The 1978 Florida Manatee Sanctuary Act regulated boat speeds [12], and later county-level slow speed buffer zones enabled re-stabilization of manatee collision deaths. Whilst perhaps at a higher than desirable level, collision deaths are no longer increasing out of control (Figure 2) although continued efforts are required to control collision occurrences (which would be demonstrated by reduced variability in the data). Alternative strategies could be tested including targeted waterway controls on boat use where manatees habitually congregate [13], or perhaps voluntary or mandatory watercraft modifications to reduce the likelihood of manatee injury or fatality.

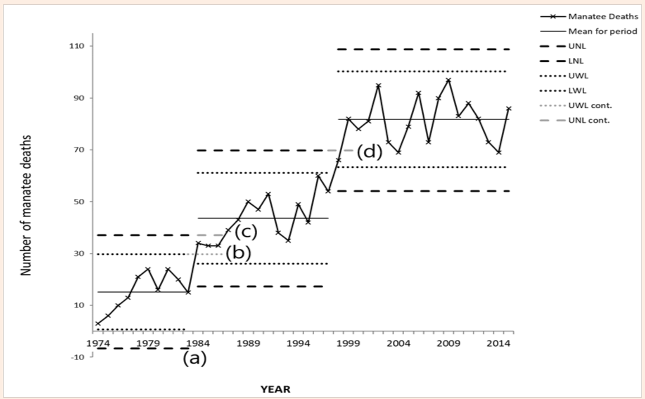

Figure 2: Florida manatee mortality (1974-2015) due to watercraft collisions showing three systems, illustrating (a) where LNL below zero indicates zero collisions as a reasonable expectation in the initial system, (b) where three points sit above the continued UWL (grey dotted line) and (c) points continue above the UNL (grey dashed line) indicating a shift to the second system, and (d) where a new, current system starts above the previous UNL (grey dashed line). The distance between outer natural limits of the third system (1998-2015) is similar to the second (1984-1997), but at a higher mean annual number of manatee deaths.

Conclusion

Systems Behaviour Charts are applicable to a range of data types, from simple operations such as turtle hatcheries, to more complex programs as required in Florida manatee conservation. Where results remain within calculated natural limits, data can be observed to arise from the same 'system', whereas data falling outside the natural limits, or contrary to SBC rules [5] indicates that the system has been exposed either to a one-off effect (exceptional) or by a more fundamental systemic change, possibly making the system itself unstable. The importance of the approach, illustrated by the sea turtle hatchery example, includes the way that SBC analysis highlights real and justifiable statements of improvement (or degradation) in performance thereby overcoming assumptions about 'success' or 'failure' in response to otherwise isolated highs and lows in the data [3]. Clarity in knowledge-based decision-making of this type is important in conservation where uncertainty in data is commonly encountered alongside the necessity to act fast [16]. Systems Behavior Charts enable a better understanding of the practical dynamics of natural and human-impacted systems to support more effective conservation management.

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Conflict of Interest

The authors have no financial interest or any other conflict of interest relating to this research.

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