Time series forecasting of greater one-horned rhinoceros poaching levels at Kaziranga National Park, Assam, India

Saureesh Das[1] and Rashmi Bhardwaj[1]*

[1]University School of Basic and Applied Sciences, Guru Gobind Singh Indraprastha University, Sec-16C, Dwarka, New Delhi–110078, India

*corresponding author: saureeshdas@gmail.com

Introduction

This paper deals with the forecasting of poaching of the greater one-horned rhinoceros (*Rhinoceros unicornis*) (GOH) at Kaziranga National Park (KNP or the Park), Assam, India. Instances of poaching adversely affect efforts to conserve and increase the rhino population of the Park. The time series of total instances of poaching of GOH at KNP from the year 1965–2019 was considered in the study. The information about the period ending 2015 was used as training and testing data, and poaching levels for the period 2016–2019 were predicted using three different forecasting methods and compared with the available actual data. Three methods of time series forecasting are compared, namely Holt's method (HM), Holt–Winters' multiplicative method (HWMM) and Holt–Winters' additive method (HWAM).

KNP was the first area in Assam gazetted for rhino protection in 1908, and the Park achieved UNESCO World Heritage status in 1985 for being the world's major stronghold of GOH and for providing habitat for a number of other globally threatened species including tigers and Asian elephants. (UNESCO website; https://whc.unesco.org/en/list/337/). GOH numbers in the Park rose from 366 in 1966 (Vigne and Martin 1994) to 2,413 in 2018 (Talukdar 2018), and KNP now holds two-thirds of the world's GOH population. The 430 km^2 Park is ideal rhino habitat, with nutrient-rich grassland growing on fertile soils created by alluvial silt deposition from seasonal flows in the Brahmaputra Valley floodplain. Although KNP has been granted maximum protection under the Indian law for wildlife conservation with enactment of Assam Forest Regulation 1891 and Biodiversity Conservation Act 2002 (UNESCO website) poaching of the GOH has been a major concern for authorities. The perimeter of KNP is contiguous on three sides with urban development and this makes it difficult to protect the Park from illegal incursions of poachers and herdsmen. Only the northern side is better protected, as the 2 km wide Brahmaputra River acts as a natural boundary.

Until 1980 GOH were poached using the pit fall technique; however, with the increase in the availability of arms due to political disturbances in the state, cases of poaching escalated rapidly, reaching a peak during 1992 (Vigne and Martin 1994). In 1989 the first case of poaching by electrocution was observed. Conservation efforts initiated in 1997, including improved fencing and increased patrolling, strengthened security in the Park and led to a reduction in poaching incidents. In 2003, poaching was brought under control and reduced to just three incidents in 2003 (Talukdar 2006, Lopez 2014). Poaching incidents increased again thereafter, to 16 incidents per year in 2007 and 27 incidents in 2013 (Soud and Talukdar 2013). From 2013 onwards poaching levels have been brought down, according to the official statistics. Thus, numbers of poaching incidents have fluctuated over time, producing a time series with abrupt highs and lows. Such short-term fluctuations in data sets are often difficult to interpret and research to define the limitations of the various methods is incomplete. Despite these difficulties, it is useful to study the properties of the time series of incidents of rhino poaching. Results can be relevant for ongoing management and conservation initiatives, as they can help predict poaching spikes and thereby prepare the Park management to respond to future threats.

Previous research drawing on methods of fractal analysis[1] established that the prediction of poaching levels using time series forecasting methods is feasible. The dispersion method is a powerful method that can be used for analysis of fractal properties of time-series data (Bassingthwaighte and Raymond 1995). The Hurst exponent (*H*) is one measure of these properties (Resta 2012). The Hurst exponent is a measure of long-term memory that calculates auto-correlations of time series over time and the rate of their decrease with increase in the lag between pairs of data values. It basically measures the amount of randomness in the given time series. A value of *H* of less than 0.5 indicates that the given time series is unpredictable, and of above 0.5 that the time series is persistent or predictable.

In previous research, the authors of this paper applied the dispersion method to study the statistical and fractal properties of the time series of incidents of rhino poaching in KNP (Bhardwaj and Das 2018). The time series of poaching showed a persistent behaviour, with the value of *H* above 0.5 indicating that present values are in sync with the trend of past observed values. The persistent pattern of the time series indicates that the prediction of poaching levels using time series forecasting methods is feasible.

In 1957, Holt developed the first forecasting method, known as the Holt method (HM), which was linear regression based and accounted only for the trend of the data. In 1960, Winter proposed the HWM (Holt–Winters' Method), which besides indicating trends accounted for the seasonality of data. The HWM is further divided into HWMM and HWAM depending upon the nature of seasonal component in data. If the seasonal variations are roughly constant over the time series, then HWAM is used for forecasting, while if the seasonal variation changes progressively over the course of the time series, then HWMM is used.

The HWAM model was applied by Szmit and Szmit (2012) to detect anomalies in network traffic and by Valakevicius and Brazenas (2015) to study exchange rate volatility. However, these forecasting techniques have not so far been used for ecological or biological time series data. This study applies these methods to predict poaching values for the years 2016–2018, using poaching data from 1965–2015 as training data. It compares values for 2016–2018 predicted using HM, HWMM and HWAM with actual data for these years. The methods are compared, and the best method is proposed on the basis of observed results.

Data and methodology

The annual data of the number of rhinos poached in KNP in the period 1965–2019 were mainly obtained from (a) Lopez (2014), covering the period 1972–2012; (b) Wikipedia (WP; 1965–2016); and KNP official data (KNPO) data, published on the websites of (c) KNP (2006–2019) and (d) the Wildlife Protection Society of India (WPSI) 2010–2017.

Furthermore, there are differences between KNPO and WPSI data for the period 2010–2016 and also among all three primary sources (Lopez 2014, KNPO and WPSI) for the period 2014–2016. Some data points are missing in the Wikipedia data (1965–2016), which were obtained from the other three sources. To address these inconsistencies, for this study we compiled different combinations of the available partial data from these four sources to create three different complete data time series (TS) for the period 1965–2019 (Table 1). For the years 2018 and 2019 the data are the same for TS-1, TS-2 and TS-3 as data for these years are only available from KNPO.

The combined plot of time series of different data sources is plotted in Figure 1a while the individual plots of time series of TS-1, TS-2 and TS-3 data are shown Figure 1b–d. The net oscillations of data (i.e. longer-term oscillations after smoothing of short-term fluctuations) show a repeating pattern, with a 32-year cycle over the period 1965–1996, followed by the onset of a second cycle. As mentioned above, the calculation by Bhardwaj and Das (2018) of the Hurst exponent (*H*) for the period 1965–2015 indicates that the rhino poaching time series is persistent in nature.

For this study we repeated this analysis for the three time series TS-1, TS-2 and TS-3. As all three time

[1]**Fractal analysis** is a contemporary method of applying non-traditional mathematics to patterns that defy understanding using traditional Euclidean concepts. In essence, it measures complexity using the **fractal** dimension: see https://en.wikipedia.org/wiki/Fractal_analysis

Table 1. Composition of TS-1, TS-2 and TS-3 time-series data. Keys to abbreviations are given in the text

Time series	Composition
TS-1	WP (1965–1971) + Lopez (1972–2012) + KNPO (2013–2019)
TS-2	WP (1965–1971) + Lopez (1972–2009) + WPSI (2010–2017) + KNPO (2018–2019)
TS-3	WP (1965–1993) + Lopez (1994–1997) + WP (1998–2006) + Lopez (2007–2012) + KNPO (2013) + WP (2014–2016) + WPSI (2017) + KNPO (2018–2019)

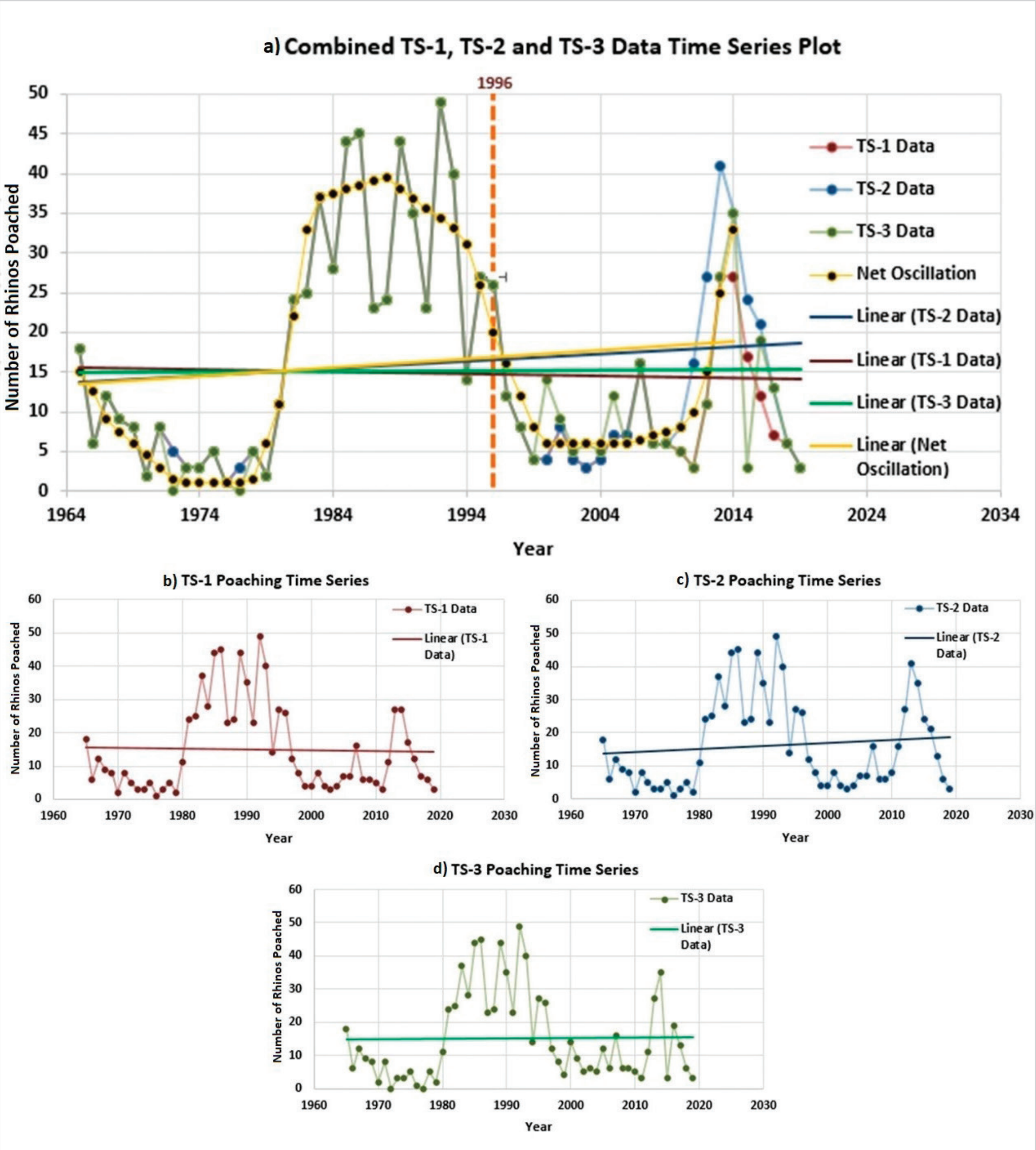

Figure 1. Time series plot of rhinoceros poaching levels in Kaziranga National Park from 1965–2019.

series show persistent behaviour with values of H between 0.5 and 1.0 (Table 2), indicating that the poaching levels can be predicted in future using forecasting tools, we proceeded with the application of the forecasting methods HM, HWMM and HWAM. These forecasting techniques are used as we observe cyclical behaviour alongside the long-term trend in the poaching data. While we acknowledge that one-and-a-half oscillations of a presumed 32-year cycle are insufficient to prove that there is a repeating pattern in the data, we assume it to be following a cycle because of the observed persistent nature in fractal analysis. As the data show only one-and-a-half oscillations of the net oscillation cycle, it is hard to assess the nature of a seasonal component and therefore we applied both HWMM and HWAM. For the three data series predictions, all were made for the years 2016–2019, using the data from 1965–1996 as training data and data from 1997–2015 as testing data.

Predicted data for 2016–2019 was compared to actual data, with deviations calculated as mean square error (MSE), mean absolute error (MAE) and mean absolute percentage error (MAPE) in order to determine the best method for prediction. We also compared predictions for the year 2020 with available data on poaching incidents for this year. The methodology used in the study is summarized in the schematic flowchart in Figure 2.

The average magnitude of error produced by the forecasting method is given by MAE, while MAPE provides information about the extent of deviation of forecasts from corresponding actual values. MSE is similar to MAE but when computing MSE the squares of difference between actual and forecast value are calculated before summing them up, instead of using absolute error values as in MAE. As a result of squaring the error values, outliers in the data contribute to a much higher total error in MSE compared to MAE. MSE is used to tune the smoothing parameters for improving the forecasting efficiency of the method.

Results

TS-1, TS-2 and TS-3 cover the time period 1965–2019, where 1965 is the first year and 2019 is the fifty-fifth year of the dataset $X = \{X_t\ ,\ t=1, 2,\ldots, \tau_2, \ldots n\}$ where $n = 55$ and τ_2 is the final year of the testing data set. Since data from period 1965–2015 is used for training and testing purposes and 2015 is the fifty-first year, $\tau_2 = 51$. Figure 1 shows a net oscillation which appears to enter a new cycle in

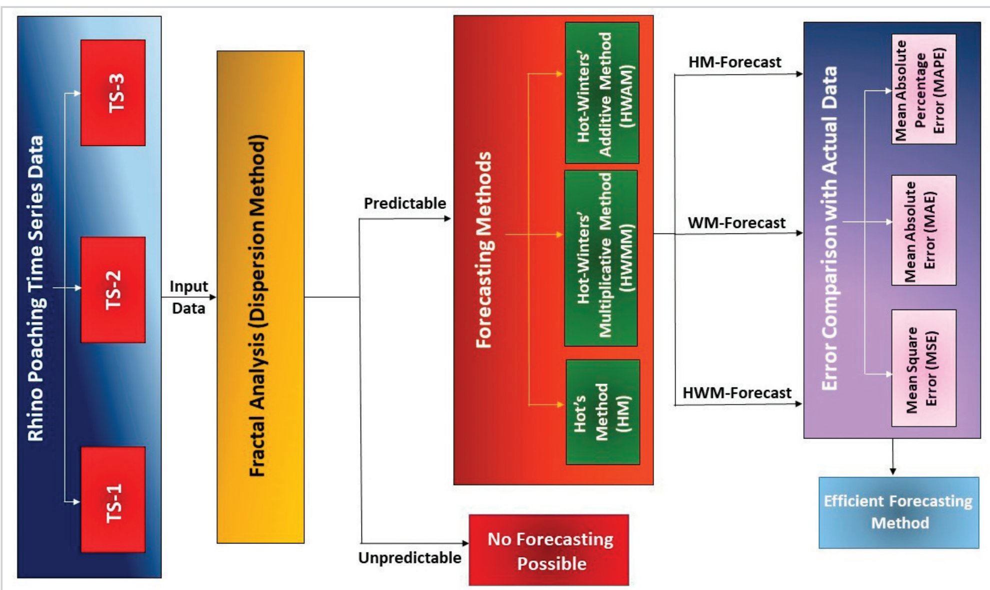

Figure 2. Schematic flowchart of the analysis.

Table 2. Hurst exponent values, the times series data of rhino poaching in Kaziranga National Park, 1965–2019

Time series	Hurst exponent (*H*)	Predictability
TS-1	0.9935	Predictable as 0.5 < H < 1.0
TS-2	0.9802	Predictable as 0.5 < H < 1.0
TS-3	0.9650	Predictable as 0.5 < H < 1.0

1996. Based on this visual analysis, the cycle duration or season period (p) is considered to be 32 years. The initial values of smoothing parameters used for forecasting are $\alpha = 0.4$, $\beta = 0.2$ and $\gamma = 0.3$. These parameters are optimized in subsequent calculations in such a way that reduces MSE to a minimum value and brings the forecasted data time series optimally in phase with the actual data[2].

Figure 3 shows the comparison plots between forecasted and actual data for the second cycle, post 1996, i.e. 1997–2019. The comparison plots for TS-1 data using the three forecasting methods are shown in panels (a)–(c), those for TS-2 in panels (d)–(f) and those for TS-3 in panels (g)–(i). Errors of all three methods calculated as MSE, MAE and MAPE are shown in panels (j), (k) and (l), respectively. For comparison, Table 3 shows values of forecasted data using the three methods against the actual values in TS-1, TS-2 and TS-3.

For the year 2020 (n + 1) no poaching data has been released yet by any of the sources considered in this study. Media outlets reported the death of two rhinos from poaching in May and August 2020[3]. Since we can find no further reports of poaching incidents in 2020, we therefore assume the actual number of poaching incidents for 2020 to be two in all the three time series. The forecasted values obtained for 2020 are compared in Table 4 and the error values are shown in Table 5.

Discussion

The results clearly show that the predictions made using the HWAM are the most accurate, compared to the other two forecasting methods. According to Tables 3 and 4, both HWMM and HWAM provide a more accurate forecast than HM. Unlike these two methods, HM does not take into account the seasonality of data (i.e. the regular oscillation frequency) and is purely regression based. This probably explains why predictions using this method were less accurate, as evidenced by higher MSE, MAE and MAPE values in comparison to HWMM and HWAM, as shown in Table 5. Furthermore, in Figure 3 (panels j–l) it can be seen that the trajectory of forecast data is much closer to actual data and there are less errors in the case of HWAM in comparison to the HWMM method. Thus the HWAM is observed to provide the most reliable forecasts, indicating the additive nature of the seasonal component in data, i.e. the seasonal variation is roughly constant throughout the considered series.

Bhardwaj and Das (2018) demonstrate that the data time series is persistent. This justifies our attempt to predict future rhino poaching trends using quality forecasting methods that account for seasonality in data time series over a net 32 year cycle. The forecast data follows the trend of actual data, showing a decline in rhino poaching in the period 2016–2019. In the case of TS-1 the forecast data for 2020 using HWMM and HWAM shows zero poaching (Table 4), which is close to the actual poaching level of just two rhino deaths as reported in the media. For both TS-2 and TS-3, year 2020 forecasts show a reduction post-2019 but they are much further from the actual value as observed in predictions for years 2016–2019 in Table 3 due to the time series composition. The forecast for TS-1 is better than TS-2 and the forecast for TS-2 is better than TS-3. Both TS-2 and TS-3 are composed of mixes of shorter data series from different sources, compared to TS-1 that is composed of three longer time series; The HWAM predictions are more accurate with higher predictability. In all cases, the HM continues to give the most erroneous forecasts.

[2]For more information on methodology see: https://otexts.com/fpp2/holt.html, https://otexts.com/fpp2/holt-winters.html and https://www.stat.ipb.ac.id/en/uploads/RA/Time%20series/Kuliah%206%20%20Metode%20Pemulusan%20Winter%20(Multiplikatif).pdf

[3]See https://www.indiatoday.in/cities/guwahati/story/assam-poachers-kill-one-horned-rhino-kaziranga-1793491-2021-04-21

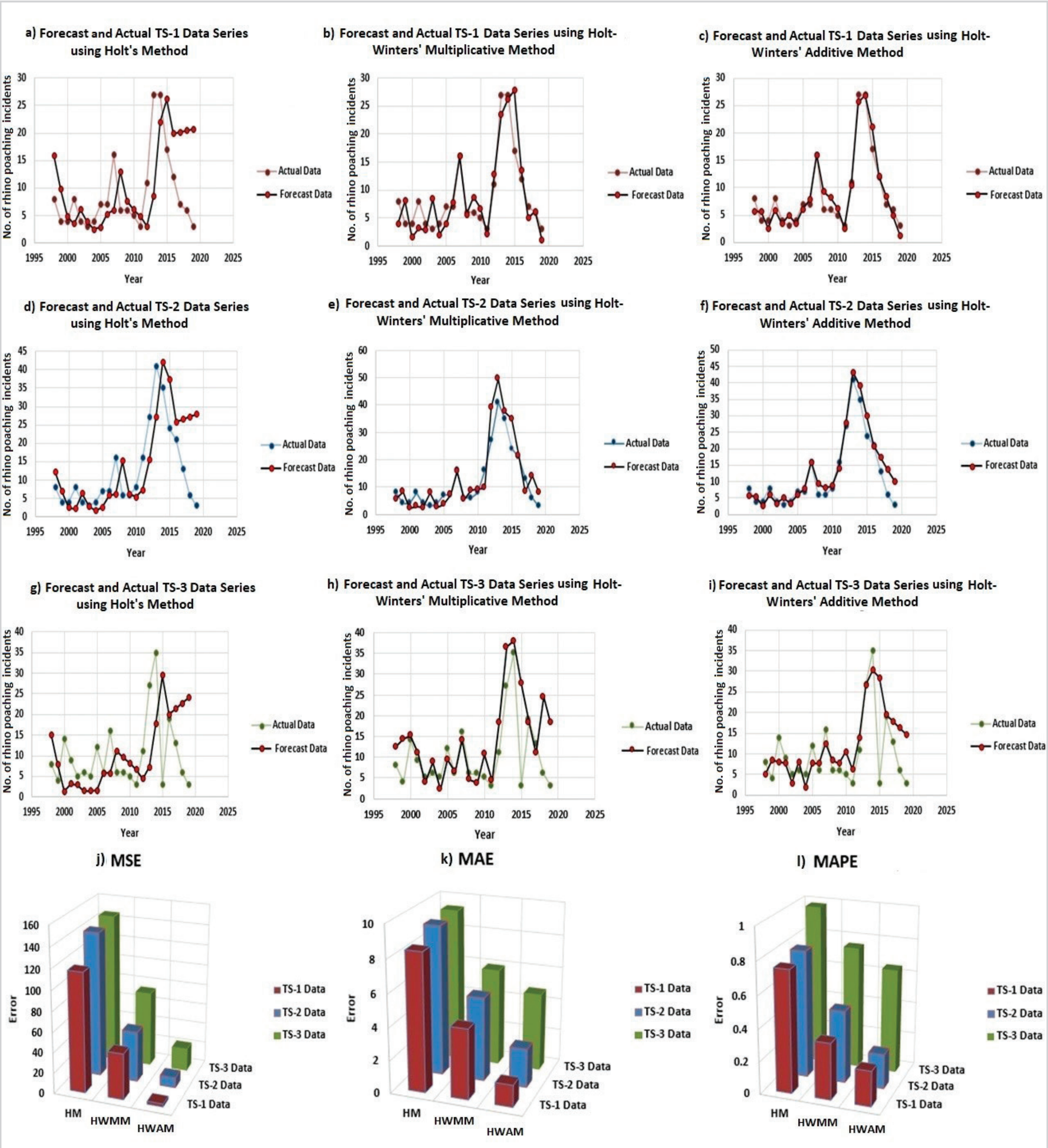

Figure 3. Comparison plot for rhinoceros poaching level forecast for the period 1997–2019.

Table 3. Comparison of forecasted and actual data for 2016–2019 period

TS	Year	Actual data	HM- forecast	HWMM-forecast	HWAM-forecast
TS-1	2016	12	19	13	12
	2017	7	20	5	8
	2018	6	20	6	5
	2019	3	21	1	1
TS-2	2016	21	26	21	21
	2017	13	26	8	17
	2018	6	27	14	13
	2019	3	28	8	10
TS-3	2016	19	20	18	19
	2017	13	21	12	17
	2018	6	23	24	16
	2019	3	24	18	14

Table 4. Comparison of forecasted data for year 2020

Year	TS	Actual data	Method		
			HM- forecast	HWMM-forecast	HWAM-forecast
2020	TS-1	2	21	0	0
	TS-2	2	29	3	6
	TS-3	2	25	11	13

Table 5. Error comparison for different forecasting methods

Method	Errors								
	MSE			MAE			MAPE		
	TS-1	TS-2	TS-3	TS-1	TS-2	TS-3	TS-1	TS-2	TS-3
HM	116.78	141.64	146.29	8.41	9.17	9.37	0.7	0.8	0.98
HWMM	44.95	49.76	73.58	4.29	5.17	5.96	0.35	0.45	0.75
HWAM	2.84	10.17	22.13	1.34	2.39	4.77	0.22	0.21	0.65

The incidence of poaching using arms intensified post-1980 and peaked in 1992 (Vigne and Martin 1994). But poaching subsided after 1996 with the introduction of improved security measures. Beyond 2020 the poaching level is predicted to remain low, with only a few incidents predicted as long as the current status quo prevails. However, it is not possible to predict the effects of external pressures in the surrounding region, such as civil unrest, political instability or Covid-19 induced poverty (i.e. loss of employment and income from tourism motivating a return to poaching). Lopez (2014) models the relationship between rhino poaching in KNP and civil unrest and obtains a good match between estimated and real data. As long as the current situation prevails the incidence of poaching may be expected to remain low; but if any change in the status quo occurs then poaching may rise once again, similar to the increase post-1980 when the poachers changed their tactics from using pits to using arms, taking advantage of the availability of guns due to political disturbance in the

State (Vigne and Martin 1994).

Assuming that poaching levels remain low until the end of the present 32-year period—which started in 1997 and ends in 2028—it is worth noting that the decline in the poaching level began earlier in the second cycle, compared with the previous 32-year period. This highlights the effectiveness of strengthened conservation measures. We recommend the use of drones for monitoring purposes and to target rhino poachers in bringing down poaching levels. Moreover, if the poaching level declines earlier in the second cycle than in the first cycle as predicted, then the decline in the third cycle can be expected to be even faster (should the status quo prevail). All these predictions are only reliable and the forecasting methods effective while the time series data continues to display the same properties of persistence and a constant frequency of oscillation. If these conditions are not met, then the forecasting methods considered in this study will not be able to predict future patterns accurately.

Conclusion

This study applies three forecasting methods, namely HM, HWMM and HWAM, to predict poaching levels of GOH in KNP. The data for the GOH poaching levels in the period 1965–2019 were obtained from KNPO, WPSI, WP and Lopez (2014). As there are discrepancies in the data from different sources, and no source contains a complete dataset, for the purposes of this study we complied three data series, TS-1, TS-2 and TS-3, composed of different combinations of data from the four sources. We applied the forecasting methods to obtain predictions for poaching levels in 2016–2019 and compared the predictions with actual reported values. For all three time series, the HWAM gave the most accurate predictions. The HWAM is superior to HM since its predictions incorporate the effects of seasonality. The predictions of the HWAM also follow the actual data trajectory more closely than the HWMM method, indicating that the seasonal variation in data is roughly constant over the time series. It is also observed that the predictions are more accurate for TS-1 which has fewer component partial data sets compared to the other two data series. It is important to further note that the fluctuations in data are a result of changes in the status quo and the one-and-a-half cycles of the net oscillation in the data are not sufficient to be absolutely certain about the pattern repetition observed in the available data. It should be emphasized that if in the future, rhino poaching trends at KNP change, all forecasting methods will provide erroneous predictions. Forecasting will also be impossible if the data loses its periodicity. For data time series of events which display seasonality and persistence, like rhino poaching incidents at KNP to date, the paper highlights the potential of forecasting methods to predict future poaching trends and thereby aid in the design and implementation of appropriate conservation measures. The limitations of a study comparing forecast methods is that predictions of future events are not entirely possible, due to unforeseeable circumstances.

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