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Stone-curlews *Burhinus oedicnemus* and recreational disturbance: developing a management tool for access

ELISABETH C. TAYLOR,[1] RHYS E. GREEN[1] & JAMES PERRINS[2]
[1] *Royal Society for the Protection of Birds and Conservation Science Group, Department of Zoology, Downing Street, Cambridge CB2 3EJ, UK*
[2] *exeGesIS Spatial Data Management Ltd, Great House Barn, New Street, Talgarth, Powys LD3 0AH, UK*

Stone-curlews *Burhinus oedicnemus* have a vulnerable population status in the UK after a large population decline and range contraction since the 1930s. Much Stone-curlew breeding habitat is open-access land designated under the Countryside and Rights of Way Act 2000. In order to guide the conservation and habitat management for this species whilst allowing recreational access, a tool known as the Stone-Curlew Access Response Evaluator (SCARE) has been developed. SCARE offers a method to assess the effects of scenarios for future changes in disturbance type, routes and frequency and will be valuable in making informed decisions about the management of public access to Stone-curlew breeding sites and the deployment of habitat creation measures.

Changes in statutory rights of access resulting from the Countryside and Rights of Way (CRoW) Act 2000 mean that research on the impacts of disturbance on breeding birds is a priority. Once likely impacts of disturbance have been identified it is necessary to examine management solutions that allow, as far as possible, conservation and access to coexist. Although there are numerous scientific studies of the effects of human disturbance on birds, there are very few that can be used to guide conservation measures in response to increases in countryside access (Liley 2001).

The CRoW Act enables people on foot to wander from linear rights of way in registered common land and open country – mountain, moor, heath and downland (Bathe 2001). Although there are provisions within the Act for restrictions and closures for conservation purposes, these must be justified and based upon research.

Stone-curlews *Burhinus oedicnemus* are ground-nesting birds of downland, heathland and arable farmland in southern and eastern England. The population of Stone-curlews in England crashed from 1000–2000 pairs in the 1930s (Sharrock 1976) to an estimated 150 pairs in the early 1980s restricted to two areas: Breckland in Norfolk and Suffolk, and downland in Wiltshire and Hampshire (Wessex) (Green 1995). The population has been subject to intensive conservation efforts since the mid-1980s and has shown some recovery. However, because the population is still small and confined to a restricted range, the Stone-curlew remains one of the most vulnerable species in the UK (Gibbons *et al.* 1996, Gregory *et al.* 2002). It is also of European conservation concern because of population declines over much of its range (BirdLife International 2004). Therefore, because of its conservation status and the location of the only breeding populations near areas with some of the highest human population densities in the UK, the Stone-curlew is one of the key species of concern with respect to potential effects of the CRoW Act.

In response to the population decline, an RSPB/English Nature recovery project was established in the mid-1980s. Stone-curlews nest on semi-natural short grassland and downland and, in larger numbers but at lower population density, on spring-sown cropland (Green *et al.* 2000). The recovery project aimed to protect crop-nesting Stone-curlews from adverse effects of agricultural operations on breeding success. It also sought to counteract habitat scarcity by providing more areas with short, sparse vegetation on sandy, stony soils. This was achieved in part through the establishment of Stone-curlew plots, 1- to 2-ha areas of cultivated land within semi-natural grassland or arable crops which provide the bare, stony habitat favoured by Stone-curlews (Green & Griffiths 1994, Green & Taylor 1995, Green *et al.* 2000).

*Corresponding author.
Email: Elisabeth.Taylor@rspb.org.uk

In 2005, the total breeding population in England reached 300 pairs for the first time since the recovery project began, attaining the 2010 Biodiversity Action Plan target 5 years ahead of schedule (Wynde 2006).

Given the vulnerable population status of the Stone-curlew and the fact that the majority of its favoured semi-natural breeding habitat is open-access land designated under CRoW, we wished to assess the effects of disturbance at present and in the future and develop an evidence-based tool for management of access on Stone-curlew sites. We therefore collected data on the behavioural responses of Stone-curlews to disturbance and used them to build a mathematical model that relates the probability of a Stone-curlew showing a behavioural response to various measurable features of disturbance. In this paper, we show how this model can be used to develop a software tool to help site managers to make decisions about the management of access and habitats.

METHODS

Our study was carried out on plots created and managed as Stone-curlew nesting sites in Wiltshire and Hampshire, UK. In this area, approximately 60% of the first breeding attempts by Stone-curlews now occur on specially created plots each year. Each breeding season, around 250 plots are prepared for Stone-curlews in this area prior to the birds' return from their wintering areas in March. We wished to select a subset of plots from these that were within the current core range of the Stone-curlew in Wiltshire and Hampshire, so that the failure of a plot to be used for breeding would be unlikely to be caused by the chance absence of potential colonists. We did this by calculating, for each available plot in 2004 and 2005, the harmonic mean distance of the plot from all known breeding attempts in the years 2000, 2002 and 2003 (the 2001 Foot and Mouth year was excluded from this process as survey coverage was not complete). Available plots were then ranked and those with the smallest harmonic mean values were selected for study.

Watches of 1-h duration were conducted at these potential Stone-curlew breeding sites at 3- to 5-day intervals between 07:00 and 21:00 h from March to September and March to July in 2004 and 2005, respectively. Watches were made from a stationary vehicle situated at least 300 m from the plot. The vantage point was selected to overlook the maximum possible area around the plot within which disturbance agents would be visible to a Stone-curlew on the plot. The same vantage point was used in every visit. Data collection began after the observer had been in position for 15 min to allow any Stone-curlew present to settle from any disturbance the observer may have caused.

During the watches, routes followed by potential disturbance agents (PDAs), e.g. a walker, a walker and a dog, or a vehicle, were mapped onto aerial photographs. A stopwatch was started when the PDA first appeared and ran until it went out of view. On sites with Stone-curlews present a focal bird was also watched simultaneously and the time at which a change in behaviour observed was recorded. If the pair was breeding, the focal bird was the one incubating eggs or nearest the chicks. For birds with no breeding attempt in progress, an individual was selected at random.

Disturbance and behaviour data were collected from 41 plots and six other areas (four areas on Salisbury Plain where vehicular disturbance has created suitable nesting habitat, one breeding attempt on a maize game-strip and one breeding attempt on set-aside farmland), and involved 40 different pairs of Stone-curlews. Disturbance data were collected from a further 33 plots where Stone-curlews were not present.

A Stone-curlew usually stretches its neck or stands up (if initially sitting) or crouches (if initially standing) as the first visible response to disturbance (E.C. Taylor and R.E. Green pers. obs.). Collectively these are referred to as 'alert' responses. Stone-curlews may also run or fly as a first response, or after becoming alert they may run and then later fly. Running and flying are referred to as 'active' responses.

To model the probability of a response to a PDA the occurrence of a response of a particular type can be treated as binary response variables. We divided PDA routes observed into 1-mm sections. In each millimetre section traversed by a PDA along a route, a watched bird could either respond in a particular way or not (the binary response). The location of the PDA was interpolated at these millimetre intervals along the route using the start time, waypoint times and end times, and from these locations the distance between the focal bird and the PDA and the speed and direction of movement of the PDA were calculated. PDA velocity was resolved into two components: towards/away from the bird and at right angles to the line joining the bird and PDA. Once a bird had responded, e.g. by becoming alert, it was then assumed not to be available to respond in the same way again, so all subsequent data for that PDA event were discarded from the alert analysis. However, data from the event could still be used for the analysis of active responses. Similarly, once a bird had run or flown it was considered not to be available to respond again in this way to that particular PDA event. This modelling approach is similar to that used in survival analysis, for example by proportional hazards methods.

The variables in Table 1 were used to fit Minimal Adequate Models (MAMs) to predict the probability of occurrence of a response using logistic regression with a backwards-elimination model selection procedure. A hypothetical example of a MAM which predicts the probability of a response to a PDA could be:

$$\text{logit}(k) = a + b_1 * (\text{bird to PDA distance}) + b_2 * (\text{stage of breeding}) + b_3 * (\text{PDA type})$$

where k is the probability of a response and a and b are fitted constants from the logistic model. In this case, stage of breeding and PDA type are factors with several states, so the b values for these actually represent groups of coefficients for each factor.

In this hypothetical example, the bird to PDA distance, stage of breeding and PDA type are all important variables in determining the probability of a response being observed. We have fitted models separately for the two response types of alert and active at different phases of breeding and with different types of PDA, and also as larger general models with some coefficients (e.g. that for the effect of distance) shared across PDA types or breeding stages.

The product of modelled probabilities of the bird not responding $(1 - k)$ for all millimetre sections of a route, subtracted from 1, gives an overall probability of a response being observed for a given PDA event. By adding together these expected probabilities of responding for all PDA events observed during a timed watch, the expected rate of responses per hour can be calculated.

The regression models of Stone-curlew behaviour were then used in this way to calculate expected rates for active responses (running and/or flying, whichever occurred first) for all the study sites, both those with and without breeding Stone-curlews. Logistic regression models were then fitted with plot occupancy (breeding pair of Stone-curlews there or not) as the binary response variable and expected rate of active responses as the independent variable.

RESULTS

An example of the behaviour model

Analyses of the behavioural response of Stone-curlews to PDAs showed that the distance between

Table 1. Data recorded for each PDA event observed. Variables derived from maps of timed movements are italicised.

Data recorded	Details
Year and Julian date	
Stage of breeding	e.g. settlement (pre-egglaying), egg, chick, roost
Position of Stone-curlew	Transferred onto aerial photo or map
Type of PDA	e.g. walker, walker + dog, jogger, vehicle
Route of PDA visible to Stone-curlew	Transferred onto an aerial photo or map
Group size of PDA	Number of different components, e.g. number of people, number of dogs
Reaction by Stone-curlew in response to PDA	Classified as alert, run, fly
Position PDA is at when Stone-curlew responds	Marked onto aerial photo or map
Time elapsed between first exposure to PDA and response	Measured in seconds
Time taken for Stone-curlew to return to plot/nest/chicks	Measured in seconds
Time at end of event	Time elapsed from start point to end point of the route taken by PDA. Measured in seconds
Distance of PDA from Stone-curlew at points along route	*Interpolated at 1-mm intervals. Measured in metres*
Distance between PDA and Stone-curlew at reaction	*Measured in metres*
Speed of PDA	*Metres per hour*
Speed of PDA directly towards or away from Stone-curlew	*Component of PDA speed along the line connecting the PDA and bird. Metres per hour*
Speed of PDA perpendicular to Stone-curlew	*Component of PDA speed perpendicular to the line connecting the PDA and bird. Metres per hour*

the Stone-curlew and the PDA had the strongest effect on the probability of both alert and active responses. The relationship of response probability to distance was negative and highly significant in all of our analyses. Hence, as a PDA comes closer to a Stone-curlew there is an increased probability, per unit distance traversed, of a response being observed. Even at long distances (> 300 m) the probability of running or flying was elevated relative to that when the PDA was further away or absent. The probability of response per unit distance traversed by the PDA also varied with PDA type; for example, after allowing for the effect of distance, birds were more likely to respond by running or flying from a walker with a dog, than a walker without a dog, or than a motor vehicle (Fig. 1).[1]

In addition to the distance between the PDA and the Stone-curlew and the disturbance type, other variables were found to be important. Given the differences between PDA types observed in Figure 1, we split PDA types into motor vehicle and non-motor vehicle PDA types[2] and modelled responses to these groups of PDA separately. For non-motor vehicles additional significant variables in the MAM were stage of breeding, disturbance type, presence of a dog and the speed of the PDA directly towards or away from the Stone-curlew (Table 2). For motor vehicles, the speed perpendicular to the Stone-curlew showed a negative relationship with the probability of an active response. Another important variable for motor vehicles was whether the PDA was on a frequently used expected route, such as a metalled track. There was a lower probability of an active response when the vehicle was on the most regularly used route at a site, referred to as the expected route (Table 3).

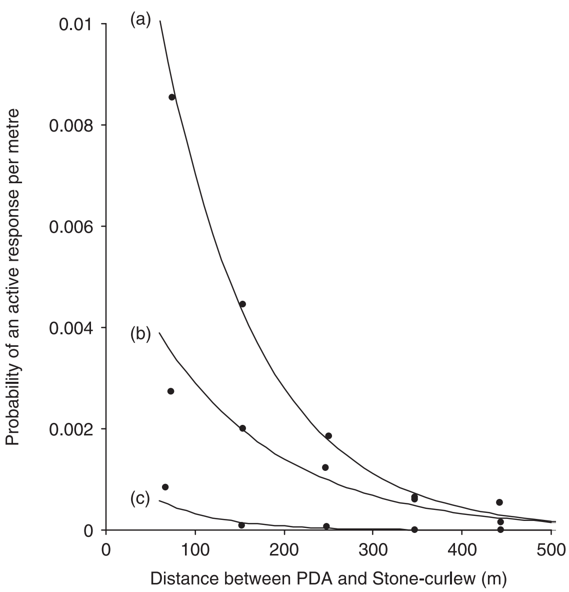

Figure 1. Probability per metre traversed of an active response (running or flying) by a Stone-curlew to a PDA in relation to distance between the bird and the PDA. Points are for distance bins and lines are fitted logistic regression models.[1] Results are shown separately for (a) walker with a dog, (b) walker and (c) vehicle. PDA, potential disturbance agents.

Variables which were not significant in either of the models were the year of study (2004 or 2005 seasons), Julian date (within each year), group size of PDA (e.g. number of people in a group of walkers) and time elapsed from first exposure of the bird to the PDA.

Occupancy of breeding sites in relation to modelled disturbance rate

Using the MAMs in Tables 2 and 3, the probability of an active response to each of the observed PDA events at sites with and without Stone-curlews could be derived and the expected rate of active responses per hour calculated for each site.

Logistic regression analysis of plot occupancy in relation to the estimated rate at which active responses occurred indicated a significant negative effect of expected disturbance rate on whether a plot was used for breeding. The proportion of plots in our sample that were used by breeding pairs for their first clutches of the season in 2004 and 2005 declined rapidly with increasing estimated rate of active responses to disturbance during spring (defined as 20 March–20 April inclusive) when the birds are settling on plots (Fig. 2).

DISCUSSION

Stone-curlews had an elevated probability of showing an active response to a potential disturbance agent, even at large distances (in excess of 500 m for a person with a dog). It therefore appears that Stone-curlews may be more sensitive to disturbance than some other wader species. For example, Lord *et al.* (2001) report flushing distances of less than 100 m for New Zealand Dotterels *Charadrius obscurus aquilonius*; and in an experimental study in which a person on foot walked directly towards waders and waterbirds in Florida, USA, Rodgers and Smith (1995) reported that the largest mean flushing distance of 15 species

Table 2. Parameter estimates from a logistic regression model relating the probability of an active response of a Stone-curlew per millimetre of route taken by non-motor vehicle PDA events to distance between the Stone-curlew and PDA event, speed directly towards or away, disturbance type (factor, four levels), and stage in breeding season (factor, five levels). The logit expected probability of response at the settlement stage, when the disturbance type is walkers on foot without a dog and for zero speed and distance is given by the intercept value. The logit of the probability of an active response to a PDA at a specified speed and distance is obtained by adding to the intercept the sum of the products of the regression coefficients (listed as parameter estimates) and dummy variables representing the factors and the observed speed and distance. Changes in deviance, degrees of freedom and *P* values from a likelihood-ratio test are shown for the effect of deleting each variable from the final MAM. The residual deviance of the model is 1878.26 with 10883 degrees of freedom.

	Parameter estimates	Reduction in residual deviance	*df*	*P*
Intercept	−12.2067			
Stage (Factor)		27.5198	4	< 0.0001
Settlement	0			
Egg	0.4290			
Chick	0.5196			
Post failure	−0.4706			
Roost post breeding	−0.6022			
Disturbance type (Factor)		58.4280	3	< 0.0001
People on foot	0			
Joggers	−1.1104			
Horse-riders	−1.6448			
Cyclists	−2.8338			
Presence of dog (Factor)	0.7674	39.4931	1	< 0.0001
Speed (directly towards or away)/metres per hour	0.00006135	17.4684		< 0.0001
Distance/metres	−0.008591	395.7836	1	< 0.0001

Table 3. Parameter estimates from a logistic regression model relating the active response of a Stone-curlew per millimetre of route taken by motor vehicle PDA events to distance between the Stone-curlew and PDA event, speed in a sideways direction, and expected route (factor, two levels). The logit expected probability of response when the PDA is on an unexpected route and for zero speed and distance is given by the intercept value. The logit of the probability of an active response to a PDA at a specified speed and distance is obtained by adding to the intercept the sum of the products of the regression coefficients (listed as parameter estimates) and dummy variables representing the factors and the observed speed and distance. Changes in deviance, degrees of freedom and *P* values from a likelihood-ratio test are shown for the effect of deleting each variable from the final MAM. The residual deviance of the model is 210.2307 on 2648 degrees of freedom.

	Parameter estimates	Reduction in residual deviance	*df*	*P*
Intercept	−10.7985			
Expected route (Factor)	−2.3248	41.8313	1	< 0.0001
Speed (sideways component) /metres per hour	−0.00005615	23.3620	1	< 0.0001
Distance/metres	−0.009353	47.9676	1	< 0.0001

was 32.0 m. For California shorebirds, flight initiation distance for five species of waders did not exceed approximately 40 m (Ikuta & Blumstein 2003). Similarly, a study of Kentish Plovers *Charadrius alexandrinus* found that most birds did not flush from PDAs at distances exceeding 40 m (Lafferty 2001). Breeding Golden Plovers *Pluvialis apricaria* showed an alarm response at an average of 187 m (Yalden & Yalden 1989), but the average flight initiation distance was not measured, and presumably would have a lower value. Raptors show reactions to disturbance at longer distances than most waders. For Spanish Imperial Eagles *Aquila adalberti* the probability of a reaction increased sharply when activities occurred at less than 450 m from the nest, but was negligible if they occurred at 800 m (Gonzalez *et al.* 2006). These distances are similar to those recorded in other large raptors such as Golden Eagle

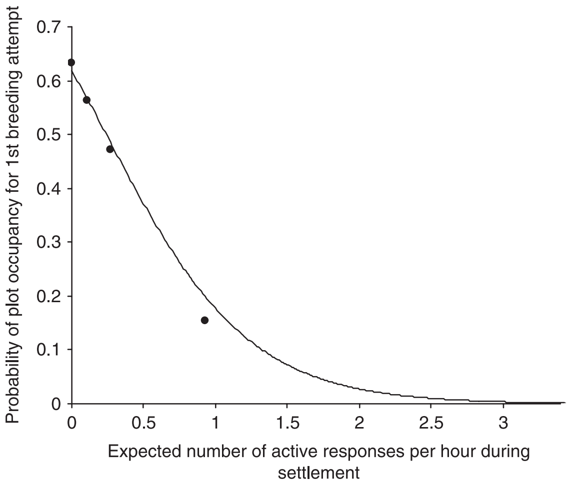

Figure 2. Probability of occupancy of nesting plots by Stone-curlew for first breeding attempts in relation to expected number of active responses per hour, calculated from observations of potential disturbance agents. The points are the proportions of occupied plots for bins of the expected number of active responses and the line is the logistic regression model fitted to the disaggregated data. Sample sizes (the number of Stone-curlew plots) for the four bins are 71, 16, 17 and 13, respectively. Data from 2004 and 2005 breeding seasons are combined. To be eligible, plots must have been prepared and available to Stone-curlews from 1 March (56 and 61 plots were available in 2004 and 2005, respectively).

Aquila chrysaetos (Holmes *et al.* 1993), and slightly higher than those recorded in Bald Eagle *Haliaetus leucocephalus* (Stalmaster & Newman 1978, Fraser *et al.* 1985, Grubb & King 1991).

For Stone-curlews the probability of an active response varied with disturbance type. In particular, there is a higher probability of an active response per unit distance traversed by the PDA when the disturbance event involved people on foot and non-motor vehicles compared with motor vehicles. These findings are supported by other studies (Richardson & Miller 1997, Gonzalez *et al.* 2006). Furthermore, in common with other studies, the presence of a dog with a walker led to a higher probability of response than to a walker alone (Burger 1981, Yalden & Yalden 1990, Lord *et al.* 2001).

Beale and Monaghan (2004) found that nest success of Black-legged Kittiwakes *Rissa tridactyla* and Common Guillemots *Uria aalge* was negatively related to 'people load', a combination parameter that included both the number of visitors per disturbance event and their distance from nests. In our study, the number of people, dogs or vehicles in a PDA event was found not to have a significant effect, in addition to the presence of the PDA itself, in any models of behavioural responses of Stone-curlews. However, this lack of association between PDA group size and active responses may have been due to low statistical power because PDA group sizes greater than one were rare in our study.

Many disturbance studies make recommendations for management of access based on mean flushing distance. These recommendations usually involve buffer zones or set-back distances where disturbance is excluded within a certain distance (Rodgers & Smith 1995, Richardson & Miller 1997, Rodgers & Schwikert 2002). We suggest that for Stone-curlew sites, the models described in this paper can provide data of practical value to users interested in the impact of specified patterns of disturbance. First, models can quantify the per-event probability of a Stone-curlew responding in a particular way to a hypothetical PDA event with specified characteristics. To do this, mapped data on the location of the focal bird (e.g. a nest-site) and the route, type and speed of the PDA are created and the logistic regression equations described above are used to generate probabilities per unit distance of an active response. From those, probabilities of response per event are calculated. Secondly, by specifying the likely frequency of PDA events, the models can be used to obtain expected rates at which responses are shown (e.g. expected number of active responses per hour).

To aid the evaluation of the impact of specified disturbance at real sites, the statistical models have been used to construct a software package known as the Stone-Curlew Access Response Evaluator (SCARE).

SCARE is a user-friendly interface whereby the user can take a built-in map, digital terrain model and information on screening vegetation for a real site and explore the consequences of various patterns of access to that site (e.g. different disturbance types and frequencies, path or track routes) and various mitigation measures (e.g. closure of areas, additional screening with boards or hedges, redirection of paths, relocation of Stone-curlew nesting plots). PDA types covered by SCARE are walkers, walkers with dogs, motor vehicles (including military vehicles), joggers, cyclists and horse-riders. The user can specify Stone-curlew locations (e.g. nest-sites) using real location data or proposals for the creation of artificial nesting plots. The user can also specify and alter routes likely to be used by PDAs, and PDA types and frequencies.

Outputs from the software include a map of the site showing the 'viewshed' (the area around the breeding site within which PDAs are visible to the bird). The user specifies the routes to be used from a file of coordinates or by dragging the cursor across the map, and identifies a mixture of PDA types and the frequency of PDA events. The program then calculates the expected rate at which a Stone-curlew would make active responses. Finally, the empirical relationship between plot occupancy and the modelled rate of disturbance is used to estimate the expected reduction in the probability of the plot being used by nesting Stone-curlews, compared with what would be expected with no disturbance.

The impact of changing the disturbance scenario can then be explored. For example, the user can change the type and frequency of PDAs, the location of an access route, the location or size of an open-access or closed area, or the location of screening vegetation, and obtain revised estimates of the impact on Stone-curlews. The effect of changing the location of the Stone-curlew plot can also be evaluated, which is of applied value because shallow cultivation of surface soil can be used by site managers to produce nesting substrates preferred by Stone-curlews and hence to shift their nesting location within a site.

SCARE reconciles the need for public access to open landscapes with the need for continued conservation of Stone-curlews at existing and future potential breeding sites. It offers a way to assess the effects of hypothetical scenarios for future changes in disturbance type, routes and frequency, including the manipulation of disturbance levels. We hope that this tool will be valuable in informing decisions concerning areas to be opened up for access or closed for part of the year when Stone-curlews are breeding. Furthermore, although SCARE is currently a single-species tool, it provides a framework by which other species could be assessed if data are available for the modelling procedure.

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ENDNOTES

[1]The models in Figure 1 relating the probability of an active response per millimetre in relation to distance between the PDA event and the Stone-curlew are given by the following equations:

People on foot without a dog:

$$\ln(p/1-p) = -12.019933 - 0.007263 * \text{distance between Stone-curlew and PDA.}$$

People on foot with a dog:

$$\ln(p/1-p) = -10.943140 - 0.009199 * \text{distance between Stone-curlew and PDA.}$$

Vehicles:

$$\ln(p/1-p) = -13.481626 - 0.014492 * \text{distance between Stone-curlew and PDA.}$$

In these models any additional effects of other explanatory variables were excluded. Figure 1 shows probabilities per metre, rather than millimetre, for clarity.

[2]PDA types were split into non-motor vehicle and motor vehicle groups for separate analysis. The non-motor vehicle group comprised people on foot, joggers, cyclists and horse-riders. The motor vehicle group included vehicles, motorbikes, tanks and other military vehicles.

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