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The Effects of Gravel Bar Construction on Breeding Long-billed Plovers

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Abstract.—In Japan, the habitat range of Long-billed Plovers (*Charadrius placidus*), a typical river-nesting species, has contracted by 17% over the past 20 years. In the Tama River, Kanto region, the Tama River Research Group created a gravel bar in 2001 and 2002 by removing an invasive and non-native woody plant, Black Locust (*Robinia pseudoacacia*), to restore the biodiversity of the river ecosystem. The study investigated the effect of the gravel bar creation on Long-billed Plovers and their nest-site preference during the breeding seasons in 2001-2004 and 2006. After gravel bar creation, the mean number (±SE) of observed Long-billed Plovers increased from 0.4 (±0.19) to 11.0 (±1.54), which indicates that artificially constructed habitats have a potential to restore populations of Long-billed Plovers. The hatching rates in the study site varied greatly (19% to 100%) from year to year, and comparison with earlier studies was difficult due to incomplete information about the breeding conditions and differences in survey methods. Nesting probability was affected negatively by gravel size and positively by distances from forest edges, even after considering spatial auto-correlation caused as a result of having continuous sampling grids. *Received 9 March 2009, accepted 24 December 2009.*

Key words.—*Charadrius placidus*, conditional autoregressive model, disturbance-dependent species, substrates size, vegetation management.

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In recent years, abundances of most bird species associated with habitats maintained by disturbance, such as flood plains, grasslands and savannas, have declined steeply (Brawn *et al.* 2001; Hunter *et al.* 2001; Newton 2004; Bart *et al.* 2007; Nebel *et al.* 2008). Among the main causes are developments leading to habitat loss and degradation through the suppression of natural disturbance (Brawn *et al.* 2001; Nebel *et al.* 2008; Kurosawa 2009). Thus, artificial habitat creation, which restores natural disturbance, is thought to be an effective means of ameliorating population declines (Brawn 2006; Caruso 2006; Eglington *et al.* 2008; Jennings and Pletter 2008).

Long-billed Plovers (*Charadrius placidus*) breed in the Ussuri Region of Russia, northeastern China, and Korea, and overwinter in northern India and China (Rai 1995). In Japan, the Long-billed Plover is a resident species and breeds on gravel and sand sediments in the upper and middle reaches of rivers (Rai 1995; Hirai 1999). Between 1978 and 1998-2002, the distribution of this species contracted by 17% in Japan (Amano and Yamaura 2007). The loss and degradation of breeding habitats is believed to have caused this range contraction (Rai 1995; Hirai 1999). Long-billed Plovers prefer exposed gravel/sand bars with little or no vegetation as breeding sites (Rai 1995; Hirai 1999). While annual floods prevent vegetation growth on most riverbeds under natural conditions, recent flow regulations by the Japanese government have reduced flood frequencies and enhanced vegetation growth in these habitats (Nakamura *et al.* 2006; Osugi *et al.* 2007). Thus, the resulting decline in the area of exposed riverbeds may have caused habitat loss/degradation for breeding plovers.

The Tama River, Kanto Region, Japan exemplifies the problems found in Japanese rivers: high degrees of urbanization, dam construction, flood regulation, loss of exposed gravel sediments and massive invasions by exotic plants (Osugi *et al.* 2007). In the river, the Tama River Research Group has carried out restoration projects since 1996 (Nakamura *et al.* 2006; Unno *et al.* 2006; Osugi *et al.* 2007). In one of its main projects, the group created an artificial exposed gravel sandbar in the middle reach of the river in order to conserve native plants and animals associated with natural riverbeds, such as *Aster kantoensis* (Asteraceae) and *Eusphingonotus japonicus* (Saussure). As the first step, all the plants, including Black Locust (*Robinia pseudoacacia*) were removed from the restoration area between March and June 2001. Then, the bare grounds were covered with gravel sediments between November 2001 and March 2002. In this area, there seem to several factors affecting nest site preference of Long-billed Plovers. First, Long-billed Plovers seem to prefer small-sized gravel because they create nests by digging shallow dents (approximately 10 cm in diameter and 3 cm in depth) and augmenting them with small stones (weight <5 g, diameter <1 cm) (Rai 1995). Secondly, disturbance factors, such as the distance from habitat edges, seem to affect nest site preference, as revealed in many shorebird species (e.g. Berg *et al.* 1992).

The project enabled us to investigate the effectiveness of habitat creation for breeding Long-billed Plovers in the Tama River. For this purpose, we investigated the (1) number of breeding Long-billed Plovers in the study site before and after the habitat creation, (2) hatching success in the study site and in other sites in Japan, and (3) relationship between nesting probabilities and environmental factors.

METHODS

Study Area

Research was conducted in the Nagata district (35°44'N, 139°19'E), located in the middle reach of the Tama River (Fig. 1). Here, water flow is constant (approximately 2 m^3/s) as it is controlled by a weir located approximately 2 km upstream from Nagata Bridge (Unno *et al.* 2006). The area is a key restoration site, as it retains some endemic species associated with typical riverbeds in the middle reaches of Japanese rivers (Osugi *et al.* 2007). Artificial exposed gravel/sand areas were created by removing all the plants such as *R. pseudoacacia* (Fig. 1). While most remaining natural areas are also exposed gravel/sand bars, a few areas are dominated by grass plants, such as *Phragmites japonica* (Poaceae) and *Miscanthus sacchariflorus* (Poaceae) (Fig. 1).

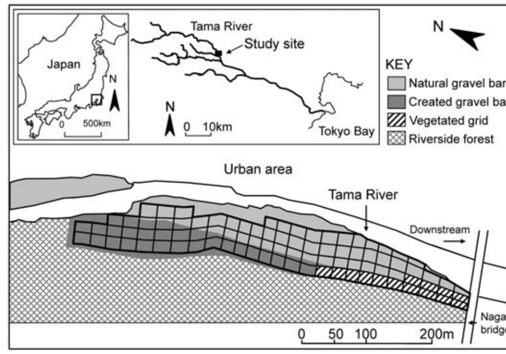

Figure 1. Study area and the location of the gravel bar created in the Nagata district of the Tama River, Kanto Region, Japan.

Long-billed Plovers initiate pairing and territory establishment in February and commence incubation in March (Rai 1995; Hirai 1999). The species nests on gravel/sand bars and forages on larvae and nymphs of aquatic insects such as Ephemeroptera and Tipulidae along river margins in their territories (Rai 1995). They are known to re-nest if they fail to breed, and their breeding season continues until August (Rai 1995; Hirai 1999; Uchida unpublished data). In the following section, we defined the breeding season as the period from March to July when this species lays eggs.

Monitoring Plover Numbers and Nests

We periodically counted the number of Long-billed Plovers in the study area (approximately 600m by 100m) by line transect census surveys from March to July in 2001-2004 and from March to June in 2006. The frequency of counts varied from two to four times a month in 2001-2004, and from once to twice a month in 2006. Two researchers conducted all the surveys. They walked through the center of the study area at a speed of 2 km/h, and recorded the time, location, number and life stage (adult or juvenile) of observed plovers. To determine the inter-annual variation in the number of observed individuals, we used only the number of adults, but could not identify the actual number of breeding pairs because we did not mark each individual.

We searched for nests at least one day a week during the breeding season from 2002 to 2004 and in 2006 (total of 22, 7, 16 and 26 days in each year). Because it was difficult to find nests by direct observations in the gravel bar due to camouflage coloration of the eggs, we observed the river margins from the opposite shore, using a spotting scope to find foraging plovers. The shore is located approximately 10 m above the gravel bar and enabled us to overlook the whole study area. After finding a foraging individual, we tracked the movements of the focal individual and identified the location where the individual sat on the ground for incubation. We visited the identified locations in the absence of plovers, confirmed the presence of a nest, and recorded the clutch size within 1 min of arrival to reduce the risk of nest predation by crows. After finding the nests, we visited all the nests at least once a week during the breeding season. We recorded the presence or absence of eggs and the clutch size on each visit to estimate the hatching success. Because female Long-billed Plovers lay one egg per day (Rai 1995) and their clutch size is commonly four (Rai 1995; Hirai 1999), we regarded a clutch as complete when the number of eggs reached four or was unchanged between two successive visits separated by at least two days. When eggs disappeared after a clutch was defined as complete, we checked the number of successfully hatched chicks. Chicks of Long-billed Plovers spend 30-50 days within the territory of the parents and forage along river margins (Hirai 1999). Thus, we counted the number of hatched chicks by observing the river margin from the opposite shore for at least two days (between 07:30 and 16:30 JST) within two weeks of hatching. When no chick was observed, we approached the nest to confirm the absence of alarm calls, because parent birds usually give alarm calls if predators approach chicks in their territory (Rai 1995).

Environmental Variables

We divided the whole study area into 89 contiguous virtual grids, the centers of which were distributed regularly (approximately 25 m apart; Fig. 1). Most grids were approximately square-shaped, but some were rectangular. To model the nesting probability of Long-billed Plovers in each grid, we selected the following two environmental variables: mean gravel size and distance from forest edges. These variables were investigated only in non-vegetated grids (exposed grids) because in vegetated grids dried grasses fully covered the surface of the ground, making gravel inaccessible to plovers. We defined a grid as "vegetated" if more than half of the total area of a grid was covered by vegetation (mostly grass plants). In February 2004, we placed a 0.5 × 0.5 m square quadrat at the center of all the exposed grids (75 out of 89), and collected from up to 1 cm below the surface of the ground all gravel of diameter longer than 0.2 cm. We classified the gravel into four categories (<1 cm, 1-2 cm, 2-3 cm and >3 cm in longest diameter), measured the total number and weight in each class grid, and then calculated the mean weight (kg) of all gravel with a diameter of >1 cm, which was used as mean gravel size in the following analysis. We did not conduct these surveys in other years because the distribution of vegetation and gravel appeared stable over the years. Also, we classified the distance from forest edges (m) in each grid into four categories (25 m, 50 m, 75 m, and 100 m) according to the location of each grid.

Data Analysis

Hatching success—We estimated hatching rates, defined as the proportion of nests from which at least one egg successfully hatched, in the study area both as apparent nest success and with the Mayfield method (Mayfield 1975). Apparent success is a more accurate estimate of true hatching success than the Mayfield estimate when nest losses do not occur constantly within the incubating period and detectability of nests is fairly high (Johnson and Shaffer 1990). As we could not assess the detectability quantitatively, we compared and discussed the results of both approaches. In addition, we reviewed the hatching rates estimated by earlier studies in other sites in Japan to compare with those in this study site.

Nest site preference—We modeled the relationships between the presence/absence of nests in 75 exposed grids and the two environmental variables, mean gravel size (kg) and distance from forest edges (m), using logistic regression with survey years as a random variable. The explanatory variables were standardized before the analysis. Because the data were sampled in contiguous grids, the presence/absence of nests in one grid may have been associated with that in neighboring grids. Therefore, we included random spatial effects in the model [the conditional autoregressive form (CAR) of logistic regression; Latimer *et al.* 2006]. The model was expressed as follows:

$$\mathrm{Log}\frac{\rho_i}{1-\rho_i} = \beta_0 + x_i\beta_i + \rho_i + \rho_{\mathrm{year}}$$

where ρ_i is the probability that the nest occurs in cell i, β_0 is an intercept, x_i is a vector of explanatory environmental variables associated with cell i, β_i is a vector of the associated coefficients, and ρ_{year} is a random effect associated with survey years. Each grid cell has an associated random effect ρ_i that adjusts the probability of the presence of the modeled nest dependent upon the values of ρ in cell i's spatial neighborhood cell j. ρ_i conditioned on ρ_j was specified as follows:

$$\rho_i/\rho_j \approx N\left(\frac{\Sigma_{j\varepsilon\delta i}\alpha_{ij}\rho_i}{\alpha_{i+}}, \frac{\sigma_\rho^2}{\alpha_{i+}}\right) \quad j \neq i$$

where a_{i+} denotes the total number of cells that were neighbors of i, and a_{ij} = 1 if sites i and j share the same boundary, and a_{ij} = 0 otherwise. The conditional variance of the Gaussian Markov random field, σ^2_ρ, is a hyper-parameter that requires a prior distribution. We assigned a gamma distribution with a mean of 1 and variance 100 as a prior distribution for the inverse of σ^2_ρ, and for the β_0, β_1 and ρ_{year} we assigned the normal priors with a mean of 0 and variance 1000. The model was fitted by the Bayesian simulation-based method in the statistical software R (R. Development Core Team 2007) and WinBUGS 1.4. We used the code provided by Fukasawa and Kadoya (2008), using R package R2WinBUGS to execute WinBUGS while running a session in R. The numbers of Markov chain Monte Carlo (MCMC) steps, burn-ins, thins and chains were 50000, 25000, 25, and 3, respectively.

RESULTS

The number of Long-billed Plovers observed during the breeding season increased after gravel bar creation between 2001 and 2002, but did not change greatly from 2004 to 2006 (Fig. 2).

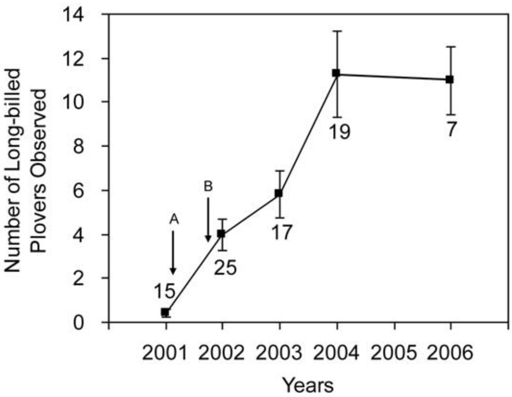

Figure 2. Inter-annual changes in the number of observed Long-billed Plovers in the breeding season (from March to July 2001-2004 and from March to June 2006) in Nagata District. Points and error bars represent mean numbers and standard errors, respectively. The number of surveys in each year is shown above or below each point. Arrow A indicates when *Robinia pseudoacacia* was removed (from March to June 2001) and arrow B when bare grounds were covered with gravel sediments (from November 2001 to March 2002).

We found 36 pairs of Long-billed Plovers in the breeding seasons from 2002 to 2004 and in 2006, and identified the precise location of nests for 30 pairs (another six pairs were found with their chicks). We found the first nest on 3 April and the last on 5 July, but the first observations of pairs with chicks occurred on 16 April, then 25 April. Of the 36 pairs, eggs successfully hatched in 15 but failed in 16, and hatching success was unknown for five. The causes of nest failure were mostly unknown (13 nests disappeared and one was wrecked), but two were predated by crows (*Corvus corone*) (confirmed by direct observations). The hatching rates in this study (and other studies) are shown in Table 1. The estimated values of apparent and Mayfield successes were similar from 2002 to 2004, whereas the values differed greatly in 2006, when a particularly large number of nests were lost. However, comparing hatching successes between our study and other studies was difficult because the hatching rates in the other sites were calculated only as apparent successes. We could not gain accurate information about the number of nests, the number of successful nests, and the number of days in which nests were predated—all of which are necessary for calculating the Mayfield success in these studies. The apparent successes in other studies varied by sites and years (from 3% to 45%).

We found 30 nests within 21 grids (five within five in 2002, one within one in 2003, eight within eight in 2004, and 16 within 13 in 2006). We excluded the data for 2003 from the CAR model due to the low number of nests caused by poor searching efforts (Seven days; see Methods). In the CAR model, the posterior distribution of parameters was converged well (i.e. the values of R-hat were close to 1). The nesting probability of Long-billed Plovers significantly increased with decreasing mean gravel size in the grids and increasing distance from forest edges (Table 2).

DISCUSSION

In recent years, vegetation encroachment of riverbeds due to the decreases in flood frequency has occurred in many Japanese rivers (Nakamura *et al.* 2006; Osugi *et al.* 2007). After the creation of a gravel/sand bar by the removal of vegetation, numbers of Long-billed Plovers increased (Fig. 1). Such indicates that artificial habitat creation can be useful for attracting breeding Long-billed Plovers. The underlying reason why Long-billed Plovers avoid vegetated areas is unknown, but it seems physically difficult for them to create suitable nests in vegetated areas (see Methods). Also, vegetated areas may be exposed to higher nest predation rates by mammals and other predators. These predators often prefer dense vegetation (Alterio *et al.* 1998; Zuria *et al.* 2007), where they pose higher nest predation risks to disturbance-dependent avian species such as members of the Charadriidae and Sternidae families (Kotliar and Burger 1986; Knopf and Rupert 1996; Johnson and Oring 2002; Marcus *et al.* 2007; Norbury and Heyward 2008). In the Tama River, there are several potential predators on plovers, such as Japanese Weasel (*Mustela itatsi*) and the Large Japanese Field Mouse (*Apodemus speciosus*) (Fujii *et al.* 1998).

Table 1. Hatching rates of Long-billed Plovers in different sites and years in Japan. Notes in parentheses next to the river's name represent the prefecture, surveyed length (substitute for the size of study area), survey frequency, survey methods[a], and reference, respectively.

Year	Number of nests	Nest success[b] Apparent	Nest success[b] Mayfield	Mayfield 95% CI[c] Lower	Mayfield 95% CI[c] Upper
Sakawa (Kanagawa, 0.7km, 5-7d/wk, tracking, Rai 1995)					
1985	5	20%	—	—	—
Toki (Saitama, 5km, 5-7d/wk, tracking and line transect census, Uchida unpublished)					
1987	39-75	45%	—	—	—
1988	39-75	26%	—	—	—
1989	39-75	3%	—	—	—
1900-1993	39-75	<15%	—	—	—
Ano (Mie, 9.5km, 1-3d/wk, tracking, Hirai 1999)					
1998	10	20%	—	—	—
Suzuka (Mie, 5km, 1-3d/wk, tracking)					
1998	13	39%	—	—	—
Tama (Tokyo, 0.7km, 1-3d/wk, tracking, this study)					
2002	6	60%	54%	23%	100%
2003	3	100%	100%	100%	100%
2004	10	86%	80%	52%	100%
2006	17	19%	0.3%	0.01%	7%

[a]Details of tracking survey are described in the methods section.
[b]Nest success was defined as the proportion of clutches in which at least one egg hatched, and calculation of the Mayfield success rate was possible only in this study (an explanation has been provided in the results section).
[c]The equation for calculating 95% confidence intervals was obtained from Jennings and Plettner (2008).

Table 2. Estimated posterior distributions of model parameters examining the nesting probability of Long-billed Plovers determined by the conditional autoregressive (CAR) model with the survey years as a random variable.

Standardized variable	Median of coefficient	95% CI[a]	R-hat
Mean gravel size (kg)	0.87	[0.25, 1.56]	1.00
Distance from forest edges (m)	-8.33	[-15.93, -2.87]	1.00

[a]95% credible interval.

Hatching rates in the study area from 2002 to 2004 were similar for both apparent and Mayfield estimates (Table 1), which may be an indication that the estimates are close to the true hatching success in those years. On the other hand, estimated rates generated by the two methods were different in 2006. We suspect that apparent success is closer to the true success rate than the Mayfield rate because one of the important assumptions of the Mayfield method, that nest losses occur constantly during an incubation period, was violated (Katayama unpublished data). However, we could not confirm whether apparent success is an accurate estimate of true success because we could not quantitatively verify high detectability of nests. Moreover, direct comparison of hatching success in this study with those in earlier studies is difficult, although the hatching rates in this study seemed to be higher than those in other sites except in 2006. This is due to differences in the survey method in each study (Table 1). To rigorously assess the nest success of Long-billed Plovers at different sites and years, survey methods and analyses have to be unified in future studies.

In exposed gravel areas, Long-billed Plovers avoided areas with large gravel sediments and/or near forest edges as nest sites. Large gravel may not be suitable as nest-building material for this species, but we surmise that the presence of small gravel (<1 cm) is important. In fact, nesting Long-billed Plovers prefer areas with gravel sediments to those covered only with sand (Rai 1995; Hirai 1999). Although other plover species are known to prefer areas with mixed substrates (Graul 1975; Colwell *et al.* 2005; Marcus *et al.* 2007; Cohen *et al.* 2008), where eggs and chicks seem to be less vulnerable to predators and/or bad weather, a suitable composition of substrates has not been quantitatively investigated (however, see Marcus *et al.* 2007).

There are several potential explanations for the effect of distance from forest edges on nest site preference. For example, locations close to forests may be associated with a high predation risk. Aerial predators such as crows, one of the main predators of Long-billed Plovers in Japan, often use elevated structures such as trees in searching for prey (Berg *et al.* 1992; Wallander *et al.* 2006), and pose higher predation risks to eggs and chicks of the Charadriidae family (Page *et al.* 1985; Berg *et al.* 1992; Lauro and Tanacredi 2002; Powell *et al.* 2002; Murphy *et al.* 2003). In addition, Long-billed Plovers may prefer locations near river margins to those near forests because of the accessibility to foraging sites. To further explore the effect of the distance from forest edges, we need to investigate the relationships between the location of nests and factors affecting breeding success directly, such as predation risk and feeding frequency.

In conclusion, our study revealed the potential effectiveness of gravel bar creation in restoring suitable nesting habitats for Long-billed Plovers and quantitatively assessed factors affecting nest site preference other than the presence of vegetation. Although these conclusions are based on a survey conducted in one study site, the nest site preferences revealed in this study are similar to those of other plover species. Thus, we believe that these conclusions are widely applicable to other parts of Japan. Nevertheless, we recognize several challenges for future conservation studies. First, the generality of nest site preferences revealed by this study must be tested in other sites in Japan. Secondly, whether the preferences are truly related to breeding success should be confirmed. Finally, we need to assess whether predator controls combined with vegetation management would further increase the breeding success of this species. These studies should contribute to the conservation of not only Long-billed Plovers but also other disturbance-dependent avian species.

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