Research Article

Determinants of Mallard and Gadwall Nesting on Constructed Islands in North Dakota

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Abstract

*Constructed islands with adequate nesting cover provide secure nesting sites for ducks because islands restrict access by mammalian predators. These islands are costly to construct and should be placed in areas that ensure the greatest use by nesting ducks. We studied mallard (*Anas platyrhynchos*) and gadwall (*A. strepera*) nesting on constructed islands in North Dakota in 1996 (*n = 20*) and 1997 (*n = 22*) to evaluate factors—particularly amount of perennial grass cover in the surrounding landscape and density of breeding pairs—that possibly influence numbers of initiated nests. We also examined effects of island characteristics, such as island vegetation, on numbers of nests. Numbers of mallard and gadwall nests on islands were negatively related to amounts of perennial grass cover in the surrounding uplands. Numbers of mallard nests were positively related to percentages of tall dense cover on islands. We found no effects of breeding-pair density on numbers of nests initiated by either species, possibly because breeding pairs were abundant on all study sites. Percent shrub cover on islands was a better predictor of island use than was percent tall dense cover. Island use by these species increased with island age and distance from mainland shore. Amounts of perennial cover in landscapes should be primary considerations in determining where to build islands. Our data suggest that use of islands by nesting mallards and gadwalls is greatest in landscapes with little perennial grass cover (i.e., high amounts of cropland). Other researchers documented a positive relation between nest success in upland covers and amount of perennial grass cover in the landscape. Therefore, islands constructed in landscapes with little perennial cover should provide greater gains in duck recruitment rates than islands constructed in landscapes with greater amounts of perennial grass cover.* (JOURNAL OF WILDLIFE MANAGEMENT 70(1):129–137; 2006)

Key words

Anas platyrhynchos, Anas strepera, *breeding-pair density, constructed islands, duck nesting, gadwall, landscape, mallard, nest density, North Dakota, perennial grass cover.*

Islands in the Prairie Pothole Region (PPR) are often sites of high duck nest density and nest success (Lokemoen et al. 1984, Willms and Crawford 1989), which appears to be related to restricted predator access (Duebbert 1966, Lokemoen et al. 1982, Duebbert et al. 1983). Considerable information on how to build and manage islands is available to managers. Characteristics of suitable wetlands (e.g., wetland size, class, emergent cover, water depth) and the islands themselves (e.g., size, shape, position, slope, distance to shore, vegetation) are generally well understood (Giroux 1981*b*, Duebbert 1982, Lokemoen and Messmer 1993). The importance of maintaining islands free of predators and providing dense cover is well established (Duebbert et al. 1983, Willms and Crawford 1989, Aufforth et al. 1990). On the other hand, little attention has been given to developing guidelines for selecting landscapes in which to build islands. Islands are costly to construct and should therefore be situated to maximize benefits to nesting waterfowl (Lokemoen 1984).

Partners in the Prairie Pothole Joint Venture of the North American Waterfowl Management Plan (PPJV) used a stochastic model of mallard productivity (hereafter the Mallard Productivity Model; Johnson et al. 1987, Cowardin et al. 1988) to simulate potential outcomes of management treatments designed to increase mallard production in the U.S. PPR (Prairie Pothole Joint Venture. 1996. Multiple-Agency Approach to Planning and Evaluation [MAAPE], Bismarck, North Dakota, USA). Construction of small (approx 0.4 ha), earthen nesting islands was one of the management treatments considered, and results from the MAAPE were used extensively in designing a habitat management plan that included islands.

About the same time the MAAPE results were released, the U.S. Bureau of Reclamation (USBR) announced intentions to build approximately 25 ha of islands in central North Dakota to partially mitigate habitat loss resulting from the flooding of Lake Audubon at Audubon National Wildlife Refuge (1998). Because constructing nesting islands is expensive, the USBR, U.S. Fish and Wildlife Service (USFWS), and other PPJV partners recognized the importance of building islands where they would provide the greatest benefit for nesting ducks.

Cowardin et al. (1983) used the Mallard Productivity Model to assess the relative potential of several management treatments—including constructed nesting islands—to increase mallard production in the U.S. PPR. Mallard females typically choose nest sites in perennial grass cover as opposed to annually tilled croplands (Klett et al. 1988, Reynolds et al. 2001). The Mallard Productivity Model is based on the premise that mallard females select nesting covers in proportion to the relative attractiveness (to nesting hens) and relative availabilities of the various cover types. Consequently, the Mallard Productivity Model is based on an implied negative relation between mallard nest numbers on

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constructed islands and amounts of preferred nesting cover in surrounding uplands. Giroux (1981*a*) suggested, but did not document, such a relation between island use and the quality of surrounding upland cover.

The Mallard Productivity Model also is based on the assumption that numbers of nests initiated on islands increase proportionally with numbers of mallard pairs (Cowardin et al. 1988). This assumption is consistent with results of Giroux (1981*a*) and Lokemoen and Woodward (1992), who found that use of islands by nesting ducks was related to densities of ponds near constructed or natural islands. Those authors speculated that island use by nesting ducks increased because greater numbers of breeding pairs were drawn to landscapes containing greater numbers of ponds.

Our primary objective was to examine effects of amounts of perennial grass cover and densities of breeding pairs in the area surrounding constructed islands on numbers of mallard and gadwall nests initiated on those islands. By examining these factors, we hoped to provide knowledge to improve decisions about future island placement, and to assess the appropriateness of the Mallard Productivity Model as a tool for simulating effects of constructed islands on productivity of nesting ducks. We focused on mallards and gadwalls because they are the most common duck species that nest on constructed islands in North Dakota (Duebbert 1982, Lokemoen and Woodward 1992), and they have similar preferences for nesting cover (Klett et al. 1988, Greenwood et al. 1995). Our secondary objective was to examine responses of nesting mallards and gadwalls to island characteristics (e.g., island vegetation, island age).

Study Area

We collected data from study sites (3,238-ha [3.2-km radius] circular area centered on 1 or more constructed islands) in the Missouri Coteau and Drift Plain physiographic areas of the PPR in North Dakota (Fig. 1; Bluemle 1991). Islands in our study were built during 1985–1995 by Ducks Unlimited, Inc. (DU) and the USBR to create nesting habitat for waterfowl. Multiple islands were constructed in some wetlands. Islands were earthen; most were rectangular, but some were dumbbell-, teardrop-, or kidney-shaped. Most islands were seeded with a dense nesting cover mixture of alfalfa (*Medicago sativa*), sweet clover (*Melilotus* spp.), and wheatgrasses (*Agropyron* spp.). Several islands had plantings of shrubs, mainly Wood's rose (*Rosa woodsii*) and western snowberry (*Symphoricarpos occidentalis*). Other island vegetation consisted of various forbs and grasses.

We conducted our study during the 1996–1997 nesting seasons, a period of above-average water conditions in North Dakota. Mid-May water indices (numbers of wet areas per 1.6 km^2 surveyed multiplied by the total area in the state [70,665 km^2]) in North Dakota during 1996 (1,009,390) and 1997 (1,050,949) were much above average (543,518) for 1948–1997 (Johnson 1998). Water indices have exceeded 1 million in only 7 years since 1948; 2 of those years were 1996 and 1997 (Johnson 2004).

Methods

Site Selection

Islands or island pairs (2 islands in the same wetland and separated by <1.6 km) had to meet the following criteria established by the PPJV to be considered for study (U.S. Prairie Pothole Joint Venture 1995): 1) located in large (>10 ha), alkaline wetlands, 2) located at least 90 m from mainland shore, 3) approximately 0.4 ha in area, and 4) effectively protect nesting waterfowl from predators occurring on the mainland. We instituted the first 3 criteria during the site-selection process and implemented the fourth criterion by

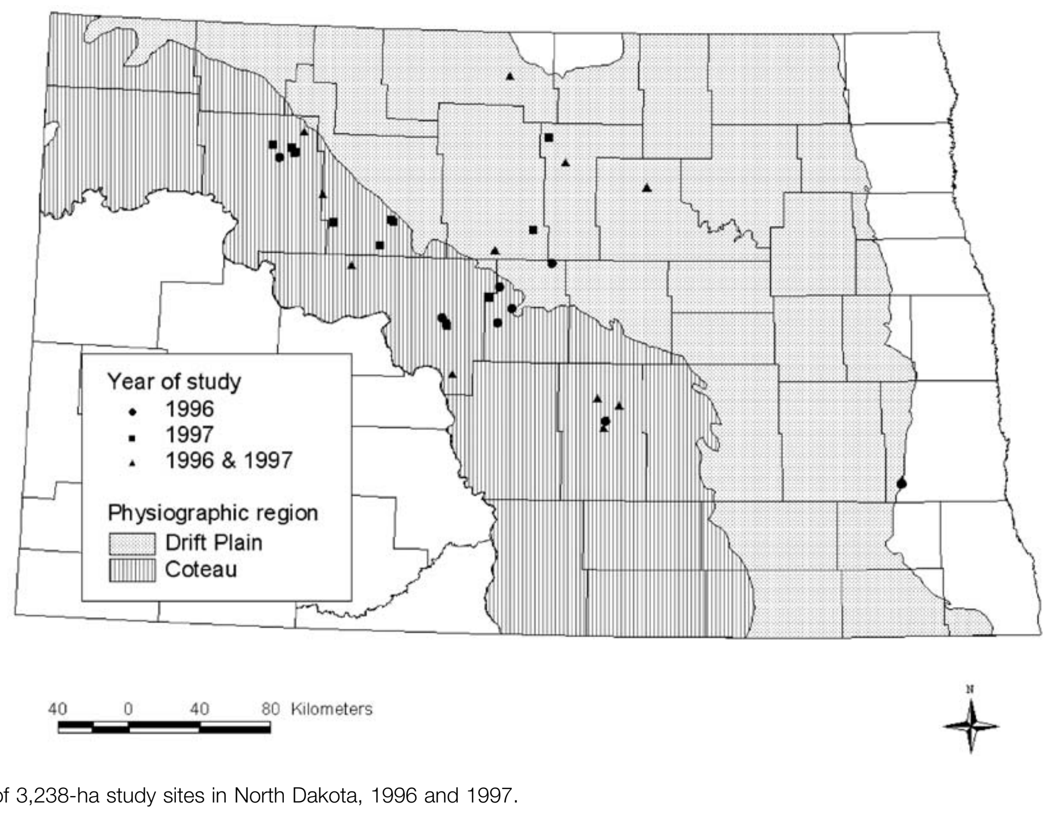

Figure 1. Locations of 3,238-ha study sites in North Dakota, 1996 and 1997.

examining our data and excluding sites that experienced high (≥65%) nest losses due to predation. In addition to the PPJV criteria, we required that 1) vegetation was established on the island (as determined by DU, USBR, or USFWS personnel); 2) no other islands or peninsula cut-offs occurred within 1.6 km of the island or island-pair being studied; and 3) wetlands, as defined by the National Wetlands Inventory (NWI; U.S. Fish and Wildlife Service, St. Petersburg, Florida, USA), comprised <40% of the area of the study site. The last criterion eliminated islands that occurred in or near extremely large wetlands where little or no upland cover existed in the surrounding area.

For each island or island pair meeting the above criteria, we used a waterfowl breeding-pair accessibility model (Reynolds et al. 1996) to index potential duck breeding pairs (mallard, gadwall, northern shoveler [*A. clypeata*], blue-winged teal [*A. discors*], and northern pintail [*A. acuta*]) in the surrounding 3,238-ha area. This model, which determines breeding duck potential from area and class of wetland basins in the landscape, allowed us to choose study sites that were likely to exhibit variation in numbers of mallard and gadwall breeding pairs. In addition, we estimated the percentage of uplands in annually tilled cropland for each potential site. Percent cropland is inversely related to percent perennial grass cover, and thus we used percent cropland as a proxy for percent perennial grass cover. Because we wanted to examine effects of both perennial grass cover and breeding-pair densities on island use by mallards and gadwalls, we categorized potential study sites as follows: 1) <24 potential duck breeding pairs/km^2 and <40% cropland, 2) <24 potential duck breeding pairs/km^2 and >60% cropland, 3) ≥24 potential duck breeding pairs/km^2 and <40% cropland, and 4) ≥24 potential duck breeding pairs/km^2 and >60% cropland.

Our goal was to randomly select about the same number of study sites from each of the 4 categories. We chose 22 sites for study in 1996 (Fig. 1). Many islands available for study in 1996 were inundated by high water levels in 1997. We selected 25 sites for study in 1997; 15 of those were sites studied in 1996.

Habitat Classification and Mapping

We used the nesting-habitat classification from Cowardin et al. (1988) to classify nesting habitats in each site into 11 classes: grassland, grassland–wildlife, hay land, planted cover, cropland, woodland, shrubland, other habitats, right-of-way, barren, and wetland. Upland habitat types were determined from U.S. Department of Agriculture Farm Service Agency aerial photos and ground and aerial surveys conducted each year. Habitat areas were digitized and imported into a Geographic Information System (GIS). The digital data for each study site were attributed and analyzed using Arc/Info Version 7.1.1 (Environmental Systems Research Institute, Redlands, California, USA). Wetland coverage was acquired from NWI and added to the GIS. Road and railroad linear features (U.S. Geological Survey Public Land Survey, 1:24,000 Digital Line Graph data) were buffered, attributed as right-of-way, and added to the GIS. We determined area (ha) and type of habitat present on each study site from the completed GIS coverage.

Wetland Assessment

We used a fixed-wing aircraft flying at approximately 4,200 m above ground level to acquire aerial videography of each study site in May 1997. Video imagery later was captured with Map and Image Processing System (MicroImages, Lincoln, Nebraska, USA) software and overlaid with digital NWI wetland polygon data. We delineated wet areas that occurred within known NWI wetland polygons. Using this method, we could delineate wetlands ≥0.004 ha and eliminate sheet-water areas that were present temporarily but did not represent breeding-pair habitat. We were unable to obtain videography in 1996.

Breeding Pairs

We used the wetland habitat classification of Cowardin et al. (1988) to assign wetland basins in each study site to 4 classes: temporary ponds, seasonal ponds, semipermanent ponds, and lakes. Because we were unable to measure areas of individual ponds in 1996, we could not estimate numbers of breeding pairs occupying wetlands within 3.2 km of the center of each study site in that year. We used regression models (Cowardin et al. 1995) along with the measured area of individual ponds to estimate numbers of mallard and gadwall breeding pairs on each study site in 1997. We used results of breeding duck surveys conducted in each wetland management district in 1997 (R. E. Reynolds, U.S. Fish and Wildlife Service, unpublished data) to adjust regression estimates for temporal and spatial departures from base regression models (see Cowardin et al. 1995).

Island Characteristics

We measured visual obstruction (an index of vegetation height and density) on each island during our first visit in May. A transect was established lengthwise through the center of each island. Parallel transects were then established on either side of the center transect halfway between the center transect and the island shore, for a total of 3 transects. Along the transects, we took visual obstruction readings (Robel et al. 1970, Kirsch et al. 1978) at 25–33 points that were 8–15 m apart, depending on the size of the island. The first and last points on each transect were ≥4 m from the water's edge. Visual obstruction readings from transect points were averaged to provide a single measurement for each study site. We also categorized the vegetation within 15 cm of each transect point into 1 of 10 vegetation classes (after Willms and Crawford 1989): 1) tall and dense forbs, 2) tall and dense grass, 3) short and sparse forbs, 4) short and sparse grass, 5) tall and sparse forbs, 6) tall and sparse grass, 7) short and dense forbs, 8) short and dense grass, 9) shrub, and 10) unvegetated.

We obtained Universal Transverse Mercator (UTM) coordinates at the center and along the perimeter of each island using a Global Positioning System (GPS) receiver. We also obtained GPS data at the mainland location nearest the island so that the minimum distance between island and shore could be determined. We differentially corrected the GPS data using North Dakota Geological Survey base station data collected at Bismarck State College (Bismarck, North Dakota, USA; lat 40°49′16.02778″N and long 100°49′0.04413″W). We imported all GPS data into a GIS and used Arc/Info to determine the area of each island (areas were summed if 2 islands were studied in a study site), distance to shore, and location (EASTING and NORTHING). Coordinates were recorded in UTM, North American Datum 1927 in zone 14.

Duck Nesting on Islands

We searched each island for nests 4 times at 3-week intervals beginning in early May. We searched islands in southern North

Dakota first, followed by more northerly sites; this pattern was repeated on subsequent searches. One to 4 people attempted to locate all nests (scrape or bowl containing $\geq$1 whole egg or egg remains) on each island by walking parallel transect lines approximately 2 m apart (after Giroux 1981*b*).

We recorded waterfowl nest data (Klett et al. 1986) on standard nest record forms obtained from Northern Prairie Wildlife Research Center (U.S. Geological Survey, Jamestown, North Dakota, USA). Each nest location was marked with a 1.5-m willow (*Salix* spp.) sapling stick placed 4 m north of the nest. Occasionally (e.g., in tall vegetation), the nest marker or a small piece (<10 cm) of plastic flagging was placed at the nest.

We checked nests on subsequent nest searches until nest fates (Klett et al. 1986) were determined. Nests were considered successful if $\geq$1 egg hatched. Because we conducted intensive searches, we believed that we found nearly all nests initiated on islands (including nests that had been destroyed or abandoned). Therefore, we report apparent rates of nest success (number successful/number found) instead of more commonly used Mayfield estimates (Mayfield 1961). Mayfield's method assumes that daily survival rates are constant among nest days, an assumption that may have been violated because depredations likely occurred catastrophically, depending on whether a predator or predators accessed an island on any given day. Johnson and Shaffer (1990) showed that in situations like ours (i.e., high nest detection rates and catastrophic mortality), apparent nest success rates are more reliable than Mayfield estimates.

Statistical Analysis and Candidate Models

We used multiple linear regression in a repeated measures design to relate explanatory variables to numbers of mallard and gadwall nests initiated on islands. We developed a set of candidate models that reflected our a priori beliefs about factors that influence mallard and gadwall use of nesting islands. Postulated effects of perennial grass cover in the study site and densities of breeding pairs (MALPAIRS, GADPAIRS) having access to constructed islands were the 2 primary factors that motivated our study. We computed the amount of perennial grass cover as the sum of the areas of grassland, grassland–wildlife, hay land, planted cover, and right-of-way. We used the ln of perennial grass cover (PGRASS) as an explanatory variable in our models because we believed that effects of perennial grass cover would diminish as the amount increased, although we were uncertain whether we would see these tapering effects within the range of values of perennial grass cover that we observed.

We expected that island vegetation, as it relates to nest concealment and security, would be an important determinant of island use by mallards and gadwalls (Giroux 1981*b*, Duebbert 1982, Duncan 1986). Both species are known to prefer nest sites with tall dense vegetation, especially brush and shrubs (Greenwood et al. 1995). We created a variable TDENSE by summing percentages of tall dense grass (TDGRASS), tall dense forbs (TDFORBS), and shrubs (SHRUB). We examined the among-island variation in TDENSE and determined that the variation was sufficient to justify including TDENSE as a variable in our set of candidate models.

Combinations of YEAR, PGRASS, and TDENSE gave rise to 8 candidate models that we evaluated using combined data from both years. We performed maximum likelihood estimation in PROC MIXED (SAS Institute 1999) with a REPEATED statement to account for correlations between years on islands that were studied in both years. Although we suspected that other variables, such as height and density of vegetation in early May (HDEARLY), the amount of wetland habitat in the study site (WETHAB), distance between the island and the nearest shore (DISTSHOR), or island age (AGE) might influence duck use of islands, we chose not to include these variables in our candidate models because of sample-size limitations. With fewer than 50 data points, we followed the recommendation of Burnham and Anderson (2002:245) and considered only models with 5 or fewer regression parameters. We used data from 1997 only to evaluate 8 models that included all combinations of PGRASS, TDENSE, and MALPAIRS or GADPAIRS.

We used information–theoretic methods (Burnham and Anderson 2002) to compare models. For each a priori candidate model, we report the maximized log-likelihood value, the number of model parameters (K), Akaike's Information Criterion with small sample size adjustment (AIC_c), ΔAIC (AIC_c for the model under consideration minus the minimum of AIC_c values for the set of candidate models), and the Akaike weight (Burnham and Anderson 2002:75). The Akaike weight for a model can be interpreted as the weight of evidence for that model relative to other models in the candidate set. Because each explanatory variable occurred in the same number of models, we estimated the relative importance of each explanatory variable by summing the Akaike weights across all models in which it occurred (Burnham and Anderson 2002:168).

We also conducted exploratory analyses to assess whether any of the following variables appeared related to number of initiated nests: TDGRASS, TDFORBS, SHRUB, HDEARLY, WETHAB, DISTSHOR, EASTING, NORTHING, number of islands in the study site (ISLANDS), AGE, and nest success (MALNS or GADNS). Exploratory analyses were conducted only in conjunction with the joint analysis of data from both years. Using our best-fitting a priori model as a benchmark, we computed ΔAIC_c values resulting from adding each of the above variables, one at a time, to that model. If the best a priori model included TDENSE, TDENSE was excluded from exploratory models involving TDGRASS, TDFORBS, and SHRUB. We viewed large reductions (>4) in AIC_c as evidence that the additional explanatory variable was related to the number of initiated nests. We also examined correlations among the explanatory variables to identify potential problems of multicollinearity or confounding of effects.

Results

We excluded 2 sites in 1996 and 3 sites in 1997 from analyses because duck nest loss due to predators exceeded 65%. Characteristics of islands on remaining sites were similar in 1996 and 1997 (Table 1). Perennial grass cover, consisting of grassland and grassland–wildlife (57%), hay land (11%), planted cover (28%), and right-of-way (4%), accounted for an average of 1,400 ha, or 43% of the landscape surrounding study islands; amounts were similar in 1996 and 1997. Wetland accounted for about 525 ha, or 16%, of the landscape. Numbers of mallard and gadwall breeding pairs were similar in 1997.

We found 946 waterfowl nests, including 371 mallard nests and 269 gadwall nests in 1996. We found 1,272 waterfowl nests, including 448 mallard nests and 346 gadwall nests in 1997. Mallard, gadwall, lesser scaup (*Aythya affinis*), blue-winged teal, northern pintail, and Canada goose (*Branta canadensis*) were the most common island-nesting species (Table 1). Mean nest success on islands meeting our analysis criterion (<65% nest loss due to predators) was 77% (SE; 2.93) for mallards, and 81% (2.79) for gadwalls. Nest success of mallards did not vary between years ($P = 0.20$), but gadwalls had higher nest success ($P = 0.02$) in 1996 ($\bar{x} \pm$ SE; 90% $\pm$ 2.76) than in 1997 (78% $\pm$ 4.26). Nest lost due to nest destruction was 13% in 1996 and 16% in 1997 and was mainly caused by mammalian and avian predators. Nest loss due to female abandonment, which may have included females killed while away from the nest, was 9% in 1996 and 13% in 1997.

Determinants of Mallard Nesting

A priori models.—Amounts of perennial grass cover in landscapes and percentages of tall dense cover on islands were important determinants of numbers of mallard nests initiated on islands (Table 2). The best-supported model from the repeated measures analysis of both years included effects of PGRASS, TDENSE, and YEAR. The second-best model had ΔAIC > 3, indicating little support for models other than the best model. The Akaike weight $w = 0.83$ for the best model provided further evidence for this conclusion. The best model for 1997 was MALNESTS = 141.0 − 18.8 × PGRASS + 0.99 × TDENSE. Standard errors were 39.9 for the intercept, 5.5 for PGRASS, and 0.22 for TDENSE. The model for 1996 included a year effect of −4.5 (5.8). Residuals from the best model plotted against predicted values and the explanatory variables provided no evidence for lack of fit or non-normality of residuals. Expected number of nests declined as perennial grass cover in the surrounding landscape increased (Fig. 2a). The rate of decline was greatest for smallest amounts of perennial grass cover. As TDENSE increased, expected number of mallard nests also increased (Fig. 3).

Analysis of 1997 data showed the strongest support for effects of PGRASS ($\Sigma w_i = 0.78$) and TDENSE ($\Sigma w_i = 0.84$) on numbers of mallard nests, but little evidence of an effect of MALPAIRS ($\Sigma w_i = 0.21$). The best model included PGRASS and TDENSE and had $w = 0.51$. The second best model (ΔAIC = 2.3, $w = 0.16$)

Table 1. Characteristics of constructed islands, amounts and types of nesting covers within a 3.2-km radius of islands, numbers of mallard and gadwall breeding pairs, and numbers of waterfowl nests found on constructed islands in North Dakota, USA, 1996–1997.

	1996 (n = 20)			1997 (n = 22)		
	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range
Island characteristics						
Age (yr)	4.65	2.39	9.00	5.73	2.66	9.00
Area (ha)	0.35	0.11	0.41	0.43	0.21	0.96
Distance from mainland (ha)	247	114	452	231	111	458
Vegetation height-density (dm)	0.74	0.39	1.59	0.76	0.57	2.23
Tall dense vegetation[a] (%)	13.9	13.0	52.1	12.5	14.1	48.6
Shrubs (%)	3.5	10.5	46.6	4.4	8.9	37.5
Tall dense grass (%)	8.2	9.1	34.0	5.6	11.2	48.0
Tall dense forbs (%)	2.3	3.8	14.3	2.5	4.6	16.0
Nesting covers[b]						
Perennial grass cover[c] (ha)	1,371	631	1,971	1,428	608	2,069
Grassland[d] (ha)	805	477	1,782	783	487	1,764
Hayland (ha)	167	165	611	151	141	611
Planted cover (ha)	337	225	725	443	275	1,118
Right of way (ha)	62	32	107	50	22	79
Cropland (ha)	1,289	743	2,198	1,236	672	2,107
Other[e] (ha)	49	18	67	49	20	66
Wetland (ha)	528	241	918	524	238	1,012
Breeding pairs						
Mallard	—[f]	—	—	311	169	632
Gadwall	—	—	—	280	179	615
Waterfowl nests on islands						
Mallard	18.6	25.6	114.0	20.4	26.1	125.0
Gadwall	13.4	12.6	48.0	15.7	13.8	57.0
Lesser scaup	4.3	5.7	25	7.3	7.9	33
Blue-winged teal	1.2	1.2	4	2.1	2.5	9
Northern pintail	1.3	2.2	7	2.0	2.3	9
Other duck spp.[g]	5.3	4.5	13	6.4	6.7	28
Canada goose	3.1	3.7	17	3.9	3.5	12

[a] Shrubs + Tall dense grass + Tall dense forbs.
[b] Cover types are from Cowardin et al. (1988).
[c] Grassland + Hayland + Planted cover + Right of way.
[d] Includes Grassland–wildlife.
[e] Includes Oddarea, Shrubland, and Woodland.
[f] Not available.
[g] Includes American wigeon (*Anas americana*), American green-winged teal (*A. crecca*), redhead (*Aythya americana*), canvasback (*A. valisineria*), and unknown species.

Table 2. Model selection criteria for 8 a priori candidate models of factors influencing numbers of mallard and gadwall nests on constructed islands in North Dakota, USA, 1996–1997 ($n = 42$). Log(L) is the value of the maximized log-likelihood function, K is the number of model parameters, AIC_c is Akaike's Information Criterion adjusted for small sample sizes, $\Delta AIC = AIC_c - \text{Minimum}(AIC_c)$, and w is the Akaike weight.

Species/Model[a]	Log(L)	K	AIC_c	ΔAIC	w
Mallard					
YEAR + PGRASS + TDENSE	−174.1	6	362.6	0	0.83
PGRASS + TDENSE	−177.1	5	365.8	3.2	0.17
YEAR + PGRASS	−181.8	5	375.3	12.7	<0.01
YEAR + TDENSE	−181.9	5	375.5	12.8	<0.01
PGRASS	−184.8	4	378.7	16.0	<0.01
TDENSE	−184.8	4	378.8	16.1	<0.01
YEAR	−190.0	4	389.0	26.4	<0.01
NULL	−193.0	3	392.6	30.0	<0.01
Gadwall					
YEAR + PGRASS	−145.8	5	303.3	0	0.86
YEAR + PGRASS + TDENSE	−147.0	6	308.4	5.0	0.07
YEAR	−150.4	4	309.9	6.6	0.03
PGRASS	−150.7	4	310.5	7.1	0.02
PGRASS + TDENSE	−151.3	5	314.3	10.9	<0.01
YEAR + TDENSE	−151.6	5	314.8	11.5	<0.01
NULL	−155.1	3	316.8	13.5	<0.01
TDENSE	−155.7	4	320.4	17.1	<0.01

[a] Explanatory variables: PGRASS = ln of perennial grass cover (ha), TDENSE = % tall dense vegetation, NULL = no explanatory variables.

involved only TDENSE, whereas the third best model ($\Delta AIC = 2.8$, $w = 0.12$) involved MALPAIRS, PGRASS and TDENSE. The model-averaged parameter estimate for MALPAIRS was 0.003 (0.009).

Exploratory models.—The addition of SHRUB to the model involving PGRASS and YEAR reduced the AIC_c value by nearly 35 units from that of the best-fitting a priori model (Table 3). This exploratory model suggested that the number of mallard nests increased by 2.06 ± 0.20 for each 1% increase in SHRUB. Addition of ISLANDS, HDEARLY, or DISTSHOR provided some reduction in AIC_c over that of the best-fitting a priori model (Table 3). ISLANDS (23.26 ± 6.30) and DISTSHOR (0.11 ± 0.02) were positively related to number of mallard nests, whereas HDEARLY (−15.67 ± 6.65) was negatively related. SHRUB and DISTSHOR were positively correlated ($r = 0.75$, $P < 0.001$).

Determinants of Gadwall Nesting

A priori models.—Gadwall nest numbers were strongly related to amounts of perennial grass cover in the landscape (Table 2). The best-supported model from the repeated measures analysis of both years included PGRASS and YEAR, and was the only model with $\Delta AIC < 4$, indicating strong support for this model. The best model for 1997 was GADNESTS = 72.4 − 8.0 × PGRASS. Standard errors were 25.5 for the intercept and 3.6 for PGRASS. The model for 1996 involved a year effect of −4.5 (1.5). Residuals from this model plotted against predicted values and the explanatory variables provided no evidence for lack of fit or non-normality of residuals. Expected numbers of gadwall nests declined with increasing amounts of perennial grass cover (Fig. 2b).

Analysis of 1997 data alone provided evidence that GADPAIRS ($\Sigma w_i = 0.22$) was unimportant relative to PGRASS ($\Sigma w_i = 0.63$) and TDENSE ($\Sigma w_i = 0.52$). The best model involving PGRASS

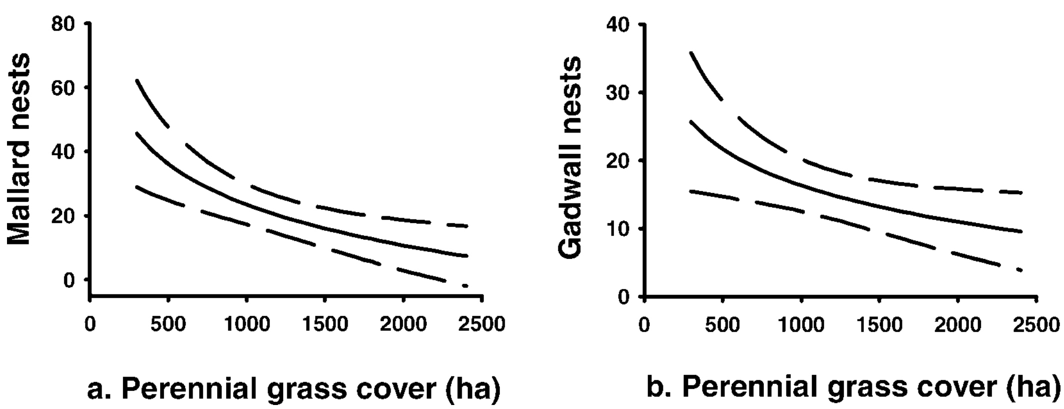

Figure 2. Expected numbers of mallard and gadwall nests on constructed islands in relation to amounts of perennial grass cover in the surrounding landscape (3,238 ha [3.2-km radius]) in the Prairie Pothole Region of North Dakota in 1996 and 1997. Expected nest numbers are from multiple regression models involving ln of perennial grass cover and year. The model for mallards also included percentage of tall dense cover (TDENSE). The relation in (a) was obtained by holding TDENSE at its mean value (13.2%) and averaging expected nest numbers from 1996 and 1997. Dashed lines are 95% confidence limits.

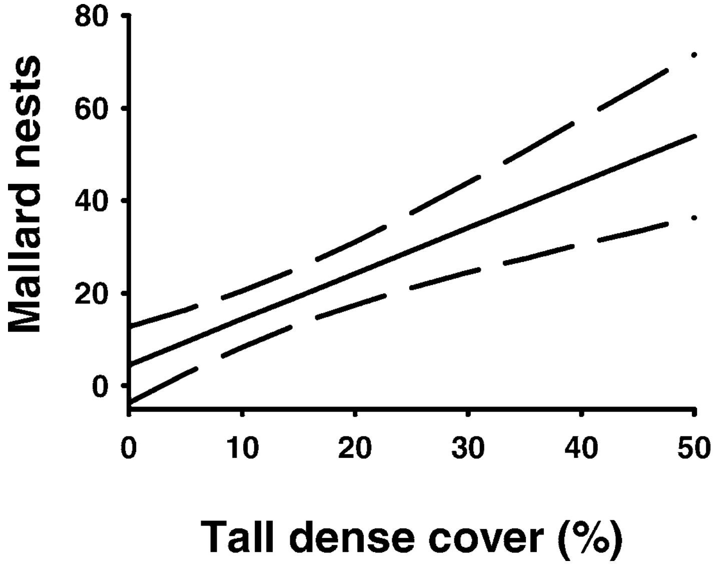

Figure 3. Expected numbers of mallard nests on constructed islands in relation to percentages of tall dense cover (TDENSE) on islands in the Prairie Pothole Region of North Dakota in 1996 and 1997. Expected nest numbers are from multiple regression models involving TDENSE, ln of perennial grass cover (PGRASS), and year. Expected numbers of nests were obtained by holding PGRASS at its mean value (1,377 ha) and averaging model predictions for 1996 and 1997. Dashed lines are 95% confidence limits.

and TDENSE ($w = 0.26$) and the second best model involving only PGRASS (ΔAIC = 0.04, $w = 0.26$) had nearly equal support. Models involving GADPAIRS (ΔAIC = 2.93 – 3.35, $w = 0.05$ – 0.06) had less support than the null model (ΔAIC = 2.0, w = 0.09). The model-averaged parameter estimate for GADPAIRS was –0.002 (0.006).

Exploratory models.—The addition of SHRUB or AGE to the best-fitting a priori candidate model (YEAR and PGRASS) improved model fit and reduced the AIC_c value by 5.7 to 8.1 units (Table 3). The model that included SHRUB suggested that the number of gadwall nests increased by 0.74 (0.18) for each 1% increase in SHRUB. Number of gadwall nests was positively related to AGE (2.1 ± 0.77), but SHRUB and AGE were positively correlated ($r = 0.52$, $P < 0.001$).

Discussion

Our analyses provide strong support for the hypothesis that numbers of mallard and gadwall nests initiated on islands are related to amounts of preferred nesting cover in surrounding uplands. Numbers of nests declined as amounts of perennial grass cover increased. Effects of increasing perennial grass cover were most pronounced for 3,238-ha landscapes with less than 1,000 ha of grass cover (Fig. 2a,b). Contrary to our expectations, use of islands by nesting mallards and gadwalls was unaffected by densities of breeding pairs in the surrounding area in 1997. Lack of data on areas of individual ponds prevented us from examining this hypothesis with data from 1996. Amounts of tall dense cover on islands were important determinants of island use by mallards, but not by gadwalls. However, exploratory analyses suggested that amounts of shrub cover were important determinants of island use by both species.

Numerous studies of duck nesting in the PPR have found lower duck nest success in landscapes dominated by annually tilled croplands than in landscapes dominated by perennial cover (Klett et al. 1988, Greenwood et al. 1995, Reynolds et al. 2001). Higgins (1977) also documented lower duck nest densities and nest success in cultivated croplands than in untilled upland areas within the same landscape. Differences generally were attributed to the influence of nesting cover quantity and quality on predator foraging behavior. These studies established that upland-nesting ducks nest less successfully in extensively cultivated landscapes than in landscapes dominated by grassland. We hypothesized that ducks that settle in areas of extensive cultivation might be drawn to islands because they provide attractive nesting cover and protection from mammalian predators, whereas ducks that settle in landscapes dominated by grassland would be less prone to nest on islands. This hypothesis is consistent with findings of Giroux (1981a), who observed that islands surrounded by poor nesting cover received increased use by nesting ducks, and with assumptions used in the Mallard Productivity Model.

Reynolds et al. (2001) found that nest success in Conservation Reserve Program cover was positively related to the amount of perennial cover in the surrounding 10.4-km^2 landscape and provided evidence that the relationship extended to other covers as well. Their result, when considered along with our finding that

Table 3. Model selection criteria for exploratory analyses in which 11 explanatory variables were individually added to the best a priori model of factors influencing numbers of mallard or gadwall nests on constructed islands in North Dakota, USA, 1996–1997 (n = 42). The best a priori model for gadwalls involved year and ln of perennial grass cover (ha). The best model for mallards involved these variables plus the percentage of tall dense vegetation. K is the number of model parameters, AIC_c is Akaike's Information Criterion adjusted for small sample sizes, and Δ is the change in AIC_c that occurred when the variable in question was added to the best a priori model.

Species/Variable[a]	Log-likelihood	K	AIC_c	Δ
Mallard				
SHRUB[b]	–156.8	6	328.1	–34.6
ISLANDS	–165.4	7	348.1	–14.5
HDEARLY	–168.6	7	354.6	–8.0
DISTSHOR	–168.7	7	354.7	–8.0
AGE	–171.3	7	359.9	–2.7
MALNS	–175.0	7	367.2	4.6
WETHAB	–177.5	7	372.3	9.7
TDFORBS[b]	–180.4	6	375.2	12.5
TDGRASS[b]	–181.0	6	378.0	15.3
EASTING	–182.7	7	382.8	20.2
NORTHING	–182.9	7	383.0	20.4
Gadwall				
SHRUB	–140.4	6	295.3	–8.1
AGE	–141.6	6	297.7	–5.7
ISLANDS	–142.9	6	300.2	–3.1
HDEARLY	–143.2	6	300.8	–2.5
DISTHOR	–144.6	6	303.5	0.2
GADNS	–144.6	6	303.7	0.3
TDFORBS	–146.1	6	306.7	3.3
TDGRASS	–147.0	6	308.4	5.1
WETHAB	–148.9	6	312.2	8.9
EASTING	–151.5	6	317.4	14.0
NORTHING	–155.1	6	324.6	21.2

[a] SHRUB = % shrub on the island, TDGRASS = % tall dense grass on the island, DISTSHOR = distance to the shore, ISLANDS = No. islands in study site, HDEARLY = height and density of vegetation in early May, AGE = island age, WETHAB = area of wetland habitat in study site, TDFORBS = % tall dense forbs on the island, MALNS = mallard nest success, and GADNS = gadwall nest success.

[b] Model did not include TDENSE = SHRUB + TDGRASS + TDFORBS.

island use by mallards and gadwalls is negatively related to the amount of perennial cover, implies that use of islands is greatest in landscapes with lowest nest success. Thus, in landscapes with low amounts of perennial cover, not only do islands receive greater use, they also result in a greater net increase in hen success compared to islands in landscapes associated with higher nest success.

Giroux (1981*a*) observed that the use of islands by nesting ducks was related to pond density in the surrounding area; islands located in impoundments that were surrounded by peripheral ponds received greater use. He attributed this relation to possible increases in the availability of invertebrates, which are required by laying females (Krapu 1974), and to the increased availability of potential territories for breeding pairs. In a study of duck nesting on natural islands in North Dakota, South Dakota, and Montana, Lokemoen and Woodward (1992) found that both mallard and gadwall nests were more likely to occur on islands with a higher density of nearby (<1.6 km) flooded wetlands than on islands with fewer nearby wetlands. Clearly, the potential number of duck nests on an island is limited by the number of available breeding pairs. We defined available breeding pairs as those pairs occupying wetlands within 3.2 km of an island or island pair. Both mallards (Dwyer et al. 1979, Lokemoen et al. 1984, Cowardin et al. 1985) and gadwalls (Duebbert 1966) will travel that far from their core wetland to a nest site. In retrospect, our inability to detect an association between numbers of duck nests and breeding-pair densities is not surprising. We observed average to above-average densities of mallards and gadwalls in 1997 (Wangler and Reynolds 2003). Managers who chose locations to build the study islands probably targeted areas with high wetland densities to ensure that breeding pairs would be abundant. In addition, our estimates of pair densities included a component of random error.

Our results supported findings of others (e.g., Giroux 1981*b*, Duebbert 1982, Duncan 1986) that tall dense vegetation on islands is important for attracting high numbers of nesting mallards. Increasing tall dense cover on an island from 0% to 50% in a landscape that is 43% (1,377 ha) perennial grass cover would be expected to increase the number of mallard nests from approximately 5 to 50 (Fig. 3).

Past research has shown that variables other than amounts of perennial grass cover in the landscape and tall dense nesting cover on islands can influence island use by nesting ducks. For example, Giroux (1981*b*) found more nests on constructed islands farther from the mainland than on islands closer to shore. Our study was not specifically designed to look at these variables, but furnished data that allowed exploratory analyses that provided insight into some potentially important relations.

In particular, our exploratory analyses suggested that percent shrub cover is a better predictor of island use than is percent tall dense cover. This finding is consistent with results of Duebbert et al. (1983) who reported that 97% of mallard and gadwall nests were initiated in western snowberry or Wood's rose cover on a natural island in northwestern North Dakota, although those covers comprised only 30% of the available nesting cover. In addition, Greenwood et al. (1995) found that both mallards and gadwalls prefer to nest in shrub cover, rather than grass cover.

Our analyses support Giroux's (1981*b*) finding that mallard use of nesting islands increased with distance from the island to the mainland shore. However, DISTSHOR and SHRUB were positively correlated, making it impossible to discern the true effect of either variable. In contrast to findings of Lokemoen and Woodward (1992), island use decreased as height and density of vegetation early in the season increased. Older islands received increased use by gadwalls, which could reflect the strong homing tendency of this species (Lokemoen et al. 1990), but also could reflect the fact that percent shrub increased with island age.

We did not find a relation between mallard or gadwall use of islands and UTM easting or northing, despite the fact that our study sites were geographically dispersed (Fig. 1). This suggests that geographic location is unimportant when deciding where to build islands in the PPR of North Dakota. However, other investigators found that nest success of 5 upland-nesting species, including mallards and gadwalls, increased from east to west and from north to south (Klett et al. 1988, Reynolds et al. 2001). Because breeding hens must choose among nesting cover types, islands should benefit duck production most in areas where nest success in other covers is lowest (i.e., eastern and northern portions of our study area), making island nesting more likely.

We attempted to minimize effects of renesting on nest numbers by excluding islands with high nest loss due to predators. Regardless, nest success varied among islands, and our sample of nests likely included both initial and renesting attempts. However, we found no relation between nest numbers and nest success on islands. This was not surprising given that the proportion of renests likely varied with nest success in the surrounding landscape, a variable that we did not measure.

Management Implications

Amounts of perennial cover in landscapes should be primary considerations in determining where to build islands. Our data indicate that the best landscapes for islands have low amounts of perennial grass cover in surrounding uplands. Our results are consistent with assumptions used in the Mallard Productivity Model, and we encourage managers to use the model when planning island construction projects. Islands situated in northeastern North Dakota generally will result in a greater net increase in mallard recruitment rates than islands to the west or south, provided other variables (e.g., amount of perennial grass cover, survival of broods and ducklings) are the same. Establishment of tall dense vegetation, especially shrubs, on constructed islands is crucial to achieving high use by nesting mallards and gadwalls. Manipulating island vegetation to increase amounts of tall dense cover would be an effective strategy for managers wanting to increase use of existing islands.

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