Table 1. Name, number, and location of sites of nesting and post-breeding observational studies of birds at Prudhoe Bay, Alaska, 1990. Sites are located on Figures 1A-D.

Site No.	Site Name	Location (Figure)
1	West Sak 17	1A
2	Ugnu 1	1A
3	West Sak 9	1A
4	West Sak 3	1A
5	Mobil Kuparuk 3-15-11-12	1B
6	Term Well C	1B
7	Hurl State	1B
8	Put River 22-33-11-13	1B
9	Getty State	1C
10	Put State 1	1C
11	Storage Pad	1C
12	Prudhoe Bay State 1	1C
13	Lake State 1	1C and 1D
14	Delta State 2	1D

Methods

Site Selection and Plot Set-up

We selected fourteen sites for the nesting study (Figs. 1A-1D). Eight of these had been study sites during 1989 (see Pollard et al. 1990). Thirteen sites contained an abandoned gravel pad from an exploratory well. One site, Put River 22-33-11-13 ("BP Pad"), originally contained an abandoned pad but since 1989 has been the focus of a major rehabilitation project by BPX, and gravel was essentially absent in 1990. (For detailed descriptions of sites, see Appendix A.)

At each site, we established a pair of study plots (disturbed and undisturbed) of 10 hectares each. One of the pair, designated as the "disturbed" plot, contained an abandoned gravel pad and surrounding tundra. Many additionally contained other disturbances such as reserve and/or flare pits, old vehicle tracks, and other areas of barren ground; one site, Put State 1, contained an old peat road. An "undisturbed" tundra plot was established near (usually one meter from but as far as 300 meters from) the disturbed plot at each site. Three undisturbed plots (Ugnu 1, West Sak 3, and Put State 1) contained minor disturbances (surface disruptions) which were vegetated and usually difficult to observe on the ground, but which could be seen on aerial photographs. At Put State 1, the peat road in the disturbed plot also passes through the undisturbed plot.

Plot boundaries at each site were set such that the two plots contained similar habitat types, excluding the affected area of the disturbed plot. To obtain the best possible habitat match, we examined color infrared (CIR) aerial photographs (scale 1"= 500') taken in 1989 by Aeromap U.S. and sketched boundaries on the photographs prior to entering the field. The ten-hectare plots were either square (316.2 m x 316.2 m) or rectangular (200 m x 500 m, or 250 m x 400 m).

In the field, we used the CIR photographs, a hand-held compass, and a surveyor's chain to set up the plots. A grid system marked at intersections with 3-ft-tall stakes was established in each plot. Grid cells were 52.7 m x 52.7 m in square plots and 50 m x 50 m in rectangular plots. Each stake was marked with a letter and number so that nests could be relocated at a later date.

To facilitate the display of nest distributions, we mapped study sites from 1"= 500' CIR aerial photographs (see Appendix A). Gravel pads, gravel spray, reserve and flare pits, obvious non-gravel disturbances, and geobotanical types in both disturbed and undisturbed plots were delineated on maps. Geobotanical types (see Appendix D for classification system) were based on Walker et al. (1983). In some cases geobotanical types were lumped when more than one type of vegetation or landform was present. We used a planimeter to measure areas of gravel and gravel-related disturbances on maps. Spatially limited disturbances (such as thermokarsting and vegetative changes around the perimeters of pads) that were too small to map at the scale we used, were not depicted on maps but can be seen on aerial photos.

Data Collection

Nest Searching. Methods for nest searches were adapted from those described by LGL (1983), Martin (1983), and Troy and Wickliffe (1990). Two census techniques—"searches" and "rope drags"—were used at each study plot. During the searches, a biologist slowly walked a zig-zag pattern to make four passes through each grid of each plot in an attempt to locate bird nests either by flushing individuals from the nest or by waiting for birds suspected of having a nest in the area to return. The rope drags involved two biologists walking abreast along the grid lines dragging a nylon rope between them in an attempt to flush tight-sitting birds from their nests. During this procedure, birds seen that had not been flushed, but that exhibited behavior indicating that they might be nesting in the area, were also observed to see if they would return to the nest. Two searches and two rope drags were used at each site during the course of the season (Table 2). The second search period overlapped the first rope drag.

Table 2. Schedule of activities for nesting study at disturbed gravel sites, Prudhoe Bay, Alaska, 1990.

Activity	Dates
Plot set-up	May 29-June 6
First Search	June 7-11
First Rope-drag	June 12-24
Second Search	June 12-20
Second Rope-drag	June 25-July 7
Nest Monitoring	June 20-July 25

When a nest was located, it was marked using methods described by LGL (1983) with a plain wooden tongue depressor on which we wrote a unique number and the species name. The tongue depressor was placed approximately one meter from the nest toward the gridline having the lower letter of the alphabet. A florescent orange tongue depressor with a direction arrow and the number of paces to the nest indicated on it was then placed on that gridline. All nests could thus be relocated. Information including species name, nest number, date, habitat type, number of eggs or young, and number of paces to the nearest grid markers was recorded in a field notebook.

Nest Monitoring. After completing the second search (Table 2), we began to monitor nests to determine hatching success. Nests were checked every three to five days. A single biologist walked through the plots and checked the status of each nest by looking for eggs, chicks, or signs of hatching or predation. Success or failure of a nest was determined using the criteria of

Troy and Wickliffe (1990). New nests found during monitoring were marked similarly to those discovered during plot set-up and nest searches.

Data Analysis

Nesting data from disturbed and undisturbed plots were analyzed and compared on the basis of nests per unit area (e.g., nests/km^2), nest success, and species diversity of nesting birds. In all cases, null hypotheses were rejected when $P \leq 0.05$. Data gathered at the rehabilitation site, Put River 22-33-11-13, were not included in statistical comparisons because gravel had been removed from this site.

Nest density data (total nests per 10-hectare plot) were paired for co-located disturbed and undisturbed plots. The null hypothesis of no difference in mean nest densities between disturbed and undisturbed plots was tested by using a Wilcoxon signed ranks test in the computer package SYSTAT® (Wilkinson 1989).

All known nests on both plot types were classified as successful or unsuccessful. The null hypothesis of no difference in nest success between disturbed and undisturbed plots was tested by using the chi-square test for differences in probabilities.

Species diversity of nesting birds was compared between disturbed and undisturbed plots in two ways. Species richness (the total number of species present) was used because of its simplicity. Shannon's diversity index (Begon et al. 1986:595), which takes into account the relative abundance of species in addition to the total number of species present, also was used because it is a commonly applied diversity measure that gives managers a wildlife-oriented option for establishing mitigation goals. The value of the index increases with the presence of more species and decreases if the distribution of relative abundance (nests, in this case) among species is uneven. Table 3 illustrates the behavior of Shannon's index for a hypothetical set of study plots.

Index data were paired for co-located plots, and the null hypothesis of no difference in mean diversity indices between disturbed and undisturbed plots was tested by a paired-sample t test in the computer package SYSTAT® (Wilkinson 1989). Green (1979) and Zar (1984) have noted the tendency of Shannon's index to underestimate the diversity of a sampled population, but our relative comparison of mean indices between disturbed and undisturbed plots should remain valid (assuming proportional underestimation of true

Table 3. Examples of Shannon's diversity index (H) for a set of hypothetical communities. Shannon's diversity index* varies positively with species richness (S) and the evenness with which individuals are distributed among species. For each community, total abundance (individuals) is denoted by T. (Table is adapted from Begon et al. 1986.)

Community 1		Community 2		Community 3		Community 4	
Species	Abundance	Species	Abundance	Species	Abundance	Species	Abundance
A	10	A	2	A	10	A	2
B	5	B	2	B	5	B	2
C	3	C	2	C	1	C	2
D	1	D	2	D	1	D	2
E	1	E	2	E	1	E	2
				F	1	F	2
				G	1	G	2
S=5		S=5		S=7		S=7	
T=20		T=10		T=20		T=14	
H=1.28		H=1.61		H=1.44		H=1.95	

*Shannon's diversity index (H) = $\Sigma P_i \ln P_i$ where P_i is the proportion of total individuals in the i^{th} species.

diversity in both habitat types). Green (1979) further advises that a high diversity index does not necessarily mean high environmental quality.

Results

Disturbed plots are compared with undisturbed plots on the basis of nest density, nest success, and species composition. Because gravel had been removed from Put River 22-33-11-13, results from that site are presented separately (Appendix A, Site 8).

Nest Density

Although more nests were initiated in the undisturbed plots (153 nests total, or 117.7 nests per km^2) than in the disturbed plots (128 nests total, or 98.5 nests per km^2) (Tables 4 and 7), we were unable to reject the null hypothesis of no difference in mean nest densities between plot types ($z=-1.37$, $P=0.17$). Higher nesting densities generally occurred in the undisturbed plot of each pair, although in four cases (Ugnu 1, Term Well C, Prudhoe Bay State 1, and Storage Pad) the disturbed plot had higher densities. The highest nesting density occurred at the disturbed plot at Ugnu 1, where 21 nests were found.

The nest density on the portions of disturbed plots unaffected by gravel was about the same as the nest density on undisturbed plots. Gravel pads and gravel spray cover, on average, approximately 25 percent of the surface area of the disturbed plots (Table 5). A total of 122 nests (125.1 nests/km^2) was found on unaffected portions of disturbed plots compared to 153 nests (117.7 nests/km^2) on undisturbed plots.

Nest Success

Nest success was higher in the disturbed plots (82 percent) than in the undisturbed plots (73 percent)(Table 4); as a consequence, there were nearly as many successful nests in the disturbed plots (105) as in undisturbed plots (111). Nevertheless, we were unable to reject the null hypothesis of no difference in nest success between plot types (chi-square=3.53, df=1, $0.05<P>0.10$). The site that showed the greatest difference in nest success between plots was Hurl State where only 7 of 18 nests (39 percent) were successful in the undisturbed plot, but 6 of 6 (100 percent) were successful in the disturbed plot. Term Well C also had very low nest success in the undisturbed plot (29 percent), but fewer total nests (7) were involved.

Table 4. Comparison of bird nesting and success by site on disturbed and undisturbed study plots, Prudhoe Bay, Alaska, 1990. N is the total number of successful nests. Sites are ranked by the total number of nests located in disturbed plots.

		Number of Species		Total Nests		Percent Success and Successful Nests (N)			
Site No.	Site	Undisturbed	Disturbed	Undisturbed	Disturbed	Undisturbed		Disturbed	
2	Ugnu 1	3	6	11	21	82	(9)	81	(17)
P	West Sak 9	5	5	15	12	80	(12)	75	(9)
6	Term Well C	6	4	7	12	29	(2)	83	(10)
12	Prudhoe Bay State 1	5	5	11	12	91	(10)	83	(10)
13	Lake State	5	5	18	12	78	(14)	75	(6)
1	West Sak 17	7	5	13	11	69	(9)	82	(9)
9	Getty State	7	5	16	10	88	(14)	80	(8)
4	West Sak 3	3	5	13	8	77	(10)	100	(8)
11	Storage Pad	4	4	7	8	71	(5)	75	(6)
10	Put State 1	7	3	11	7	100	(11)	86	(6)
7	Hurl State	7	5	18	6	39	(7)	100	(6)
5	Mobil Kuparuk 13-15-11-12	5	5	9	5	44	(4)	60	(3)
14	Delta State 2	2	2	4	4	100	(4)	100	(4)
	Overall	13	16	153	128	73	(111)	82	(105)

Table 5. Percentage of area covered by gravel and tundra disturbances on disturbed study plots, Prudhoe Bay, Alaska, 1990. Sites are ranked by the percent gravel disturbance.

Site No.	Site	Percent Gravel Disturbance*	Percent Tundra Disturbance**	Percent Total Disturbance
3	West Sak 9	39		39
14	Delta State 2	39		39
12	Prudhoe Bay State 1	33	40	73
4	West Sak 3	28		28
7	Hurl State	28	5	33
1	West Sak 17	26		26
5	Mobil Kuparuk 13-15-11-12	25		25
6	Term Well C	21		21
2	Ugnu 1	20		20
10	Put State 1	18	8	26
9	Getty State	17		17
11	Storage Pad	17		17
13	Lake State 1	13		13
	Mean	25	4	29

* Includes gravel pad, gravel spray, and associated reserve pits and overburden.

** Includes obvious non-gravel disturbances to tundra such as vehicle tracks and barren ground.

Species Composition

Overall, the number of species (richness) that nested on disturbed plots (16) was higher than that on undisturbed plots (13) (Table 4). Taking into account the abundance of each nesting species, however, we were unable to reject the null hypothesis of no difference in mean Shannon's diversity indices (Table 6) between disturbed and undisturbed plots ($t = 0.81$, d.f. = 12, $P = 0.43$).

Semipalmated Sandpiper, Pectoral Sandpiper, and Lapland Longspur were by far the most common (>23 total nests each) species nesting in both disturbed and undisturbed plots (Table 7). There was no significant difference in the mean numbers of nests of Semipalmated Sandpiper ($z=0.62$, $P=0.53$) and Lapland Longspur ($z=-0.50$, $P=0.62$) between disturbed and undisturbed plots. There were more Pectoral Sandpiper nests in undisturbed plots than in disturbed plots, and the difference was statistically significant ($z=-2.46$, $P=0.01$). When only successful nests are considered, the total number of nests of these three species combined was almost the same in disturbed and undisturbed plots (82 and 84 respectively).

Moderately abundant species (those with 7 to 23 total nests) generally nested more commonly in undisturbed plots than in disturbed plots. One exception to this was Red-necked Phalarope, which was more common in disturbed plots. This may have been caused by this species' apparent preference for thermokarst sites, which occurred on tundra around the perimeter of some gravel pads. They seemed to select thermokarst sites around Ugnu 1, Term Well C, Getty State, and Prudhoe Bay State 1. Three species—Dunlin, Stilt Sandpiper, and Buff-breasted Sandpiper—had only one nest each in disturbed plots, but had 6 or 7 nests each in undisturbed plots. These numbers are small and whether or not these species are responding to differences in habitats within the study plots is unclear.

More species that were uncommon (<3 total nests) nested in disturbed than in undisturbed plots, and the overall higher species richness in disturbed plots resulted mainly from differences in this category. Among species with fewer than 3 nests total, three (Canada Goose, King Eider, and Rock Ptarmigan) nested only in undisturbed plots, but six (Greater White-fronted Goose, Northern Shoveler, Willow Ptarmigan, Ruddy Turnstone, Baird's Sandpiper, and Snow Bunting) nested only in disturbed plots (Table 7).

Table 6. Number of nesting species (irrespective of success) and Shannon's diversity indices for disturbed and undisturbed plots, Prudhoe Bay, Alaska, 1990. Sites are ranked by diversity-index values calculated for disturbed plots.

		Number of Species		Shannon Diversity Index	
Site No.	Site	Undisturbed	Disturbed	Undisturbed	Disturbed
5	Mobil Kuparuk 13-15-11-12	5	5	1.52	1.61
7	Hurl State	7	5	1.85	1.56
13	Lake State 1	5	5	1.49	1.55
1	West Sak 17	7	5	1.80	1.50
2	Ugnu 1	3	6	1.04	1.50
9	Getty State	7	5	1.72	1.50
4	West Sak 3	3	5	0.91	1.49
12	Prudhoe Bay State 1	5	5	1.59	1.47
3	West Sak 9	5	5	1.40	1.36
6	Term Well C	6	4	1.75	1.33
11	Storage Pad	4	4	1.28	1.26
10	Put River 1	7	3	1.85	1.00
14	Delta State 2	2	2	0.56	0.56
	Mean	5.1	4.5	1.44	1.36
	Overall (all sites combined)	13	16	1.94	1.84

Table 7. Comparison of nesting density and success of bird species on disturbed and undisturbed study plots, Prudhoe Bay, Alaska, 1990. Species are ranked by the total number of nests found on both plot types combined.

	Density in nests/square km (total number of nests)		Percent Success (number of successful nests)	
Species	Undisturbed	Disturbed	Undisturbed	Disturbed
Lapland Longspur	30.8 (40)	27.7 (36)	78 (31)	75 (27)
Semipalmated Sandpiper	26.2 (34)	28.5 (37)	76 (26)	95 (35)
Pectoral Sandpiper	29.2 (38)	17.7 (23)	71 (27)	87 (20)
Red-necked Phalarope	5.4 (7)	12.3 (16)	86 (6)	81 (13)
Dunlin	5.4 (7)	.8 (1)	71 (5)	100 (1)
Buff-breasted Sandpiper	5.4 (7)	.8 (1)	86 (6)	100 (1)
Red Phalarope	3.8 (5)	2.3 (3)	60 (3)	100 (3)
Lesser Golden Plover	3.8 (5)	1.5 (2)	60 (3)	0
Stilt Sandpiper	4.6 (6)	.8 (1)	50 (3)	100 (1)
Oldsquaw	.8 (1)	.8 (1)	0	0
Ruddy Turnstone		1.5 (2)		50 (1)
Gr. White-fronted Goose		.8 (1)		100 (1)
Canada Goose	.8 (1)		100 (1)	
Northern Shoveler		.8 (1)		0
King Eider	.8 (1)		0	
Willow Ptarmigan		.8 (1)		100 (1)
Rock Ptarmigan	.8 (1)		0	
Baird's Sandpiper		.8 (1)		0
Snow Bunting		.8 (1)		100 (1)
Total or Mean	117.7 (153)	98.5 (128)	73 (111)	82 (105)

Discussion

In this section, we discuss nest density and nest success patterns, and compare them with the findings of other researchers. On this basis we present some ideas about how gravel placement may affect the quality of adjacent nesting habitats.

Nest Density

The average nest densities for both disturbed plots (98.5 nests/km^2) and undisturbed plots (117.7 nests/km^2) (Table 7) were relatively high compared to most other previously reported nest densities for the Arctic Coastal Plain. In the Prudhoe Bay oil field, densities ranged from 42 to 89.2 nests/km^2 on various types of disturbed and undisturbed plots over almost 10 years of studies (Troy 1982; Troy and Burgess 1983; Troy et al. 1983; Troy 1986, 1988; Troy and Carpenter 1990; Troy and Wickliffe 1990). However, Norton et al. (1975) reported higher densities (93.4 to 99.9 nests/km^2) than Troy and his colleagues during two years of studies in the Prudhoe Bay oil field in the early 1970's. On an inland plot south of Deadhorse, nest densities averaged 120 nests/km^2 (Hohenberger et al. 1980, 1981). On study plots at Barrow, nest densities ranged from 42.4 to 154.5 (average = 93.6) nests/km^2 (Myers and Pitelka 1975a, b; Myers et al. 1977a, b; 1978a, b; 1979a, b, c; 1980a, b, c; 1981a, b, c). Nest densities on study plots in ANWR were generally low (Spindler and Miller 1983, Oates et al. 1987), although Martin and Moitoret (1981) had densities up to 136.5 nests/km^2 on a plot in the Canning River Delta.

The three most common species in this study (Semipalmated and Pectoral sandpipers and Lapland Longspur) often have been some of the most common species in the studies cited above for the Arctic Coastal Plain. Semipalmated Sandpipers, and probably to a lesser extent Lapland Longspurs, generally exhibit less variation in numbers from year to year than do Pectoral Sandpipers, which often show strong year-to-year fluctuations and have clumped distributions (Pitelka et al. 1974, Custer and Pitelka 1977).

Of the common species, only Pectoral Sandpiper showed a significant difference in nest density between disturbed and undisturbed plots; nest density was higher in undisturbed plots. Nests of Pectoral Sandpipers were located on a number of our study plots near gravel pads, notably West Sak 9 and West Sak 3. At West Sak 9 (Site 3), 4 Pectoral Sandpiper nests were located on tundra near the north side of the gravel pad (Fig. A-3). At West Sak 3 (Site 4), a Pectoral Sandpiper nest was found on disturbed tundra inside a flare pit southeast of the pad (Fig. A-4). During the previous season, a Pectoral Sandpiper nested at the breach in the gravel berm surrounding this same flare pit (pers. obs.). Pectoral Sandpiper nests also were located near gravel pads at West Sak 17 (Site 1), Term Well C (Site 6), Hurl State (Site 7), Getty State (Site 9), and Put State 1 (Site 10). Since some Pectoral Sandpipers do not seem to avoid nesting sites near abandoned gravel pads, the reasons for higher nest densities of this species in undisturbed plots may be related to factors other than the presence of these pads.

The high nest densities that we found during the 1990 field season were not confined to this study. C. Moitoret, U.S. Fish and Wildl. Serv. (pers. comm.), found densities of 89.9 and 94.2 nests/km^2 on two large plots in the Kuparuk oil field near some of our westernmost study sites. During the previous two seasons, densities in these same plots had ranged from 49 to 67 nests/km^2. Ongoing studies by D. Troy, Troy Ecol. Res. Assoc. (pers. comm.), also had higher densities in 1990 than in previous seasons.

Reasons for these relatively high nesting densities in 1990 may be related to weather conditions. Birds begin nesting on the tundra as it becomes clear of snow (Custer and Pitelka 1977, Seastedt and MacLean 1979, Holmes 1966), and a late snow melt can cause a delay in the arrival of some birds to the nesting grounds (Pitelka 1959) or a delay in nest initiation (Green et al. 1977). Troy (1988) reported lower levels of bird use of tundra habitats during years of cold and/or late snow melt at Prudhoe Bay. Holmes (1970) found that the effects of severe climatic conditions on the food supply of Dunlin at Barrow could affect their breeding density. On Bathurst Island in the Canadian High Arctic, cold weather and late snow-melt caused disastrous nesting conditions for tundra nesting birds in some years (Mayfield 1978). Catastrophic reductions in nesting caused some years to be classified as "nonbreeding years" by Mayfield (1983).

The 1990 nesting season may represent a year of optimal conditions for tundra-nesting bird species because snow cover had disappeared from the Prudhoe Bay region before May 28. In a removal experiment, Holmes (1966) felt that there was a critical time by which pairing and mating must take place. He found that, with one exception, Dunlin territories were reoccupied prior to June 15, but not thereafter. Thus, during years in which snow persists into mid-June, tundra habitats may not be clear in time for birds to reach maximum nesting densities.

Observer-related factors may also influence observed differences in nest densities among studies or years. Spindler and Miller (1983) point out the difficulties in duplicating search effort and pattern among different census crews and crew leaders, and in duplicating nest-finding skills among observers and years. Thus, sets of nest density data are most validly compared when gathered by the same people in the same year.

Habitat fragmentation has been identified as a possible factor negatively affecting bird use of tundra habitats (Meehan 1986), although Troy (1988) found that fragmentation of tundra by oil field facilities did not appear to influence bird use. Habitat fragmentation should not have had any effect on the comparisons made between disturbed and undisturbed study plots in our study. Each site was located in an area surrounded by roads, pipelines, and facilities so that each of the paired plots within a given site was contained within the same tundra "fragment."

Nest Success

When compared with others' results, nest success in the current study was high both in disturbed plots (82 percent) and in undisturbed plots (73 percent) (Table 4). Nest success at P-Pad in the Prudhoe Bay oil field declined from 54 percent to 36 percent over two years (Troy and Carpenter 1990), while nest success at the Pt. McIntyre reference area during the same years declined from 63 percent to 44 percent. Nest success for other studies at Prudhoe Bay has ranged from 39 percent to 76 percent for nests of known outcome (Troy et al. 1983, Troy 1986). Norton et al. (1975) found nest success of 38 percent and 86 percent over two years on study plots at Prudhoe Bay, although his method of measuring success differed slightly from the above studies. On an inland plot south of Deadhorse, the nest success doubled over a two-year period from 35 percent to 70 percent (Hohenberger et al. 1980, 1981). During five years of study at Barrow, nest success averaged approximately 66 percent (Myers and Pitelka 1975a, b; Myers et al. 1977a, b; 1978a, b; 1979a, b, c; 1980a, b, c; 1981a, b, c).

Nest predation by Arctic foxes probably was responsible for most of the losses during this study. Troy and Carpenter (1990) reported heavy nest losses due to Arctic foxes at P-Pad, and Norton et al. (1975) felt that removal of Arctic foxes may have increased the nest success on his study plots. Wiggins and Johnson (1991) hypothesized that the increased abundance of nesting

Common Eiders (*Somateria mollissima*) along the Endicott causeway may be related to the absence of Arctic foxes there after break-up.

A reduction in nest density has been postulated to reduce predation (Pitelka et al. 1974). Experiments by Page et al. (1983) showed a decrease in nesting success of Snowy Plovers in California with an increase in nest density. He felt that the maintenance of low nesting density was an important antipredator adaptation. Since nesting densities at Prudhoe Bay seemed to be higher than usual in 1990, we might have expected lower nest success than in other years due to effects of predation, assuming predator populations were at normal levels. However, for this study, overall nest success was relatively high. It is only when we look at the individual study plots (Table 4) that low nest success appears for some plots. The undisturbed plot at Hurl State, for instance, had a relatively high nest density and relatively low nest success. This may be an example of predation operating in a density-dependent fashion on a local level to regulate nest success.

Effects of Gravel Placement

According to Connors (1983), tundra covered with gravel is lost as bird nesting habitat. This is probably true immediately after gravel placement has occurred and while pads are being used during oil field operations. The abandoned gravel pads that were part of this study did not serve as nesting habitat for most species. However, some species (Greater White-fronted Goose, Red-necked Phalarope, Baird's Sandpiper, Lapland Longspur, and Snow Bunting) did have nests on gravel. Nests occurred on gravel at Ugnu 1 (4 nests), Storage Pad (1 nest), and Prudhoe Bay State 1 (1 nest). These sites have been abandoned for some time, and varying amounts of plant colonization and thermokarsting have altered the gravel substrate. Nests on pads usually were associated with vegetation, although a Baird's Sandpiper nested on barren gravel.

Abandoned gravel pads do not seem to adversely affect the suitability of adjacent tundra as nesting habitat. On average, gravel covered approximately 25 percent of the area of the disturbed study plots (Table 5). If we assume that this area is totally lost as nesting habitat, and that the remaining habitat in the disturbed plots is equal in value to equivalent amounts of habitat in the undisturbed plots, then we can calculate the number of nests we would expect to find on disturbed plots. Since 153 nests were found on undisturbed plots, we would expect to find 75 percent of that number, or 115 nests, on the undisturbed portions of disturbed plots. In actuality, 128 nests were found on disturbed plots. Subtracting the 6 nests that were found on gravel leaves 122 nests on the undisturbed portions of disturbed plots. This would seem to indicate that any effect of abandoned gravel pads on nesting habitat does not go beyond the limits of the area covered by gravel.

To a certain degree, abandoned gravel pads may enhance the suitability of adjacent tundra as nesting habitat. Thermokarsting of tundra near the edges of gravel pads produces water-filled pits and other areas of microrelief. Red-necked Phalaropes seem to be attracted to these areas. This may have been responsible for the higher number of nests of this species (16 vs. 7) in disturbed plots (Table 7), although this difference was not statistically significant. Studies of abandoned peat roads in the Prudhoe Bay oil field by Troy (1991) suggest that thermokarsting and enhanced microrelief may increase bird use of an area for nesting. He reported that thermokarsting and vegetation changes associated with peat roads probably benefited birds. He suggested that in reclaiming abandoned sites one should strive for heterogeneity of habitat, and that a combination of ridges and ditches might increase bird use of an area. Other studies also have suggested that greater variability of microrelief may benefit tundra nesting birds (e.g., Norton et al. 1975, Martin and Moitoret 1981). Further studies on the effects to nesting habitats of thermokarsting and variability of microrelief may prove beneficial in developing plans for future rehabilitation of gravel facilities.

Conclusions

The findings of this study concerning bird nesting and abandoned gravel pads are encouraging in many ways. Although there was a tendency for more nests to be found on undisturbed tundra plots than on disturbed tundra plots containing abandoned gravel pads, the difference in mean nest densities between plot types was not significant statistically. Of the common species, only Pectoral Sandpiper showed a statistically significant difference in nest density between disturbed and undisturbed plots. It nested more commonly in undisturbed plots than in disturbed plots, but this difference may not have been related to the presence of the abandoned gravel pads. In some cases, disturbed study plots actually had higher nest densities than did nearby undisturbed plots, even though gravel covered an average of approximately 25 percent of the area in disturbed plots. Excluding the gravel-covered area in disturbed plots, we found that the density of nests on the two plot types was about the same.

Similarly, the presence of abandoned gravel pads did not seem to affect nest success or species diversity of nesting birds. There was a tendency (not statistically significant) for disturbed plots to have greater nest success than undisturbed plots, and there were almost as many successful nests on disturbed plots as on undisturbed plots overall. On a per-plot basis, there was a slight tendency for undisturbed plots to have more nesting species than nearby disturbed plots; but more species nested on all disturbed plots combined than on all undisturbed plots combined. There also was a tendency for undisturbed plots to have a higher Shannon's diversity index value than disturbed plots, but again the difference was not significant statistically.

Although gravel fill generally does not serve as nesting habitat for tundra-nesting bird species, some birds did nest on abandoned gravel pads during this study. These nests were all located on older pads that had some naturally occurring plant colonization and thermokarsting. In some cases, abandoned gravel pads may have enhanced the suitability of adjacent tundra as nesting habitat by creating water-filled pits and a greater degree of microrelief as the result of thermorkarsting near the pad.

Overall, these findings suggest that the nesting-habitat value of undisturbed tundra surrounding abandoned gravel pads is similar to that of undisturbed tundra elsewhere. Nest density, nest success, and species diversity of nesting birds all were similar on both disturbed and undisturbed plots. The association of some nests with natural vegetation and thermokarst on and near abandoned gravel fill indicates that manipulation short of restoration may improve the value of abandoned sites as nesting habitat for some birds.