

Response of Pacific Loons (*Gavia pacifica*) to Impoundments at Prudhoe Bay, Alaska

KENNETH KERTELL¹

(Received 5 February 1996; accepted in revised form 24 June 1996)

ABSTRACT. Reproductive success and foraging effort of Pacific loons (*Gavia pacifica*) were compared between impoundments and natural ponds in the Prudhoe Bay oil field, Alaska, in 1992 and 1993. Pacific loons successfully reproduced on both impoundments and ponds. Though success tended to be lower on impoundments, no significant differences were detected between the two water body types. The principal cause of reproductive failure on both impoundments and ponds in 1993 appears to have been predation by arctic foxes (*Alopex lagopus*) during incubation. Predation losses on impoundments often were associated with large water-level drawdowns, which apparently increased opportunities for predation of stranded clutches. I found no differences in chick mortality or adult foraging effort between impoundments and ponds. Over 99% of the prey items delivered to chicks were invertebrates captured in freshwater wetlands. Reproductive output of Pacific loons may be improved by increasing the stability of water levels at impoundments used for nesting. I found no evidence that draining impoundments would improve habitat for loons (or invertebrate-eating waterfowl species) at Prudhoe Bay.

Key words: Pacific loon, *Gavia pacifica*, Prudhoe Bay, impoundments, impact assessment, Alaska

RÉSUMÉ. En 1992 et 1993, on a établi une comparaison du taux de réussite de la reproduction et de la quête de nourriture du huart du Pacifique (*Gavia pacifica*) entre les bassins de retenue et les étangs naturels situés dans le champ pétrolifère de Prudhoe Bay en Alaska. Le huart du Pacifique se reproduisait bien sur les bassins comme sur les étangs. Malgré un taux ayant tendance à être plus faible sur les bassins, on n'a pas remarqué de différences notables entre les deux nappes d'eau. En 1993, la raison principale de l'échec de la reproduction sur les retenues comme sur les étangs semble avoir été la prédation effectuée par le renard arctique (*Alopex lagopus*) au cours de l'incubation. Les pertes dues à la prédation sur les bassins étaient souvent liées à de grands rabattements de nappe qui, selon toute apparence, facilitaient l'accès des prédateurs aux pontes échouées. On n'a trouvé aucune différence dans la mortalité juvénile ou dans la quête de nourriture entre les bassins et les étangs. Plus de 99 p. cent des proies rapportées aux poussins étaient des invertébrés capturés dans des marais d'eau douce. On pourrait rendre la reproduction du huart plus efficace en préservant la stabilité du niveau des eaux dans les bassins qui servent à la nidification. On n'a pas trouvé de preuves à l'effet que le drainage des bassins améliorerait l'habitat du huart (ou des espèces d'oiseaux aquatiques se nourrissant d'invertébrés) à Prudhoe Bay.

Mots clés: huart du Pacifique, *Gavia pacifica*, Prudhoe Bay, bassins de retenue, évaluation environnementale, Alaska

Traduit pour la revue *Arctic* par Nésida Loyer.

INTRODUCTION

Within oil fields in arctic Alaska, water impounded beside gravel roads and pads constitutes one of the major human-induced landscape disturbances in terms of area affected (Walker et al., 1987). Some scientists and regulatory agency personnel have expressed concern about the potential negative effects of impoundments on wildlife populations due to habitat loss or alteration. Options for mitigating such potential effects, including draining impoundments through installation of culverts, are being considered by the oil industry. However, for mitigation plans to be successful, they must be based on knowledge of how wildlife populations are actually affected by impoundments. When such knowledge is unavailable, selected species are sometimes used as "indicators" to infer impacts for a wider array of species. An indicator species is defined by Landres et al. (1988:317) as "an organism

whose characteristics (e.g., presence or absence, population density, dispersion, reproductive success) are used as an index of habitat attributes too difficult, inconvenient, or expensive to measure for other species or environmental conditions of interest." Thus, an indicator can serve as a surrogate for other species.

Pacific loons have attributes that make them one of the few arctic waterbirds for which impacts of oil development can be measured easily. They rely almost entirely on freshwater habitats for food during the breeding season (Bergman and Derksen, 1977; McIntyre, 1994), and often spend the entire reproductive season within one oil field. During this time their life-support needs may be met within a single small wetland (Davis, 1972; Bergman and Derksen, 1977). They are easy to observe and respond to habitat differences in ways detectable to observers. They are relatively easy to relocate following dispersal from nest sites. Finally, they are abundant

¹ SWCA, Inc. Environmental Consultants, 343 South Scott Avenue, Tucson, Arizona 85701, U.S.A.

in arctic wetlands, providing resource managers with the opportunity to collect data in a variety of locations and habitat types.

Several researchers have studied loons to assess habitat conditions. Strong (1990) concluded that habitat conditions for breeding common loons (*Gavia immer*) are reflected most accurately by reproductive output, and that the best measurement of reproduction may be a count of prefledged chicks 7–10 weeks old. Dickson (1993) similarly indicated for red-throated loons (*Gavia stellata*) that reproductive success, as measured by young that survive to fledging, was a good indication of local habitat conditions. Andres (1993) suggested that local foraging behavior of Pacific loons should be determined before they are used as an indicator of freshwater habitat conditions. The relationship between prey availability and the foraging tactics of vertebrate consumers in aquatic systems has been used to assess habitat quality not only for loons (Alvo, 1986) but for other species as well, including sea otters (*Enhydra lutris*) (Estes et al., 1986) and dippers (*Cinclus cinclus*) (Omerod and Tyler, 1987).

This paper compares reproductive success and foraging effort of Pacific loons on impoundments and natural ponds, and thereby evaluates impoundments as waterbird habitat at Prudhoe Bay.

METHODS

Study Area

I studied Pacific loon biology in the Prudhoe Bay oil field, between the Kuparuk River and the Putuligayuk River, on the Arctic Coastal Plain of Alaska (Fig. 1). The oil field borders the Beaufort Sea and is located in a region of low relief covered by numerous shallow lakes and ponds (Walker et al., 1980).

Temporary and permanent impoundments together account for a major proportion of the acreage disturbed in the Prudhoe Bay region. Most instances of impounded water occur where gravel roads and pads block drained thaw-lake basins or other low-lying areas (Alexander and Miller, 1978; Brown et al., 1984; Walker et al., 1986; Walker et al., 1987). The amount of acreage flooded by impoundments usually peaks as snowmelt ends around mid-June. In the Prudhoe Bay oil field, many of the flooded areas are temporary; they drain completely by mid-summer after the ice plugging road culverts melts and surface run-off rates subside (Alexander and Miller, 1978; Klinger et al., 1983; Walker et al., 1987). However, other flooded areas are permanent, draining only partially.

Water Body Classification

Some terms require definition. I often refer to impoundments and natural ponds as *water bodies*. *Wetland* refers to a class or type of impoundment or pond (e.g., Shallow-*Arctophila*) and therefore differs from the regulatory

definition of wetland (Environmental Laboratory, 1987). *Impoundments* are water bodies created by anthropogenic alterations to the landscape surface.

Water bodies with territorial or nesting Pacific loons were plotted on a 1991 hydrological map (1" = 500') of the Prudhoe Bay oil field produced from aerial photography taken in July and August. These water bodies were then classified as natural ponds or impoundments on the basis of a 1983 map (Lederer et al., 1984) depicting impoundment locations in the oil field. A recent analysis of pre-development aerial photographs (Noel et al., 1995) indicates that some water bodies depicted as "impoundments" by Lederer originally were natural ponds that were enlarged by the presence of impounded spring runoff following the construction of nearby roads and drilling pads. I found that the accumulation of surface water not only enlarged temporarily the size of these water bodies, but, more importantly, resulted in earlier thaw dates, apparently by enhancing heat absorption (Truett and Kertell, 1992). They were therefore used earlier by loons than nearby natural ponds. Furthermore, because the majority of loons initiated nests in early spring, several nests placed within temporarily impounded portions of these water bodies were left stranded above water as drying of spring meltwater progressed. Therefore, the presence of impounded water has the potential to impact loon use and reproduction, whether or not these water bodies are modified natural ponds.

In 1993, water body size was measured from a digital version of the 1991 hydrological map using MapInfo® (MapInfo Corporation, Troy, New York). For impoundments with large drawdowns, boundaries prior to drawdown were estimated visually, transposed onto the digital hydrology map, and measured using MapInfo®. Percent open water was estimated daily in 1992 at 15 randomly selected impoundment/pond pairs with and without nesting loons until the water bodies were 100% ice-free. I classified water bodies with nesting loons in the field according to a classification system developed by Bergman et al. (1977), except that I did not use the Basin-complex wetland type because it may contain any or all of the other wetland classes (Derksen et al., 1979; Taylor, 1986).

Nest Success

I located territorial Pacific loon pairs within approximately 0.8 km of gravel roads and pads by scanning water bodies from a parked vehicle with 10× binoculars and a spotting scope with a 20–45× zoom lens. In 1992, I did not search for nests until the beginning of July, 7–10 days after peak nest initiation that year. In 1993, I started nest surveys on 10 June, eight days before the first nest was initiated.

Nest construction and clutch initiation were observed for the majority of pairs in 1993. For nests located after laying had taken place, clutch initiation dates were calculated by back-dating from the date of egg-hatching. For this purpose, I assumed an incubation period of 26 days (Johnson and Herter, 1989). A clutch was considered to be a replacement if it was found within an identified territory following the

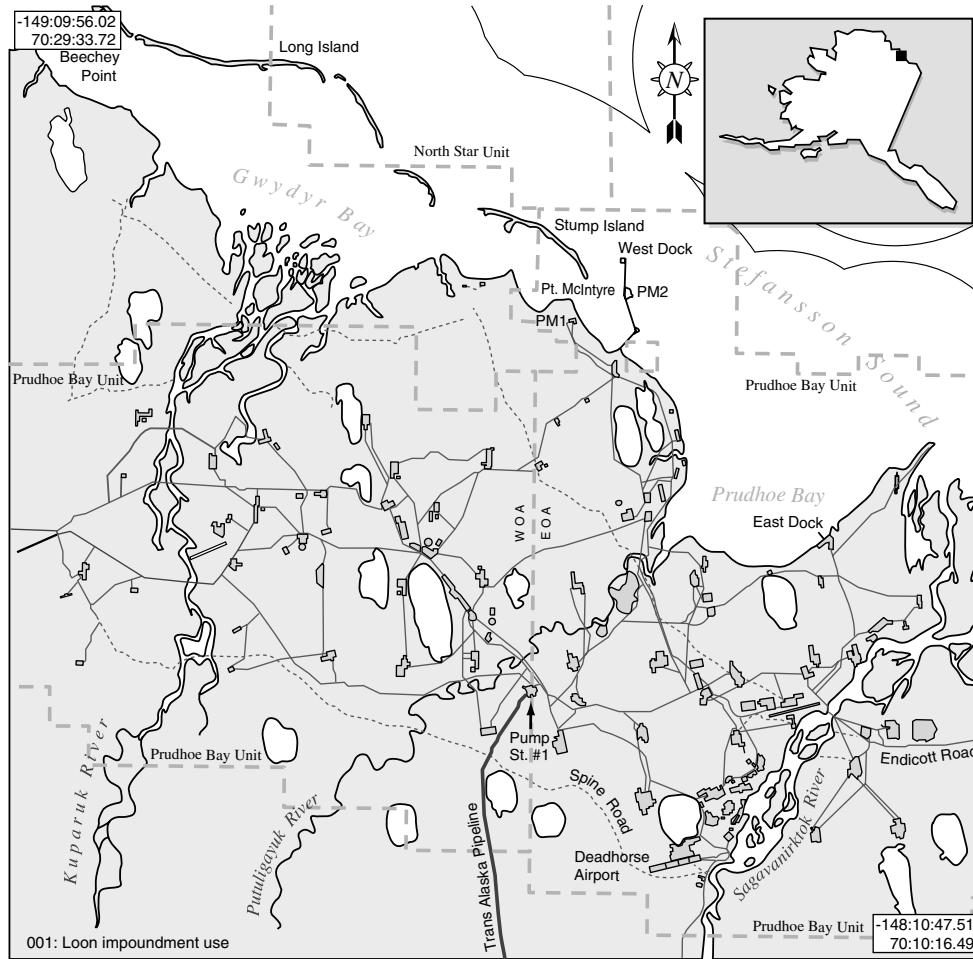


FIG. 1. Prudhoe Bay study area.

known failure of an earlier clutch. In such cases, I assumed that both clutches were initiated by the same pair of adults.

Loon pairs were checked daily with binoculars or spotting scope from a parked vehicle to determine stage of nesting. Following nest initiation, nests were checked daily to monitor their fate. To avoid disturbing nesting birds, which might have increased the chances of predation on eggs, I did not visit active nests on foot to observe breeding behavior or determine clutch sizes. Nest sites were classified as (1) natural island, (2) platform (constructed by loons from mud and/or emergent vegetation), or (3) mainland shoreline (including peninsulas).

Nest success is defined as the number of breeding pairs that hatched at least one young. When nesting was successful, I determined hatching date, number of young, survival of young, and frequency and timing of movements from the nest site to adjacent water bodies. Hatching was considered to have occurred on the day when at least one young was first observed, and production estimates were based on the number of young observed immediately after hatch. Newly hatched young were sometimes difficult to observe because they either hid or were brooded by adults; thus hatching dates were sometimes approximated on the basis of adult behavior (e.g., adults roosted near the nest site) or by counting forward from

the date of nest initiation. Through daily visits to water bodies, I was able to track movements of individual families by noting the number and size of young. Surviving young were monitored daily until 5 August in 1992 and until 27 August in 1993. Survival to 27 August was considered a reasonably good indication of breeding success at Prudhoe Bay since by then most chicks were over five weeks old, hence within about 10 days of fledging (Parmelee et al., 1967).

A nest that appeared inactive (i.e., the adults were absent from the water body) or continued to be attended by an incubating adult well beyond the normal incubation period was visited on foot to determine nest fate. Each failed nest was assigned to one of four categories:

- (1) *Disappeared*. No trace of shell or membrane was found.
- (2) *Predated*. Traces of membrane were found in or near the nest bowl or where predators were observed at the nest.
- (3) *Deserted*. The clutch was found intact and there was no evidence of activity for at least two days.
- (4) *Unknown*. The nest was inaccessible to researchers because of water body depth.

TABLE 1. Wetlands used by Pacific loons for nesting in 1993, Prudhoe Bay, Alaska (wetland type after Bergman et al., 1977).

Wetland type	Ponds (%)	Impoundments (%)
Flooded tundra	0	1 (2.4)
Shallow-CAAQ ¹	20 (24.7)	19 (45.2)
Shallow-ARFU ²	38 (46.9)	17 (40.5)
Deep-ARFU	23 (28.4)	4 (9.5)
Beaded stream	0	1 (2.4)
Coastal wetlands	0	0
Deep-open lakes	0	0
Total	81 (100)	42 (100)

¹ CAAQ = *Carex aquatilis*

² ARFU = *Arctophila fulva*

Foraging Effort

In 1992 and 1993, adult loons with young were selected for detailed observations of foraging effort. Observations were conducted at six pairs of ponds and impoundments in 1992, and at eight pairs of ponds and impoundments in 1993. At these sites, time spent foraging, time spent feeding young, and number and duration of foraging “bouts” were recorded during four-hour observation periods. A bout refers to a period during which relatively brief feeding behaviors were repeated several times in succession. Two loon pairs, one at a natural pond and one at an impoundment, and each with the same number of young of similar age, were observed concurrently by two observers during morning and afternoon observation periods. Three observation periods (12 hours total) were conducted for each pair. To estimate total prey delivered to young at each site, prey delivery rates (number of prey per 10-minute period) were recorded at intervals of 30 minutes when loons were foraging. Although I could not accurately identify individual prey items during prey exchange, I could distinguish between invertebrates and fish by size and shape.

Data Analysis

I used contingency table analysis to compare impoundments with ponds relative to loon choice of wetland type and nest substrate, nest success, and productivity. Yates’s correction was applied to all two-by-two contingency tables. Paired-sample *t*-tests were used to compare foraging times and prey delivery rates. I considered tests to be statistically significant at $p < 0.05$. Standard deviations (SD) are provided as the measure of variability throughout the text.

RESULTS

Wetland Use

I located 46 nests in 1992 (24 on natural ponds and 22 on impoundments) and 123 nests in 1993 (81 on natural ponds and 42 on impoundments). In 1993, the three most commonly used wetland classes on both impoundments and ponds were

TABLE 2. Sizes of water bodies used for nesting by Pacific loons in 1993, Prudhoe Bay, Alaska.

Water body type	(n)	Mean area (ha)	SD	Range
Pond	81	10.71	15.92	0.35 – 65.30
Impoundment ¹	42	8.20	9.64	0.50 – 43.10

¹ size before drawdown

Shallow-*Carex*, Shallow-*Arctophila*, and Deep-*Arctophila* (Table 1). No nests were placed on Deep-open Lakes. The impoundments and ponds that had nests in 1993 showed wide variation in size (Table 2).

Presumably many birds returned to the same wetland in 1993 that they had used the previous year. Ninety percent of the impoundments ($n = 22$) and 79% of the ponds ($n = 24$) that were used for nesting in 1992 were used again in 1993. In 1993, 50% of the pairs on impoundments ($n = 20$) and 32% of the pairs on ponds ($n = 19$) nested on water bodies where nests had failed in 1992.

Nest Site Selection

Pacific loons tended to prefer natural islands and platforms as nesting sites (Table 3). In 1993, the majority of nests on impoundments (79%) and natural ponds (73%) were located on these two substrate types (Table 3). Choice of nest substrate in 1993 was independent of water body type ($\chi^2 = 2.37$, d.f. = 2, $p = 0.31$).

In 1993, nest success by substrate type tended to be different between impoundments and ponds (Table 3). For nests located on islands and platforms, a greater percentage were successful on ponds (28 of 59, 48%) than on impoundments (9 of 33, 27%). A large percentage (17 of 21, 81%) of mainland nests on ponds failed. On impoundments, 50.0% of mainland nests were successful, but the sample size was small ($n = 8$).

Timing of Breeding

Mean clutch initiation dates and mean hatch dates were similar on ponds and impoundments (Table 4). In 1992, impoundments ($n = 15$) were 100% ice-free on 9 June, six days earlier than ponds ($n = 15$), but first clutches were initiated on 18 June and 19 June, respectively. Thaw dates were not recorded in 1993.

In 1993, Pacific loons laid replacement clutches on both impoundments ($n = 5$) and ponds ($n = 5$). Mean date of replacement clutches for all water bodies pooled was 10 July (range 3–19 July). Average time between the loss of the original clutch and the initiation of the second clutch was 12.4 days (± 3.7).

Nest Success

Although nest success tended to be higher on ponds than on impoundments in 1993 (Table 5), it was not significantly different (41% versus 33%, but $\chi^2 = 0.65$, d.f. = 1, $p = 0.42$). The majority of failed nests on both water body types

TABLE 3. Nest success by substrate type in 1993, Prudhoe Bay, Alaska.

Nest substrate	Impoundment nests			Pond nests		
	Successful	Unsuccessful	Total (%)	Successful	Unsuccessful	Total (%)
Natural island	7	19	26 (61.9)	19	20	39 (48.2)
Vegetation platform	2	5	7 (16.7)	9	11	20 (24.7)
Mainland shore (including peninsula)	4	4	8 (19.0)	4	17	21 (25.9)
Unknown	1	0	1 (2.4)	1	0	1 (1.2)
Total	14	28	42 (100.0)	33	48	81 (100.0)

TABLE 4. Nesting chronology of Pacific loons in 1992 and 1993, Prudhoe Bay, Alaska.

Year	Water body type	Mean clutch initiation date \pm SD (range)		Hatch date \pm SD (ranges)
		First attempts	All nests	
1992	Pond	22 June \pm 2.4 (n = 14) (18 – 27 June)	23 June \pm 5.4 (n = 15) (18 June – 11 July)	18 July \pm 2.8 (n = 13) (15 – 25 July)
	Impoundment	23 June \pm 3.5 (n = 12) (19 June – 2 July)	26 June \pm 7.8 (n = 14) (19 June – 13 July)	19 July \pm 3.8 (n = 10) (15 – 28 July)
1993	Pond	23 June \pm 2.3 (n = 63) (19 June – 1 July)	26 June \pm 8.1 (n = 80) (19 June – 6 August)	22 July \pm 6.9 (n = 32) (14 July – 9 August)
	Impoundment	21 June \pm 2.1 (n = 33) (18 – 27 June)	25 June \pm 7.7 (n = 42) (18 June – 15 July)	23 July \pm 9.1 (n = 14) (13 July – 7 August)

contained no eggs or egg remains in 1993 (Table 6). Because 1992 studies began after clutch initiation, results likely underestimate predation losses early in the incubation period.

Natural ponds tended to produce more young than impoundments (Table 5). However, the proportion of pairs with 0, 1, and 2 young at hatch was not significantly different between the two water body types in 1992 ($\chi^2 = 0.37$, d.f. = 2, $p = 0.83$) or 1993 ($\chi^2 = 2.40$, d.f. = 2, $p = 0.30$).

In 1993, water-level drawdowns affected nest success on impoundments but not on ponds. Impoundment drawdowns occurred between 15 June and 15 July. Drawdowns were the result of culvert thaw or drying of recently flooded tundra bordering deeper, more stable pools. At some impoundments, drawdowns were extensive and rapid. At other impoundments, where culverts were absent or ineffective, water levels remained relatively constant, fluctuating slightly with yearly rainfall cycles in a manner similar to that observed at natural ponds in 1993. At the eight impoundments with the largest drawdowns, reductions in surface area ranged from 25% to 69%, and averaged about 48%. Of the 13 nests located on these eight impoundments, only 15% were successful. In 1992, two impoundment nests were predated following large drops in water level.

Nest predation was rarely observed in 1992 or 1993. In 1993, nests where predation was directly witnessed, or where there was circumstantial evidence of predation (i.e., egg remains or fox tracks at the nest), accounted for 31% of failed pond nests and 14% of failed impoundment nests (Table 6). Direct predation was witnessed on two occasions when parasitic jaegers (*Stercorarius parasiticus*) were observed feeding at nests which were later found to contain shell fragments. From the number of “disappeared” and “predated”

clutches in 1993, my best estimate of the overall impact of predators is that they were responsible for the loss of over 95% of failed clutches on ponds (n = 48) and impoundments (n = 28). Predation estimates for impoundments may have been too high because of the difficulty in determining whether nests had been deserted because of water-level drawdowns or other events prior to predation.

Survival of Young

Although chick survival tended to be lower on impoundments than on ponds (Table 5), the proportion of loon pairs with 0, 1, and 2 young was not significantly different at the end of field observations (5 August in 1992 and 27 August in 1993) in either 1992 ($\chi^2 = 1.81$, d.f. = 2, $p = 0.40$) or 1993 ($\chi^2 = 2.40$, d.f. = 2, $p = 0.30$). In 1993, the majority of chick mortality on impoundments apparently occurred immediately after hatch. On the first day of observations, 58% (n = 33) of loon pairs at successful pond nests had two chicks, but only 36% of loon pairs at successful impoundment nests had two chicks. Otherwise, the percentage of young that survived to the end of field observations in August was similar on the two water body types in 1993: 71% on ponds and 74% on impoundments (Table 5).

Dispersal

In 1993, Pacific loons commonly dispersed from both natal ponds and natal impoundments (Table 7). Half of the families that moved from nest sites on impoundments (n = 8) and 63% of the families that moved from nest sites on ponds (n = 16) returned to the natal water body at least once prior to

TABLE 5. Pacific loon productivity on ponds and impoundments in 1992 and 1993, Prudhoe Bay, Alaska.

	Pond		Impoundment	
	1992 ¹	1993	1992 ¹	1993
Number of nests found	24	81	22	42
Nest success (%)	58	41	50	33
Number of young at hatch	20	52	16	19
Number of young per nest at hatch	0.83	0.64	0.73	0.45
Number of young in August ²	15	37	7	14
Hatched young that fledged (%)	—	71	—	74
Number of young per nest in August ²	0.63	0.46	0.41	0.33

¹ Because 1992 studies began after clutch initiation, results likely underestimate predation losses early in the incubation period. Also, 1992 studies ended in early August well before young fledge.

² Studies ended on 5 August in 1992 and on 27 August in 1993.

the end of observations. Although loons tended to disperse more frequently from small impoundments and ponds than from large ones, there was wide variation in water body size (Table 7).

Oil field infrastructure (i.e., gravel roads and pads) did not prevent overland movement from either impoundments or ponds. I observed one chick from a pond nest crossing a gravel road, and I have indirect evidence (families observed on opposite sides of roads on alternate visits) that five additional families with flightless chicks (four from impoundments and one from a pond) crossed roads during dispersal.

Foraging Effort

In both 1992 and 1993, the amount of time spent foraging by adults was similar on impoundments and ponds (Table 8). During an average four-hour observation period, adults foraged longer in 1993 (60% on impoundments and 54% on ponds) than in 1992 (54% on impoundments and 48% on ponds). Foraging times were not significantly different on the two water body types in either 1992 ($t = 0.73$, d.f. = 5, $p = 0.50$) or 1993 ($t = 1.00$, d.f. = 7, $p = 0.35$).

Although loons on impoundments tended to deliver more prey to young than did loons on ponds (Table 8), prey deliveries per four-hour period were not significantly different between the two water body types in 1992 ($t = 0.89$, d.f. = 5, $p = 0.41$) or 1993 ($t = 0.73$, d.f. = 7, $p = 0.49$). In both years, prey delivery rates were much more variable on impoundments than on ponds (Table 7). There was no pattern between years (higher at ponds in 1992 and higher at impoundments in 1993) in the percent of time both adults simultaneously delivered prey to young (Table 8).

Loon chicks were fed a diet consisting almost entirely of freshwater invertebrates. Over 99% of prey items delivered in 1992 ($n = 5146$) and 1993 ($n = 23\,363$) were invertebrates captured in freshwater wetlands. Small fish (approximately 2–4 cm in length) were the only other prey items I observed being delivered to young. A total of 4 fish and 11 fish were delivered by adults in 1992 and 1993, respectively. Fish were brought to the nest site by adults returning from unknown

TABLE 6. Fate of failed nests in 1993, Prudhoe Bay, Alaska.

Nest Fate	Pond (%)	Impoundment (%)
Disappeared	31 (64.6)	23 (82.1)
Predated	15 (31.2)	4 (14.3)
Avian	3	2
Fox	2	2
Unknown	10	0
Deserted	1 (2.1)	1 (3.6)
Unknown	1 (2.1)	0 (0.0)
Total	48 (100.0)	28 (100.0)

TABLE 7. Dispersal of Pacific loons on ponds and impoundments in 1993, Prudhoe Bay, Alaska.

	Ponds	Impoundments
Successful nests	33	14
Families that dispersed (%)	49	57
Average age of chick when family dispersed (days)	10.9	17.8
Average size of water body from which families dispersed (ha)	5.6 ± 6.23 (n = 16)	7.6 ± 14.4 (n = 8)
Average size of water body at which families remained (ha)	24.0 ± 20.6 (n = 17)	10.2 ± 9.1 (n = 6)

locations, presumably the nearshore Beaufort Sea (where adult loons were often observed foraging) or large inland lakes.

DISCUSSION

Wetland Use

Invertebrate availability apparently plays an important role in nest site selection by Pacific loons. At Prudhoe Bay, loons nested only in wetland types in which the depth of the water is less than 1 m (Hobbie, 1984). Maximum depth in Deep-open Lakes, on which no loons were found nesting in 1992 or 1993, is about 2 m. Wetlands more than 1.7 m deep (the thickness of the ice cover) contain fish (Hobbie, 1984), and therefore have a lower abundance and diversity of invertebrates (Butler et al., 1980).

Selection of shallow water bodies in this study area also may have been related to factors other than food for the young. In addition to food availability, nest pond requirements for common loons include (1) isolation from conspecifics, (2) adequate nest sites, (3) abundant aquatic vegetation, and (4) protection from wave action (McIntyre, 1983). It is possible that many of these requirements are better provided in shallow wetlands than in Deep-open Lakes.

Nest Site Selection

Throughout their range in North America, Pacific loons prefer to nest on islands (Davis, 1972; Bergman and Derksen,

TABLE 8. Foraging effort of Pacific Loon pairs in 1992 and 1993, Prudhoe Bay, Alaska.

Year	Water body type	Number of pairs	Average number of foraging bouts per 4-hr period	Average length of complete foraging bouts per 4-hr period (min)	Average time adults fed young per 4-hr period (min)	Average percent of time young fed by 1 and 2 adults per 4-hr period	Average number of prey deliveries per 10-min period	Estimated total prey deliveries per 4-hr period (excluding fish)
1992	Pond	6	3.0 (± 1.1)	50.8 (± 32.3)	113.9 (± 32.5)	48 (± 20), 52 (± 20)	62.2 (± 27.5)	665.1 (± 282.7)
	Impoundment	6	2.4 (± 0.6)	78.1 (± 23.6)	129.1 (± 32.5)	63 (± 39), 37 (± 39)	67.8 (± 31.3)	853.8 (± 414.0)
1993	Pond	8	2.9 (± 0.9)	48.9 (± 14.0)	128.7 (± 25.2)	73 (± 16), 27 (± 16)	95.4 (± 19.3)	1216.6 (± 311.4)
	Impoundment	8	2.7 (± 0.7)	45.3 (± 22.2)	144.0 (± 47.3)	40 (± 27), 60 (± 27)	100.1 (± 54.6)	1462.5 (± 871.5)

1977), apparently because foxes visit island nests less frequently than mainland nests (Petersen, 1979). Selection of island nest sites may be less adaptable on impoundments than on ponds because of hydrological differences between the two water body types. Water levels in natural arctic wetlands tend to be relatively stable and predictable (Hohman et al., 1992), but impoundment water regimes often are not (Truett and Kertell, 1992). Therefore, there is increased risk that island nest sites on impoundments may become attached to the mainland and shoreline nests may become stranded on dry land as water levels fall during the course of the breeding season.

Timing of Breeding

Timing of breeding at Prudhoe Bay was similar to that reported at Point Storkersen, Alaska. From 1971 to 1973 at Point Storkersen, dates of clutch initiation on natural ponds were between 20 and 23 June (Bergman and Derksen, 1977).

Water level might be more important than timing of spring thaw in determining breeding dates at Prudhoe Bay. In a study of common loons, Barr (1986) found that adults waited for specific nest sites to become available as water levels receded. Although impoundments were available earlier than ponds at Prudhoe Bay, loons that selected territories on impoundments nested at the same time as those using ponds. Like the common loon, they might have been waiting for spring water levels to stabilize before nesting.

Schamel and Tracy (1985) have suggested that the ability of loons to produce replacement clutches is a valuable adaptation to occasional high rates of arctic fox (*Alopex lagopus*) predation in western Alaska. However, in northern Alaska young loons from late clutches often do not fledge before lakes and ponds freeze (Johnson and Herter, 1989). Thus, replacement of clutches at Prudhoe Bay may be less adaptive than at subarctic locations.

Nest Success

In both 1992 and 1993, predation by arctic foxes apparently was the major cause of clutch loss on both impoundments and ponds in this study. Foxes typically remove entire eggs from the vicinity of the nest before eating or caching them (Tinbergen, 1972; Kertell, pers. obs.), and it is likely that they

were responsible for the majority of empty nests. However, glaucous gulls and common ravens (*Corvus corax*) will sometimes fly with whole eggs before eating them (Davis, 1972; Petersen, 1979; Kertell, pers. obs.) and cannot be totally discounted as a potential cause of empty nests.

It was impossible to determine if loss of most clutches was the result of direct predation or of scavenging following nest desertion. Stranded clutches (clutches left on dry land following water-level drawdowns) are less accessible to incubating loons and more difficult to defend against foxes (Gotmark et al., 1989). For common loons, Barr (1986) found that 33% more clutches hatched successfully in territories with water-level fluctuations of less than 1.5 m. Belant and Anderson (1991) reported nest failure when receding water levels increased the distance of the nest to water by 3 m. Although flooding was a major cause of arctic loon nest failure in northern Sweden (Gotmark et al., 1989) and Scotland (Mudge and Talbot, 1993), I observed no instances of loon nest loss due to rising water levels at Prudhoe Bay. Pacific loons at Prudhoe Bay do not begin to initiate nests until around the third week of June, after peak water levels have occurred.

The degree to which reproductive failure was the result of human disturbance at Prudhoe Bay could not be determined. Impoundments are located immediately adjacent to oil field roads and drilling pads, where the potential for human disturbance is greater than for the majority of natural ponds. Temporary abandonment of nests following disturbance likely results in increased opportunities for predation by glaucous gulls and parasitic jaegers (Gotmark et al., 1990), which are common at Prudhoe Bay (Kertell, pers. obs.). I observed workers displace loons from their nests at Prudhoe Bay on two occasions, but neither instance resulted in loss of eggs or nest abandonment.

Survival of Young

Since Pacific loons almost always lay two eggs (Johnson and Herter, 1989), chicks on impoundments apparently suffered higher mortality immediately after hatch, either from higher rates of partial predation or from starvation, than did chicks on ponds. At other arctic locations, most chick mortality apparently resulted from starvation of the youngest chick in the brood. Davis (1972) and Bergman and Derksen (1977), for example, found that the youngest chick often died within

two weeks of hatch because of competition for food with its older sibling. A chick weakened by lack of food is especially vulnerable to hypothermia and fatigue during this period (Alvo, 1986). Therefore, although prey delivery rates at Prudhoe Bay were not significantly different between impoundments and ponds, there may have been differences between the two water body types in the type or nutritional quality of prey.

In this study, avian predators likely were responsible for most chick predation at ponds and impoundments in both 1992 and 1993. Glaucous gulls, for example, are known to prey heavily on young birds (Johnson and Herter, 1989; Barry and Barry, 1990). In northwest Canada, the glaucous gull was the only predator species seen taking the young of red-throated loons (Dickson, 1993). Predation on red-throated loon chicks was apparently limited to those less than 10 days old, and the greatest loss of young occurred in a year when there was a significantly large number of glaucous gulls in the study area (Dickson, 1993).

In 1993, production rates at Prudhoe Bay were within the range of production rates (0.17–0.41 young/territorial pair) reported for arctic loons (see Mudge and Talbot, 1993). However, arctic loon production was based on number of nearly fledged young per territorial pair rather than on young per nesting attempt. I was unable to determine the percentage of territorial birds that failed to initiate nests.

Dispersal

At Prudhoe Bay, dispersal from impoundments and ponds may have been related to food availability. Davis (1972) found that the average size of 35 territories at McConnell River, Northwest Territories, was 3.66 ha, considerably larger than the average size (2.22 ha) of nest ponds there. Consequently, 57% of territories included more than one pond, and birds that nested on small ponds often moved to nearby ponds to feed.

Foraging Effort

For visual predators like loons, water body selection may represent a balance between food abundance and foraging efficiency (Heglund et al., 1994). Eriksson (1985) considered water transparency to be a factor important in the selection of lakes by arctic loons, and suggested that their use of oligotrophic lakes in southwest Sweden was consistent with the need for high water transparency to maintain an adequate prey capture rate. Based on similar average prey delivery rates at impoundments and ponds, prey detectability appears to have been similar in the two water body types in my study. I can provide no reasons for greater variability in prey delivery rates on impoundments than on ponds.

Invertebrate prey choice could not be determined at Prudhoe Bay. Invertebrate prey items reportedly taken by Pacific loons breeding in the Arctic include fairy shrimp (Order Anostraca), tadpole shrimp (Order Notostraca), and caddisfly larvae (Order Trichoptera) (Davis, 1972; Bergman and

TABLE 9. Monthly mean temperatures (°C) at Deadhorse, Alaska in 1992 and 1993. Weather data were provided by the Alaska State Climate Center, University of Alaska, Anchorage.

Year	April	May	June	July	August
1992	-17.4	-5.9	3.6	8.3	6.7
1993	-14.2	-4	3.7	10.3	6.2
Difference (1993 – 1992)	+3.2	+1.9	+0.1	+2.0	-0.5

Derksen, 1977). Among these and other potential prey, probably only fairy shrimp and large cladocerans occur at densities high enough to account for the high rates of prey delivery (over 300 prey per 10-minute period) observed by loons subsurface dabbling in open water at Prudhoe Bay. Fairy shrimp are frequently clumped in dense swarms (Stross et al., 1980) and are high in protein content (71.9% of dry weight: Driver et al., 1974; Krapu and Swanson, 1975). In 1992, I collected a sample of large cladocerans (*Eurycerus lamellatus*, 4 mm long) at two water bodies, and, because they also occur at high densities (Stross et al., 1980), the presence of these organisms may have resulted in high prey delivery rates.

Greater prey delivery rates at both impoundments and ponds in 1993 than in 1992 may have resulted from greater invertebrate production in 1993. At Barrow, Alaska, chironomid larval growth was more rapid at water temperatures of 10°C and 15°C than at 5°C (Butler et al., 1980). Although I did not measure water temperatures, monthly air temperature readings averaged higher in 1993 than in 1992 in all months but August in the Prudhoe Bay area (Table 9).

Foraging observations during this study do not support the conclusion of Andres (1993) that Pacific loons rely on marine resources (i.e., marine fish or invertebrates) to the same degree as red-throated loons, which are known to feed their young exclusively fish (Bergman and Derksen, 1977). Andres' conclusion was based on the observation that red-throated and Pacific loons nested at equal densities and were observed flying north to marine waters at the same frequency in his study area on the Colville River Delta, Alaska.

Adult loons in my study did not usually leave the nest pond to capture food for the young, but may have been foraging to supplement their own diet. I frequently observed both Pacific and red-throated loons flying northward from the breeding area toward marine waters and judged it likely that many of the loons performing these flights were breeders, considering that often only one adult was present at the nest pond during chick feeding. However, if adults were foraging in the Beaufort Sea, only on 15 occasions in 1992 and 1993 did they return to nest sites with fish. In Canada, sticklebacks (*Pungitius pungitius*) and grayling (*Thymallus thymallus*) were among fish prey captured by Pacific loons during the breeding season (Davis, 1972).

Particulate composition and organic content of the sediments are correlated with distribution and abundance of certain invertebrates (Wetzel, 1983). Even if benthic habitats in impoundments contain higher levels of peat and drowned

tundra vegetation than benthic habitats in ponds, these differences do not appear to have significantly influenced foraging efficiency. Loons in my study foraged successfully in both impoundments and natural ponds despite any potential differences in substrate type.

CONCLUSIONS

It is a reasonable speculation, based on observations made during this study, that impoundments increase the abundance and diversity of resource patches potentially available to breeding Pacific loons. However, although the importance of wetland diversity to breeding waterbirds is widely recognized (Swanson et al., 1979; Weller, 1988, 1990), it is not known whether or not the loon population at Prudhoe Bay is limited by available foraging habitat. Furthermore, it is not known whether loons that nest on impoundments would normally have nested on ponds, or whether the presence of impoundments provides nesting opportunities for birds that would not have nested otherwise.

The principal cause of nest failure on both impoundments and natural ponds appears to have been predation by arctic foxes during incubation. Predation losses on impoundments, however, were often associated with large water-level drawdowns, which apparently increased opportunities for predation of stranded clutches. Considering the high degree of site fidelity exhibited by some loon species (McIntyre, 1974; Alvo, 1986; Strong, 1990), it is possible that many Pacific loon pairs at Prudhoe Bay will return in the future to impoundments with large water-level fluctuations and that nest success will continue to be lower than at natural ponds, even though impoundments are otherwise productive and suitable for nesting.

Depending on the management objective, the presence of some impoundments may be consistent with wildlife management goals on the Coastal Plain of Alaska. For Pacific loons and waterfowl that nest on islands or pond shorelines, overall reproductive output may be improved by maintaining stable water levels on those impoundments that have the largest water-level drawdowns and a history of previous nesting. At other impoundments, the needs of waterbird species, particularly shorebirds and dabbling ducks, may be best served by allowing drawdowns to occur and increasing the availability of invertebrate-rich sediments. I found no evidence to suggest that draining impoundments would improve habitat value for loons (or invertebrate-eating waterfowl species) at Prudhoe Bay.

ACKNOWLEDGEMENTS

This study was funded by BP Exploration (Alaska) Inc. (BPX). I thank Chris Herlugson (Supervisor, Environmental Assessment, BPX) and Michelle Gilders (Environmental Scientist, BPX) for their interest and support. I am grateful to John Luginbuhl, Mark Miller, Jeff Wickliffe, Carlos Paez, and Steve Johns for assistance

in the field. Special appreciation is extended to John Luginbuhl for managing the loon study in 1993 during periods when I was in Anchorage. I am grateful to Bob Pollard and Bob Rodrigues for help with logistics. Joe C. Truett contributed valuable insight during early discussions on impact assessment research. Joe C. Truett, Lynne Dickson, Stephen Johnson, and Lynn Noel reviewed and improved the final manuscript. The study was conducted while I was employed by LGL Alaska Research Associates, Inc., Anchorage, Alaska.

REFERENCES

- ALEXANDER, V., and MILLER, M.C. 1978. Effects of road construction on nearby ponds and lakes on Alaska's north slope. Report RLO-2229-T9-2. Fairbanks: University of Alaska, Institute of Marine Sciences. 51 p.
- ALVO, R. 1986. Lost loons of northern lakes. *Natural History* (Sept.):59–64.
- ANDRES, B.A. 1993. Foraging flights of Pacific, *Gavia pacifica*, and red-throated, *G. stellata*, loons on Alaska's coastal plain. *Canadian Field-Naturalist* 107:238–240.
- BARR, J.F. 1986. Population dynamics of the common loon (*Gavia immer*) associated with mercury-contaminated waters in northwestern Ontario. Occasional Paper 56. Ottawa: Canadian Wildlife Service. 25 p.
- BARRY, S.J., and BARRY, T.W. 1990. Food habits of glaucous gulls in the Beaufort Sea. *Arctic* 43:43–49.
- BELANT, J.L., and ANDERSON, R.K. 1991. Common loon, *Gavia immer*, productivity on a northern Wisconsin impoundment. *Canadian Field-Naturalist* 105:29–33.
- BERGMAN, R.D., and DERKSEN, D.V. 1977. Observations on Arctic and red-throated loons at Storkersen Point, Alaska. *Arctic* 30:41–51.
- BERGMAN, R.D., HOWARD, R.L., ABRAHAM, K.F., and WELLER, M.W. 1977. Water birds and their wetland resources in relation to oil development at Storkersen Point, Alaska. Resource Publication 129. Washington, D.C.: U.S. Department of Interior, U.S. Fish and Wildlife Service.
- BROWN, J., BROCKETT, B.E., and HOWE, K.E. 1984. Interaction of gravel fills, surface drainage, and culverts with permafrost terrain. CRREL Report No. 84-11. Hanover, New Hampshire: U.S. Army Cold Regions Research and Engineering Laboratory.
- BUTLER, M., MILLER, M.C., and MOZLEY, S. 1980. Macrobenthos. In: Hobbie, J.E., ed. *Limnology of tundra ponds: Barrow, Alaska*. VS/IBP Synthesis Series 13. Stroudsburg, Pennsylvania: Dowden, Hutchinson, and Ross. 297–339.
- DAVIS, R.A. 1972. A comparative study of the use of habitat by Arctic loons and red-throated loons. London: Ph.D. Dissertation, University of Western Ontario. 288 p.
- DERKSEN, D.V., ELDRIDGE, W.D., and ROTHE, T.C. 1979. Waterbird and wetland habitat studies. In: Lent, P.C., ed. *Studies of selected wildlife and fish and their use of habitats on and adjacent to NPR-A 1977-78*. Anchorage: U.S. Department of Interior, National Petroleum Preserve of Alaska. 229–311.
- DICKSON, D.L. 1993. Breeding biology of red-throated loons in the Canadian Beaufort Sea region. *Arctic* 46:1–7.

- DRIVER, E.A., SUGDEN, L.G., and KOVACH, R.J. 1974. Calorific, chemical and physical values of potential duck foods. *Freshwater Invertebrate Biology* 4:281–292.
- ENVIRONMENTAL LABORATORY. 1987. Corps of Engineers wetlands delineation manual. Technical Report Y-87-1, Vicksburg, Mississippi: U.S. Army Engineer Waterways Experiment Station.
- ERIKSSON, M.O.G. 1985. Prey detectability for fish-eating birds in relation to fish density and water transparency. *Ornis Scandinavica* 16:1–7.
- ESTES, J.A., UNDERWOOD, K.E., AND KARMANN, M.J. 1986. Activity-time budgets of sea otters in California. *Journal of Wildlife Management* 50:626–636.
- GOTMARK, F., NEERGAARD, R., and AHLUND, M. 1989. Nesting ecology and management of the Arctic loon in Sweden. *Journal of Wildlife Management* 54:515–522.
- GOTMARK, F., NEERGAARD, R., and AHLUND, M. 1990. Predation of artificial and real Arctic loon nests in Sweden. *Journal of Wildlife Management* 54:429–432.
- HEGLUND, P.J., JONES, J.R., FREDRICKSON, L.H., and KAISER, M.S. 1994. Use of boreal forested wetlands by Pacific loons (*Gavia pacifica* Lawrence) and horned grebes (*Podiceps auritus* L.): Relations with limnological characteristics. *Hydrobiologia* 279/280:171–183.
- HOBBIE, J.E. 1984. The ecology of tundra ponds of the Arctic Coastal Plain: Community profile. Report FWS/OBS-83/25. Washington, D.C.: U.S. Department of Interior, Fish and Wildlife Service. 52 p.
- HOHMAN, W.L., ANKNEY, C.D., and GORDON, D.H. 1992. Ecology and management of postbreeding waterfowl. In: Batt, B.D.J., Afton, A.D., Anderson, M.G., Ankney, C.D., Johnson, D.H., Kadlec, J.A., and Krapu, G.L., eds. Ecology and management of breeding waterfowl. Minneapolis: University of Minnesota Press. 128–189.
- JOHNSON, S.R., and HERTER, D.R. 1989. The birds of the Beaufort Sea. Anchorage: BP Exploration (Alaska) Inc. 372 p.
- KLINGER, L.F., WALKER, D.A., WALKER, M.D., and WEBBER, P.J. 1983. The effects of a gravel road on adjacent tundra vegetation. In: Prudhoe Bay Waterflood Project, environmental monitoring program, 1982. Anchorage: U.S. Army Corps of Engineers, Alaska District.
- KRAPU, G.L., and SWANSON, G.A. 1975. Some nutritional aspects of reproduction in prairie nesting pintails. *Journal of Wildlife Management* 39:156–162.
- LANDRES, P.B., VERNER, J., and THOMAS, J.W. 1988. Ecological uses of vertebrate indicator species: A critique. *Journal of Conservation Biology* 2:316–328.
- LEDERER, N.D., WALKER, D.A., and WEBBER, P.J. 1984. Cumulative development of the Prudhoe Bay field. Map prepared at Institute of Arctic and Alpine Research, Boulder, Colorado, in cooperation with the U.S. Department of Interior, U.S. Fish and Wildlife Service. Available at LGL Alaska Research Associates, Inc., 4175 Tudor Centre Drive, Suite 101, Anchorage, Alaska 99508-5917, U.S.A.
- McINTYRE, J.W. 1974. Territorial affinity of a common loon. *Bird Banding* 45:178.
- . 1983. Nurseries: A consideration of habitat requirements during the early chick-rearing period in common loons. *Journal of Field Ornithology* 54:247–253.
- . 1994. Loons in freshwater lakes. *Hydrobiologia* 279/280:393–413.
- MUDGE, G.P., and TALBOT, T.R. 1993. The breeding biology and causes of nest failure of Scottish black-throated divers, *Gavia arctica*. *Ibis* 135:113–120.
- NOEL, L.E., SCHICK, C.T., and JOHNSON, S.R. 1995. Quantification of habitat alterations and bird use of impoundments in the Prudhoe Bay oil field, Alaska, 1994. Unpubl. report. Available at BP Exploration (Alaska) Inc., Environmental and Regulatory Affairs Department, P.O. Box 196612, Anchorage, Alaska 99519-6612, U.S.A.
- OMEROD, S.J., and TYLER, S.J. 1987. Dippers *Cinclus cinclus* and grey wagtails *Motacilla cinerea* as indicators of stream acidity in upland Wales. In: Diamond, A.W., and Fillion, F., eds. The value of birds. ICBP Technical Publication 6. Cambridge: International Council for Bird Preservation. 191–208.
- PARMELEE, D.F., STEPHENS, H.A., and SCHMIDT, R.H. 1967. The birds of southeastern Victoria Island and adjacent small islands. Bulletin 222. Ottawa: National Museum of Canada.
- PETERSEN, M.R. 1979. Nesting ecology of Arctic loons. *Wilson Bulletin* 91:608–617.
- SCHAMEL, D., and TRACY, D.M. 1985. Replacement clutches in the red-throated loon. *Journal of Field Ornithology* 56:282–283.
- STRONG, P.I.V. 1990. The suitability of the common loon as an indicator species. *Wildlife Society Bulletin* 18:257–261.
- STROSS, R.G., MILLER, M.C., and DALEY, R.J. 1980. Zooplankton. In: Hobbie, J.E., ed. Limnology of tundra ponds: Barrow, Alaska. VS/IBP Synthesis Series 13. Stroudsburg, Pennsylvania: Dowden, Hutchinson, and Ross. 251–296.
- SWANSON, G.A., KRAPU, G.L., and SERIE, J.R. 1979. Foods of laying female dabbling ducks on the breeding grounds. In: Bookhout, T.A., ed. Waterfowl and wetlands: An integrated review. Madison, Wisconsin: Proceedings of the 39th Midwest Fish and Wildlife Conference. 47–57.
- TAYLOR, E.J. 1986. Foods and foraging ecology of oldsquaws (*Clangula hyemalis* L.) on the Arctic Coastal Plain of Alaska. M.S. thesis, University of Alaska, Fairbanks. 130 p.
- TINBERGEN, N. 1972. Food hoarding by foxes (*Vulpes vulpes*). In: The animal and its world. Cambridge, Massachusetts: Harvard University Press. 315–328.
- TRUETT, J.C., and KERTELL, K. 1992. Tundra disturbance and ecosystem production: Implications for impact assessment. *Environmental Management* 16:485–494.
- WALKER, D.A., WEBBER, P.J., EVERETT, K.R., and BROWN, J. 1980. Geobotanical atlas of the Prudhoe Bay region, Alaska. CRREL Report 80–14. Hanover, New Hampshire: U.S. Army Cold Regions Research and Engineering Laboratory. 73 p.
- WALKER, D.A., BINNIAN, E.F., LEDERER, N.D., NORDSTRAND, E.A., WALKER, M.D., and WEBBER, P.J. 1986. Cumulative landscape impacts in the Prudhoe Bay oil field, 1949–1983. Final report to U.S. Department of Interior, U.S. Fish and Wildlife Service, Habitat Resources Section,

- Anchorage, Alaska, by Institute of Arctic and Alpine Research, University of Colorado, Boulder. Available at the U.S. Fish and Wildlife Service Library, 1011 E. Tudor Road, Anchorage, Alaska 99503, U.S.A.
- WALKER, D.A., WEBBER, P.J., BINNIAN, E.F., EVERETT, D.R., LEDERER, N.D., NORDSTRAND, E.A., and WALKER, M.D. 1987. Cumulative impacts of oil fields on northern Alaskan landscapes. *Science* 238:757–761.
- WELLER, M.W. 1988. Issues and approaches in assessing cumulative impacts on waterbird habitat in wetlands. *Environmental Management* 12:695–701.
- . 1990. Waterfowl management techniques for wetland enhancement, restoration, and creation useful in mitigation procedures. In: Kusler, J.A., and Kentula, M.E., eds. *Wetland creation and restoration: The status of the science*. Washington, D.C.: Island Press. 517–528.
- WETZEL, R.G. 1983. *Limnology*. Philadelphia, Pennsylvania: Saunders College Publishing. 767 p.