vegetation of the alpine zone is already dormant. Forage selection and range use patterns are dealt with in detail in Hoefs (1975).

Literature Cited

Blood, D. A. 1963. Some aspects of behaviour of a bighorn herd. Canadian Field-Naturalist 77(2): 77–94.

Egorov, O. V. 1967. Wild ungulates of Yakutia. Israel program for scientific translations, Jerusalem. United States Department of Commerce.

Dixon, J. S. 1938. Birds and mammals of Mount McKinley National Park. United States Department of Interior,

Hoefs, M. 1975. Ecological investigation of Dall sheep and their habitat. Ph.D. thesis, University of British Columbia, Vancouver.

Hoefs, M., I. McT. Cowan, and **V. J. Krajina.** 1975. Phytosociological analysis and synthesis of Sheep Mountain, southwest Yukon Territory, Canada. Syesis 8 (Supplement 1): 125–228.

Hopkins, A. D. 1920. The bioclimatic law. Journal of Washington Academy of Science 10: 34–40.

Hultén, E. 1968. Flora of Alaska and neighboring territories. Stanford University Press, Stanford, California.

Murie, A. 1944. The wolves of Mount McKinley. Fauna of

TABLE 1 — Shorebird eggshell thickness from various North American areas

Species, Region sampled	Early period (E)	Recent period (R)	No. of eggs[a] E	No. of eggs[a] R	Mean index ± SE E	Mean index ± SE R	% Change
Jacana spinosa, E. Mexico	1896–1923	1948–1965	56(13)	88(22)	0.76 ± 0.006	0.77 ± 0.004	+ 1.3
Haematopus ostralegus palliatus, Texas & U.S. Atlantic coast	1882–1946	1955–1969	51(20)	54(20)	1.49 ± 0.014	1.42 ± 0.010	– 4.7***
H. o. bachmani, U.S.Pacific coast	1892–1947	1949–1966	52(20)	34(13)	1.52 ± 0.014	1.47 ± 0.017	– 3.3***
Himantopus mexicanus, Utah	1898–1930	1959	68(17)	24(6)	1.06 ± 0.008	1.04 ± 0.015	– 1.9
Recurvirostra americana, California	1918–1944	1948–1972	77(20)	32(8)	1.11 ± 0.008	1.15 ± 0.014	+ 3.6*
Pluvialis dominica, Alaska	1900–1945	1949–1968	68(17)	58(15)	0.82 ± 0.006	0.82 ± 0.006	—
P. squatarola, Alaska	1924–1947	1948–1965	87(22)	96(25)	0.98 ± 0.004	1.00 ± 0.007	+ 2.0*
Charadrius semipalmatus, Manitoba	1931–1945	1948–1953	58(15)	26(8)	0.62 ± 0.006	0.61 ± 0.08	– 1.6*
C. wilsonia, Texas	1900–1941	1952–1965	46(16)	20(7)	0.84 ± 0.007	0.83 ± 0.007	– 1.2*
C. wilsonia, Florida	1906–1935	1951–1968	24(8)	27(9)	0.83 ± 0.007	0.85 ± 0.008	+ 2.4
C. vociferus, California	1910–1941	1948–1977	80(20)	47(14)	0.81 ± 0.007	0.79 ± 0.007	– 2.5*
C. alexandrinus, California	1926–1941	1948–1961	60(20)	21(7)	0.72 ± 0.005	0.73 ± 0.008	+ 1.4
Limosa fedoa, Alberta	1929–1947	1950–1969	65(17)	43(11)	1.24 ± 0.012	1.23 ± 0.007	– 0.8
Numenius phaeopus, Manitoba	1933–1945	1951–1953	80(20)	27(7)	1.05 ± 0.006	1.09 ± 0.011	+ 3.8**
N. americanus, Utah	1914–1947	1948–1958	77(21)	50(13)	1.45 ± 0.011	1.43 ± 0.014	– 1.4
Tringa solitaria, Alberta	1926–1946	1963–1967	48(12)	16(4)	0.64 ± 0.004	0.65 ± 0.012	+ 1.6
Catoptrophorus semipalmatus, Texas	1882–1941	1952–1968	77(20)	19(5)	1.12 ± 0.009	1.10 ± 0.009	– 1.8
Actitis macularia, California	1910–1937	1950–1966	68(18)	67(17)	0.64 ± 0.007	0.64 ± 0.005	—
Arenaria interpres, Alaska	1928–1947	1951–1965	68(17)	64(16)	0.73 ± 0.005	0.75 ± 0.008	+ 2.7*
A. melanocephala, Alaska	1924–1945	1951–1963	69(18)	63(16)	0.81 ± 0.005	0.80 ± 0.006	– 1.2
Phalaropus tricolor, California	1933–1946	1951–1972	79(20)	30(8)	0.72 ± 0.006	0.70 ± 0.010	– 2.8
P. lobatus, Alaska	1931–1945	1951–1963	70(18)	78(20)	0.54 ± 0.004	0.52 ± 0.004	– 3.7*
P. fulicarius, Alaska	1922–1946	1951–1963	75(20)	78(20)	0.54 ± 0.003	0.53 ± 0.004	– 1.9
Calidris pusilla, Alaska	1914–1947	1951–1961	99(26)	77(20)	0.46 ± 0.002	0.46 ± 0.004	+
C. mauri, Alaska	1924–1934	1951–1965	78(20)	72(20)	0.47 ± 0.003	0.46 ± 0.003	– 2.1*
C. minutilla, Manitoba	1932–1945	1948–1953	44(12)	43(12)	0.45 ± 0.005	0.44 ± 0.003	– 2.2
C. bairdi, Alaska	1922–1945	1960–1963	67(18)	16(5)	0.51 ± 0.003	0.50 ± 0.009	– 2.0
C. alpina, Alaska	1911–1947	1951–1965	71(18)	88(23)	0.58 ± 0.004	0.58 ± 0.004	+
Micropalama himantopus, Manitoba	1931–1945	1950–1970	79(20)	29(8)	0.57 ± 0.004	0.56 ± 0.004	– 1.8

[a]Number of clutches represented given in parenthesis.
$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$, t-test.

and in the eggs of *Philohela minor* (14.9 μg/g wet weight) in New Brunswick (Dilworth et al. 1972). In a DDT-sprayed area around Churchill, Manitoba, the invertebrate prey of shorebirds contained DDE residues of 0.3 and 0.4 μg/g wet weight, and shorebirds there accummulated DDE residues of up to an average of 39.4 μg/g wet weight (Brown and Brown 1970).

The DDE residue levels reported in these latter studies were at least as high as those associated with serious eggshell thinning in certain raptors and fish-eating birds (Blus et al. 1974; Peakall 1976; Kiff et al., *in press*), yet there have been no reports of such changes in the eggshells of these or other shorebirds. This study was undertaken to determine whether significant changes in eggshell thickness of American shorebirds have occurred since the introduction of DDT in the mid-1940s.

Methods

Empty dry eggshells of charadriine shorebirds in the collection of the Western Foundation of Vertebrate Zoology were weighed to the nearest 0.001 g on a Mettler P120 balance, and their length and breadth were measured to the nearest 0.01 mm with Helios dial calipers. A shell thickness index (shell weight × 100/length × breadth) was calculated for each eggshell; such an index is correlated with actual eggshell thickness (Anderson and Hickey 1972). Eggs that were broken, that had blowholes greater than 3 mm in diameter, or that were collected in an advanced stage of incubation, were excluded from the analyses. The nomenclature and species sequence used here follows Morony et al. (1975).

Results

The mean thickness indices for pre-1947 (before-DDT) and post-1947 (since-DDT) North American shorebird eggshells are shown in Table 1. Seven species had slightly thicker eggshells in the recent samples, four showed no change, and 16 species had thinner eggshells in the post-1947 samples. Eggs of another species, *Charadrius wilsonia*, were thicker in Florida but thinner in Texas than pre-1947 indices. The maximum amount of difference between the pre- and post-1947 samples were -4.7% in the "American" Oystercatcher (*Haematopus ostralegus palliatus*) in Texas and along the southern Atlantic coast of the United States. Recent eggshells of the "black" Oystercatcher (*H. o. bachmani*) in California and Oregon were 3.3% thinner than the mean thickness of the pre-1947 sample.

Many shorebirds included in this study migrate and winter in South American countries where DDT is still intensively used. For comparative purposes, we also measured eggshells of three resident species of Chilean shorebirds of three different families (Table 2). As with the North American species, only minor changes were noted. The only statistically significant difference, -4.1%, was found in a plover, *Vanellus chilensis*.

Discussion

Eggshell thinning exceeding 20% has generally resulted in reproductive failure and population declines in the species involved (Keith and Gruchy 1972; Stickel 1975), but the biological significance of thinning less than 10% is not well understood (Faber and Hickey 1973). In this study, the maximum increase (+3.8%) was similar to the maximum decrease (-4.7%) in thickness index. Although statistically significant, these minor index changes are probably due to sampling artifacts (e.g., observer error, insufficient sample size, geographical variation), rather than pesticide effects. We know of no biological phenomena which could readily explain an increasing shell thickness within the span of time these eggs were collected.

Disruptions in eggshell ultrastructure and chemical composition that reduced egg hatchability in a population of Common Terns (*Sterna hirundo*) were attributed to DDE contamination even in the absence of marked shell thinning (Fox 1976). Thus, the lack of substantial thinning of American shorebird eggshells

TABLE 2 — Eggshell thickness of Chilean shorebirds

Species	Early period (E)	Recent period (R)	No. of eggs[a] E	No. of eggs[a] R	Mean index ± SE E	Mean index ± SE R	% Change
Nycticryphes semicollaris	1934 - 1938		28(15)		0.93 ± 0.011		
		1962 - 1969		19(11)		0.90 ± 0.013	- 3.2
Vanellus chilensis	1934 - 1941		24(8)		1.21 ± 0.017		
		1960 - 1968		33(10)		1.16 ± 0.011	- 4.1*
Gallinago paraguaiae	1933 - 1940		40(20)		0.87 ± 0.008		
		1957 - 1969		22(12)		0.88 ± 0.013	+ 1.1

[a]Number of clutches given in parentheses.
*$P < 0.05$.

in recent years does not prove that these species are free of pesticide-induced reproductive problems.

It is possible that shorebirds have a lower sensitivity to DDE-induced eggshell thinning than many higher trophic-level species, in addition to usually possessing lower residue burdens. Peakall (1975) categorized the charadriiforms as being "moderately sensitive" to DDE, based on data on Herring Gulls (*Larus argentatus*) presented in Hickey and Anderson (1968).

Although DDE residues in these species have evidently not reached a level at which they cause eggshell thinning, migrant shorebirds may still represent the most important source of DDE contamination for Arctic raptors, including Peregrine Falcons (*Falco peregrinus*) and Gyrfalcons (*F. rusticolus*). Several studies have indicated that migratory shorebirds possess the highest organochlorine residues of any prey item taken by these falcons (Cade et al. 1968; Enderson and Berger 1968; White et al. 1973; Walker 1977).

Acknowledgments

We appreciate the support of Ed N. Harrison and the Western Foundation of Vertebrate Zoology. Critical review by A. J. Erskine, J. J. Hickey, and D. B. Peakall enhanced the quality of the paper. Julie Kiff and Dana Gardner assisted in preparation of the manuscript.

Literature Cited

Anderson, D. W. and **J. J. Hickey.** 1972. Eggshell changes in certain North American birds. Proceedings of the XV International Ornithological Congress. pp. 514–540.

Blus, L. J., B. S. Neely, Jr., A. A. Belisle, and **R. M. Prouty.** 1974. Organochlorine residues in Brown Pelican eggs: relation to reproductive success. Environmental Pollution 7: 81–91.

Brown, J. J. and **A. W. A. Brown.** 1970. Biological fate of DDT in a sub-arctic environment. Journal of Wildlife Management 34: 929–940.

Cade, T. J., C. M. White, and **J. R. Haugh.** 1968. Peregrines and pesticides in Alaska. Condor 70: 170–178.

Clark, D. R., Jr. and **M. A. R. McLane.** 1974. Chlorinated hydrocarbon and mercury residues in woodcock in the United States, 1970–1971. Pesticides Monitoring Journal 8: 15–22.

Cooke, A. S. 1973. Shell thinning in avian eggs by environmental pollutants. Environmental Pollution 4: 85–52.

Dilworth, T. G., J. A. Keith, P. A. Pearce, and **L. M. Reynolds.** 1972. DDE and eggshell thickness in New Brunswick woodcock. Journal of Wildlife Management 36: 1186–1193.

Dilworth, T. G., P. A. Pearce, and **J. V. Dobell.** 1974. DDT in New Brunswick woodcocks. Journal of Wildlife Management 38: 331–337.

Enderson, J. H. and **D. D. Berger.** 1968. Chlorinated hydrocarbon residues in peregrines and their prey species from northern Canada. Condor. 70: 149–153.

Faber, R. A. and **J. J. Hickey.** 1973. Eggshell thinning, chlorinated hydrocarbons, and mercury in inland aquatic bird eggs, 1969 and 1970. Pesticides Monitoring Journal 7: 27–36.

Flickinger, E. L. and **K. A. King.** 1972. Some effects of aldrin-treated rice on Gulf Coast wildlife. Journal of Wildlife Management 36: 706–727.

Fox, G. A. 1976. Eggshell quality: Its ecological and physiological significance in a DDE-contaminated Common Tern population. Wilson Bulletin 88: 459–477.

Hickey, J. J. and **D. W. Anderson.** 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162: 271–273.

Keith, J. A. and **I. M. Gruchy.** 1972. Residue levels of chemical pollutants in North American birdlife. Proceedings of the XV International Ornithological Congress. pp. 437–454.

Kiff, L. F., D. B. Peakall, and **S. R. Wilbur.** Recent changes in California Condor eggshells. Condor. *In press.*

Kreitzer, J. F. 1972. Thickness of the American Woodcock eggshell, 1971. Bulletin of Environmental Contamination and Toxicology 9: 281–286.

McLane, M. A. R., L. F. Stickel, and **J. D. Newsom.** 1971. Organochlorine pesticide residues in woodcock, soils, and earthworms in Louisiana, 1965. Pesticides Monitoring Journal 5: 248–250.

McLane, M. A. R., L. F. Stickel, E. R. Clark, and **D. L. Hughes.** 1973. Organochlorine residues in woodcock wings, 11 states — 1970–71. Pesticides Monitoring Journal 7: 100–103.

Morony, J. J., Jr., W. J. Bock, and **J. Farrand, Jr.** 1975. Reference list of birds of the world. American Museum of Natural History, New York. 207 pp.

Peakall, D. B. 1975. Physiological effects of chlorinated hydrocarbons on avian species. *In* Environmental dynamics of pesticides. *Edited by* R. Haque and V. H. Freed. Plenum Publishing Company, New York. pp. 343–360.

Peakall, D. B. 1976. The peregrine falcon (*Falco peregrinus*) and pesticides. Canadian Field-Naturalist 90: 301–307.

Pearce, P. A. 1971. Side effects of forest spraying in New Brunswick. Transactions of the Thirty-sixth North American Wildlife and Natural Resources Conference. pp. 163–170.

Ratcliffe, D. A. 1970. Changes attributable to pesticides in egg breakage frequency and eggshell thickness in some British birds. Journal of Applied Ecology 7: 67–115.

Stickel, W. H. 1975. Some effects of pollutants in terrestial ecosystems. *In* Ecological toxicology research. *Edited by* A. D. McIntyre and C. F. Mills. Plenum Publishing Company, New York. pp. 25–74.

Walker, Wayman. 1977. Chlorinated hydrocarbon pollutants in Alaskan Gryfalcons and their prey. Auk 94: 442–447.

White, C. M., W. B. Emison, and **F. S. L. Williamson.** 1973. DDE in a resident Aleutian Island peregrine population. Condor 75: 306–311.

Received 2 October 1978
Accepted 2 January 1979