EFFECTS OF EGG OILING ON LARID PRODUCTIVITY AND POPULATION DYNAMICS

STEPHEN J. LEWIS[1] AND RICHARD A. MALECKI

New York Cooperative Wildlife Research Unit, Department of Natural Resources, Cornell University, Ithaca, New York 14853 USA

ABSTRACT.—Small quantities of petroleum may adhere to the plumage, feet, or nest materials of breeding birds and be transferred to their eggs during incubation. In this study, oil was applied to naturally incubated Great Black-backed Gull (*Larus marinus*) and Herring Gull (*L. argentatus*) eggs, and its effects on reproductive success were assessed. Embryo survival was inversely proportional to the quantity of petroleum applied to eggshell surfaces. Dose responses, however, were dependent on embryonic age at the time of treatment. Eggs of either species, treated with 10–20 μl of No. 2 fuel oil 4–8 days after laying, experienced significant reductions in hatching success. Embryos oiled past the midpoint of the 28-day incubation period were insensitive to as much as 100 μl of petroleum. Fuel oil weathered outdoors for several weeks was as toxic as fresh oil to larid embryos. Productivity estimates obtained following various oil treatments indicated that only under severe conditions (e.g. large doses of petroleum contaminating young embryos) could egg oiling have a significant impact upon populations of the Herring Gull and species with similar life-history characteristics. Species that are more sensitive to oil, however, those having lower reproductive potentials and higher postfledging mortality rates or those subject to other stresses, may be more adversely affected by oil pollution. *Received 12 August 1983, accepted 2 February 1984.*

OIL pollution can affect aquatic birds in a variety of ways (see reviews by Bourne 1976, Holmes and Cronshaw 1977, Ohlendorf et al. 1978, and Clapp et al. 1982). Most petroleum entering the marine environment arises from chronic and low-level discharges rather than from catastrophic accidents [National Academy of Sciences (NAS) 1975, Whittle et al. 1982]. Thus, the possibility exists that during daily activities around harbors, waters near refineries or drilling platforms, and other polluted areas, breeding birds may pick up small quantities of oil on their plumage, feet, or nest materials (O'Connor 1967, Birkhead et al. 1973, Gochfeld 1979). Upon returning to their nests, adults can transfer the oil to the surface of their eggs during incubation. Contamination of eggs in this manner has been observed following actual pollution incidents (Gladstone 1929, Rittinghaus 1956, Jouanin 1967, Birkhead et al. 1973, Anonymous 1982) and confirmed by experimentation (Hartung 1965, King and Lefever 1979, Albers 1980, Lewis 1982). The probability of egg oiling is enhanced because birds may remain contaminated for several weeks following initial contact with a single slick at sea (Dixon and Dixon 1976) or may be exposed repeatedly at a chronic pollution source. In addition, the colonial nature of most seabirds makes large-scale, simultaneous exposure to a given pollution incident likely (Bourne 1976).

Egg oiling can stunt embryonic growth, induce teratogenic malformations, and decrease hatchability (reviewed in Eastin and Hoffman 1978, Stickel and Dieter 1979, Ellenton 1982). The degree to which these effects are manifested depends on the amount of oil transferred to eggs (Albers 1977, Hoffman 1978, Szaro et al. 1980), the stage of incubation at which the contamination occurs (Szaro and Albers 1977, Albers 1978), and the composition of the oil (Szaro et al. 1978, Ellenton 1982). As spilled oil weathers, evaporation, dissolution, photooxidation, microbial degradation, and other processes alter its physical and chemical characteristics (Jordon and Payne 1980, Whittle et al. 1982). Because birds are more likely to encounter oil that is in some stage of weathering than that which has been freshly spilled, it is important to examine the embryotoxicity of weathered petroleum. Studies to date suggest that such oil may remain lethal for several

---

[1] Present address: Division of Refuge Management, U.S. Fish and Wildlife Service, Washington, D.C. 20240 USA.

weeks (Szaro et al. 1980) or may even increase in toxicity over time (Macko and King 1980).

Generally, artificially incubated Mallard (*Anas platyrhynchos*) eggs have been used in investigations of the effects of egg oiling (e.g. Albers 1977, Szaro et al. 1978, Hoffman 1979). Few field studies have been conducted, and these have monitored embryo survival for only 1-2 weeks post-treatment (e.g. Albers and Szaro 1978, King and Lefever 1979, White et al. 1979; but see McGill and Richmond 1979). These approaches yield conservative results, because they do not incorporate natural stresses, which also can affect reproductive success. To obtain realistic results that are useful in population models, one must follow the fates of oiled eggs at the nest site throughout the entire breeding cycle. Furthermore, physiological and behavioral differences between waterfowl and seabirds necessitate further testing with marine species, which are most susceptable to oil pollution (Holmes and Cronshaw 1977, Clapp et al. 1982).

The objectives of this study were to: (1) determine the productivity of two marine bird species following an application of fresh and weathered fuel oil to naturally incubated eggs of various, known ages; and (2) examine population-level impacts of oil-induced reproductive failures. Great Black-backed Gulls (*Larus marinus*) and Herring Gulls (*L. argentatus*) served as test subjects in our studies. Gulls are good indicator species for other seabirds, because they are abundant, relatively easy to monitor, biologically well known, and vulnerable to oil contamination (O'Connor 1967, Birkhead et al. 1973, Dixon and Dixon 1976, Powers and Rumage 1978).

METHODS

Experiments were conducted between mid-April and mid-July 1978-1980 on Appledore Island, Isles of Shoals, Maine, located about 16 km southeast of Portsmouth, New Hampshire. The 39-ha island has nearly 600 breeding pairs of Great Black-backed Gulls and over 2,200 pairs of Herring Gulls. McGill (1977) and Borror (1980) give background data on the reproductive ecology and population dynamics of these colonies.

External contamination of naturally incubated eggs was simulated by using a microliter syringe with repeating dispenser to deliver 10, 20, 50, or 100 μl of oil per egg to shell surfaces (Albers 1977). All eggs in a given nest were treated identically. Eggs at control nests were handled similarly to those at treated nests but were not oiled. A given clutch of eggs was treated at 4, 8, 16, or 24 days ($\pm$1 day) of age. (Hatching occurs at 28 days in these species.) Clutch age was computed as the average age of all eggs in a nest. Because the first- and second-laid eggs of gulls are only partially incubated by the time the third is laid (Parsons 1972), the three eggs in a nest were considered 2, 1, and 0 days old, respectively, at the time of clutch completion. Oil treatments were randomized among nests but temporally and spatially distributed so as to minimize any possible effects of clutch initiation date or nest location on reproductive success (see McCrimmon 1980 and references therein).

A standard reference oil, No. 2 fuel oil, was obtained from the American Petroleum Institute for use in these experiments. This refined product, commonly used as home heating fuel, is frequently spilled at sea or released as an urban or industrial effluent. Eggs were contaminated with either fresh or weathered oil. Weathering was accomplished outdoors by placing 460 ml of oil over seawater in a container measuring 0.45 m diameter by 0.45 m deep with a surface area of 0.159 m^2. At 1-, 2-, 4-, 8-, 16-, and 32-day intervals, samples were skimmed from the surface of the container and stored in pentane-rinsed glass jars. During the weathering period, daily mean ($\pm$1 SE) minimum and maximum temperatures were 6.8 ($\pm$0.5)°C and 20.3 ($\pm$1.1)°C, respectively. The oil was sheltered from the rain during weathering.

Following oiling, the reproductive success of gull nests was determined by periodically monitoring egg hatchability, chick growth and survival, and fates of eggs and young. Nests in which no eggs hatched were checked to obtain data on the incidence and success of renesting. Hatching success (number of eggs hatched/number of eggs treated) was computed on a per-nest basis, because treatments were applied randomly and independently to clutches (nests), not eggs, and all eggs in a given clutch were under the same genetic, parental, environmental, and treatment influences (Albers and Szaro 1978). Many hatching-success values were outside the 30-70% range, so proportions were transformed before statistical analyses by means of an arcsin $\sqrt{\%}$ correction, which normalizes binomial data, homogenizes variances, and makes means and variances independent of each other (Mosteller and Youtz 1961, Coon et al. 1979). One-way analyses of variance were performed on the among-nest, within-treatment means of the transformed percentages (Albers 1980) to detect differences in hatching success among nests in which eggs of different ages were treated with a given dosage of oil, or a given dosage of oil weathered for different lengths of time was applied to eggs. When F-tests indicated significant treatment differences, specific separation of means was accomplished by Duncan's New Multiple Range Test (Helwig and Council 1979).

TABLE 1. Hatching success (percentage of eggs hatching per nest) of Great Black-backed and Herring gull eggs following external contamination with unweathered No. 2 fuel oil during various stages of incubation. Clutches were treated within ±1 day of the age noted. Mean clutch sizes for the two species were 2.9 and 2.8 eggs, respectively.

Oil treatment		Hatching success (%)			
		Great Black-backed Gull		Herring Gull	
Dose (μl/egg)	Mean clutch age (days)	$\bar{x}$ ± SE (number of nests)	Treatment differences[a]	$\bar{x}$ ± SE (number of nests)	Treatment differences[a]
0 (control)	8	83 ± 2 (180)	A	75 ± 2 (228)	A
10	8	61 ± 8 (18)	AB	59 ± 7 (25)	A
	4	38 ± 18 (8)	B	23 ± 6 (25)	B
20	24	83 ± 8 (10)	A	83 ± 7 (9)	A
	16	65 ± 12 (11)	AB	70 ± 9 (16)	AB
	8	38 ± 4 (51)	B	41 ± 4 (74)	B
	4	0 ± 0 (15)	C	0 ± 0 (14)	C
50	16	62 ± 10 (15)	A	75 ± 6 (25)	A
	8	16 ± 5 (15)	B	27 ± 5 (37)	B
100	24	83 ± 10 (4)	A	80 ± 5 (25)	A
	16	57 ± 10 (10)	A	57 ± 7 (25)	A
	8	7 ± 7 (5)	B	7 ± 7 (5)	B

[a] Duncan's New Multiple Range Test: letters represent differences among ages within a dose. Ages not having a letter in common were significantly different ($P < 0.01$); treatments denoted by A did not differ from controls. Analyses were performed on arcsin transformations of the hatching data.

RESULTS AND DISCUSSION

Hatching success in response to oil dose and timing of treatment.—About 83% of the unoiled eggs in Great Black-backed Gull nests and 75% of those in Herring Gull nests hatched (Table 1). These values are similar to those found in previous years on Appledore Island and in other geographic locations (McGill 1977, McGill and Richmond 1979). Oiled eggs hatched at a rate inversely proportional to the quantity of petroleum applied to their shell surfaces. (Actual dosages were somewhat less than indicated, because a portion of the oil applied to eggs was lost through adherence to the plumage of incubating adults.) Dose responses, however, were dependent upon embryonic age at the time of treatment. Four-day-old embryos of both species were sensitive to as little as 10 μl of unweathered No. 2 fuel oil, whereas 10–20 μl were needed to significantly reduce hatching in eggs treated at 8 days of age (Table 1). Embryos oiled past the midpoint in the 28-day incubation period were resistant to levels of up to 100 μl of fuel oil. The latter dosage is probably an upper limit; Lewis (1982) determined that adult Herring Gulls with 10 ml of No. 2 fuel oil on their breast plumage transferred an average of only 62 μl to their incubated eggs.

Great Black-backed Gull and Herring Gull embryos exhibited similar response patterns to egg oiling (Table 1). Black-backed eggs are about 25% larger in volume than those of Herring Gulls, but the embryonic growth rates of both species are nearly identical (Harris 1964) during the period of greatest sensitivity to oil, i.e. the first half of incubation. Therefore, when contaminated at that stage of development, embryos received similar dosages on a per-weight basis. In addition to embryo size, eggshell porosity, egg composition, and embryonic physiological capabilities probably influence the sensitivity of different bird species to petroleum. Unfortunately, a lack of standardized test conditions across studies precludes quantitative interspecific comparisons, although several other species have been examined (see Albers and Szaro 1978, Hoffman 1978, Patten and Patten 1978, Stickel and Dieter 1979, and references therein).

Our finding that younger embryos are more sensitive to oiling confirms a pattern noted by Albers (1978) in Mallards; hatching success of this species is most affected by petroleum dur-

TABLE 2. Hatching success (percentage of eggs hatching per nest) of Great Black-backed and Herring gull eggs following external contamination with fresh and weathered No. 2 fuel oil. Eggs were 7–9 days old at treatment. Mean clutch sizes for the two species were 2.9 and 2.8 eggs, respectively.

Oil treatment		Hatching success (%)			
		Great Black-backed Gull		Herring Gull	
Dose (μl/egg)	Number of days of weathering	$\bar{x}$ ± SE (number of nests)	Treatment differences[a]	$\bar{x}$ ± SE (number of nests)	Treatment differences[a]
0 (control)	—	83 ± 2 (121)	A	76 ± 2 (179)	A
20	0	32 ± 6 (25)	B	47 ± 5 (41)	B
	1	35 ± 7 (25)	B	57 ± 7 (26)	AB
	2	35 ± 7 (24)	B	38 ± 8 (25)	B
	4	41 ± 7 (20)	B	38 ± 8 (20)	B
	8	53 ± 13 (5)	AB	43 ± 12 (10)	B
	16	42 ± 7 (24)	B	59 ± 7 (25)	AB
	32	73 ± 8 (15)	A	79 ± 4 (25)	A
50	0	9 ± 5 (11)	B	27 ± 6 (32)	B
	1	0 ± 0 (5)	B	30 ± 7 (10)	B
	2	11 ± 7 (6)	B	26 ± 9 (9)	B
	4	10 ± 5 (10)	B	23 ± 8 (10)	B
	8	7 ± 5 (9)	B	32 ± 7 (18)	B
	16	43 ± 12 (10)	B	34 ± 6 (29)	B
	32	(0)		53 ± 6 (29)	AB

[a] Duncan's New Multiple Range Test: letters represent differences among stages of weathering within a dose. Stages not having a letter in common were significantly different ($P < 0.01$); treatments denoted by A did not differ from controls. Analyses were performed on arcsin transformations of the hatching data.

ing the first 10–18 days of its 26-day incubation period. Patten and Patten (1978) found that Glaucous-winged Gull (*Larus glaucescens*) eggs treated with 100 μl of North Slope crude oil on the 11th day of incubation hatched at a significantly greater rate than eggs oiled with only 20 μl on day 8. These studies, and others in which eggs were aged by back-dating those that hatched (Szaro and Albers 1977, Coon et al. 1979, McGill and Richmond 1979), suggest a consistent pattern, although the period of greatest sensitivity varies with test conditions and the species involved. The existence of an age-dependent dose response pattern implies that the timing and duration of an oil-pollution incident can be major determinants of its potential reproductive effects. Adults oiled late in incubation (i.e. past the midpoint) may not pose a significant hazard to their eggs. Furthermore, a synchronous seabird colony will only be sensitive to egg oiling for a short period of time, determined by its specific chronology. Because it will suffer many losses if a spill does occur then, however, measures that will decrease bird-oil encounters (e.g. curtailing drilling and transportation operations, hazing, or cleanup activities) should be enacted at that time. An asynchronous colony, having individuals in various stages of incubation at any one time, may be more adversely affected by chronic pollution, which might contaminate adults repeatedly.

Hatching success in response to weathered oil.—To examine the effects of weathered oil on egg hatchability, we standardized embryonic age at treatment at 7–9 days. In this stage of development, Great Black-backed and Herring gull embryos were as sensitive to weathered as they were to fresh No. 2 fuel oil at 20 and 50 μl-per-egg dosages (Table 2). Only after a month of weathering was the composition of the petroleum altered sufficiently to pose no significant threat at the 20 μl level, although it was still marginally toxic at 50 μl (Table 2). Kuwait crude oil weathered for 2 days was also not significantly different from its unweathered form in its toxicity to these species (Lewis 1982). Szaro et al. (1980) found No. 2 fuel oil to be significantly less toxic to Mallard embryos after 2 weeks of artificial weathering; Prudhoe Bay crude oil remained lethal for 3 weeks, possibly because it was less susceptible to photo-oxidation. Even though these weathered oils eventually became less toxic than fresh oils, both types still induced a significant degree of hatching failure. Macko and King (1980) reported that a month-old, naturally weathered crude oil was actually more harmful to Tricolored (Louisiana) Heron (*Egretta tricolor*) eggs than when it was fresh, speculating that the increased toxicity was due to the formation of oxygenated derivatives.

The observation that weathered oils may be as embryotoxic as fresh oils probably reflects the resistance of polycyclic aromatics, which are relatively large molecules, to evaporation, dissolution, and other weathering processes (Hallett et al. 1983). Aromatic hydrocarbons (Albers 1977, Hoffman 1978, Szaro et al. 1978), particularly polycyclics and their methylated derivatives (Hoffman and Gay 1981, Ellenton 1982), are the components of oil most lethal to embryos. Thus, their slow degradation results in the continued toxicity of weathered oils. The eventual reduction in toxicity over time may reflect the complete loss of low-boiling, volatile materials such as monocyclic benzene derivatives; these compounds are probably necessary to keep the larger, heavier polycyclics in solution, which facilitates their absorption through the egg shell and membranes (Hoffman and Gay 1981).

The weathering of petroleum is a complex phenomenon involving many processes and is dependent upon both the original composition of an oil and environmental conditions (Jordon and Payne 1980, Whittle et al. 1982). The system used to weather the test oil in this experiment only partially duplicated field conditions. In an actual pollution incident where a bird becomes contaminated with oil, additional weathering will occur on the adult's plumage before its return to the nest. These factors make it difficult to predict the embryotoxicity of a given oil. Nevertheless, the fact that weathered oil can be as toxic to embryos as fresh oil increases the likelihood that bird-oil encounters will result in harmful reproductive effects. Oil can become trapped in sheltered, shallow, soft-bottomed areas such as estuaries, tidal flats, salt marshes, and lagoons. In such environments, it degrades slowly and can be resuspended (Stevenson 1978, Macko and King 1980, and references therein). These sites provide important habitats for birds and other organisms and should receive maximum protection from petroleum contamination. Cleanup activities enacted soon after a major spill occurs can remove or disperse surface oil, greatly reducing potentially adverse effects on birds. Unfortunately, chronic, low-level inputs, which are responsible for most marine oil pollution, are not as evident and are seldom cleaned up.

Population impacts of oil-induced reductions in avian productivity.—These experiments and others indicate that substantial embryo mortality can result if contaminated adult birds transfer sufficient quantities of fresh or weathered oils to their eggs during the first one-third to one-half of incubation. Such losses may not be readily apparent, because seabirds exhibit delayed breeding and it would take several years for the loss of a cohort to be manifested. Whether dramatic or subtle, however, the ultimate significance of oil-induced reproductive failures lies in their potential to depress population densities to levels that make recovery prolonged, if not impossible. It is thus important to expand upon the egg oiling findings as they relate to seabird populations.

One approach to examining the population consequences of egg oiling is to determine whether or not it can reduce productivity below the level needed to maintain population stability. Data for this type of analysis (Henny 1972, Ricklefs 1973, DiCostanzo 1980) are available for the Herring Gull. This species has a mean annual adult mortality rate of 4–9%, and about 63% of the fledged young survive to 5 yr, the age of first breeding (Kadlec and Drury 1968, Chabrzyk and Coulson 1976, Coulson et al. 1982). Assuming an equal sex ratio in adults and fledglings and that all pairs breed, an average of 0.13–0.29 young must fledge per nest to balance adult mortality. To determine whether or not observed productivity after various oil treatments was depressed below this range, we converted hatching-success figures to measures of productivity, i.e. mean number of young fledged per pair. This was done for each treatment by multiplying the mean proportion of eggs hatching per nest (Table 1) by the average clutch size (2.80 eggs) and the survival rate of Herring Gull young between hatching and fledging. Chicks hatching from oiled eggs survived and grew at rates comparable to those from control nests (Lewis 1982; see also Szaro et al. 1978, Albers 1980), so the normal survival rate of 0.52 (Lewis 1982) was used. Fledging success values obtained in this

TABLE 3. Hatching success (mean percentage of eggs hatching per nest) and productivity (mean number of chicks fledging per nest) of Herring Gull nests following external contamination of eggs with unweathered No. 2 fuel oil during various stages of incubation. Productivity was calculated by multiplying each hatching-success value by the mean clutch size (2.80 eggs) and chick survival rate from hatching to fledging (0.52). Sample sizes are given in Table 1.

Oil treatment			
Dose (μl/egg)	Mean clutch age (days)	Hatching success (%)	Productivity (chicks per nest)
0 (control)	8	75	1.09
10	4	23	0.33
	8	59	0.86
20	4	0	0
	8	41	0.60
	16	70	1.02
	24	83	1.21
50	8	27	0.39
	16	75	1.09
100	8	7	0.10
	16	57	0.83
	24	80	1.16

manner (Table 3) were thus direct functions of hatching success.

Normal productivity in this study (and others) was slightly more than one chick per nest annually (Table 3). This is obviously more than sufficient to maintain population stability and partially explains worldwide increases in this species (Kadlec and Drury 1968, Duncan 1978). Only when eggs received large doses of oil (≥50 μl/egg) a third of the way through incubation (day 8) or smaller amounts (10–20 μl/egg) earlier in incubation (day 4) was productivity depressed to levels less than or equal to the 0.3 chick per pair limit (Table 3). Responses of this magnitude are similar to those reported by Keith (1966) in a DDT-contaminated Herring Gull population, in which only 12% of the eggs laid produced fledged young (0.3–0.4 young per pair).

This analysis suggests that only under rather severe conditions could egg oiling hypothetically do more than slow the rate of population increase in the ubiquitous and abundant Herring Gull. Additional factors, not considered in the life-equation approach, may partially compensate for oil-induced reproductive failures and further enhance population recovery. Most seabird populations are not closed, and individuals experiencing reproductive losses could emigrate from a polluted area. This behavior was noted in Herring Gulls whose eggs were sprayed with an oil-formaldehyde mixture as a control measure (Gross 1950, Kadlec and Drury 1968). Colony fidelity and habitat saturation make such emigration likely only when large numbers of a regional population are simultaneously affected, as would occur in the event of large-scale and chronic oil pollution.

Small or temporary reductions in recruits, resulting from single oil spills or low-level, chronic incidents, are likely to be filled through immigration of surplus, nonbreeding birds into affected populations. Evidence for this compensatory mechanism comes from Herring Gull culling experiments (Charbryzk and Coulson 1976, Duncan 1978). The proportions of nonbreeding adults in Herring Gull (Kadlec and Drury 1968) and Atlantic Puffin (*Fratercula arctica;* Harris 1983) populations have been estimated at 20% and 30%, respectively. Thus, a regional seabird population may be maintained by a few very productive colonies capable of producing excess individuals that can, through immigration, fill losses arising in other colonies from oil or other factors (DiCostanzo 1980).

Density-dependent changes in natality or mortality rates may also offset oil-induced reproductive failures to some degree. If losses exceed some critical threshold value, postfledging survival rates may increase because of lowered competition on the wintering grounds from a smaller cohort of hatching-year birds (DiCostanzo 1980). This would decrease the number of new breeders needed to maintain a population. Fecundity and fledging success also may increase in years following poor reproduction. Coulson et al. (1982) found egg size, an index to productivity, to increase following culling of Herring Gull populations. Another possible response, also noted in the Herring Gull control program (Duncan 1978), is the earlier entry of recruits into the breeding population. More research is needed to demonstrate the generality of these compensatory processes in avian populations.

These points suggest that the Herring Gull and species with similar life-history traits may be able to compensate, to some degree, for oil-induced reproductive losses, thereby making population fluctuations minor and short-lived;

population impacts may not be as severe as observations of individuals indicate. Species such as the alcids, however, which have lower reproductive potentials, higher postfledging mortality rates, greater sensitivities to oil, or are subject to other stresses, may be more adversely affected. Furthermore, any breeding population exposed to petroleum is likely to suffer from other forms of contamination besides egg oiling. The survival of chicks, juveniles, and adults may be directly or indirectly lowered following petroleum ingestion, plumage contamination, or oil-induced food shortages (see NAS 1975, Bourne 1976, Holmes and Cronshaw 1977, Clapp et al. 1982). From a population standpoint, postfledging losses are theoretically more deleterious than reproductive failures to long-lived, slow-maturing species like seabirds (Young 1968, Ford et al. 1982). Because postfledging survival rates determine the productivity requirements of a population, greater reproductive rates will be needed to offset higher juvenile and adult mortality. For instance, if the annual survival rate of adult Herring Gulls drops from the normal 93.5% to between 87.4% and 32.5%, as noted following culling of between 7% and 65%, respectively, of the breeding birds in a colony (Duncan 1978), a productivity of 0.40 to 2.15 chicks per nest (versus the normal 0.21) would be necessary to maintain population stability.

The complexity of quantitatively assessing population impacts resulting from petroleum contamination and other perturbations is apparent when one considers the multitude of variables involved. Information on the number of individuals of each sex and age class suffering lethal and sublethal effects must be combined with data on population abundance and distribution, sex and age composition, proportion of nonbreeding adults, reproductive potential, rates of emigration, immigration, and postfledging survival, relationships of natality and mortality to density, and the influence of non-oil-related stresses (e.g. adverse weather, food shortages, human disturbances, predation, and other contaminants) on population members. Simulation modeling recently has been used to predict changes in the densities, structure, and recovery rates of marine bird populations in response to various oil-spill scenarios (Ford et al. 1982, Samuels and Lanfear 1982). Although this approach can yield useful information, its proponents emphasize that it is presently limited by a general lack of information on the values, variability, and interactions of most input parameters. Until more quantitative data are available, the only logical course of action concerning petroleum-related activities is a conservative one.

ACKNOWLEDGMENTS

Financial support for this work was provided by the Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, through a contract (No. 14-16-0009-77-947) with the New York Cooperative Wildlife Research Unit (Cornell University, New York State Department of Environmental Conservation, U.S. Fish and Wildlife Service, and the Wildlife Management Institute cooperating). Fieldwork was made possible through the able assistance of K. Andres, C. Fichtel, P. McGill-Harelstad, L. Lewis, and E. Volk, and the logistical support of the Shoals Marine Laboratory. C. Brownie advised on statistical matters, and P. Albers, T. Cade, J. E. Kautz, D. McCrimmon, Jr., M. Richmond, and several anonymous reviewers commented on earlier drafts of the paper. We express our sincere thanks to all of these people and organizations. Final responsibility for the contents of this paper is ours.

LITERATURE CITED

ALBERS, P. H. 1977. Effects of external applications of fuel oil on hatchability of Mallard eggs. Pp. 158–163 *in* Fates and effects of petroleum hydrocarbons in marine ecosystems and organisms (D. A. Wolfe, Ed.). New York, Pergamon Press.

———. 1978. The effects of petroleum on different stages of incubation in bird eggs. Bull. Environ. Contam. Toxicol. 19: 624–630.

———. 1980. Transfer of crude oil from contaminated water to bird eggs. Environ. Res. 22: 307–314.

———, & R. C. SZARO. 1978. Effects of No. 2 fuel oil on Common Eider eggs. Marine Pollution Bull. 9: 138–139.

ANONYMOUS. 1982. Marshland pollution clean-up impasse. Marine Pollution Bull. 13: 218.

BIRKHEAD, T. R., C. LLOYD, & P. CORKHILL. 1973. Oiled seabirds successfully cleaning their plumage. Brit. Birds 66: 535–537.

BORROR, A. C. 1980. Breeding birds of the Isles of Shoals, with special reference to Appledore Island. Ithaca, New York, Shoals Marine Laboratory, Cornell Univ.

BOURNE, W. R. P. 1976. Seabirds and pollution. Pp. 403–502 *in* Marine pollution (R. Johnston, Ed.). New York, Academic Press.

CHARBRZYK, G., & J. C. COULSON. 1976. Survival and recruitment in the Herring Gull, *Larus argentatus*. J. Anim. Ecol. 45: 187–203.

CLAPP, R. B., D. MORGAN-JACOBS, & R. C. BANKS. 1982. Marine birds of the southeastern United States and Gulf of Mexico. Part II. Anseriformes. U.S. Fish Wildl. Serv., Biol. Serv. Prog., FWS/OBS-82/20.

COON, N. C., P. H. ALBERS, & R. C. SZARO. 1979. No. 2 fuel oil decreases embryonic survival of Great Black-backed Gulls. Bull. Environ. Contam. Toxicol. 21: 152-156.

COULSON, J. C., N. DUNCAN, & C. THOMAS. 1982. Changes in the breeding biology of the Herring Gull (*Larus argentatus*) induced by reduction in the size and density of the colony. J. Anim. Ecol. 51: 739-756.

DICOSTANZO, J. 1980. Population dynamics of a Common Tern colony. J. Field Ornithol. 51: 229-243.

DIXON, T. J., & T. R. DIXON. 1976. Olympic Alliance oil spillage. Marine Pollution Bull. 7: 86-90.

DUNCAN, N. 1978. The effects of culling Herring Gulls (*Larus argentatus*) on recruitment and population dynamics. J. Appl. Ecol. 15: 697-713.

EASTIN, W. C., JR., & D. J. HOFFMAN. 1978. Biological effects of petroleum on aquatic birds. Pp. 561-582 *in* Proceedings of the conference on assessment of ecological impacts of oil spills (Amer. Inst. Biol. Sci., Ed.). Arlington, Virginia, AIBS.

ELLENTON, J. A. 1982. Teratogenic activity of aliphatic and aromatic fractions of Prudhoe Bay crude and fuel oil No. 2 in the chicken embryo. Toxicol. Appl. Pharmacol. 63: 209-215.

FORD, R. G., J. A. WIENS, D. HEINEMANN, & G. L. HUNT. 1982. Modelling the sensitivity of colonially breeding marine birds to oil spills: guillemot and kittiwake populations on the Pribilof Islands, Bering Sea. J. Appl. Ecol. 19: 1-31.

GLADSTONE, H. S. 1929. The oil menace. Bird Notes 13: 175.

GOCHFELD, M. 1979. Prevalence of oiled plumage of terns and skimmers on Western Long Island, New York: baseline data prior to petroleum exploration. Environ. Pollution 20: 123-130.

GROSS, A. C. 1950. The Herring Gull-cormorant control project. Proc. Intern. Ornithol. Congr. 10: 532-536.

HALLETT, D. J., F. I. ONUSKA, & M. E. COMBA. 1983. Aliphatic and aromatic components of weathered and unweathered Southern Louisiana crude oil. Marine Environ. Res. 8: 73-85.

HARRIS, M. P. 1964. Aspects of the breeding biology of the gulls *Larus argentatus, L. fuscus*, and *L. marinus*. Ibis 106: 432-456.

———. 1983. Biology and survival of the immature puffin, *Fratercula arctica*. Ibis 125: 56-73.

HARTUNG, R. 1965. Some effects of oiling on reproduction of ducks. J. Wildl. Mgmt. 29: 872-874.

HELWIG, J. T., & K. A. COUNCIL. 1979. SAS user's guide, 1979 edition. Cary, North Carolina, SAS Inst., Inc.

HENNY, C. J. 1972. An analysis of the population dynamics of selected avian species. U.S. Fish Wildl. Serv. Wildl. Res. Rept. No. 1.

HOFFMAN, D. J. 1978. Embryotoxic effects of crude oil in Mallard ducks and chicks. Toxicol. Appl. Pharmacol. 46: 183-190.

———. 1979. Embryotoxic and teratogenic effects of petroleum hydrocarbons in Mallards (*Anas platyrhynchos*). J. Toxicol. Environ. Health 5: 835-844.

———, & M. L. GAY. 1981. Embryotoxic effects of benzo(a)pyrene, chrysene, and 7, 12-dimethylbenz(a)anthracene in petroleum hydrocarbon mixtures in Mallard ducks. J. Toxicol. Environ. Health 7: 775-787.

HOLMES, W. N., & J. CRONSHAW. 1977. Biological effects of petroleum on marine birds. Pp. 359-398 *in* Effects of petroleum on arctic and subarctic marine environments and organisms, vol. 2. Biological effects (D. C. Malins, Ed.). New York, Academic Press.

JORDON, R. E., & J. R. PAYNE. 1980. Fate and weathering of petroleum spills in the marine environment: a literature review and synopsis. Ann Arbor, Michigan, Ann Arbor Science Publishers, Inc.

JOUANIN, C. 1967. Chronique noir: le naufrage du "Torrey Canyon." Courr. Nat. 1-2: 18-19. (In French, cited in Nelson-Smith 1972).

KADLEC, J. A., & W. H. DRURY. 1968. Structure of the New England Herring Gull population. Ecology 49: 644-676.

KEITH, J. A. 1966. Reproduction in a population of Herring Gulls (*Larus argentatus*) contaminated by DDT. J. Appl. Ecol. (Suppl.) 3: 57-70.

KING, K. A., & C. A. LEFEVER. 1979. Effects of oil transferred from incubating gulls to their eggs. Marine Pollution Bull. 10: 319-321.

LEWIS, S. J. 1982. Effects of oil on avian productivity and population dynamics. Unpublished Ph.D. dissertation. Ithaca, New York, Cornell Univ.

MACKO, S. A., & S. M. KING. 1980. Weathered oil: effect on hatchability of heron and gull eggs. Bull. Environ. Contam. Toxicol. 25: 316-320.

MCCRIMMON, D. A., JR. 1980. The effects of timing of breeding, dispersion of nests, and habitat selection on nesting success of colonial waterbirds. Trans. Linnaean Soc. New York 9: 87-102.

MCGILL, P. A. 1977. Breeding ecology and competition between Great Black-backed and Herring gulls. Unpublished M.S. thesis. Ithaca, New York, Cornell Univ.

———, & M. E. RICHMOND. 1979. Hatching success of Great Black-backed Gull eggs treated with oil. Bird-Banding 50: 108-113.

MOSTELLER, F., & C. YOUTZ. 1961. Tables of the Freeman-Tukey transformations for the binomial and Poisson distributions. Biometrika 48: 433-440.

NATIONAL ACADEMY OF SCIENCES (NAS). 1975. Petroleum in the marine environment. Washington, D. C., Natl. Acad. Sci.

NELSON-SMITH, A. 1972. Oil pollution and marine ecology. London, England, Elek Sci. Books, Ltd.

O'CONNOR, R. 1967. The Torrey Canyon. A census of breeding auks in Cornwall. Seabird Bull. 4: 38-45.

OHLENDORF, H. M., R. W. RISEBROUGH, & K. VERMEER. 1978. Exposure of marine birds to environmental pollutants. U.S. Fish Wildl. Serv. Wildl. Res. Rept. No. 9.

PARSONS, J. 1972. Egg size, laying date and incubation period in the Herring Gull. Ibis 114: 536-541.

PATTEN, S. M., JR., & L. R. PATTEN. 1978. Effects of petroleum exposure on the breeding ecology of the Gulf of Alaska Herring Gull group (*Larus argentatus* × *Larus glaucescens*) and reproductive ecology of large gulls in the Northeast Gulf of Alaska. Pp. 151-310 *in* Environmental assessment of the Alaskan Continental Shelf. Ann. Rept. Principal Investigators, vol. 7. Boulder, Colorado, Natl. Ocean. Atmos. Admin. Environ. Res. Lab.

POWERS, K. D., & W. T. RUMAGE. 1978. Effect of the Argo Merchant oil spill on bird populations off the New England coast, 15 December 1976-January 1977. Pp. 142-148 *in* In the wake of the Argo Merchant: proceedings of a symposium. Kingston, Rhode Island, Center Ocean Mgmt. Studies, Univ. Rhode Island.

RICKLEFS, R. E. 1973. Fecundity, mortality, and avian demography. Pp. 366-435 *in* Breeding biology of birds (D. S. Farner, Ed.). Washington, D. C., Natl. Acad. Sci.

RITTINGHAUS, H. 1956. Etwas über die "indirekte" Verbreitung der Ölpest in einem Seevogelschutzgebiete. Ornithol. Mitteilungen 8(3): 43-46.

SAMUELS, W. B., & K. J. LANFEAR. 1982. Simulations of seabird damage and recovery from oilspills in the northern Gulf of Alaska. J. Environ. Mgmt. 15: 169-182.

STEVENSON, J. C., ED. 1978. Recovery potential of oiled marine northern environments. J. Fish. Res. Board Can. 35: 499-796.

STICKEL, L. F., & M. P. DIETER. 1979. Ecological and physiological/toxicological effects of petroleum on aquatic birds. U.S. Fish Wildl. Serv., Biol. Serv. Prog., FWS/OBS-79/23.

SZARO, R. C., & P. H. ALBERS. 1977. Effects of external applications of No. 2 fuel oil on Common Eider eggs. Pp. 164-167 *in* Fate and effects of petroleum hydrocarbons in marine ecosystems and organisms (D. A. Wolfe, Ed.). New York, Pergamon Press.

———, ———, & N. C. COON. 1978. Petroleum: effects on Mallard egg hatchability. J. Wildl. Mgmt. 42: 404-406.

———, N. C. COON, & W. STOUT. 1980. Weathered petroleum: effects on Mallard egg hatchability. J. Wildl. Mgmt. 44: 709-713.

WHITE, D. H., K. A. KING, & N. C. COON. 1979. Effects of No. 2 fuel oil on hatchability of marine and estuarine bird eggs. Bull. Environ. Contam. Toxicol. 21: 7-10.

WHITTLE, K. J., R. HARDY, P. R. MACKIE, & A. S. MCGILL. 1982. A quantitative assessment of the sources and fates of petroleum compounds in the marine environment. Phil. Trans. Royal Soc. London Biol. Sci. 297: 193-218.

YOUNG, H. 1968. A consideration of insecticide effects on hypothetical avian populations. Ecology 49: 991-994.