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Estimating the Mortality of Seabirds Following Oil Spills:
Effects of Spill Volume

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A statistical analysis of 45 oil spills shows a weak log-log correlation between spill volume and numbers of seabirds killed. This relationship cannot be used to predict mortality and loses its significance if one extreme case is omitted. The data show the wide variance in mortality in spills of all sizes. A loose 'rule-of-thumb' that is often used in poorly documented spills is that the overall mortality is ten times the actual body count. There is no justification for this notion. The mean estimate used is 4–5 times the body count, but each spill should be examined independently.

It is generally accepted that there is no clear relationship between the volume of oil spilled at sea and the resultant number of oiled seabirds. This concept appears to be based on evidence from extreme cases, where many birds die from small spills or, conversely, few birds die from large spills (e.g. Bourne & Bibby, 1975; National Research Council, 1985). There appear to be no previous attempts to test this concept using statistical tests on a large sample of spills. I report the results of such a test, using published estimates from 45 spills.

I also examine the notion that the overall mortality is approximately one order of magnitude greater than the actual count of dead or debilitated birds. Oiled seabirds found alive or dead on beaches represent only a fraction of the overall mortality. Many processes affect the proportion of oiled birds found, including the distribution and density of birds at sea, wind, ocean currents, distance of the spill from the shore, numbers of people involved in the recovery of birds, topography, density of scavengers on beaches, sinking of carcasses at sea and burying of carcasses on beaches (Ford *et al.*, 1987; Page *et al.*, 1990). Ideally, these parameters should be measured at the time of the spill, but this is seldom feasible. Where these processes are poorly understood or cannot be quantified, a general rule-of-thumb is that the body count represents only 10% of the overall mortality (Tanis & Morzer Bruijns, 1968; Bourne, 1970; National Research Council, 1985). This assumption is tested by comparing body counts and estimated total mortality in a number of incidents.

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Materials and Methods

Information was obtained from published material, including reviews by Vermeer & Vermeer (1975), Morant *et al.* (1981), National Research Council (1985) and Hooper *et al.* (1987). Where possible, the original sources were used, but in a few cases the data summarized in the review articles were used. Material from recent spills was obtained from original reports.

All measures of the amount of oil spilled were converted to tonnes (t). It was usually not possible to distinguish between long tons (1.016 t) and short tons (0.907 t), and so both measures were taken to be equivalent to a metric tonne. The regression analysis used mean values of seabird mortality where possible. If a mean was not given, the mid-point of a range of values was used, or the minimum mortality, if that was all that was available. Regression analyses were done using SYSTAT (Wilkinson, 1990).

Results

Numbers of oiled seabirds vs. volume of spill

Table 1 lists 45 oil spills which affected seabirds. This is obviously not an exhaustive list of such spills, but rather a sample of relatively well-documented spills. Most involved shipping accidents which spilled either bunker fuel or crude oil, a few involved land-based spills into the sea or estuaries. In some cases the source of oil was not known. Most of the spills were in temperate coastal oceans in the northern hemisphere (Europe and North America), with fewer from the temperate southern hemisphere (southern Africa and South America).

Neither the number of oiled seabirds counted ($r^2=0.038$, $N=35$, $P>0.05$), nor the total estimated mortality ($r^2=0.014$, $N=25$, $P>0.05$) was significantly correlated with spill volume, when tested with a simple linear regression. When plotted on log–log axes (Fig. 1A and B), however, weak positive correlations were found between spill volume (V, in tonnes) and both the number of oiled birds counted (N_c) and the total

TABLE 1
Mortality of seabirds resulting from oil spills.

Year	Vessel name or source of the oil	Site	Spill volume (t)	Oiled birds No. found	Oiled birds Estimated mortality	Reference (see below)
1991	Tenyo Maru	Off Vancouver Island, British Columbia	330	4 300	?	6
1989*	Exxon Valdez	Prince William Sound, Alaska	36 400	31 000	350 000–390 000	4, 5, 7
1988*	Nestucca	Gray's Harbor, WA	770	12 535	56 000	10
1988	Barge MCN5	Anacortes, WA	240	None reported		3
1987	Stuyvesant	150–300 km off northern B.C.	2000	Not known		3, 6
1986*	Apex Houston	S. California	87	4198	10 577	11
1985	Arco Anchorage	Port Angeles, WA	800	1917	4000	6, 12
1984*	Puerto Rican	San Francisco Bay	4900	1300	4815	8, 9
1984	Unknown	Whidbey Island Puget Sound, WA	17	> 406	> 1500	6, 13
1984	Mobiloil	Columbia River and WA coast	660	450	?	6, 13
1983	Swedish tanker	Kattegat, Denmark	500		50 000	21
1981	Deivos	Helgoland, Norway	1000	> 3000	14 000	22
1979	Kurdistan	Cape Breton, NB	7900	1697		1
1979		Douarnenez Bay, France	30–60	*ca.* 100		23
1979	Russian tanker	Ventpils, Sweden	5500	3053		24
1978	Amoco Cadiz	Brittany, France	200 000	4572	20 000	1, 4, 17
1978	Pantelis a Lemos	Cape coast, South Africa	300	*ca.* 100		25
1978	Outfall	Dounreay, UK	68	650	> 1000	18
1976	Olympic Games	Delaware River, PA	450			3
1976	Barge STC-101	Chesapeake Bay, V	833		20 000–50 000	26
1975	Olympic Alliance	Dover Spit, UK	2000	> 199		19
1974	Oriental Pioneer	Struisbaai, South Africa	200	'thousands'		20
1974	Metula	Magellan Strait	50 000	3000		27
1972	Dewdale	Cromarty Firth, UK	30		1000	2
1972	Oswego Guardian, Texanita	Ystervark Point, South Africa	10 000	> 400		20
1971	Barge U17	Padilla Bay, WA	767	> 374	Not known	6
1971	Collision	San Francisco	2700	7380	20 000	1, 2
1971	Wafra	Cape Agulhas, South Africa	6000–10 000	> 1216		20
1970	Kazimah	Robben Island, South Africa	1000	> 560		20
1970	Arrow	Cape Breton, NB	10 000	567	7000	1, 2
1970	Irving Whale	SE Newfoundland	< 30	625	5000	1, 2
1969*	Hamilton Trader	Irish Sea, UK	700	4400	5900–10 600	1, 15
1969	Palva	Uto, Finland	150	1000	3000	2
1969		Loch Indaal, UK	115	449		1
1969		Waddensee, Netherlands	150	14 564	35 000–41 000	1, 2, 27
1968	Esso Essen	Cape Peninsula, South Africa	4000	1250	14 000–19 000	2
1968	Tank Duchess	Tay Estuary, UK	87	1368		1, 2
1967	Torrey Canyon	English Channel	119 328	7815	30 000	1, 2, 5
1966	Seestern	Medway, UK	1700	2772	5000	1, 2, 16
1961	Collision	Poole, UK	300	487		1
1959		Lower Weser, Germany	360	7032	14 132	
1956	Seagate	Olympic Peninsula, WA	Not known		> 3000	2
1955	Gerda Maersk	Elbe, Germany	8000		500 000	2
1952	Fort Mercer and Pendleton	Monomoy, Mass.	22 400		> 3500	2
1937	Frank Buck	San Francisco	11 800		10 000	2

*Examples of studies in which experimental data and/or modelling was used to improve estimates of bird mortality.

References: 1. National Research Council (1985); 2. Vermeer & Vermeer (1975); 3. Cohen & Aylesworth (1990); 4. Piatt & Lensink (1989); 5. Piatt *et al.* (1990); 6. Washington Dept. Ecology (Unpubl.); 7. Stewart *et al.* (1991); 8. Point Reyes Bird Obs. (1985); 9. Ford *et al.* (1987); 10. Ford *et al.* (1991); 11. Page *et al.* (1990); 12. Speich (1986); 13. Speich & Thompson (1987); 14. Heubeck & Richardson (1980); 15. Hope Jones *et al.* (1970); 16. Clark (1984); 17. Hope Jones *et al.* (1978); 18. Bowman (1978); 19. Dixon & Dixon (1976); 20. Morant *et al.* (1981); 21. Clausager (1983); 22. Röv (1982); 23. Thomas & Monnat (1983); 24. Broman & Hjernquist (1982); 25. Cooper (1978); 26. Roland *et al.* (1977); 27. Bourne & Bibby (1975).

Conversion: 50 barrels = 7 tonnes (National Research Council, 1985); 1 barrel = 0.14 tonnes; 1 tonne = approx. 300 gallons (US); 1 tonne = approx. 1 ton; 1 tonne = approx. 1100 litres.

estimated mortality (N_t), giving the following regression equations:

$$\text{Log } N_c = 2.508 + 0.224 \log V \quad (1)$$
$$(r^2 = 0.141, N = 35, P < 0.05).$$

$$\text{Log } N_t = 3.218 + 0.260 \log V \quad (2)$$
$$(r^2 = 0.240, N = 25, P < 0.05).$$

These weak log-log statistical relationships are of little or no predictive value. The r^2 values show that variation in spill volume explained only 14% of the variability in the number of oiled birds counted, and similarly only 24% of the variability in estimated mortality. Indeed, the relationship is so weak that if the single data point from the *Exxon Valdez* spill was excluded from each sample then the relationships would no longer be statistically significant (i.e. probability $P > 0.05$).

The present data are also biased because exceptionally large spills attract considerable public attention which may result in detailed investigations of seabird mortality, whereas small spills are often overlooked. Small spills, often smaller than 100 t, are known to have killed tens of thousands of seabirds, but estimates of the spill volume were not made. Examples of such spills are given in Table 2. If data from these small spills were included in the regression analysis, assuming each has a spill volume of 200 t, then no significant correlations between bird numbers counted or estimated could be found (P > 0.05 in all cases, whether using unconverted numbers or log–log comparisons). Again this demonstrates the weakness of the relationship found in equations (1) and (2).

Ratio between counts and estimates of oiled birds

There are 21 reports listed in Table 1 which give both counts of oiled birds and estimates of overall mortality. On average, the estimates were 4.4 (SD = 3.8) times higher than the actual counts. Only three cases appear to fit the '10% rule-of-thumb', with estimates of overall mortality ten times the body count. It is clear, however, that most estimates were based on very little factual information on the losses of birds at sea or on beaches and thus represent best guesses. In several cases, indicated with Asterisks on Table 1, researchers undertook experiments to measure the losses of carcasses at sea or on beaches, or applied models to account for such losses. Within this sub-sample the ratio of estimated total mortality to actual body count averaged 4.9 (SD = 4.1).

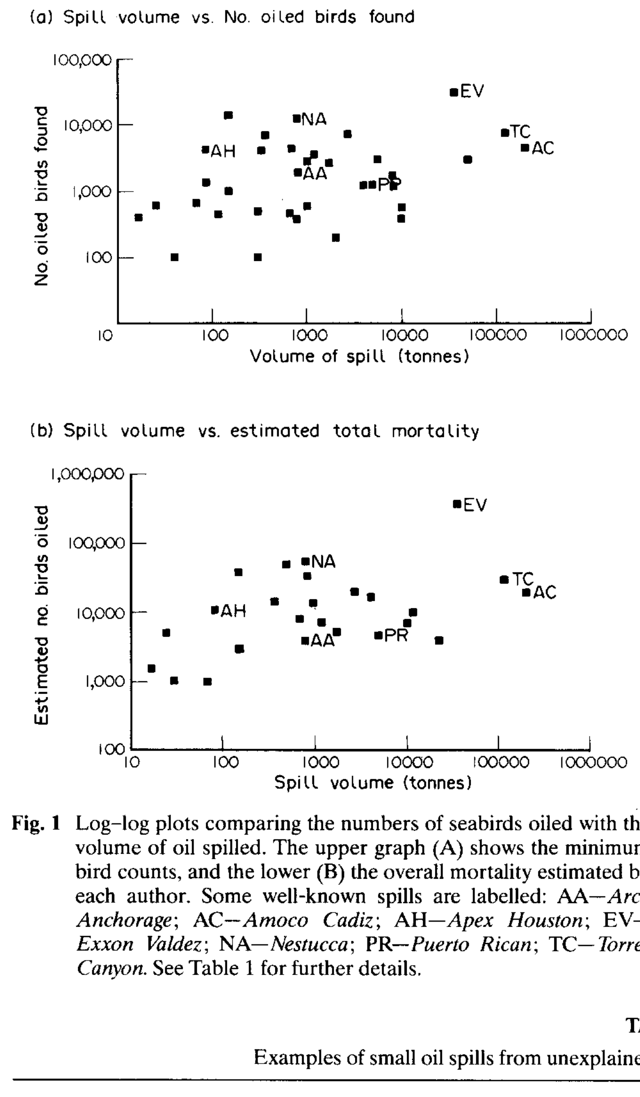

Fig. 1 Log–log plots comparing the numbers of seabirds oiled with the volume of oil spilled. The upper graph (A) shows the minimum bird counts, and the lower (B) the overall mortality estimated by each author. Some well-known spills are labelled: AA—*Arco Anchorage*; AC—*Amoco Cadiz*; AH—*Apex Houston*; EV—*Exxon Valdez*; NA—*Nestucca*; PR—*Puerto Rican*; TC—*Torrey Canyon*. See Table 1 for further details.

Discussion

These analyses confirm that there is no consistent relationship between the volume of oil spilled and the resultant seabird mortality. Only a small part of the variability in mortality is explained by variation in volume. Other factors, notably the density of seabirds in the affected area, wind velocity and direction, wave action, distance to the shore, and temperature (oil may form tar balls more quickly in warm seas) are also involved and may have greater bearing on the resultant mortality (Bourne & Bibby, 1975; Ford *et al.*, 1987; Page *et al.*, 1990). An immediate investigation of these parameters at the time of a spill is needed if seabird mortality is to be adequately estimated.

I found no justification for estimating overall mortality of birds as one order of magnitude greater than the body count. Most estimates were more conservative and averaged 4–5 times higher than the body counts. Here again, it is dangerous to generalize. Spills which occur close to well populated shores are likely to have a greater proportion of the oiled birds discovered than those occurring well out to sea or off more remote shores. Each spill should be investigated independently.

This review demonstrates the need to get information from smaller spills, which may kill as many seabirds as the more widely publicized large spills. Authorities also need to break the habit of paying little heed to spills which do not threaten populated shorelines. Oil slicks which are carried out to sea can kill as many seabirds as those that come ashore.

This is part of a study made to investigate the effects of the *Nestucca* oil spill in British Columbia and the State of Washington. Funding for this research came from Environment Canada, Pacific and Yukon Region. I thank Gary Kaiser and Steve Pond for their advice during this project.

TABLE 2

Examples of small oil spills from unexplained sources which killed large numbers of seabirds.

Year	Site	No. birds oiled	Details	References
1979	Varangerfjord, North Norway	> 5000 found; 10–20 000 estimated dead	Minor traces of oil on shore. Two to three small slicks at sea, covering few thousand m^2	Barrett, 1979
1972	Northern Kattegat, Denmark	30 000 estimated	Suspected small volume released from vessels	Joensen, 1973
1972	Waddensee, Denmark	> 30 000 estimated	Suspected small volume released from vessels	Joensen, 1973
1983	Normandy, France	5000 found	No oil on beaches	Duncombe, 1983
1970	NE England and E Scotland	12 400 found 50 000 estimated	Suspected small amounts from general cargo vessels	Greenwood *et al.*, 1971
1959	SE Newfoundland	> 12 000 found	Suspected flushing of tanks	Horwood, 1959

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