Marine Pollution Bulletin, Volume 26, No. 9, pp. 495–501, 1993.
Printed in Great Britain.

0025-326X/93 $6.00+0.00

Drift-Block Experiments to Analyse the Mortality of Oiled Seabirds off Vancouver Island, British Columbia

DEBBI A. HLADY* and ALAN E. BURGER†
*Integrated Management Branch, British Columbia Environment, 780 Blanshard Street, Victoria, British Columbia, Canada V8V 1X5
†Biology Department and Bamfield Marine Station, University of Victoria, Victoria, British Columbia, Canada V8W 2Y2

We used wooden drift-blocks, simulating carcasses, to estimate the proportion of oiled seabirds which might come ashore following an oil spill off Vancouver Island, British Columbia, Canada. Blocks were released at an inshore site (1–2 km offshore), and at four offshore sites (35–116 km offshore). In the month following releases, we recovered 43% and 53% of the inshore blocks in summer and winter, respectively, but only 10% of the offshore releases in the winter. Most blocks were found within 10 km of the release sites, but a few travelled >400 km. Recovery rates of inshore blocks were not strongly affected by tidal flow, whereas wind and the Vancouver Island Coastal Current had significant effects. Block size had little effect on recovery or distance travelled. Fewer blocks were recovered from rocky shores and more from sand and gravel beaches than expected, and many blocks were mixed among logs and kelp jetsam. These data indicate that seabird mortality following marine oil spills could be greatly underestimated, particularly if the spills occurred far offshore.

The impact of oil spills on seabirds is usually assessed by counting oiled birds which come ashore on beaches. A large proportion of the affected carcasses are never seen, however, because they sink, drift out to sea, are scavenged, or are overlooked on beaches (Ford *et al.*, 1987; Page *et al.*, 1990). Estimates of the proportion of oiled carcasses recovered after a spill range between 0.3–56% (National Research Council 1985; Camphuysen, 1989), based on experiments where carcasses (e.g. Hope Jones *et al.*, 1970, Bibby & Lloyd, 1977; Piatt *et al.*, 1990) or wooden drift-blocks (Threlfall & Piatt, 1982) were released at sea and recovered on the shore.

In this study we released drift-blocks off the west coast of Vancouver Island, British Columbia to gauge the proportion of carcasses likely to come ashore, and to assess the effects of recoveries of block size, tides, wind, distance from shore and shoreline substrates. The coast of British Columbia is subject to moderate rates of chronic oil pollution (Vermeer & Vermeer, 1975; Kay, 1989; Cohen & Aylesworth, 1990), and was affected by five spills exceeding 1000 barrels between 1985 and 1991 (Burger, in press). More than 300 tankers carrying Alaskan crude pass through the Strait of Juan de Fuca annually, and the total shipment of crude and refined petroleum off southern British Columbia exceeds 250 million barrels per year (Shaffer *et al.*, 1990). The spill from the barge *Nestucca* off Gray's Harbor, Washington deposited an estimated 10 000 oiled seabirds on Vancouver Island in 1989 (Rodway *et al.*, 1989; Burger, 1990). The paucity of information on the fate of dead birds off this coast was a major obstacle in assessing the effects of this spill (Ford *et al.*, 1991; Burger, 1990).

Materials and Methods

Block production

Blocks were cut from standard 9×4 cm fir/hemlock lumber (density 0.5 g cm^{-3}) in three lengths (40, 20, and 10 cm), with mean weights of 701, 346, and 182 g, respectively, to simulate large (murre), medium (guillemot), and small (auklet) alcid seabirds. Alcids (Family Alcidae) are the most common victims of oiling in northern seas (Bourne, 1976; Camphuysen, 1989). Blocks were painted fluorescent orange for maximum visibility, and labelled with a return address. Paper labels, fixed to the wood with varnish, were used in 1989 and laminated plastic tags (Floy Tag, Seattle) were nailed to the blocks in 1990. Each block had a unique number which allowed us to determine the time and place of release.

Block release

Blocks were released off the west coast of Vancouver Island at an inshore site in the summer of 1989 and the winter of 1990, and at offshore sites in the winter of 1990 (Fig. 1). The inshore site was 1–2 km off Pachena Bay, SE of Barkley Sound. Blocks were released from a boat in batches of 10 per minute along a 1.5 km line. There were two inshore releases of 150 blocks (50 of

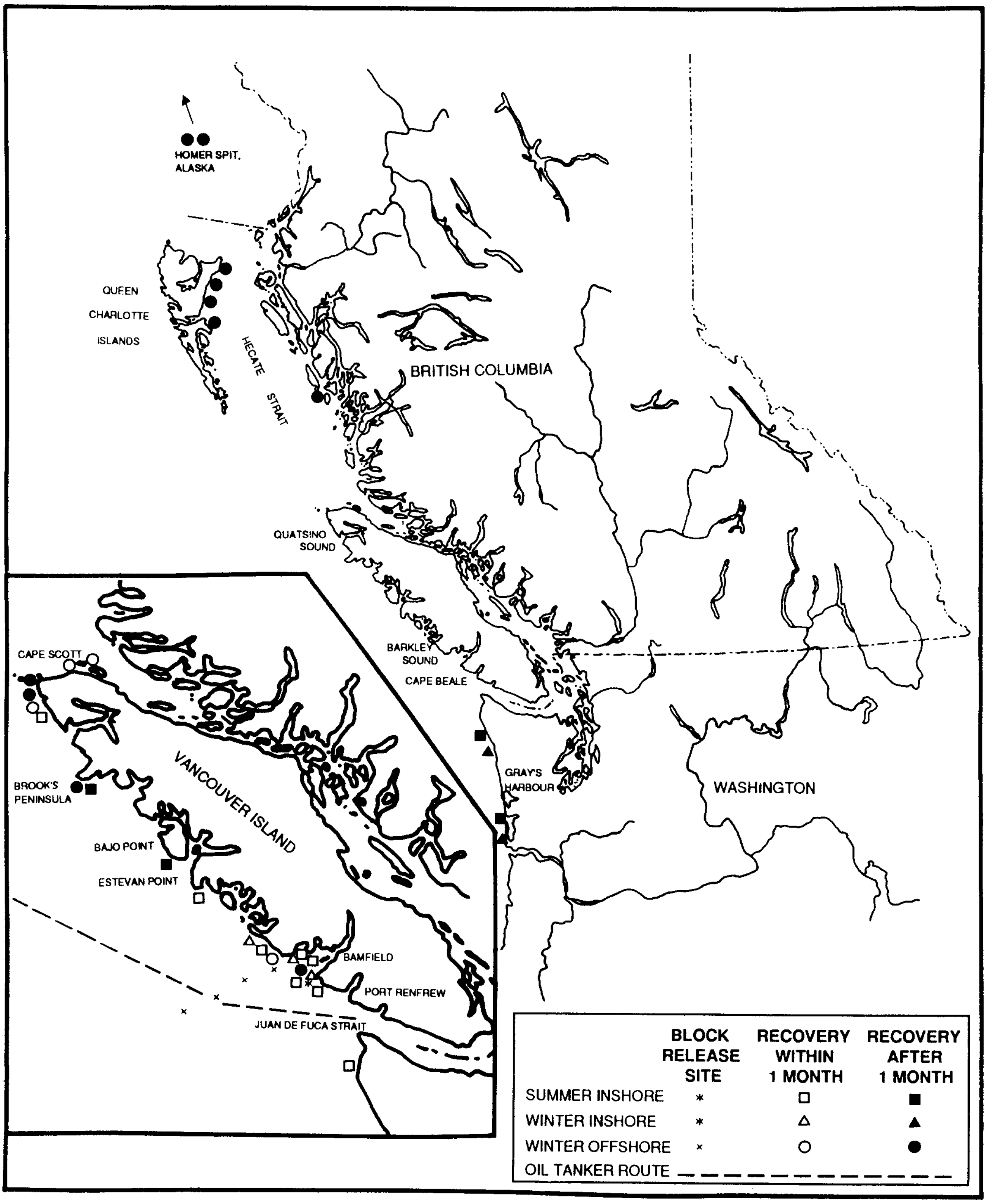

Fig. 1 Map showing the location of inshore and offshore sites where drift blocks were released off Vancouver Island and sites where blocks were subsequently recovered. The number of blocks found at each site is not indicated by the symbols, but see Table 2 for numbers recovered at various distances from release sites. The dashed line indicates the route used by more than 300 tankers per year, carrying Alaskan crude oil into the Strait of Juan de Fuca.

each size) in each season, for a total of 300 inshore blocks per season. In summer the two releases were made on the same day (23 June 1989) to test the effects of tidal flow during spring tides: the first at 13:25 (Pacific Daylight Time) during the maximum incoming flow, and the second at 19:10 during the maximum outgoing flow. Poor weather prevented us from repeating the tidal test in winter, but fortuitously, we could compare the effects of different wind conditions by releasing 150 blocks on successive days (29 and 30 January 1990). Both releases occurred with the spring tides at maximum incoming flow (10:40 and 11:20, respectively).

The offshore releases were made on 6 February 1990, during a cruise of the research vessel *Tully*. Batches of 75 blocks (25 of each size) were released at each of four stations, 35, 56, 86 and 116 km offshore, perpendicular to the coast, between 48°39.7'N, 125°47.4'W and 48°15.2'N, 126°40.0'W (Fig. 1).

Search effort and project publicity

Following the releases, we searched the shoreline within 10–30 km of the release site for blocks on foot and from boats. Crews of the Canadian Coast Guard, local lighthouse keepers, wardens of Pacific Rim National Park, students from Bamfield Marine Station, and hikers on the West Coast Trail were recruited for detailed searches. In general, beaches within 10 km of release sites were searched 2–6 times. In the winter of 1990, when fewer tourists visited the beaches, we used a Coast Guard helicopter for a low-altitude search of 300 km of shore, between Port Renfrew and Bajo Point. The project was also widely publicized on local radio and newspapers, and through posters in local stores and public buildings. Details of search efforts and publicity are given in Hlady & Burger (1990).

In this analysis we considered only blocks recovered within one month of release. This was conservatively taken as the time that a bird carcass could remain relatively intact and recoverable. The date of recovery does not necessarily coincide with the date the block came ashore, because beaches were not visited every day.

Shoreline substrates

The substrate on which blocks were found was recorded as sand, gravel, rock (boulders and rocky shelves), and tidal mudflats. To compare the rates of block recovery with available substrates, we restricted this analysis to 25 km of coast, between Cape Beale and Michigan Creek, where the shore substrate had been analysed from topographic maps (Department of Environment, 1983), and where 95% and 67% of the blocks were found in summer and winter, respectively. This area was thoroughly searched by boat and on foot in both seasons. We also recorded whether blocks were found on the open shore, or among kelp jetsam and beached logs.

Statistical tests

Chi-squared tests were used throughout to test for significant differences in frequencies.

Results

Inshore release

The summer release on 23 June 1989 was followed by light, variable winds and low swells. Many blocks remained near the release site until a storm passed through on the 24-26 June. Strong SE winds, followed by strong W and NW winds, resulted in heavy onshore swells, which brought many blocks ashore within 5 km of the release site. In the following week, winds were more consistently SE and carried some blocks NW up the coast of Vancouver Island.

The winter blocks were released on two days, 29 and 30 January 1990, with very different winds. On the afternoon following the first release, strong S and SE winds, with a rising tide and following swell, drove many blocks high onto the shore within a few km of the release site and 88 (58%) were recovered on the first search of adjacent beaches. The next afternoon following the second release, the winds were still strong, but now from the NW and appeared to carry the blocks parallel to, or away from the shore. Some 20–30 of these blocks were seen from the air, 25 km SE of the release site on the same day. Once they had moved away from the shore, these blocks evidently moved N and NW with the prevailing current (see below).

Within one month of each inshore release, a total of 43% of the summer blocks and 53% of the winter blocks were recovered (Table 1). In both seasons, 94% of the recovered blocks were found within the first 16 days. The proportion recovered increased with increasing block size (Table 1), but these differences were not statistically significant in summer, winter or in the combined data (χ^2 tests, $P > 0.05$ in each case).

The two summer releases were made at differing tidal flows, but yielded no significant differences in the proportions recovered (Table 1, $P > 0.05$), although in the first few days more blocks were recovered from the incoming than the outgoing tide. In winter, variations in wind direction significantly affected the rates of recoveries (Table 1, $P > 0.001$). Almost twice as many blocks were recovered from the 29 January release (strong onshore winds) compared to the 30 January (strong offshore winds). Block size did not affect recovery rates from either tide phase in summer or with differing wind conditions in winter (Table 1, $P > 0.05$ in each case).

Block size had no significant effect on the distance travelled in summer or winter (Table 2, $P > 0.05$ in each case). Most blocks (68%) were found within 5 km of the inshore release site, and 75% within 10 km. In general, blocks travelled further in winter than in summer (Table 2, $P < 0.001$): only 12% of the summer blocks went further than 10 km, compared to 35% of the winter blocks. However, a few summer blocks travelled considerable distances: one was found on the Washington Coast over 100 km to the SE (two others were found in Washington after the one-month cut-off period), and

TABLE 1

Numbers of small, medium and large blocks recovered within one month after inshore releases in the summer (23 June 1989) and winter (29 and 30 January 1990). Each release (two per season) consisted of 150 blocks (50 of each size). Percentage recovery shown in parentheses.

	Block size			Total Recovered
	Small	Medium	Large	No. Blocks/ % of release
Summer 1989				
Incoming tide	24	22	27	73 (48.7)
Outgoing tide	11	21	24	56 (37.3)
Total	35	43	51	129 (43.0)
Winter 1990				
29 Jan. (Wind S/SE)	32	34	35	101 (67.3)
30 Jan. (Wind NW)	17	20	22	59 (39.3)
Total	49	54	57	160 (53.3)
Both seasons	84	97	108	289 (48.2)
(%)	(42.0)	(48.5)	(54.0)	

TABLE 2

Numbers of small, medium and large blocks which were found <5.0, 5.1–10.0, and >10 km from the inshore release site, in the summer (1989), and winter (1990). Percentages in parentheses

	Distance (km) <5.0	5.1–10.0	>10.0	Total
Summer 1989				
Small	29	3	3	35
Medium	31	6	10	47*
Large	37	11	3	51
Total	97	20	16	133*
(%)	(72.9)	(15.1)	(12.0)	
Winter 1990				
Small	30	0	19	49
Medium	36	0	18	54
Large	38	0	19	57
Total	104	0	56	160
(%)	(65.0)		(35.0)	
Both seasons				
Small	59	3	22	84
Medium	67	6	28	101
Large	75	11	22	108
Total	201	20	72	293
(%)	(68.6)	(6.8)	(24.6)	

*Four blocks which lost their labels were included here, but are not included in Tables 1 and 3.

TABLE 3

Numbers of blocks recovered at various distances from the inshore release site, showing the effects of tidal flow (summer 1989) and wind direction (winter 1990)

	Distance (km) <5.0	5.1–10.0	>10.0	Total Recovered No. Blocks/ % of release
Summer 1989				
Incoming tide	59	10	4	73 (48.7)
Outgoing tide	36	10	10	56 (37.3)
Total	95	20	14	129
(%)	(73.6)	(15.5)	(10.9)	
Winter 1990				
29 Jan. (Wind S/SE)	89	0	12	101 (67.3)
30 Jan. (Wind NW)	15	0	44	59 (39.3)
Total	104	0	56	160
(%)	(65.0)		(35.0)	

three blocks were found near the northern tip of Vancouver Island up to 340 km from the release site. Two winter blocks were also found in Washington 6 months after release. Blocks released on the outgoing tide during summer travelled slightly further than those on the incoming tide (Table 3, P=0.05), and those released during offshore NW winds on 30 January travelled much further than those released during inshore S/SE winds on 29 January (Table 3, $P<0.001$).

Block size had no effect on the proportions recovered from the three major shore substrates (sand, gravel, and rock) in either summer or winter (Fig. 2, $P>0.05$ in each case). With blocks of all sizes pooled, we found no significant differences between summer and winter in depositions on these substrates (Fig. 2, $P>0.05$). Although more than half the shoreline within 25 km to the release site was rocky, significantly fewer blocks were found on rocky shores than expected, more on sand and gravel (Fig. 2, <0.001, summer and winter).

Block size did not affect the proportions recovered among kelp, logs, or on the open shore (Fig. 3, $P>0.05$). With all sizes combined, however, there were very marked differences between the seasons ($P<0.001$). A greater proportion were found among logs in winter, which was a consequence of greater wave action and frequent storms which moved logs and debris. Overall, we found more than a quarter of the summer blocks and about two thirds of the winter blocks among kelp or log jetsam.

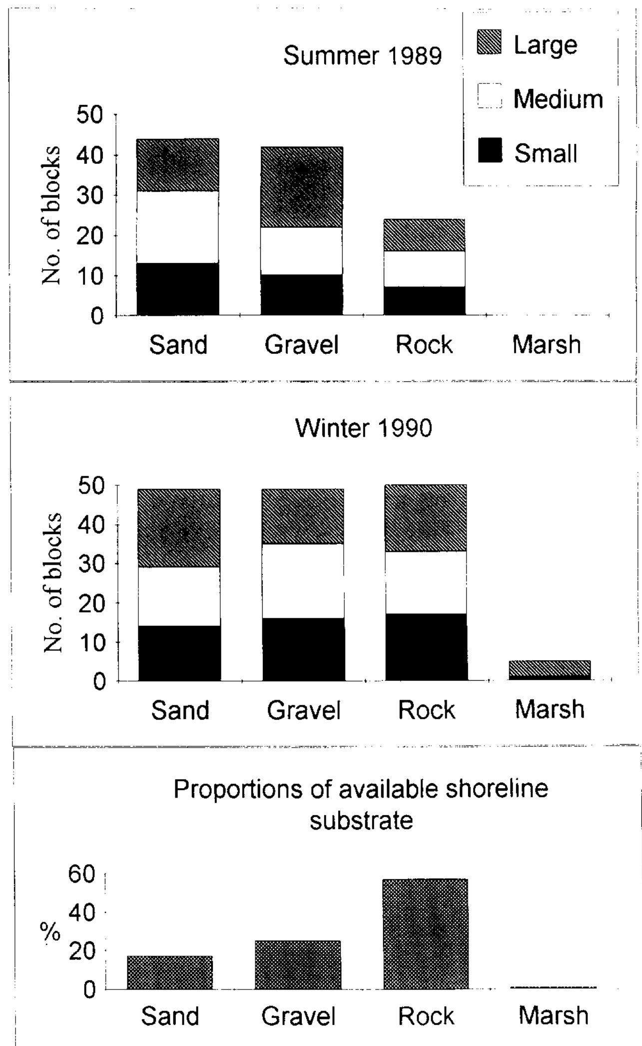

Fig. 2 Numbers of drift blocks of each size class found on various shore substrates on Vancouver Island, compared with the linear proportions of these substrates along 25 km of shoreline adjacent to the inshore release site.

Offshore releases

Only 29 (9.7%) of the 300 blocks were found within a month: five from the 35 km release site, 23 from 56 km, one from 86 km and none from 116 km offshore. These blocks were all found within 25 days of being released and 83% were found within 16 days. Similar numbers of each block size: eight small, ten medium and eleven large ($P>0.05$). This sample was too small for testing of the effects of other variables.

All the offshore blocks were found to the N or NW of the release sites, and 86% were found on the 30 km of shore immediately N of the release transect. Several blocks travelled considerable distances in relatively little time before being recovered (e.g. 300 km in 16 days (1 block); 400 km in 23 days (2 blocks). After the 1 month cut-off period 19 blocks were found on the Queen Charlotte Islands, >700 km from the release site within

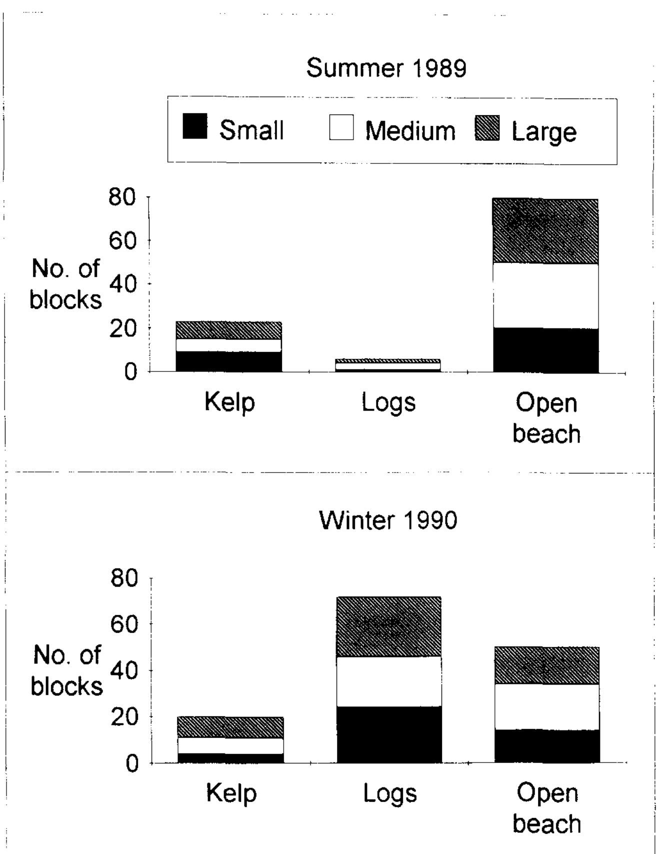

Fig. 3 Numbers of drift blocks of each size class found among kelp jetsam, beached logs or on open beach on Vancouver Island.

10 weeks (13 from the 116 km offshore release site and 6 from 35 km offshore) and two blocks from the 35 km release site were found in Alaska (Homer Spit and Clam Gulch) 6 months after release.

Discussion

Effects of block size

Larger blocks were found more frequently than smaller ones, but the differences were small and not statistically significant. Block size had no significant effects on the distances travelled, or the relationship between the effects of tidal flow or shore substrate. It is not known to what extent these results apply to bird carcasses of various sizes. We suspect that small carcasses, lacking the conspicuous coloration of small blocks, would be much more difficult to detect on beaches than larger carcasses, particularly if caught among jetsam.

Effects of tides, winds and currents

Blocks and dead birds floating at sea are affected by a combination of wind, currents, and tides. The interactions of these and other physical processes, such as salinity gradients, are extremely complex off the west coast of Vancouver Island, but some general patterns which apply to this study have been identified (Thomson, 1981; Thomson *et al.*, 1989). The NW flowing Vancouver Island Coastal Current, which persists all year, is an important conduit over the inner shelf, but also acts as a barrier to cross-shelf movements. The prevailing winds tend to be from the NW in summer, and if sufficiently strong, can counter the effects of the current at the surface. Winter winds tend to be from the SE and re-inforce the current. Further offshore, beyond the 200 m depth contour, lies the reversible, wind-driven Shelf-Break Current which flows NW in summer and SE in winter.

The tendency for blocks to drift both north and south in summer, but only northwards in winter is consistent with the combined effects of the Vancouver Island Coastal Current and the seasonally prevailing winds. Many of our blocks which were not recovered within a month might have remained within this current, or drifted seaward where the chances of coming ashore were reduced. This was demonstrated by the large numbers found in the Queen Charlotte Islands after the one month cut-off period.

The direction of drift in blocks was also consistent with the movements of oiled carcasses following recent oil spills. After the *Nestucca* oil spill off Gray's Harbor, Washington in the winter of 1988–1989, thousands of heavily oiled, decomposed carcasses of offshore species were deposited along the length of western Vancouver Island, 200–300 km from the spill site (Rodway *et al.*, 1989; Burger, 1990). In contrast, almost all of the birds killed by the *Tanyo Maru* oil spill off the mouth of Juan de Fuca Strait in the summer of 1991, were found to the SE in Washington, driven by the prevailing NW winds (Unpubl. data Washington Dept. of Ecology).

Tidal flow appeared to have little effect on overall recoveries, but the wind significantly affected movements and recoveries of the inshore blocks. This was most evident when comparing the two inshore releases in winter. After the first release, strong onshore winds and waves drove many blocks directly ashore. A larger proportion of these blocks was found than from the second release, and from a more restricted area of coast. Onshore winds following the summer release were also responsible for the high rate of recovery within 5 km of the release site.

The direction and speed of drifting seabird carcasses is strongly influenced by wind (Hope Jones *et al.*, 1970; Bibby & Lloyd, 1977; Camphuysen, 1989, Ford *et al.*, 1991). In our study, many blocks did not come ashore despite strong onshore winds and waves, and some were recovered at considerable distances, both up and down the coast. This suggests that the interpretation of seabird mortality from coastal oil spills will be strongly influenced by seasonal wind and currents. Most significantly, the result shows that many carcasses might remain at sea even with favourable onshore winds and waves.

Effects of shore substrates

Fewer blocks were found on rocky shores, and more on sand and gravel, than expected from the proportions of available shoreline. Two factors account for this. First, blocks (and birds) are less likely to be seen when deposited among boulders. Oiled carcasses are thus likely to be underestimated on rocky shores. Second, the probability of deposition is lower on rocky shores than on gently shelving sand or gravel beaches. Small, rocky coves accumulate jetsam, but headlands and exposed rocky shores seldom do.

We found 25–64% of the blocks among kelp or log jetsam, in situations where less conspicuous carcasses would easily be missed. Semi-permanent deposits of large logs are common on exposed beaches of Vancouver Island, and big piles of kelp are also deposited there, particularly in winter. A significant portion of beached carcasses would end up among kelp or logs, leading to underestimates of their numbers. Oiled carcasses were still emerging from beneath sand and jetsam on Vancouver Island, 3–4 months after the *Nestucca* spill (Rodway *et al.*, 1989).

Implications for assessing seabird mortality

Our data suggests that only a small proportion of birds which die at sea would be detected on Vancouver Island or other beaches. Despite diligent searching, we recovered only 43% and 53% of the summer and winter blocks, respectively, dropped 1–2 km from the shore. We found only 10% of the offshore blocks, and fewer than 1% of the blocks released 86–116 km offshore. These most distant offshore stations lie within the present routes of tankers carrying Alaskan crude into the Strait of Juan de Fuca (Fig. 1). Significant mortality of seabirds, which could result from a very small spill (Barrett, 1979), could easily remain undetected. A few oiled birds found on the beaches of Vancouver Island might represent hundreds of thousands of deaths (50–100 km offshore).

Wooden blocks do not necessarily mimic seabird carcasses in every way. Oiled birds might move toward the shore while alive, which would make them more likely to come ashore than blocks. On the other hand, there are at least three reasons why blocks would be more likely to be recovered than carcasses. Blocks are likely to remain buoyant for longer periods than birds. Experiments in Washington and British Columbia indicate that most alcids sink within two weeks at sea (Ford *et al.*, 1991; Burger, 1991). Second, the large populations of scavenging birds and mammals rapidly remove beached seabirds on Vancouver Island (Burger, 1991), but would not affect blocks. Third, carcasses are less conspicuous than our fluorescent orange blocks, and far more likely to be overlooked, especially if wrapped in jetsam. Threlfall & Piatt (1982) recovered significantly more orange/yellow drift-blocks than those painted black and white to mimic seabirds. Dead birds are easily overlooked, even during detailed searches (Pain, 1991). Stutzenbaker *et al.* (1986) found that only 12% of 50 waterfowl carcasses placed in exposed positions on vegetation was found by teams of searchers, whereas none of the 50 which were concealed in vegetation was found.

Overall, it seems certain that blocks are more likely to be found than carcasses. Our results therefore indicate the maximum proportion of carcasses which should be recovered under similar conditions. Further investigation is needed to compare drift-blocks with real carcasses, and to determine the rates of sinking and scavenging of carcasses. This study indicates that only a small portion of an affected seabird population would be recovered on Vancouver Island following an offshore or inshore oil spill.

This project was funded by the Policy and Planning Branch, British Columbia Ministry of Environment and the Bamfield Marine Station. We thank the many people who assisted in all phases of this project, and in particular, John Bones, Gary Bowes, Dave Hegstrom, Bob McIntyre, Phil Lambert, John McInery, Shirley Pakula, Rick Wilson, students and staff of Bamfield Marine Station, the captain and crew of the *R.V. Tully*, lightkeepers, wardens of Pacific Rim National Park, the manager and staff of the Mahalat Parks District workshop. We are especially grateful for considerable boat and helicopter time, and cheerful assistance of the Canadian Coast Guard, particularly Search and Rescue Bamfield and Victoria. Rick Thomson provided valuable advice on ocean currents.

Barrett, R. T. (1979). Small oil spill kills 10–20,000 seabirds in North Norway. *Mar. Pollut. Bull.* **10**, 253–255.

Bibby, C. J. &. Lloyd, C. S. (1977). Experiments to determine the fate of dead birds at sea. *Biol. Conserv.* **12**, 295–309.

Bourne, W. R. P. (1976). Seabirds and pollution. In *Marine Pollution*, Vol. 6 (R. Johnston, ed.). Academic Press, London.

Burger, A. E. (1990). Effects of the 'Nestucca' oil spill on seabirds along the coast of Vancouver Island in 1989. Unpubl. Report Environment Protection Service, Environment Canada, Vancouver, British Columbia.

Burger, A. E. (1991). Experiments to improve the assessment of mortality in oiled seabirds. Unpubl. report Environment Protection Service, Environment Canada, Vancouver, British Columbia.

Burger, A. E. (in press). The effects of oil pollution on seabirds off the west coast of Vancouver Island. In *Seabirds of the west coast of Vancouver Island* (K. Vermeer, R. W. Butler & K. H. Morgan, eds.). *Spec. Publ. Can. Wildl. Serv.*, Ottawa.

Camphuysen, C. J. (1989). Beached bird surveys in the Netherlands 1915–1988: seabird mortality in the southern North Sea since the early days of oil pollution. Werkgroep Noordzee, Amsterdam.

Cohen, P. & Aylesworth, R. (1990). Oil spill risk for southern B.C./northern Washington coast marine area. Final report of the States/British Columbia oil spill task force. Appendix VII. Publ. Province of British Columbia and the States of Washington, Oregon, Alaska and California.

Department of Environment (1983). Shoreline protection and cleanup manual: Bamfield to Esquimalt, Vancouver Island. British Columbia Environment, Reg. Program Report: 83-4.

Ford, R. G., Casey, J. L., Hewitt, C. L., Lewis, D. B., Vaourjean, D. H., Warrick, D. R. & Williams, W. A. (1991). Seabird mortality resulting from the Nestucca oil spill incident, winter 1988–89. Report for Washington Dept. Wildlife. Ecological Consulting Inc., Portland, Oregon.

Ford, R. G., Page, G. W., & Carter, H. R. (1987). Estimating mortality of seabirds from oil spills. Pp. 747–751, in Proc. 1987 Oil Spill Conference, American Petroleum Institute, Washington, D.C.

Hlady, D. A. & Burger, A. E. (1990). Drift-block experiments to analyze the mortality of oiled seabirds. Unpubl. Report Emergency Services Branch, British Columbia Environment, Victoria, British Columbia.

Hope Jones, P., Howells, G., Reese, E. I. S. & Wilson, J. (1970). Effect of *Hamilton Trader* oil on birds in the Irish Sea in May 1969. *Brit. Birds* **63**, 97–110.

Kay, B. H. (1989). Pollutants in British Columbia's marine environment: a status report. Environment Canada, Conservation and Protection, SOE Report No. 89-1, Vancouver, British Columbia.

National Research Council (1985). Oil in the sea: inputs, fates and effects. National Academy Press, Washington, D.C.

Page, G. W., Carter, H. R. & Ford, R. G. (1990). Numbers of seabirds killed or debilitated in the 1986 *Apex Houston* oil spill in Central California. *Studies Avian Biol.* **14**, 164–174.

Pain, D. H. (1991). Why are lead-poisoned waterfowl rarely seen?: the disappearance of waterfowl carcasses in the Camargue, France. *Wildfowl* **42**, 118–122.

Piatt, J. F., Lensink, C. J., Butler, W., Kendziorek, M. & Nysewander, D. R. (1990). Immediate impact of the "Exxon Valdez" oil spill on marine birds. *Auk* **107**, 387–397.

Rodway, M. S., Lemon, J. F., Savard, J.-P. & McKelvey, R. (1989). Nestucca oil spill: impact assessment on avian populations and habitat. Tech. Rep. Ser. No. 68. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia.

Shaffer, M. and Associates Ltd. (1990). Crude oil and petroleum product traffic in British Columbia and Puget Sound. Final Report of the States/British Columbia oil spill task force, Appendix IV. Publ. Province of British Columbia and the States of Washington, Oregon, Alaska and California.

Stutzenbaker, C. D., Brown, K. and Lobpries, D. (1986). Special report: an assessment of the accuracy of documenting waterfowl die-offs in Texas coastal marsh. In *Lead poisoning in wild waterfowl, a workshop* (J. C. Feierabrend and A. B. Russell, eds). CLIPCIP, National Wildlife Federation, Washington, D.C.

Thomson, R. E. (1981). Oceanography of the British Columbia coast. *Can Spec. Publ. Fish Aquat. Sci.* **56**.
Thomson, R. E., Hickey, B. M. & LeBlond, P. H. (1989). The Vancouver Island coastal current: fisheries barrier and conduit. In *Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models* (R. J. Beamish and G. A. McFarlane, eds.), pp. 265–296. *Can Spec. Publ. Fish. Aquat. Sci.* **108**.
Threlfall, W. & Piatt, J. F. (1982). Assessment of offshore oil mortality and corpse drift experiments. Unpubl. report for Mobil Oil Canada Ltd, Memorial University, St. John's Newfoundland.
Vermeer, K. & Vermeer, R. (1975). Oil threat to birds on the Canadian West Coast. *Can. Field Nat.* **89**, 278–298.

Marine Pollution Bulletin, Volume 26, No. 9, pp. 501–507, 1993.
Printed in Great Britain.
0025-326X/93 $6.00+0.00

Coprostanol (5β-cholestan-3β-ol) in Lagoonal Sediments and Mussels of Venice, Italy

M. R. SHERWIN*‡, E. S. VAN VLEET*§, V. U. FOSSATO† and F. DOLCI†
**Department of Marine Science, University of South Florida, 140 Seventh Avenue South, St. Petersburg, FL 33701, USA*
†Istituto di Biologia del Mare, Riva 7 Martiri 1364/A, 30122 Venezia, Italy
‡Present Address: Ogden Environmental and Energy Services, 5510 Morehouse Drive, San Diego, CA 92121, USA
§To whom correspondence should be addressed.

Coprostanol, a fecal sterol indicative of mammalian waste, was analysed in sediments and mussels collected from 25 stations in the canals and lagoon of Venice, Italy, to investigate dispersal and accumulation of untreated sewage. Concentrations of sedimentary coprostanol ranged from 0.2 μg g^{-1} in a reference station in the northern Adriatic Sea to 41 μg g^{-1} in an interior canal of Venice. These values made up 4% to 44% of the total sterols, and indicated which areas of the lagoon had the greatest contribution from sewage discharge. Coprostanol concentrations found in mussels were lower and less variable than in sediments, indicating that sedimentary coprostanol concentrations are a better indicator of sewage discharge in the lagoon. Areas with high sedimentary coprostanol concentrations either lacked mussels entirely or contained mussels showing severe environmental stress. Data suggest that sedimentary coprostanol concentrations appear to be a useful indicator of potential ecological problems in the lagoon and canals of Venice due to the direct input of untreated waste.

The dispersion of municipal wastes in marine systems has been followed in a variety of ways. Most approaches have used naturally occurring sewage constituents such as fecal coliform bacteria, ammonia, or biodegradable organic matter as a tracer for effluent in the water column or sediments. Each of these methods suffers from drawbacks such as lack of specificity or sensitivity, or need to complete analyses within a few hours of discharge or collection (Goodfellow *et al.*, 1977). Most of these techniques are useful only as short-term tracers for the dispersion of wastewater. Use of the fecal sterol coprostanol (5β-cholestan-3β-ol) is now a generally accepted approach for longer-term investigation of sewage dispersal.

Coprostanol is produced primarily in the intestines of mammals (including man) by enteric microbial reduction of cholesterol, the main steroid found in the tissues of vertebrates (Rosenfeld & Hellman, 1971; Escalona *et al.*, 1980). Because this process is the only known source of coprostanol, the presence of this compound in natural environments is considered a reliable indicator of mammalian fecal contamination (Murtaugh & Bunch, 1967; Smith *et al.*, 1967; Yde *et al.*, 1982). Some marine mammals have also been shown to contain a high percentage of epicoprostanol (5β-cholestan-3α-ol) in addition to coprostanol (Venkatesan & Santiago, 1989). Human waste, however, contains only the 3β isomer (coprostanol), not epicoprostanol. Advantages of using coprostanol as an indicator for fecal material are that it is relatively resistant to microbial alteration and has a longer lifetime in the marine environment than pathogenic bacteria. Estimates of the lifetime of pathogens in marine waters are on the order of days to weeks (Bianchi & Mircea, 1976; Bianchi & Bensoussan, 1977; Solic & Krstulovic, 1992); however, once deposited in marine sediments, pathogens can survive for several months to a few years