EFFECTS ON THE NESTUCCA OIL SPILL ON SEABIRDS ALONG THE COAST OF VANCOUVER ISLAND IN 1989

Alan E. Berger

TECHNICAL REPORT SERIES NO. 179
Pacific and Yukon Region 1993
Canadian Wildlife Service

Environment Canada
Environnement Canada

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Canada

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CANADIAN WILDLIFE SERVICE

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This series may be cited as:

Burger, A. E. 1993. Effects of the Nestucca oil spill on seabirds along the coast of Vancouver Island in 1989.

Technical Report Series No. 179. Canadian Wildlife Service, Pacific and Yukon Region, British Columbia

Issued under the Authority of the
Minister of Environment
Canadian Wildlife Service

Catalogue No. CW69-5/179E
ISBN 0-662-20827-7
ISSN 0831-6481

Copies may be obtained from:
Canadian Wildlife Service
Pacific and Yukon Region
P.O. Box 340,
Delta, British Columbia
Canada V4K 3Y3

Printed on recycled paper

ACKNOWLEDGEMENTS

This study was funded by Environment Canada, Contracts KA601-8-4184 and KA601-0-3033. Many people contributed to the oiled bird data including employees of Environment Canada, the Canadian Coast Guard and volunteers. I thank Gary Kaiser, Moira Lemon, Rick McKelvey, Mike Rodway, Jean-Pierre Savard and Kees Vermeer (all with the Canadian Wildlife Service), Brian Hauger (Washington State Department of Wildlife), Lee Harding and Steve Pond (Environment Canada), Doug Swanston, Dave LeBlanc, Adrian Dorst, Harry Carter, John Piatt, Art Sowls and Steve Speich for provision of data, and useful discussions. Andre Breault, Don Garnier and Kati Martini kindly allowed me to use their gull observations. I thank Jacquie Lee, Wendy Matheson, Marion Pierce and Lesley Rimmer for assistance in Bamfield, and Cam and Joy Finlay and Douglas Fryer for useful advice and assistance. A special thanks to Barry Campbell, Mac Elder, Bill McIntyre, Dan Vedova, Earl Wilson and other staff of Pacific Rim National Park for providing high quality beach survey data and accomodation, and Glenn Ford and Janet Casey (Ecological Consulting, Inc.) for sharing data and ideas.

ABSTRACT

1) The spill of 875,000 litres of Bunker C oil from the barge Nestucca off Gray's Harbor, Washington on 23 December 1988 resulted in 3568 dead oiled seabirds coming ashore on Vancouver Island. Identified oiled birds included 31 species, dominated by Common Murres *Uria aalge* (42%), Cassin's Auklets *Ptychoramphus aleuticus* (32%), other alcids (9%), scoters (6%) and gulls (4%). The breeding colonies of the affected birds were not known.

2) Most of the Nestucca victims found on Vancouver Island were offshore species (82%), well decomposed (70%) and encapsulated in thick oily mousse (75% had >95% of their plumage saturated). This suggested that most carcasses were oiled in offshore shelf waters early in the spill and drifted for many days before coming ashore. The encapsulating oil probably buoyed these carcasses and most of the lightly-oiled offshore carcasses probably sank.

3) Flotation tests showed that 21% of heavily oiled alcid carcasss sank 21-25 days after the spill, 44% after 25-35 days, and 63% after 50-60 days. Other experiments indicated that many carcasses would have sunk before stranding, or if re-washed off beaches, leading to underestimates of mortality.

4) Scavengers had eaten 54% of all the oiled carcasses, including 48% of all oil-saturated carcasses. Some secondary oiling of scavenging gulls and eagles was reported. Scavenging would have led to underestimates of beached carcasses, and certainly killed or debilitated many of the 10,000-20,000 scavenging birds which winter on this coast.

5) Data from beached bird surveys and marine censuses were compared with the Nestucca data. The oiled sample showed a high proportion of offshore species and diving birds (particularly alcids). Surface feeding birds (fulmars and gulls), and the large populations of inshore wintering waterfowl and seabirds were less affected.

6) Many beached carcasses were not tallied. Three methods were used to estimate the total number of beached oil carcasses on Vancouver Island, with these results:

i) a probability model based on rates of deposition and persistence of carcasses on beaches: minimum 11,800 carcasses;

ii) estimates based on the lengths of affected coastline: 7800-14,000 carcasses;

iii) estimates based on numbers of carcasses per bag of oil debris removed: 8300 carcasses, 95% confidence limits 5900-10,700.

Likely sources of error point to higher estimates in each case. Overall, a reasonable, conservative conclusion is that 10,000 oiled carcasses came ashore on Vancouver Island.

7) Many oiled birds did not come ashore. On the basis of experimental work done in Washington, Ford et al. (1991) estimated that only 25% of the offshore species destined for Vancouver Island came ashore, and the overall mortality in Washington and British Columbia was 56,250 birds (probable range 47,500-68,500 birds).

8) The 10,000 Vancouver Island carcasses represent a kill at sea of 16,800 Common Murres, 12,800 Cassin's Auklets, 3,300 other offshore species and 1,800 inshore species.

9) The density of spill victims on beaches was 33-39 times higher than that recorded during monthly beached bird surveys on Vancouver Island. Furthermore, the Nestucca mortality occurred after the peak of natural mortality (September through December) and therefore killed birds which would have survived the winter under normal conditions.

10) Censuses of local breeding colonies of murres and Cassin's Auklets failed to detect any significant effects of the oil spill, but the census methodology and paucity of comparative data made it unlikely that changes would have been detected.

RÉSUMÉ

1) Suite au déversement, le 23 décembre 1988, de 875 000 litres de mazout lourd échappé de la barge Nestucca près de Gray's Harbor (État de Washington), on a ramssé sur le rivage de l'île de Vancouver 3 658 oiseaux morts qui avaient été mazoutés. Parmi les oiseaux identifiés, on a relevé 31 espèces, dominées par la marmette de Troil, Uria aalge (42 %), l'alque de Cassin, Ptychoramphus aleuticus (32 %), d'autres alcidés (9 %), des macreuses (6 %) et des mouettes et goélands (4 %). On ne sait pas où se trouvaient les colonies de nidification des oiseaux affectés.

2) La plupart des victimes de la marée noire du Nestucca retrouvées sur l'île de Vancouver étaient des espèces péelgiques (82 %), dans un état avancé de décomposition (70 %), et étaient enrobées dans une épaisse mousse de mazout (75 % avaient > 95 % du plumage saturé). Cela indique que la plupart des carcasses ont été mazoutées dans les eaux pélagiques de la plate-forme au début de la marée noire et ont dérivé pendant de nombreux jours avant de l'échouer. La gaine d'huile qui entourait les carcasses les a probablement aidées à flotter, et il est bien possible que la plupart des carcasses faiblement mazoutées aient coulé.

3) Des essais de flottaison ont montré que 21 % des carcasses d'alcidés fortement mazoutées ont coulé 21 à 25 jours après la marée noire, 44 % après 25 à 35 jours et 63 % après 50 à 60 jours. D'autres expériences ont indiqué que de nombreuses carcasses ont dû couler avant de s'échouer ou ont été emportées par les vagues, de sorte que la mortalité est sous-estimée.

4) Les charognards s'étaient attaqués à 54 % de toutes les carcasses mazoutées, dont 48 % de toutes les carcasses saturées de pétrole. On a signalé un certain mazoutage secondaire des

mouettes et goélands et des aigles nécrophages. L'activité des charognards a probablement causé une sous-estimation du nombre de carcasses échouées, et a certainment tué ou affaibli bon numbre des 10 000 à 20 000 oiseaux nécrophages qui hivernent sur cette côte.

5) Les résultats des relevés sur les oiseaux échoués et des dénombrements en mer ont été comparés aux données sur la marée noire du Nestucca. L'échantillon de spéciments mazoutés a révélé une forte proportion d'espèces pélagiques et d'oiseaux plongeurs (particulièrement des alcidés). Les oiseaux de surface (fulmars, mouettes et goélands) et les grandes populations de sauvagine et d'oiseaux de mer qui hivernent sur le littoral ont été moins affectés.

6) Bon nombre des carcasses échouées n'ont pas été dénombrées. Trois méthodes ont été utilisées pour estimer le nombre total de carcasses mazoutées sur l'île de Vancouver, avec les résultats suivants :

i) modèle probabiliste fondé sur les taux d'échouage et de persistance des carcasses sur les plages : minimum de 11 800 carcasses;

ii) estimation fondée sur la longueur de littoral touché : 7 800 à 14 000 carcasses;

iii) estimation fondée sur le nombre de carcasses par sac de débris mazoutés ramassés : 8 300 carcasses, seuil de confiance de 95 %, 6 900-10 700 carcasses.

Dans chaque cas, des sources vraisemblables d'erreur permettent de penser que les estimations devraient être plus élevées. Dans l'ensemble, on peut, de façon raisonnable et prudente, conclure que 10 000 carcasses mazoutées se sont échouées sur l'île de Vancouver.

7) De nombreux oiseaux mazoutés ne se sont pas échoués. A partir de travaux expérimentaux réalisés dans l'État de Washington, Ford et al. (1991) ont estimé que 25 % seulement des oiseaux pélagiques à destination de l'île de Vancouver se sont échoués, et que la mortalité totale pour l'État de Washington et la Colombie-Britannique était de 56 250 oiseaux (fourchette probable de 47 500 - 68 500 oiseaux).

8) Les 10 000 carcasses de l'île de Vancouver représentent une mortalité en mer de 16 800 marmettes de Troïll, 12 800 alques de Cassin, 3 300 autres spéciments d'espèces pélagiques et 1 800 oiseaux d'espèces littorales.

9) La densité des victimes de la marée noire sur les plages était 33 à 39 fois plus élevée que le résultat des relevés mensuels des oiseaux échoués sur l'île de Vanocuver. En outre, la mortalité causée par cette marée noire s'est produite après le pic de mortalité naturelle (septembre à décembre) et a donc tué des oiseaux qui auraient survécu en hiver dans des conditions normales.

10) Les dénombrements des colonies nicheuses de marmettes et d'alques de Cassin n'ont pas relevé d'effet notable de la marée noire, mais la méthodologie utilisée et la médiocrité des données comparatives rendent peu probable la possibilité de détecter des modifications.

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INTRODUCTION

On 23 December 1988, the oil barge Nestucca was damaged off Gray's Harbor, Washington and began leaking oil. The barge was towed 45 km offshore, near to the edge of the continental shelf. About 875,000 litres of Bunker C oil were spilled, leading to widespread oiling of beaches along the coasts of Washington and Vancouver Island, with heavy mortality of seabirds. A total of 10,336 oiled birds were collected on beaches in Washington: 7244 were found dead, 2065 died or were euthanized at treatment centres, and 1027 were cleaned and released (Ford et al. 1991). Oil and oiled birds were first reported on the coast of Vancouver Island, British Columbia on 3 January 1989, and for the next two months intensive efforts were made to monitor the extent of the spill, record the mortality of marine organisms, and clean up the affected coast (Duval et al. 1989, Harding and Englar 1989).

This report documents the impact of the Nestucca spill on seabirds, based on the data collected from British Columbia. It supplements the reports produced by Rodway et al. (1989), Larsen and Richardson (1990), Ford et al. (1991) and Burger (1992). There are six major objectives:

1) to document the numbers, types, degree of oiling and state of decomposition of birds which were recovered on Vancouver Island;

2) to compare the species composition of the oiled birds with that of offshore and inshore populations wintering off SW Vancouver Island;

3) to estimate the total number of oiled birds to land on Vancouver Island, taking into account the large numbers of carcasses which were not tallied;

4) to estimate the total at-sea mortality represented by the birds recovered on Vancouver Island, taking into account the losses of carcasses at sea;

5) to compare the Nestucca victims with normal seabird mortality off Vancouver Island; and

6) to assess the impact of the spill on predatory and scavenging birds on Vancouver Island.

GENERAL METHODS AND SOURCES OF DATA

The Nestucca spill affected hundreds of km of coastline, and involved thousands of people on Vancouver Island. The priority in most affected areas was to clear the beaches of oiled debris. Consequently the records of the numbers of oiled birds found were incomplete, particularly in remote areas where no biologists or park wardens were involved with the assessments and cleanups. Many of the carcasses recovered were deeply imbedded in thick oil and there is no doubt that a substantial proportion of the beached carcasses were not recognized, even in areas such as Pacific Rim National Park (PRNP) where the shores were searched daily. It was

therefore necessary to make indirect estimates of the total beached carcasses on Vancouver Island.

Data were taken from reports produced for Environment Canada (Duval et al. 1989, Harding and Englar 1989), the Pacific Rim National Park (Wilson 1989), the Canadian Coast Guard (Stewart et al. 1989), the Canadian Wildlife Service (Rodway et al. 1989), and the Tofino Volunteer Oil Workers (D. LeBlanc, pers. comm.). In addition I interviewed many people involved with cleaning beaches and tallying seabirds, and obtained information from the daily reports (Oil Spill Facts) put out by the Coast Guard during the cleanup, field notes and maps made by crews assessing the coast (particularly M. Lemon, M. Rodway and D. Swanston), field notes made by the Parks Canada wardens, Coast Guard, Environment Canada and the Tofino Volunteer group. Further details on the methodology are given in each section.

PART ONE: VICTIMS OF THE NESTUCCA SPILL

Rodway et al. (1989) give details of the numbers, species composition and distribution of the oiled birds, and the incidence of oiling on seabird nesting habitat. Some of their data are reproduced here (Tables 1 and 2). The efforts made to count and collect seabirds were very variable, being generally less complete on more remote beaches and islands. Reliable collections over periods of several weeks were made on the beaches of Pacific Rim National Park (PRNP). All beaches between, and including, Florencia Bay and Schooner Cove were walked daily by the park wardens, volunteers and paid contractors between 3 January and 11 February 1989, and at irregular, but frequent intervals thereafter.

Only 33 oiled birds were captured alive on Vancouver Island (Rodway et al. 1989), and are not considered further in this report. Many shorebirds were oiled by this spill in Washington (Larsen and Richardson 1990), but there was no evidence that this was a significant problem on Vancouver Island, where wintering populations of shorebirds are generally small.

Species composition of oiled birds

Alcids (family Alcidae) comprised 81% of the 856 oiled carcasses identified, with Common Murres (42%) and Cassin's Auklets (32%) dominant (Table 2). Pacific Loons (2%), White-winged (3%) and Surf Scoters (3%), Glaucous-winged Gulls (2%) and Ancient Murrelets (2%) were the only other species to exceed 1% of the total. Species with a largely inshore winter range, including all loons, grebes, waterfowl, gulls (except kittiwakes), Pigeon Guillemots and Marbled Murrelets comprised 18% of the identified total, and offshore species or those with broad marine ranges, such as murres, comprised 82% (Table 2, N = 846, omitting unidentified alcids).

Latitudinal variation in the composition of oiled birds The composition of oiled birds changed with increasing latitude (Table 3). Oiled birds found in Washington included a higher proportion of Common Murres and inshore species (particularly grebes and scoters), and a smaller proportion of Cassin's Auklets and offshore species, than found on Vancouver Island.

Oiled birds were found along the entire west coast of Vancouver Island. Samples for most species were too small to detect significant changes in proportions with latitude, but the proportionate numbers of Common Murres (decreasing northward) and Cassin's Auklets (increasing northwards) did differ significantly (Table 3, $x^2 = 10.754$, df = 3, $P<0.05$). One interpretation of this difference is that Cassin's Auklets were oiled further offshore than many of the murres and were carried further northwards before beaching.

Extent of oiling and decomposition of oiled carcasses

I examined a sample of birds collected between 12 January and 2 February 1989 to record the proportion of the carcass' surface covered with oil, the state of decomposition and the amount of scavenging which had occurred. The birds came from several beaches on Vancouver Island, but most were found on the PRNP beaches. About 75% of these carcasses were saturated with oil (Table 4). Lightly oiled birds were all inshore species, and a few Common Murres which have a wide marine range. All the Cassin's Auklets in this sample were saturated with oil.

There was a significant difference between the state of decomposition of lightly- and heavily-oiled carcasses (Table 5; $x^2 = 30.68$, df = 1, $P<0.001$). Only 8% of the lightly-oiled birds (primarily inshore species) were severely decomposed, in contrast to 87% of the heavily-oiled birds (mostly murres and offshore species). These data support the idea that lightly-oiled birds from offshore probably sank before reaching Vancouver Island, while the thick oily coating and gases trapped within the carcass kept the heavily-oiled birds afloat.

Buoyancy of the beached carcasses

In an attempt to account for factors which might affect the count of carcasses I conducted buoyancy tests on a sample of oil-saturated Common Murres and Cassin's Auklets. To control for the effects of scavenging I restricted the tests to birds intact or with <5% of their flesh eaten. Two batches of birds were collected at different times after the spill (Table 6). Birds from the second sample (B) were kept after the initial tests, left exposed to air (temperature range -5 to +7°C), rain, snow and wind and re-tested 25 days later.

There were no significant differences in buoyancy between Common Murres and Cassin's Auklets from any of the samples (Table 6, x^2 tests, $P>0.05$ in each sample). Data from both species were therefore combined to provide adequate samples for testing the effects of time on buoyancy. Twenty-one percent of the birds collected 21-25 days after the spill (sample A) sank when tested in seawater. Birds in a second sample (B), collected 25-35 days after the spill, were less bouyant (44% sank), and when this sample was re-tested 25 days later (B') some Cassin's Auklets showed further reductions in buoyancy (Table 6). These changes were gradual, with no significant differences between collections A and B ($x^2 = 22$, df = 2, $P>0.05$), or between B and B' ($x^2 = 1.129$, df = 2, $P>0.05$), but the differences between A and B' were significant ($x^2 = 87$, df = 2, $P<0.01$).

These results show three factors which would lead to underestimates of at-sea mortality. First, there is evidence that lightly oiled offshore species sank before reaching Vancouver Island. This is supported by experiments using radio-tagged carcasses released off Washington (Ford et al. 1991). Second, the buoyancy tests showed that many beached birds would have sunk if carried back into the sea by waves. Third, the tests suggest that the buoyancy provided by the encasing oil might be lost with time, causing birds at sea to sink. Other experiments have shown that oiled carcasses lost buoyancy over several weeks, whether they were floating in seawater, or sitting on land (Burger 1991).

Scavenging of oiled carcasses Scavenging of oiled carcasses was evident from the time the birds first came ashore. In the selected sample, 54% of the carcasses had been partly eaten and in 39% substantial amounts of flesh were removed (Table 7). Large birds were more frequently eaten than smaller birds, and a greater proportion of Common Murres (67%) was eaten than the smaller Cassin's Auklets (26%; $x^2 = 17.67$, df = 2, $P<0.001$). On the other hand, a greater proportion of small carcasses may have been dragged off the beaches by scavengers.

During examination, the carcasses were scored for degree of oiling:

0 = no oil,
1 = light oiling (<10% of plumage area lightly covered),
2 = moderate (11-50 % covered),
3 = heavy (51-90% covered),
4 = saturated (>90% thickly covered);

and degree of scavenging:

0 = intact,
1 = light scavenging (<10% eaten),
2 = heavy scavenging (>10% eaten).

Lightly oiled birds were scavenged more frequently than heavily oiled ones, but scavenging was evident for all grades of oiling (Table 8). About 48% of 111 oil-saturated carcasses were partially eaten (Table 8). In many cases the carcass were completely encased in thick oil, through which the scavenger had ripped to feed on the inner organs.

The high proportion of scavenging indicates that beach counts would underestimate carcass numbers, if carcasses were dismembered or dragged off the shoreline. The principal scavengers appeared to be gulls, crows, ravens and Bald Eagles, but raccoons, river otters, mink, dogs and wolves were seen on the beaches during the cleanup and would also have removed carcasses. Experiments on Vancouver Island and the Olympic Peninsula (Washington) have shown that scavengers remove most carcasses from beaches within 2-4 days (Burger and Ford, submitted). The effects of secondary oiling on scavengers are discussed in Part Six.

PART TWO: ORIGINS OF AFFECTED BIRDS AND PROBABLE SITES OF OILING

In this section data on the species composition, abundance and distribution of birds in the pelagic zone (roughly >400 m offshore, Vermeer et al. 1983) and inshore waters off Vancouver Island are summarized and compared with the data on oiled birds. The composition of the avifauna changes significantly with seasons and so only data from winter (late November through early March) were used here.

Seabirds in the pelagic zone

The best way to investigate the seabirds at risk to an oil spill is to conduct aerial or shipboard transects over the spill area and its predicted path, as soon as possible after the spill and for the period that the oil persists (Ford et al. 1987, Piatt et al. 1990, Page et al. 1990). This was not done following the Nestucca spill, although Ford et al. (1991) conducted aerial surveys in the area affected by Nestucca in January 1990.

Few data are available on the distribution and abundance of pelagic seabirds off Vancouver Island in winter (Morgan et al. 1991). Data from two series of surveys made in February 1973 (Vermeer et al. 1983) and in March and November 1985 (Vermeer et al. 1987) are given in Table 9. It is difficult to compare or lump data from different census series because of the differences in detectability of birds (aerial surveys report only half of the birds present and underestimate the importance of small birds and alcids; Savard 1982, Vermeer et al 1983). Several generalizations can be drawn from these data, however, and applied to the analysis of the oiling effects.

In February 1973 seabirds, particularly gulls and alcids, were more common off southwestern Vancouver Island (latitude 48 - 49:30°N) than further north (Fig. 1). Much of the oil from the Nestucca passed through this zone. Bird densities were highest 30-60 km offshore, over the continental shelf and slope (Table 9). Procellariiforms, kittiwakes, and small alcids (mostly Cassin's Auklets) were common only in the 30-60 km zone or >60 km out, but large gulls (Glaucous-winged, Thayer's and Herring Gulls) and Common Murres were also abundant in the 0-30 km zone. Loons, grebes, cormorants and waterfowl were uncommon in the open sea (Table 9). The maps of distribution and abundance of birds in Morgan et al. (1990) support these conclusions.

Diving birds, particularly alcids, were more common, and surface feeding birds, particularly gulls, less common in the oiled sample than expected from their offshore abundance (Figs. 2 and 3). Among the alcids, Common Murres, mid-sized alcids (Rhinoceros Auklet, Tufted Puffin, Pigeon Guillemot) and small alcids (dominated by Cassin's Auklets) appeared in the oiled samples in roughly the same proportions as offshore (Fig. 4).

Birds of inshore waters, bays and inlets

Oil from the spill came ashore along the entire west coast of Vancouver Island, and the huge populations of waterbirds which winter along this coast were potentially at risk. Data from broad-scale aerial surveys (Vermeer et al. 1983), small-scale boat surveys (K. Vermeer unpubl. data, A. E. Burger, unpubl. data, Hatler et al. 1978) and helicopter surveys made during the Nestucca cleanup (Rodway et al 1989) were compared with the Nestucca victims (Tables 10-12). The species composition in each of the inshore surveys was broadly similar, dominated by ducks, with diving ducks particularly abundant in more open habitat and dabbling ducks in shallow, sheltered waters.

Detailed statistical comparisons of the species composition of inshore birds and oiled birds are difficult, due to the high frequency of zero values, and the large number of potential bird categories. Detailed tests are, however, not necessary in this instance because the trends are obvious and the differences between the census results and the oiled birds very striking.

Large and diverse populations of inshore waterbirds were exposed to the oil off Vancouver Island, but very few of these birds were killed. Several species, including Western Grebes, Pelagic Cormorants and several species of ducks occurred in very large numbers but contributed only trivially to the oil mortality (Tables 10-12). Among the inshore species, only Surf and White-winged Scoters and Glaucous-winged Gulls were found oiled in appreciable numbers. Some of these gulls might also have been oiled offshore.

If we accept that the vast majority of the alcids and kittiwakes, and probably some of the Pacific Loons and Glaucous-winged Gulls were oiled offshore, then it seems likely that only Surf and White-winged Scoters were oiled inshore in significant numbers. Moreover, the advanced state of decomposition of some scoters indicates that they were oiled off Washington and carried northwards to reach Vancouver Island.

Breeding sites of affected birds

During the fall and winter seabirds generally disperse away from the summer colonies. Very little is known about the migration and overwintering habits of seabirds from the eastern North Pacific. Pelagic species which breed in British Columbia are believed to move southward and, in many species, out to sea to overwinter (Campbell et al. 1990). The natal origin of the Nestucca victims is thus impossible to determine with certainty. Estimates of the populations of affected species which breed in Washington, B.C. and Alaska are given in Table 13. On the basis of this information, it seems likely that most of the Common Murres affected were from U.S. colonies. Rodway (1990a) could find no evidence that the spill had affected the murre population at Triangle Island, the only significant colony in B. C. Cassin's Auklets appear to move to the continental shelf edge following breeding, and those killed by the spill were probably from the very large colonies in B.C.

PART THREE: ESTIMATING THE NUMBERS OF CARCASSES BEACHED ON VANCOUVER ISLAND.

Counts of oiled birds on beaches represent only a fraction of the stranded birds. Beaches of the PRNP were thoroughly searched, with most beaches searched daily between 3 January and 11 February and less frequently after 11 February. Most other beaches, however, were searched only once or a few times. Obviously many birds were overlooked, removed with oily debris, washed back to sea or removed by scavengers before and after these searches. Three independent methods were used to estimate the total number of carcasses which washed ashore:

i) a probability model based on the deposition rate and persistence of carcasses on beaches;

ii) correlation between numbers of birds and lengths of affected coastline in each area; and,

iii) correlation between birds and bags of oiled debris collected.

A model to estimate numbers of beached carcasses

Ford et al. (1987) constructed a model to estimate total numbers of birds coming ashore after an oil spill. The model calculates the expected proportion of the total carcass deposition likely to be on a beach on any day, based on the rates of deposition and disappearance of birds on well-searched beaches. These proportions are then used to estimate total numbers of carcasses (N_t) deposited during the spill period (t), on beaches with incomplete censuses. The model requires the following data:

O_d - the observed number of carcasses on the day (d) of the census;

S - the proportion of beached carcasses which persist on the beach from one day to the next;

P_i - the proportion of the total number of beached carcasses which comes ashore on day i;

i - the index for days (i = 1 on the first day the oiled birds come ashore);

d - the day the census was made on the beach (hence d-1 would be the number of days over which carcasses were deposited up to the day of the census).

The equation for the model is:

$$N_t = \sum_{i=1}^{d} \frac{O_d}{S^{d-i} P_i}$$

This model was used to estimate total numbers of beached birds following oil spills in California (Ford et al. 1987, Page et al. 1990), and in a modified form, has been applied to the Nestucca and Exxon Valdez investigations in Washington and Alaska, respectively (Ford et al. 1991, R.G. Ford pers. comm.).

The model was applied to data from Vancouver Island beaches for the first 20 days that oiled birds came ashore, since 98% of all birds came ashore during that time (Fig. 5) and most beaches were visited within that period (Table 1, Rodway et al. 1989). The calculations are shown in Appendix 1.

The first step was to calculate P_i. The daily counts made at PRNP beaches between 3 January and 11 February provide the necessary information. The daily variations in numbers of beached birds at each beach in the park were similar, and so P_i was estimated from pooled data from all beaches in the park (Table 1, Fig. 5). These indicate, for example, that the proportions of birds coming ashore were 0.238, 0.110, 0.226 and 0.084 for days 1 through 4, respectively (Fig. 5, Appendix 1). It was assumed that other beaches had the same pattern of beachings as the park beaches.

The second step was to derive a value for S. The persistence of carcasses on beaches from day to day will vary according to the slope and exposure of the beach, the tidal range, the frequency of scavenging or removal by people and the probability that carcasses might be covered with sand or debris (Page et al. 1982, 1990). Ideally S should be measured empirically at a range of beaches at the time of the oiling, but this is not always feasible. Other studies in Alaska (Piatt et al. 1990), California (Ford et al. 1987, Page et al. 1990), Belgium (Kuyken 1972), and Norfolk, U.K. (Stowe 1982) reported S values ranging between 0.59 to 0.97 (reviewed by Burger and Ford, submitted). Two studies using chicken carcasses on shores in Barkley Sound, Vancouver Island, in the summer of 1989 showed mean daily persistence of 0.84 (intact carcasses; Humphries 1989) and 0.38 (portions of carcasses; Dale 1989). Two studies using seabird carcasses placed on Pachena Beach, Vancouver Island in the winter of 1990-1991 and 1992-1993 produced S values of 0.45 and 0.81 (mean 0.63), while a study at three sites on the Olympic Peninsula, Washington produced a mean S value of 0.78 (Burger and Ford, submitted).

In the present study I ran the model five times, with variable S set at 0.6, 0.7, 0.8, 0.9 and 1.0. A value of 0.7 was assumed to be most appropriate for Vancouver Island, based on the studies reviewed above, and the substantial amount of scavenging observed. In other words 70% of the beached carcasses were assumed to have remained visible on the beach from one day to the next.

The third step is to calculate the sum of $P_i S_{d-i}$, giving the proportions of the total beachings available of the beach on each of the first 20 days. These calculations are shown in detail in Appendix 1, with S set at 0.7, and the results of calculations with variable S values are summarized in Table 14. The estimated proportions to be found on each day are strongly influenced by variations in S. For example if a census was made on the tenth day, estimates of the sum of $P_i S_{d-i}$ would be 0.088, 0.123, 0.205, 0.386 and 0.764 with S set at 0.6, 0.7, 0.8, 0.9 and 1.0, respectively (Table 14). This means that the carcasses present on the beach on day 10 would constitute 12.3% of the total likely to come ashore on that beach during the 20 day stranding period, assuming carcass persistence of 0.7.

The final step is to calculate the total number of carcasses expected at each site. The date of arrival of the first oiled birds (data from Duval et al. 1989) was taken as day 1 for each site. The calculations for all sites along Vancouver Island at which oiled birds were found are shown in Table 15, with S set at 0.7, giving an expected total of 11,795 carcasses. Other values of S give estimates of 18,396 (S = 0.6), 7,246 (S = 0.8), 4,817 (S = 0.9), and an unrealistic value of 3456 (S = 1.0, which assumes that all beached carcasses remain visible on the surface).

In conclusion, assuming that S at 0.7 is most appropriate, the model predicted that at least 11,795 oiled carcasses were stranded on Vancouver Island. Since the model did not account for the birds which washed up in PRNP but were not counted, the estimate is conservative.

Estimating carcass numbers from the length of affected shore

In this analysis I estimated the total number of oiled carcasses which came ashore by comparing densities (carcasses per affected km) in nine coastal zones of Vancouver Island (Appendix 2). Bird data were from Rodway et al. (1989), and zones were named following Harding and Englar (1989). Confirmation on the length of coastline oiled, and the degree of oiling, were obtained through interviews with wardens of PRNP, volunteers and the volunteer coordinator, members of the Canadian Wildlife Service survey crews and by examining the field maps used by Environment Canada during their helicopter surveys (courtesy of Lee Harding and Doug Swanston).

Baseline carcass densities were derived from two areas: the Long Beach section of Pacific Rim National Park (20.5 km); and the larger Area 3 (Appendix 2: Florencia Bay to Hot Springs Cove) which included the park beaches (64 km). These areas were selected on the following criteria:

a) they had the most intensive cleanup operations, focussed on the beaches of PRNP and the shores of Clayoquot Sound;

b) carcasses were regularly reported throughout the cleanup period, whereas in most other areas carcasses were reported only once or twice (see Rodway et al 1989);

c) there was a high density of biologists, park wardens, naturalists and professional ornithologists working there, who reported bird numbers, and most cleanup personnel were aware of the need to report oiled birds;

d) they fell within the centre of the most affected coastline. Even within this area, however, a significant portion of carcasses would have gone unreported because they were buried in the sand, were washed back to sea, they were not recognized among the clumps of oiled debris, or because cleanup personnel failed to report them to any authority. Extrapolations based purely on the actual number reported are therefore minimum estimates of the actual total of beached carcasses.

A total of 200.1 km of affected coastline was identified (Appendix 2). About 93% of these shores were reported to have Class 3,4 or 5 oiling (Appendix 2), but the few Class 2 shores were included in the analysis because many carcasses came from such lightly oiled shores. Within the PRNP beaches 1435 carcasses were found in 20.5 km, giving a density of 70.0 carcasses per km. Extrapolated to the entire affected shoreline (200.1 km) this yields a total of 14,007 carcasses on Vancouver Island. Using Area 3 as a baseline gives 2473 carcasses in 64.1 km (38.6 carcasses km^{-1}) which would extrapolate to 7724 carcasses for Vancouver Island.

It could be argued that Area 3, and the PRNP-Long Beach area in particular, was more heavily oiled than the average for Vancouver Island. On the other hand, interviews with cleanup personnel indicated that all the oiled birds in these areas were not tallied. Many were bagged with debris, burned, buried under the sand or washed back to sea. The numbers actually reported even in the well-searched areas were thus underestimates.

Conservatively, therefore, this analysis shows that at least 7800 oiled carcasses, and possibly as many as 14,000 washed ashore on Vancouver Island.

Estimating beached birds from numbers of bags of debris

In this approach the numbers of oiled carcasses which beached were estimated through comparisons with the numbers of bags of oiled debris cleaned off the affected shores.

Despite detailed examination of all the available data (see Appendix 2), it was impossible to determine the location of all of the debris collected (450 t; Stewart et al. 1989). The most accurate comparison between birds and bags was thus made using discrete areas for which reliable data could be obtained. The criteria for the selection were that the data on birds and bags were collected at the same time (or within a few days of each other), the areas selected were geographically discrete (well defined beaches, coves or islands) so that data from neighbouring sites were unlikely to be included inadvertently, and the persons making the reports were aware of the need for data on oiled birds.

Numbers of oiled carcasses reported from each site were taken from Rodway et al. (1989). Estimates of the bags of oiled debris were obtained from Harding and Engler (1989), Stewart

et al. (1989), daily reports from the Canadian Coast Guard (Oil Spill Facts), the daily log kept by the Tofino Volunteer group and in a few cases from the notes of individuals involved with the cleanup. (The contractor Sprayaway did not allow access to his notes, but most of his data were already available in the daily Oil Spill Fact reports). Each bag of debris was estimated to weigh 50 pounds (22.7 kg), so that one tonne of debris represented 44 bags.

The analysis used data from 15 sites, scattered throughout the affected area on Vancouver Island, and including a broad selection of shore types and degrees of oiling (Table 16). The mean value from these sites was 0.42 carcasses per bag of debris, with 95% confidence limits of this estimate lying between 0.30 and 0.54 birds per bag. Using this result, the total number of birds beached on Vancouver Island was estimated, from the total amount of debris removed (450 tonnes, or 19,800 bags), to be 8316, with 95% confidence limits between 5940-10,692 carcasses.

Conclusions on the numbers of carcasses on Vancouver Island

The three methods produced different results and this was not unexpected, given the fragmented nature of the data. The conservative estimates (rounded) of stranded carcasses were: 11,800 (probability model); 7,800-14,000 (beach distance method); and 5,900-10,700 (debris bags method). The sources of error in each method point to higher values. In particular, the methods assumed that all of the carcasses deposited on PRNP beaches were tallied, but obviously many were washed back to sea, buried under sand or jetsam, removed but not tallied, or removed by scavengers. Likewise the third method assumed that the average bag of debris weighed 50 pounds, whereas many cleaners in the latter part of the cleanup filled bags to only about 30 pounds. This value would lead to a total estimate of almost 14,000 carcasses.

Taking all these potential sources of error into account leads to the conservative conclusion that at least 10,000 oiled carcasses came ashore on Vancouver Island.

PART FOUR: OILED BIRDS LOST AT SEA AND TOTAL MORTALITY ESTIMATES

Freshly dead seabirds generally float, but as their plumage becomes waterlogged and they decompose they tend to sink. There are few data on the fate of dead birds at sea. Coulson et al. (1968) found that 25% of shags known to have died at sea were found on beaches, despite onshore winds. Bibby and Lloyd (1977) released dead gulls at sea and found 59%, 11% and 44% on beaches downwind in three trials. Hope-Jones et al.(1970) released 400 oiled carcasses of alcids at sea and recovered 20% of these on well-searched beaches, after they had drifted for 105-190 km. They estimated that at least half the carcasses sank within 9-21 days of oiling. Piatt et al. (1990) released 100 tagged murre carcasses 10 km offshore during the Exxon Valdez spill in Alaska and recovered only three. In all of these studies some losses could be attributed to the failure of people to find all the carcasses actually landing on the beaches. Ford et al. (1987) assumed that the loss of alcid carcasses was constant at 15% per day, leading to estimated losses at sea of 60% and 30% of Common Murres oiled in two separate incidents close to the California coast. Oiled carcasses placed in a seawater tank and agitated to simulate benign ocean

conditions lost buoyancy at a relatively constant rate, and 9% of the grebes and 2% of the alcids (Common Murres and Ancient Murrelets) sank per day (Burger 1991).

An experiment using wooden drift blocks to simulate birds was performed off southwestern Vancouver Island following the Nestucca spill (Hlady and Burger, 1993). In winter, 53% of blocks released 1 km from the shore were recovered, with most being recovered during strong onshore winds. Only 10% of 300 blocks released 35-116 km offshore, were recovered, despite extensive searches. The bright red blocks were more buoyant and more conspicuous than dead seabirds suggesting that a very large proportion of seabird carcasses would not come ashore and be tallied. The experiments also confirmed that the northwest flowing Vancouver Island Coastal Current, in conjunction with prevailing SE winter winds, would tend to drive carcasses parallel with the island, while eddies off the island might take them further out to sea. The inshore experiments showed that without strong onshore winds, floating carcasses might not come ashore, even with incoming tides and even if carcasses were within 1 km of the shore. Most of the Nestucca victims found on Vancouver Island were offshore species (82%), well decomposed (70%) and encapsulated in thick oily mousse, indicating that they had been killed soon after the spill when the oil was still buoyant and fairly liquid. The carcasses probably drifted for 6-12 days and 150-250 km (direct distance from Gray's Harbor to Ucluelet is 220 km), after being oiled. A fairly substantial loss due to sinking and scavenging would be expected during this time, based on the studies cited above, and on the relatively high proportion of beached carcasses which sank (see above). Storms following the spill would have facilitated the waterlogging of the carcasses.

Experimental work off the Washington and B.C. coasts by Ford et al. (1991), using radio-tagged carcasses and testing buoyancy of seabird carcasses, revealed that only 25% of the birds oiled offshore by the Nestucca spill would have come ashore on Vancouver Island. This result is in accord with the other studies reviewed above. This suggests that the carcasses which stranded on Vancouver Island, or sank *en route* to the island represent a total mortality of about 40,000 seabirds. Overall, Ford et al. (1991) estimated that the Nestucca spill killed 56,000 seabirds (probable range 47,500-68,500).

The species composition of the kill represented by the carcasses stranded on Vancouver Island was estimated, based on the proportions of carcasses actually found (Table 17). Of the 10,000 carcasses which came ashore on the island, 18% were inshore species and it was conservatively assumed that none of these birds were lost at sea. The remaining 82% were Common Murres (42%), Cassin's Auklets (32%) and other offshore species (8%). If the beached birds represent 25% of total mortality, then this amounts to 16,836 murres, 12,796 Cassin's Auklets, 3284 other offshore species (Table 17). It should be stressed that these are aproximate estimates of the mortality of each species.

The Marbled Murrelet is listed as a threatened species in Canada. The loss of about 143 Marbled Murrelets in this spill represents about 0.9% of the estimated 16,000 birds thought to occur off Vancouver Island (Rodway 1990b).

PART FIVE: COMPARISON OF NESTUCCA VICTIMS WITH NORMAL BIRD MORTALITY

The mortality of seabirds following an oil spill may not only be considerably higher than normal, but may also affect a different sector of the avifauna than natural causes. This was assessed by comparing the Nestucca victims with birds found dead during systematic beached bird surveys. Beached bird surveys record the numbers and species of dead birds found on selected beaches during monthly searches, usually done on foot. These surveys are done in many parts of the world and are an accepted method of monitoring seabird mortality and rates of oiling (e.g. Avery 1989, Camphuysen 1988, Kuyken 1978, Stenzel et al. 1988, Stowe 1982).

Surveys made during the fall and winter (September through February) on several beaches on SW Vancouver Island, between Tofino and Pachena Beach, near Bamfield were compared with the Nestucca data (Burger 1992, 1993). The overall fall and winter density of carcasses recovered after the Nestucca spill in the Long Beach/Tofino area (38.6 carcasses km^{-1}) was 39 times higher than the mean recorded during systematic surveys in the same area (0.99 carcasses km^{-1}, 35 surveys totalling 121 km) and 33 times higher than the surveys for SW Vancouver Island in general (1.17 carcasses km^{-1}, 84 surveys totalling 178 km). Year-round, about 10% of the beached carcasses found on SW Vancouver Island were oiled (Burger, 1993).

Comparisons of the types and species of birds found are made in Fig. 6. The Nestucca victims included a greater proportion of diving birds, particularly alcids (auks) and sea ducks. This is typical of oil spill mortality in northern seas (Barrett 1979, Camphuysen 1988, Hope Jones et al. 1970, Piatt et al. 1990). There was also a significant difference in the proportion of Cassin's Auklets (13% in beach surveys, 32% in Nestucca sample), indicating that the Nestucca spill had a major impact on birds which winter well offshore. This is supported by the lower proportion in the Nestucca sample of some inshore diving species such as loons, grebes and cormorants (Fig. 6). Northern Fulmars and gulls were comparatively rare in the Nestucca sample, but such aerial, surface- feeding species are usually less affected by oil spills than diving birds.

Mortality in seabirds is highly seasonal. In many species the greatest mortality occurs from late summer through early winter, with high mortality among newly independent juveniles and among adults which are moulting and stressed after breeding. Beach surveys made through 14 years in California showed that maximum mortality occurred from late summer (July) through early winter (December) in Common Murres and Cassin's Auklets (Stenzel et al. 1988). Similarly, 73% of carcasses from year-round beached bird surveys in British Columbia were found in September through December. Natural mortality of Common Murres and Cassin's Auklets off SW Vancouver Island is concentrated in these months (Fig. 7). The Nestucca spill, which killed birds in late December through January, would have had an additive, rather than a complementary effect on natural mortality. In other words, the Nestucca victims were birds which would probably have survived the winter under normal circumstances.

PART SIX: EFFECTS OF SECONDARY OILING ON SCAVENGERS

This section reviews the types and probable numbers of birds which ate the stranded Nestucca carcasses, data on the numbers of oiled gulls and eagles seen during cleanup operations and the probable toxic effects the ingested oil had on these birds.

Secondary oiling of predators and scavengers was a major concern during the cleanup operation, particularly within Pacific Rim National Park (PRNP), where the removal of oiled carcasses from beaches was a priority (Wilson 1989). Unfortunately, regular censuses of scavenging birds were not undertaken, and few counts of oiled gulls were made. The numbers and probable impacts of oiling due to scavenging of oiled carcasses have therefore been assessed from other independent data and from known affects of oil on birds.

Predatory and scavenging birds affected

Carrion-eating species which are common along the shores of Vancouver Island in winter include: Bald Eagles, Mew, Thayer's and Glaucous-winged Gulls, Northwestern Crows and Common Ravens (Hatler et al. 1978, Campbell et al. 1990). Red-tailed Hawks are regular, but uncommon, along the shoreline and may take dead birds. Herring, Western and Glaucous Gulls are usually present in small numbers in winter. Waterbirds are a major prey item for Bald Eagles on the west coast of Vancouver Island (Vermeer and Morgan 1989). Eagles and falcons (Peregrine Falcons and Gyrfalcons) were seen to prey on oiled waterbirds in the Pacific Northwest in winter (Fry 1986, Lowell 1986), but Peregrines are uncommon, and Gyrfalcons rare along the west of Vancouver Island (Campbell et al. 1990).

Numbers of birds exposed to oiled carcasses

There were no complete census surveys of scavengers made at the time of the spill, and the densities of these birds along the west coast during winter are poorly known. An estimated 20-30,000 Bald Eagles winter in coastal British Columbia (Campbell et al. 1990). The wintering population of eagles on the east coast of Vancouver Island and the Gulf Islands exceeds 1500 (K. Vermeer pers. comm.), but the west coast has not been censussed. There are at least 6000 pairs of Glaucous-winged Gulls nesting on the west coast of the island (Vermeer et al. 1992a), most of which probably remain in the area in winter, along with many thousands of migrant gulls. Aggregations of over 14,000 gulls have been reported in Barkley Sound in late winter (Haegele and Schweigert 1989).

Helicopter surveys were made by the Canadian Wildlife Service during the Nestucca cleanup operations in January and February 1989 (Rodway et al. 1989). Over 3500 gulls and 127 eagles were reported during these flights, and the birds were distributed over the entire affected area. Falcons, ravens and crows were not counted. The principal aim of the flights was to look for beached oil and slicks, and the counts of birds were incomplete. This is obvious when comparing the helicopter counts from the Pachena Bay-Bamfield area (two eagles and 5 gulls) with the

Christmas Bird Count made in the same area a few weeks earlier on 17 December 1988 (68 eagles and 346 gulls; A.E. Burger unpubl. data).

Aerial transects made in January and February 1977 yielded densities of 11.0 gulls km^{-1} for SW Vancouver Island (from Barkley Sound south) and 4.3 and 4.8 gulls km^{-1} for the coastline and inlets, respectively, of NW Vancouver Island (Barkley Sound to Cape Scott; Vermeer et al. 1983). Extrapolations from these data give 770 gulls between Barkley Sound and Port Renfrew (70 km), and 1530 gulls north of Barkley Sound (150 linear km). The aerial transects covered a strip only 65 m wide (Vermeer et al. 1983). The overall densities of gulls along the entire coast would thus be many fold higher. For example, Vermeer et al. (1992b) reported mean densities of 300 gulls km^{-2} in the estuaries of west Vancouver Island.

Taking all these data into consideration, a conservative estimate of at least 500 Bald Eagles, 10,000 gulls, 4000 crows, 100 ravens and 100 other predatory-scavenging birds were present along the west coast of Vancouver Island at the time the oiled carcasses came ashore in the winter of 1989. These birds were distributed throughout the affected area.

Scavenging of oiled carcasses and secondary oiling

As discussed earlier in this report, over half of the oiled carcasses on the beaches were completely or partially eaten by scavengers, including at least 48% of the oil-saturated carcasses. Assuming similar proportions of scavenging among the 10,000 carcasses which came ashore, about 5,000 oiled carcasses would have been scavenged.

Little effort was made at the time of the cleanup to make accurate estimates of oiled scavengers. Eagles, gulls, ravens and crows were reported to feed on oiled carcasses by several observers (Rodway et al. 1989, personal observations). Eagles with oiled heads were reported on several occasions; including two in the Broken Islands on 8 January (Wilson 1989); two on Effingham Island on 21 January (Harding and Englar 1989), and other unspecified sites (Rodway et al. 1989). No eagles were included within the sample of 856 oiled carcasses identified (Rodway et al. 1989), but it is probable that any that died as a result of the spill would have fallen from trees into the forest undergrowth. About 90% of the radio-tagged Bald Eagles which died during studies which followed the Exxon Valdez spill in Alaska were found in brush, away from the beachfront (Stewart et al. 1991).

Oiled gulls were frequently seen, over the entire coast of Vancouver Island from Klanawa River north to Triangle Island (Rodway et al. 1989; pers. obs.). Detailed observations were made by ornithologists at four sites in PRNP (Table 18). Between 16-21 January 1989 30% of the gulls had oiled plumage. Most of the oiling resulted from eating oiled carcasses rather than from birds landing in slicks, because oiling was most common in the head region (65% of all oiled gulls), breast (30%), and back (22%) and less common on the flank (7%), wingtips (4%), tail (12%) and legs (2%) (N=129 oiled birds observed on 16, 19 and 21 January 1989 at the Landfill and Combers in PRNP by A. Breault, D. Garnier and K. Martini). Several birds were

oiled in more than one body tract. Oiled birds were uncommon by the end of March 1989 (Table 18).

Gulls, excluding the pelagic Kittiwakes, made up 25 (2.9%) of the 856 identified carcasses on Vancouver Island, and if applied to the expected total of 10,000 beached carcasses this indicates that at least 290 gulls died soon after the spill. This is certainly an underestimate because gulls are semi-terrestrial and might have died away from the shore and not found. For example, four gulls were found dead at the PRNP landfill, over 1 km from the shore (A. Breault and D. Garnier, unpubl. data). Most dead gulls were lightly oiled, unlike most other victims.

No ravens, crows, falcons or hawks were found dead or oiled. Again, these are land birds, which usually perch in the forest, and would most probably die in places where they would not be found. Evidence of secondary oiling would be difficult to see on crows and ravens because they have black plumage and legs.

Effects of oil on birds

There have been numerous studies of the effects of oil on birds (see reviews by Fry and Lowenstine 1985, Leighton et al. 1985, National Research Council 1985, Leighton 1991). Fouling of the plumage leading to hypothermia and waterlogging are probably the most common causes of death among seabirds. In addition, ingested oil can result in a wide variety of lethal and debilitating effects, including gut lesions, liver cell disassociation, kidney tubule necrosis, adrenal hypertrophy and corticosterone stress, hemolysis, disruption of ovarian and ovogenesis functions, mutagenic effects, reduced hatchability of eggs and altered chick growth (Ainley et al. 1981, National Research Council 1985, Fry and Lowenstine 1985, Leighton et al. 1985, Butler et al. 1988, Boersma et al. 1988). The disruptive effects from even minor contact with oil can persist in seabirds for more than one breeding season (Fry et al. 1986), although this does not always occur (Butler et al. 1988).

Birds can ingest oil by preening oiled plumage, scavenging oiled carcasses, eating contaminated prey or mistaking oil globules for food. SCUBA divers reported numerous small tar-balls suspended in coastal waters off Vancouver Island following the Nestucca spill (Harding and Englar 1989). Oil globules from undetected or small spills might also aggregate at tidal slicks or ocean fronts where many seabirds forage. Residues of petroleum hydrocarbons have been found in the stomachs of both Leach's and Fork-tailed Storm Petrels, in Alaska and Washington, suggesting that they ingested oil droplets (Boersma 1986, Boersma et al. 1988). Storm Petrels appear to be capable of digesting certain long- chain hydrocarbons, possibly because their diets normally include similar natural compounds (Boersma et al. 1988). The long-term effects of low-level, chronic ingestion of oil on these or other species are poorly known.

Potential sub-lethal and long-term problems for seabirds and scavengers, resulting from contact or ingestion of oil from the Nestucca spill are discussed further in Burger and Fry (1993).

PART SEVEN: EFFECTS OF NESTUCCA OIL ON POPULATIONS AND HABITATS OF BIRDS

The effects of the Nestucca spill on local bird populations were difficult to assess, for many reasons, including: the difficulties of censusing burrowing alcids; the absence of a prior series of complete censuses of colonies in B.C.; and the problems of separating the spill effects from year-to-year variations in population and attendance due to natural phenomena (e.g. prey availability). In the summer following the spill, the Canadian Wildlife Service censused Common Murres and Cassin's Auklets on Triangle Island, the principal breeding colony of both species in B.C. They found no evidence that the spill had affected these populations (Rodway 1990a, Rodway et al. 1990). The estimated population of Cassin's Auklets was higher than average, due to higher burrow- occupancy rates. Numbers of murres were also higher, but this was attributed to a more complete survey of the cliffs than in previous years. Part of the murre colony exibited breeding failure, but this could not be linked with the spill. Most of the affected murres must have come from colonies in Washington, Oregon or Alaska, because the spill killed at least 30,000 murres (Ford et al. 1991), but the total breeding population in B.C. is only 8640 birds (Rodway 1991).

Vermeer et al. (1992a) found no strong evidence to link the Nestucca spill with recent declines in the breeding populations of Pelagic Cormorants and Glaucous-winged Gulls off Vancouver Island. These species comprised 0.1% and 2.0%, respectively, of the 856 oiled birds identified on Vancouver Island (Rodway et al. 1989). The loss of cormorants cannot be discounted, however, because some of the areas where cormorants declined might not have been well searched during the cleanup (Vermeer et al. 1992a).

The spill had few detectable impacts on inshore habitats used by birds. Rodway (1989a,b) found little change in the behaviour or distribution of birds where eelgrass and other shallow communities had been oiled in Barkley Sound, Tofino, or Grice Bay. Herring failed to spawn in some traditional spawning sites off Stubbs Island, near Tofino, which resulted in far fewer Surf Scoters than usual. Brant appeared to avoid areas where eelgrass had been oiled near Stubbs Island, but their populations and behaviour were otherwise unaffected.

CONCLUSIONS

The fate and movements of oiled seabirds are generally poorly understood and strongly influenced by local oceanic and shoreline features, and short-term weather and currents. Greater efforts are being made to interpret seabird mortality following marine oil spills, but comparative data are still sparse. Canadian wildlife agencies and oil companies should be well prepared to track spills and monitor seabird aggregations in their path during the spill event. Post-spill analyses can never replicate the intricate, dynamic array of factors which affect oiled birds at sea and on the shore.

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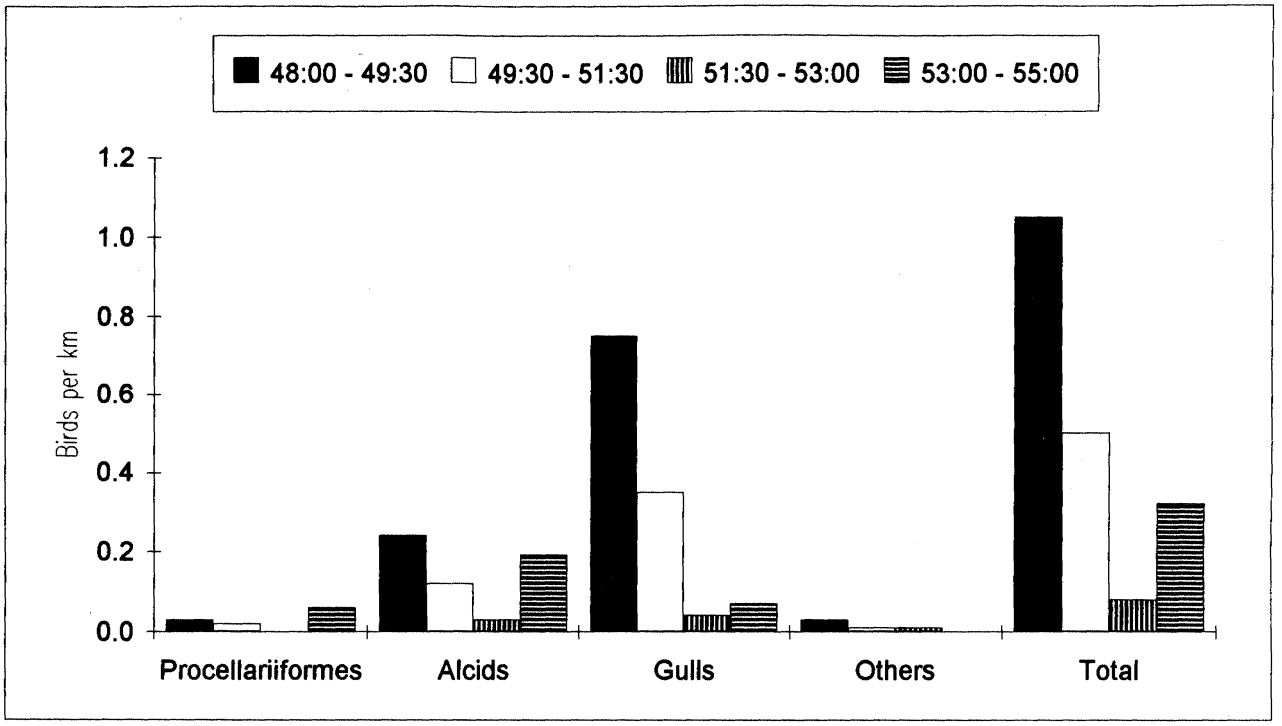

Figure 1. Variations in the densities of seabirds in four latitudinal zones off Vancouver Island in winter, based on data from aerial surveys in February 1973 (Vermeer et al. 1983).

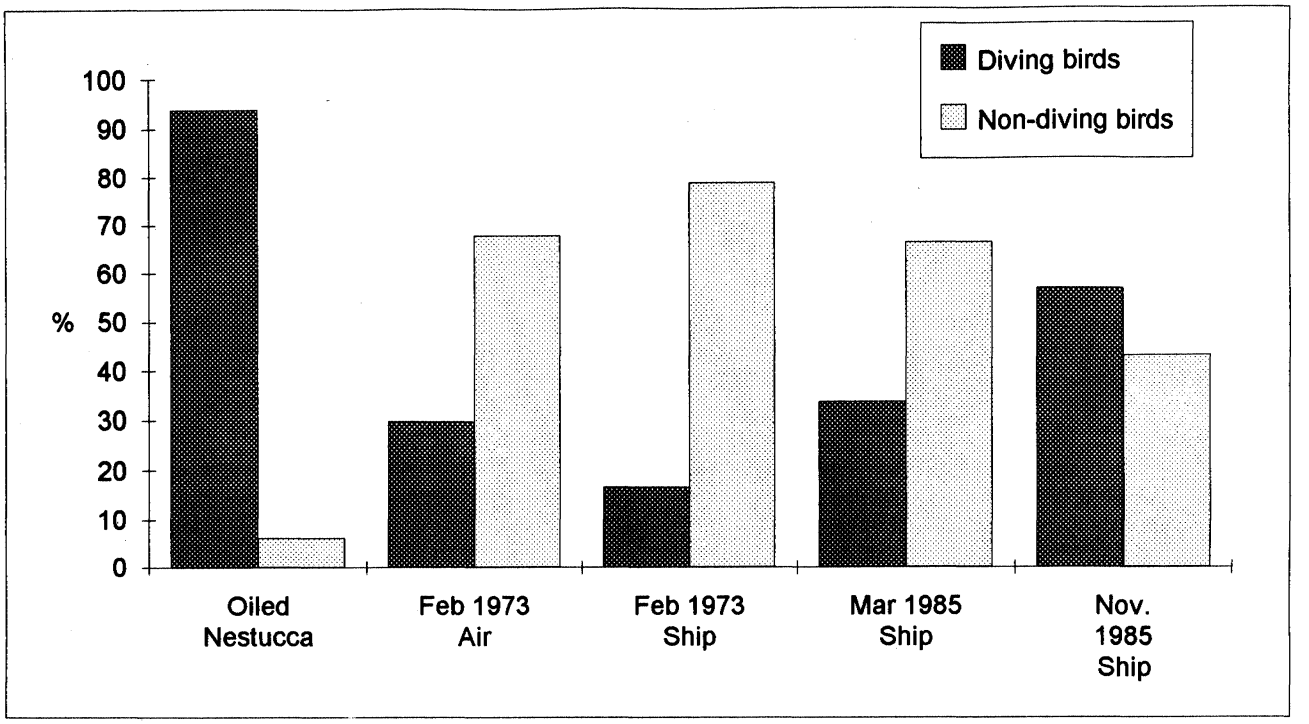

Figure 2. Proportions of diving and non-diving birds among the Nestucca spill victims found on Vancouver Island, compared with those recorded in offshore aerial and shipboard surveys in winter off SW Vancouver Island.

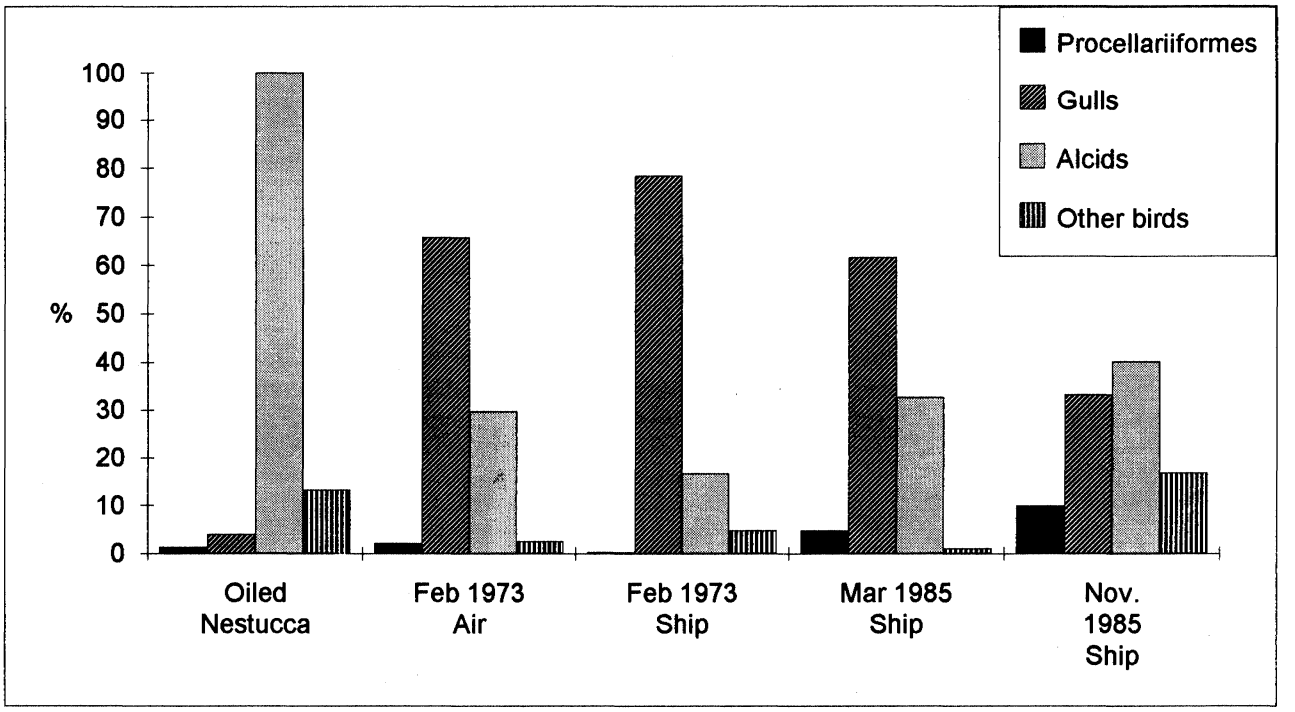

Figure 3. Proportions of Procellariiformes, gulls, alcids, and other seabirds among the victims of the Nestucca spill, compared with those recorded in offshore aerial and shipboard surveys during winter off SW Vancouver Island.

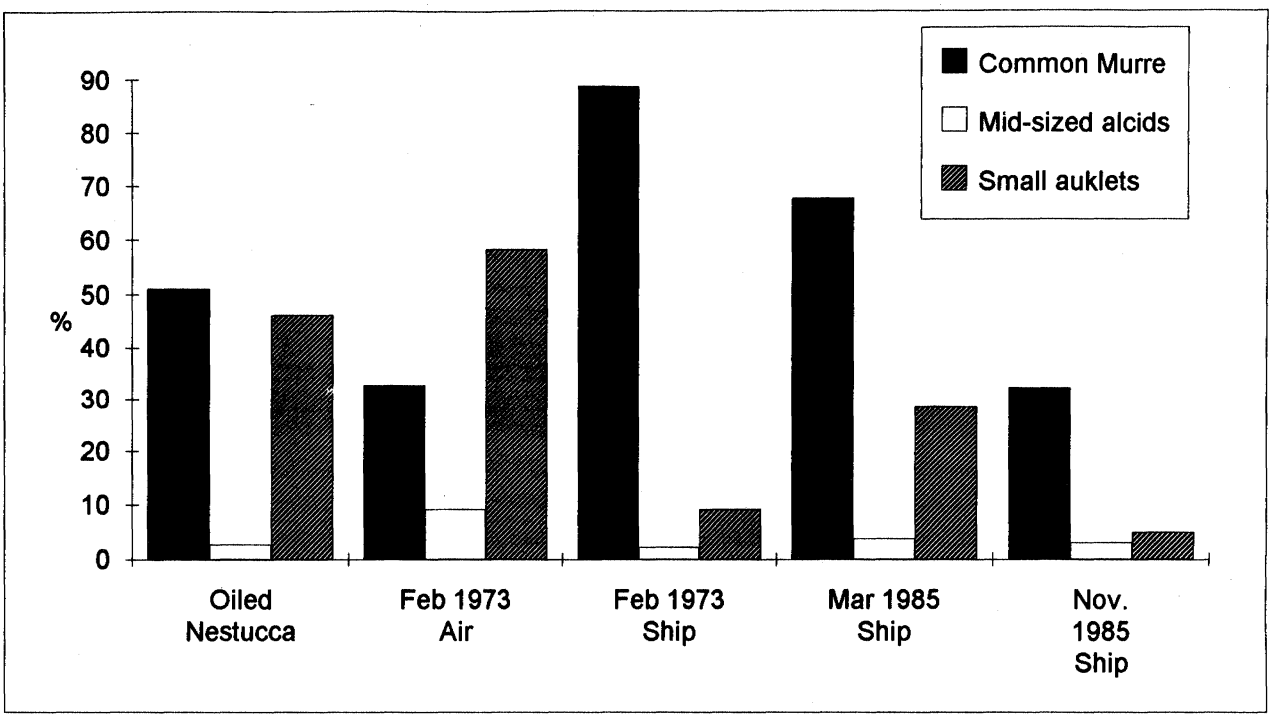

Figure 4. Proportions of Common Murres, mid-sized alcids (Rhinoceros Auklets, puffins and Pigeon Guillemots) and small auklets (mostly Cassin's Auklets) among the victims of the Nestucca spill found on Vancouver Island, compared with those recorded in offshore aerial and shipboard surveys during winter off SW Vancouver Island.

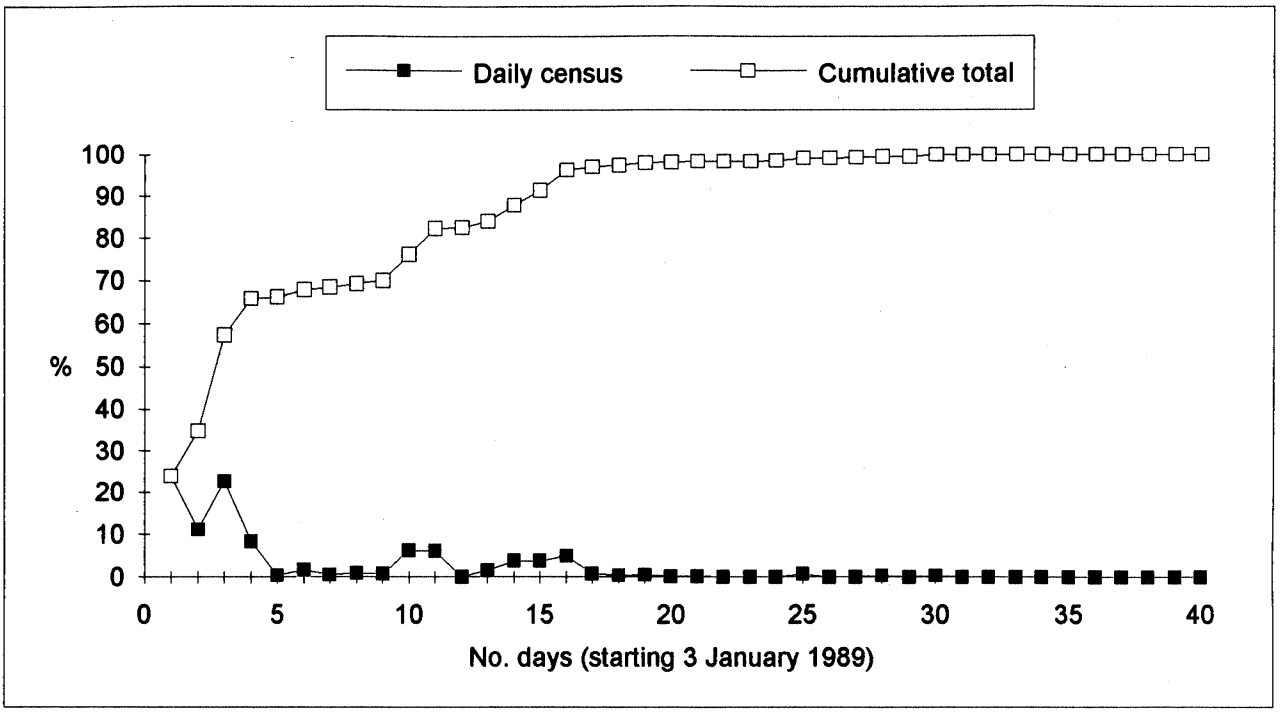

Figure 5. Daily and cumulative percentages of the total number of oiled carcasses found on PRNP beaches, between 3 January and 11 February 1989.

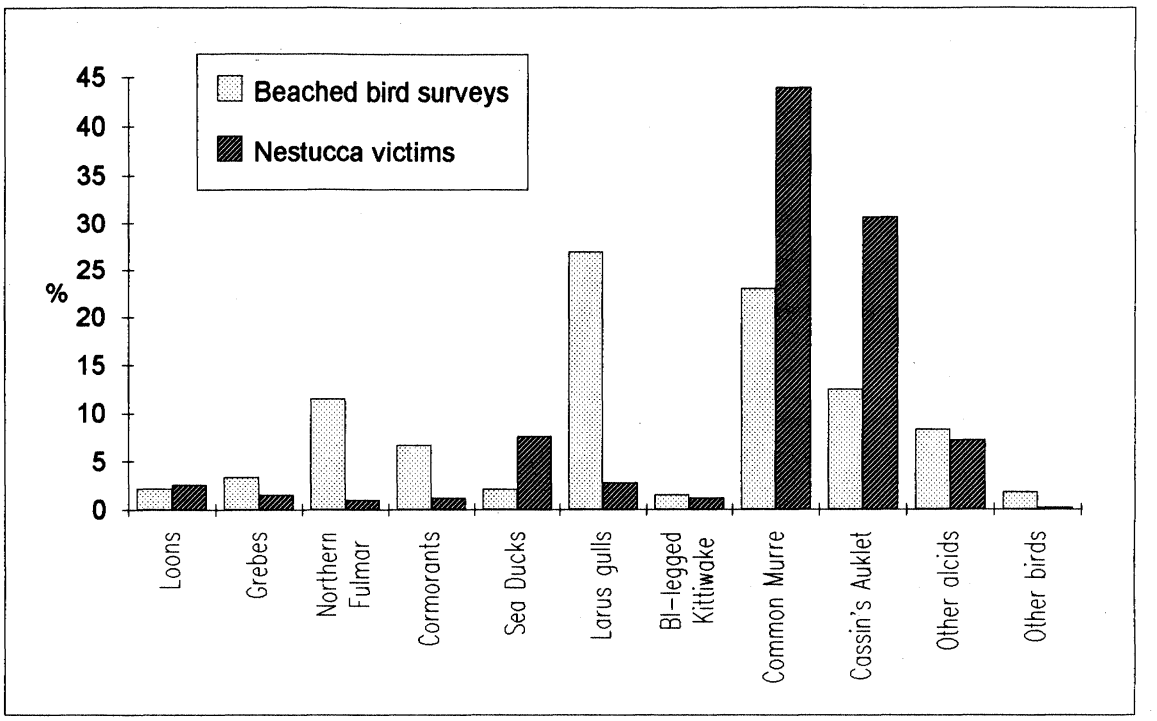

Figure 6. Comparison of the species composition of seabirds found in autumn and winter (September through March) during beached bird surveys (1987-1991) on SW Vancouver Island (Tofino to Port Renfrew) with the Nestucca victims found in the same area (January to March 1989).

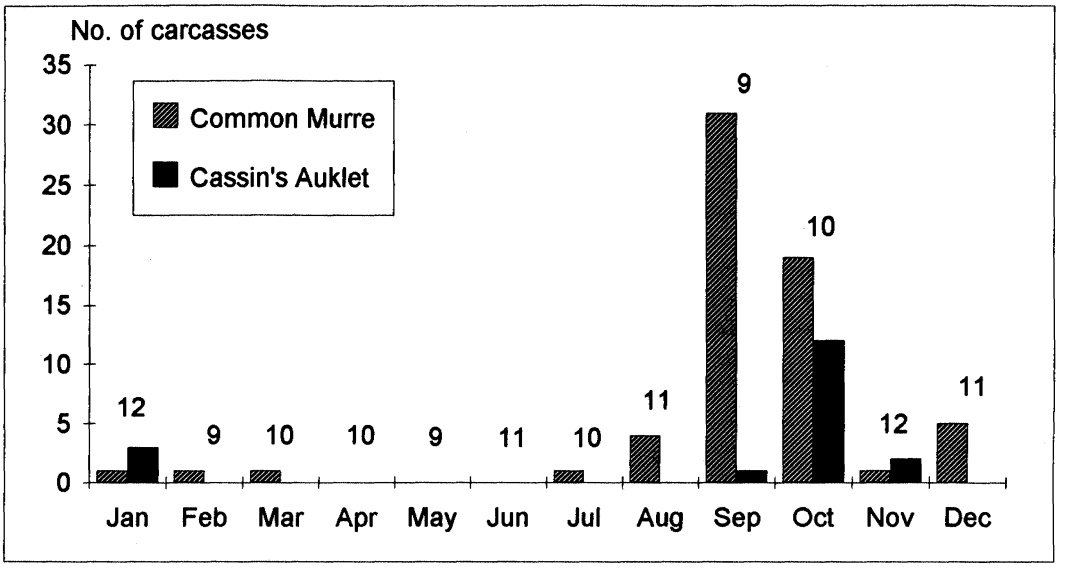

Figure 7. Monthly totals of carcasses of Common Murres and Cassin's Auklets found on year-round beached bird surveys on SW Vancouver Island (Port Renfrew - Tofino). The sample sizes are the number of beach surveys made each month.

Table 1. Dead, oiled birds found on the west coast of Vancouver Island, 3 January to 8 February 1989.

	JANUARY																											FEBRUARY							SITE	AREA
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	8	TOTALS	TOTAL
Sooke to Port Renfrew:										12k																											12	12
Port Renfrew to Pachena Pt.:																																						257
Carmanah to Bonilla																					50a																50	
Wyac			20a																																		20	
Clo-oose									26a																												26	
Hope Pt. - Tsusiat									40a																												40	
Klanawa																		26d																			26	
Darling River														40n				30d																			70	
unspecified														17																							17	
Pachena Pt. to Cape Beale:																																						135
Pachena Point																		4a																			4	
Pachena Bay					36a												20a														3d						59	
Keeha Bay									10c									10	15d																		35	
Cloutus beaches																			30p																		30	
Seabird Rocks									5c									2																			7	
Barkley Sound:																																						165
Topaltos Beach									12p											1j																	13	
Helby Island																		2p																			2	
Benson Island										14h																											14	
Dicebox Island											4h																		2								6	
Broken Group				20			3	3	4	4	1		2		2					3a																	42	
Toquart Bay																			1a																		1	
Mayne Island																																	6a				6	
Macoah Passage																		3a	3a								14a										20	
George Fraser Island																											3a										3	
Beg Island																																	3a				3	
mouth Ucluelet Inlet																		14a	2a						1a		16a						2a				35	
Stuart Bay										3p																	17a										20	
Park Beaches:																																						1435
Florencia Bay	75	20	75	16	3	5	1	4	3	22	3	1	6	?	7	1	8	0	5b	0	0	0	0	0	0	0	0	0									255	
Quisites Pt.																											10b						2b				12	
Wickaninnish Beach	97	33	97	40	0	0	0	4	3	13	37	0	2	27	14	69	2	0	2	3	1	0	0	0	9	0	1	4									458	
Combers Beach	79	20	70	10	0	10	3	3	1	37	4	0	5	3	1		1	0			0	0	0	0	0	0	0	0		4	1						252	
Long Beach	50	55	60	39	3		2	1	1	15	29	0	0	20	23b		0	5b	0	0	1	0	0	0	0	0	0	0		1							313	
Schooner Cove	38	29	20	14	0	10	1	1	2	2	12	0	2	2	7	0	0	0	1b		0	1	0	1	0	0	0	2									145	
Portland Pt. to Sharp Pt.:																																						1030
Portland Point											12p																										12	
Radar Beach		6		6	12	0			2									10b						5					5b								46	
Chesterman's Beach									150b							1b															1b						152	
Cleland I.									1c							2c																					3	
Blunden and Bartlett I.							40a																														40	
Flores Island																					30b																30	
Vargas I. & Clayoquot Snd. area									625b*		50b					60b	6b	4b																			745	
Kahawisc															10b																						10	

cont'd

Table 1. continued

	JANUARY																									FEBRUARY							SITE	AREA
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	8	TOTALS	TOTAL
Sharp Pt. to Cape Cook:																																						119
Nomais Cove															1p																						1	
Escalante Point												1c			7p	3e		1			20b															32	
Friendly Cove															1a																						1	
Calvin Ck. to Beano Ck.																					4e	2e		1e										1e			8	
Bajo Point															2e	16e	2e	2e																	4e		26	
N of Tatchu Pt.																3p																					3	
Thornton Island												1c																									1	
Mission Group										3p			3e		2e	9e												1e									16	
Kyuquot										3d																											3	
'Gull' It. (Bunsby)																				5c																	5	
Acous Pen.																																		1e			1	
Jackobson Pt.																				4p																	4	
Battle Bay															6p																			1e			7	
E of Clerke Pt.near Quineex Rf.																				8e																	8	
W. end Brooks Pen.											1c																										1	
Cape Cook to Cape Scott:																																						65
Bay N of Bonner It.																				1c																	1	
Side Bay																		50f																			50	
Lawn Pt.																						1p															1	
Grant Bay																						5g															5	
N of Hanna Pt.																						1g															1	
Winnifred Is.																						1c															1	
Guise Bay																						2g															2	
W of Guise Bay													1c									1g															2	
Hansen Lagoon																						1c															1	
Lanz Island																						1c															1	
TOTALS																																					3226	3226

* cumulative tally to 11 Jan/89.

Key to letter codes:

Code	Source of data
no code	Pacific Rim National Park Wardens
a -	Nuu-chah-nulth Tribal Council
b -	Dave LeBlanc - Tofino volunteers
c -	Canadian Wildlife Service team
d -	Alan Burger
e -	D.F.O. - sea-otter surveillance team
f -	Karl Sturmanis Kwakiutl District Council
g -	Doug Swanston
h -	Al Whitney - Pacific Synergies Tours
j -	Carl Ostrom - P.R.P.
k -	Provincial Parks
m -	U.B.C. volunteers
p -	EPS database

Table 2. Species composition of a sample of dead, oiled birds found on the west coast of Vancouver Island from 3 January to 5 February 1989.

	Barkley Sound and south	Park[1] Beaches	Clayoquot[2] Sound area	North of Clayoquot	Unspecified Location	Totals
Common Loon		2				2
Pacific Loon	2	13	3	1	1	20
Red-throated Loon		2				2
Loon sp.				1		1
Western Grebe		1				1
Red-necked Grebe		5				5
Horned Grebe	2	2			1	5
Grebe sp.	1					1
Northern Fulmar	1	6	2		1	10
Short-tailed Shearwater	1					1
Double-crested Cormorant		1				1
Brandt's Cormorant		6	1		2	9
Pelagic Cormorant				1		1
Cormorant sp.	1	1				2
Black Scoter ♂		2				2
White-winged Scoter ♂	1	16		1	1	19
♀/imm		4				4
unsexed		3			1	4
Surf Scoter ♂		15	2		1	18
♀/imm		4	1		1	6
Scoter sp.	1	1				2
Harlequin Duck ♂		2				2
Oldsquaw ♂		1				1
Common Goldeneye ♂		1				1
Red-breasted Merganser		1				1
Duck sp.		3				3
Sanderling		1				1
Herring Gull - adult		1				1
Glaucous-winged Gull - adult	2	4			2	8
- 2nd yr.		1			1	2
- imm.	2	5				7
California Gull	1					1
Black-legged Kittiwake						
- adult		6				6
- immature		1				1
- unaged		2				2
Gull sp.	2	2			2	6
Common Murre	43	276	15	7	15	356
Pigeon Guillemot	2	3				5
Marbled Murrelet	4	5	1	1	1	12
Ancient Murrelet	1	16	1	3		21
Cassin's Auklet	21	202	29	10	12	274
Parakeet Auklet	4	8	1		2	15
Unidentified small alcids	1	5	1	1	1	9
Rhinoceros Auklet		1				1
Tufted Puffin	1	1	1			3
CAAU/MAMU					1	1
TOTALS (excluding unidentified pieces)	94	632	58	26	46	856
Unidentified pieces	1	10		1		12

1 Park Beaches - Florencia Bay to Schooner Cove.
2 Clayoquot Sound - Portland Point to Sharp Point.

Table 3. Changes in species composition of oiled seabirds between Washington and the Vancouver Island coast. Data for Washington from the U.S. Fish and Wildlife Service (courtesy of B. Hauger); data from Vancouver I. from Rodway et al. (1989).

					Along Vancouver Island (South to North)							
	Washington State		Vancouver Island		Barkley Sound and south		PRNP park beaches		Clayoquot Sound		North of Clayoquot	
Species	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Loons	83	1.0	24	3.0	2	2.1	17	2.7	3	5.7	2	7.7
Grebes	748	9.0	11	1.4	3	3.2	8	1.3	0	0.0	0	0.0
Procellariiformes	82	1.0	10	1.2	2	2.1	7	1.1	1	1.9	0	0.0
Cormorants	16	0.2	11	1.4	1	1.1	8	1.3	1	1.9	1	3.8
Scoters	824	9.9	51	6.3	2	2.1	45	7.1	3	5.7	1	3.8
Other waterfowl	18	0.2	8	1.0	0	0.0	8	1.3	0	0.0	0	0.0
Large Gulls	130	1.6	20	2.5	7	7.4	13	2.0	0	0.0	0	0.0
Bl.-legged Kittiwake	23	0.3	9	1.1	0	0.0	9	1.4	0	0.0	0	0.0
Common Murre	6067	73.2	341	42.2	43	45.7	276	43.4	15	28.3	7	26.9
Pigeon Guillemot	1	0.0	5	0.6	2	2.1	3	0.5	0	0.0	0	0.0
Marbled Murrelet	17	0.2	11	1.4	4	4.3	5	0.8	1	1.9	1	3.8
Ancient Murrelet	0	0.0	21	2.6	1	1.1	16	2.5	1	1.9	3	11.5
Cassin's Auklet	72	0.9	262	32.4	21	22.3	206	32.4	25	47.2	10	38.5
Parakeet Auklet	1	0.0	13	1.6	4	4.3	8	1.3	1	1.9	0	0.0
Other alcids	206	2.5	12	1.5	2	2.1	7	1.1	2	3.8	1	3.8
Totals	8288	100	809	100	94	100	636	100	53	100	26	100
Inshore species *	1837	22.2	141	17.4	21	22.3	107	16.8	8	15.1	5	19.2
Offshore species **	312	3.8	65	8.0	9	9.6	47	7.4	5	9.4	4	15.4

* Inshore birds included all loons, grebes, cormorants, scoters, other waterfowl, large gulls, Pigeon Guillemots and Marbled Murrelets.

** Offshore birds included all Procellariiformes, kittiwakes, and alcids (except guillemots and Marbled Murrelets) Common Murres and Cassin's Auklets were excluded from these groups.

Table 4. Numbers of carcasses showing various degrees of oiling, recovered on Vancouver Island after the Nestucca spill.

	Degree of oiling on the plumage					
Oiling class:	0	1	2	3	4	
% plumage oiled:	0	1-5%	6-50%	51-95%	>95%	Total
INSHORE SPECIES						
Pacific Loon			2		2	4
Common Loon		1	1			2
Western Grebe				1		1
Horned Grebe			1			1
Brandt's Cormorant	1		2		2	5
Pelagic Cormorant				1		1
Surf Scoter			1		2	3
White-winged Scoter		2	1	2		5
Red-breasted Merganser					1	1
Marbled Murrelet				2		2
Glaucous-winged Gull	1	1	1	1	1	5
Other Larus gulls	2					2
Total inshore species	4	4	9	7	8	32
Percentage	12.5	12.5	28.1	21.9	25.0	100
OFFSHORE AND WIDE-RANGING SPECIES						
Northern Fulmar					3	3
Common Murre	1	1	3	4	42	51
Cassin's Auklet					53	53
Parakeet Auklet				1	5	6
Ancient Murrelet				1	2	3
Tufted Puffin			1		1	2
Small auklets			1		4	5
Black-legged Kittiwake			2	1		3
Total offshore spp.	1	1	7	7	110	126
Percentage	0.8	0.8	5.6	5.6	87.3	100
Total - all species	5	5	16	14	118	158
Percentage	3.2	3.2	10.1	8.9	74.7	100

Table 5. State of decomposition of oiled carcasses recovered on Vancouver Island after the Nestucca spill.

Bird group		Fresh or slight decomposition	Serious rotting
Inshore species			
Lightly oiled		8	1
Heavily oiled		2	7
Offshore/Widespread			
Lightly oiled		4	0
Heavily oiled		4	34
All birds			
Lightly oiled		12	1
	(%)	(92)	(8)
Heavily oiled		6	41
	(%)	(13)	(87)
Total		18	42
	(%)	(30)	(70)

Table 6. Results of buoyancy tests. The percentage of oil-saturated carcasses which sank when submersed in seawater is shown (sample sizes in parentheses)

Sample	Days after spill	Common Murre	Cassin's Auklet	Both species
A	21-25	20 (14)	21 (19)	21 (33)
B	25-35	50 (6)	40 (10)	44 (16)
B' (B re-tested)	50-60	50 (6)	70 (10)	63 (16)

Table 7. Numbers of oiled carcasses found intact, lightly scavenged (<10% eaten) and heavily scavenged (>10% eaten) on Vancouver Island between 18 January through 2 February 1989.

Species	Intact	Light	Heavy	Total
Loons	2	2	2	6
Grebes	1	0	1	2
Northern Fulmar	0	1	2	3
Cormorants	1	0	7	8
Scoters	4	1	4	9
Other waterfowl	1	0	0	1
Large gulls	1	2	6	9
Bl.-legged Kittiwakes	1	0	1	2
Common Murre	17	11	24	52
Cassin's Auklet	39	4	10	53
Other alcids	6	1	10	17
All birds	67	21	57	145
(%)	(46.2)	(14.5)	(39.3)	(100)

Table 8. Scavenging rates of oiled Nestucca victims with varying coverage of oil on the plumage. Data from carcasses collected between 18 Jan - 2 Feb 1989.

Oil covering body (%)	Amount of scavenging: Carcass intact	Light (<10% eaten)	Heavy (>10% eaten)	Total
<10	2	1	7	10
11-50	3	3	6	12
51-90	4	2	6	12
A) Total <90	9	6	19	34
B) Total >=90	58	15	38	111
Total	67	21	57	145
(%)	46.2	14.5	39.3	100.0

Chi-squared test (A) vs. (B): Chi-sq. = 7.15, df = 2, $P<0.05$.

Table 9. Mean densities (birds/km) and percentage composition of seabirds, estimated from aerial and shipboard surveys in winter off SW Vancouver Island (latitude 48 00' to 49 30'N. Distance offshore is indicated for some surveys.

Bird species	A) Aerial surveys February 1973						B) Shipboard surveys February 1973				D) Shipboard March 1985		C) Shipboard Nov 1985	
	0-30 k	(%)	30-60km	(%)	>60 km	(%)	0-30 k	(%)	30-60k	(%)		(%)		(%)
Loons	-	-	-	-	-	-	-	-	-	-	0.002	0.0	0.135	5.0
Northern Fulmar	0.00	0.0	0.01	0.6	0.01	1.6	0.00	0.0	0.00	0.0	0.068	1.2	0.200	7.3
Other petrels	0.01	1.2	0.05	3.0	0.00	0.0	0.00	0.0	0.09	0.6	0.203	3.5	0.070	2.6
Total Procellariiform	**0.01**	**1.2**	**0.06**	**3.6**	**0.01**	**1.6**	**0.00**	**0.0**	**0.09**	**0.6**	**0.271**	**4.7**	**0.270**	**9.9**
Cormorants	-	-	-	-	-	-	-	-	-	-	0.017	0.3	0.278	10.2
Anseriformes	-	-	-	-	-	-	-	-	-	-	0.032	0.6	0.043	1.6
Glaucous-W. Gull	-	-	-	-	-	-	-	-	-	-	0.784	13.7	0.052	1.9
Herring and Thayer's Gulls	-	-	-	-	-	-	-	-	-	-	0.493	8.6	0.470	17.2
Total large gulls	0.55	67.9	1.12	66.7	0.15	24.2	6.56	72.3	10.13	62.5	1.752	30.5	0.731	26.8
Bl.-legged Kittiwa	0.03	3.7	0.26	15.5	0.13	21.0	0.19	2.1	3.24	20.0	1.784	31.1	0.174	6.4
Total gulls	**0.58**	**71.6**	**1.38**	**82.1**	**0.27**	**43.5**	**6.75**	**74.4**	**13.37**	**82.4**	**3.536**	**61.6**	**0.905**	**33.2**
Common Murre	0.14	17.3	0.09	5.4	0.04	6.5	2.12	23.4	0.97	6.0	1.230	21.4	0.878	32.2
Rhinoceros Auklet	-		-		-		0.00	0.0	0.12	0.7	0.066	1.2	0.000	0.0
Mid-sized alcids	0.03	3.7	0.02	1.2	0.02	3.2	-		-		-		0.000	0.0
Cassin's Auklet	-		-				0.00	0.0	0.49	3.0	0.470	8.2	0.135	5.0
Marbled Murrelet	-	-	-	-	-	-	-	-	-	-	0.047	0.8	0.000	0.0
Small Auklets	0.01	1.2	0.09	5.4	0.28	45.2	-				-		0.000	0.0
Total alcids	**0.18**	**22.2**	**0.20**	**11.9**	**0.34**	**54.8**	**2.12**	**23.4**	**1.58**	**9.7**	**1.877**	**32.7**	**1.092**	**40.1**
Other birds	0.04	4.9	0.04	2.4	0.00	0.0	0.20	2.2	1.18	7.3	-		-	
Total, all birds	**0.81**		**1.68**		**0.62**		**9.07**		**16.22**		**5.737**		**2.723**	
Distance surveyed (km)	173.4		219.8		196.8		5.2		56.7					
Reference:	1		1		1		1		1		2		2	

References: 1: Vermeer et al. (1983); 2: Vermeer et al. (1987)

Table 10. Avian species composition in inshore and sheltered waters along the west coast of Vancouver Island, compared with oiled birds found on Vancouver Island after the Nestucca spill.

	Vancouver I. SW Coast		Vancouver I. West Coast		Vancouver I. West C. Inlets		Barkley Sound Trevor Channel		Barkley Sound Deer Island		Barkley Sound Loudoun Channel		Barkley Sound Bamfield Inlets		Oiled Birds	
Species/type	birds/km	%	birds/km	%	birds/km	%	Mean No.	%	Mean No.	%	Total No.	%	Mean No.	%	Number	%
Loons	0.01	0.0	0.0	0.0	0.9	1.9	10.8	0.3	5.2	0.8	11.0	2.6	5.1	1.0	25.0	2.9
Grebes	0.1	0.5	0.3	2.0	2.0	4.4	517.3	12.2	83.5	12.1	35.0	8.2	33.6	6.6	12.0	1.4
Cormorants	0.3	1.1	1.6	10.5	0.3	0.7	131.5	3.1	169.9	24.6	94.0	22.0	39.4	7.8	13.0	1.5
Diving Ducks	8.4	35.5	3.3	21.6	16.3	35.5	2235.5	52.9	261.3	37.9	162.0	37.9	313.0	61.7	63.0	7.4
Dabbling Ducks	3.4	14.4	4.5	29.4	20.1	43.8	9.5	0.2	2.1	0.3	0.0	0.0	45.2	8.9	0.0	0.0
Swans and Geese	0.3	1.1	1.3	8.5	1.5	3.3	29.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gulls	11.0	46.6	4.3	28.1	4.8	10.5	1103.8	26.1	140.2	20.3	39.0	9.1	69.1	13.6	34.0	4.0
Alcids	0.2	0.8	0.0	0.0	0.0	0.0	187.3	4.4	27.9	4.0	86.0	20.1	1.9	0.4	697.0	81.4
Other birds				-	-	-	-	-	-	-	-	-	-	-	12.0	1.4
Totals	23.6	100	15.3	100	45.9	100	4224.5	100	690.1	100	427.0	100	507.3	100	856.0	100
Time of census	Jan/Feb 1973		Jan/Feb 1973		Jan/Feb 1973		Dec - Feb 1987 - 1988		Dec - Feb 1986 - 1989		Oct - Mar 1972 - 1973		Dec - Feb 1986 - 1988		Jan - Feb 89	
Method of census	Aerial		Aerial		Aerial		Small boat		Small boat		Small boat		Small boat		This study	
Reference:	1		1		1		2		3		4		3			

1: Vermeer et al. (1983)

2: K. Vermeer (unpublished data)

3: A. E. Burger (unpublished data)

4: Hatler et al. (1978)

Table 11. Waterfowl species composition in inshore and sheltered waters along the west coast of Vancouver Island, compared with oiled birds found on Vancouver Island after the Nestucca spill.

	Vancouver I. SW Coast		Vancouver I. West Coast		Vancouver I. West C. Inlets		Barkley Sound Trevor Channel		Barkley Sound Deer Island		Barkley Sound Loudoun Channel		Barkley Sound Bamfield Inlets		Oiled Birds	
Species/type	birds/km	%	birds/km	%	birds/km	%	Mean No.	%	Mean No	%	Total No.	%	Mean No.	%	Number	%
Loons	0.01	0.0	0.0	0.0	0.9	1.9	10.8	0.3	5.2	0.8	11.0	2.6	5.1	1.0	25.0	2.9
Grebes	0.1	0.5	0.3	2.0	2.0	4.4	517.3	12.2	83.5	12.1	35.0	8.2	33.6	6.6	12.0	1.4
Cormorants	0.3	1.1	1.6	10.5	0.3	0.7	131.5	3.1	169.9	24.6	94.0	22.0	39.4	7.8	13.0	1.5
Diving Ducks	8.4	35.5	3.3	21.6	16.3	35.5	2235.5	52.9	261.3	37.9	162.0	37.9	313.0	61.7	63.0	7.4
Dabbling Ducks	3.4	14.4	4.5	29.4	20.1	43.8	9.5	0.2	2.1	0.3	0.0	0.0	45.2	8.9	0.0	0.0
Swans and Geese	0.3	1.1	1.3	8.5	1.5	3.3	29.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gulls	11.0	46.6	4.3	28.1	4.8	10.5	1103.8	26.1	140.2	20.3	39.0	9.1	69.1	13.6	34.0	4.0
Alcids	0.2	0.8	0.0	0.0	0.0	0.0	187.3	4.4	27.9	4.0	86.0	20.1	1.9	0.4	697.0	81.4
Other birds				-	-	-	-	-	-	-	-	-	-	-	12.0	1.4
Totals	23.6	100	15.3	100	45.9	100	4224.5	100	690.1	100	427.0	100	507.3	100	856.0	100
Time of census	Jan/Feb 1973		Jan/Feb 1973		Jan/Feb 1973		Dec - Feb 1987 - 1988		Dec - Feb 1986 - 1989		Oct - Mar 1972 - 1973		Dec - Feb 1986 - 1988		Jan - Feb 89	
Method of census	Aerial		Aerial		Aerial		Small boat		Small boat		Small boat		Small boat		This study	
Reference:	1		1		1		2		3		4		3			

1: Vermeer et al. (1983)

2: K. Vermeer (unpublished data)

3: A. E. Burger (unpublished data)

4: Hatler et al. (1978)

Table 12. Birds observed from helicopters during low-level flights over inshore waters of SW Vancouver Island between 11 January and 2 February 1989, following the Nestucca spill, compared to oiled birds found dead in the same area. Data from Rodway et al. (1989).

	Barkley Sound and south				PRNP area and Clayoquat Sound			
	Sightings		Oiled		Sightings		Oiled	
Species/type	No.	%	No.	%	No.	%	No.	%
Loons	19	1.1	2	2.1	0	0.0	20	2.9
Grebes	157	8.7	3	3.2	0	0.0	8	1.2
Cormorants	334	18.6	1	1.1	3595	44.3	9	1.3
Diving Ducks	435	24.2	2	2.1	905	11.1	57	8.3
Dabbling Ducks	30	1.7	0	0.0	950	11.7	0	0.0
Swans and Geese	71	3.9	0	0.0	495	6.1	0	0.0
Shorebirds	361	20.1	0	0.0	1318	16.2	1	0.1
Gulls	284	15.8	7	7.4	829	10.2	22	3.2
Alcids	20	1.1	77	81.9	0	0.0	564	81.9
Other birds	88	4.9	2	2.1	29	0.4	8	1.2
Totals	1799	100	94	100	8121	100	689	100

Table 13. Estimated numbers of breeding seabirds from Washington (Speich and Wahl 1989), British Columbia (Rodway 1990b, 1991) and Alaska (A. Sowls unpubl. data). The population estimates from Alaska are from preliminary data.

Species	Washington	British Columbia	Alaska
Double-crested Cormorant	3,296	4,064	20,000
Brandt's Cormorant	554	190	200
Pelagic Cormorant	4,866	8,990	150,000
Glaucous-winged Gull	37,000*	58,000	500,000
Black-legged Kittiwake	0	0	2 million
Common Murre	31,000	8,640	6 million
Pigeon Guillemot	4,270	9,350	200,000
Marbled Murrelet	2,417	45,000	250,000
Cassin's Auklet	87,600	2.7 million	1 million
Rhinoceros Auklet	60,800	719,000	200,000
Tufted Puffin	23,340	77,900	4 million
Ancient Murrelet	0	543,000	800,000

* Western Gulls, with a small proportion of G.-W. Gulls

Table 14. Calculated values of the sum of Pi.S for variable values of S for the first 20 days of strandings. The sum of Pi.S is the equivalent of the proportion of the total stranded population of oiled carcasses likely to be found on the beach on each day.

	Persistence value (S)				
Day	0.6	0.7	0.8	0.9	1.0
1	0.238	0.238	0.238	0.238	0.238
2	0.253	0.277	0.301	0.325	0.349
3	0.378	0.420	0.467	0.519	0.575
4	0.311	0.378	0.457	0.550	0.658
5	0.191	0.269	0.370	0.500	0.663
6	0.132	0.206	0.314	0.467	0.680
7	0.084	0.149	0.256	0.425	0.685
8	0.060	0.113	0.214	0.392	0.694
9	0.043	0.086	0.178	0.360	0.701
10	0.088	0.123	0.205	0.386	0.764
11	0.113	0.146	0.224	0.407	0.824
12	0.068	0.103	0.180	0.367	0.824
13	0.057	0.088	0.160	0.347	0.840
14	0.071	0.098	0.164	0.349	0.877
15	0.079	0.105	0.168	0.350	0.914
16	0.097	0.123	0.184	0.365	0.963
17	0.066	0.094	0.155	0.336	0.970
18	0.043	0.069	0.127	0.306	0.974
19	0.031	0.054	0.107	0.281	0.980
20	0.021	0.040	0.088	0.255	0.982

Table 15. Estimates of total strandings of oiled carcasses on Vancouver Island beaches, based on the model by Ford et al. (1987), with the daily persistence of beached carcasses set at 0.7 (see text).

Beach/region	Date oiled birds ashore	Time of census		Corpse count on census day	Estimated proportion on census day (P*S)	Estimate total count	Actual total count	
		Date	Day of oiling					
Sooke to Port Renfrew	Jan 2?	Jan 12	11	12	0.146	82	12	
Carmanah to Bonilla	Jan 1	Jan 23	23	50	0.040	1250	50	*
Wyac	Jan 1	Jan 5	5	20	0.269	74	20	
Clo-oose	Jan 1	Jan 11	11	26	0.146	178	26	
Hope Pt. to Tsusiat	Jan 1	Jan 11	11	48	0.146	329	48	
Klanawa	Jan 1	Jan 20	20	26	0.040	650	26	
Darling River	Jan 1	Jan 16	16	40	0.123	325	70	
Unspecified	Jan 1	Jan 16	16	17	0.123	138	17	
Pachena Point	Jan 2	Jan 20	19	4	0.054	74	4	
Pachena Bay	Jan 2	Jan 7	6	36	0.206	175	59	
Keeha Bay	Jan 2	Jan 11	10	10	0.123	81	35	
Cloutus Beach	Jan 2	Jan 21	18	30	0.069	435	30	
Seabird Rocks	Jan 2	Jan 11	10	5	0.123	41	7	
Topaltos	Jan 3	Jan 11	10	12	0.123	98	13	
Helby Island	Jan 3	Jan 20	18	2	0.069	29	2	
Benson Island	Jan 3	Jan 12	10	14	0.123	114	14	
Dicebox Island	Jan 3	Jan 13	11	4	0.146	27	6	
Broken Group	Jan 4	Jan 6	3	20	0.420	48	42	
Torquart Bay	Jan 4	Jan 21	18	1	0.069	14	1	*
Mayne Island	Jan 4	Feb 4	32	6	0.040	150	6	
Maccoah Passage	Jan 4	Jan20-21	17	6	0.094	64	20	*
George Fraser Island	Jan 4	Jan 29	26	3	0.040	75	3	*
Beg Island	Jan 4	Feb 4	31	3	0.040	75	3	
North Ucluelet Inlet	Jan 4	Jan 20	17	14	0.094	149	35	*
Stuart Bay	Jan 4	Jan 29	26	17	0.040	425	20	
PARK BEACHES	Jan 3	-	-	1435	-	1435	1435	**
Portland Point	Jan 3	Jan 12	10	12	0.123	98	12	
Radar Beach	Jan 3	Jan 3-6	2	24	0.277	87	46	
Chesterman's Beach	Jan 3	Jan 11	9	150	0.086	1744	152	
Cleland Island	Jan 5	Jan 11	7	1	0.149	7	3	
Blonden & Bartlett Is.	Jan 5	Jan 9	5	40	0.269	149	40	
Flores Island	Jan 5	Jan 23	19	30	0.054	556	30	
Vargas Island area	Jan 5	Jan 5-11	4	625	0.269	2323	745	
Katawisc	Jan 5	Jan 17	13	10	0.088	114	10	
Sharp Pt. - Cape Cook	Jan 6-12	Jan12-23	7-18	119	-	119	119	***
Cape Cook - C. Scott	Jan13-15	Jan15-24	2-12	65	-	65	65	***
Total all areas						11795	3226	

* Censused >20 days after first oiling, persistence estimated at 0.040

** Park beaches were censused daily and used as the basis of the model

*** Censuses incomplete and usually <5 birds per beach. Model not applied.

Table 16. Comparison between numbers of oiled seabirds and numbers of bags of oiled debris reported from discrete areas on Vancouver Island, during the period of intensive cleanup. The areas and sites are as named in Harding and Englar (1989).

Area	Site	Dates	Scale of oiling	# birds	# bags	Birds per bag	Authority (see codes below)
Darling	Klanawa Beach	20 Jan	3/4 M	26	40	0.65	HE/Burger
Darling	Darling River	16 Jan	2-4	40	40	1.00	Vol/UBC team/Swanston
Pachena	Keeha Bay	20-21 Jan	4	15	30	0.50	HE/Burger
Pachena	Seabird Rocks	11-20 Jan	2	2	5	0.40	HE/Vedova
Pachena	South of Black R.	20 Jan	3/4 L	4	25	0.16	HE/Swanston
Barkley	Austin & Turtle Is.	22 Jan	-	2	5	0.40	HE/Baird
Deer	Helby I.	20 Jan	-	2	6	0.33	HE/Johnson, Dennis
Long	Schooner Cove	3-24 Jan	4	145	271	0.54	HE/Rodway/Vol
Long	Portland Point	13 Jan	5	12	41	0.29	HE/Tremblay
Clayoquot	Wickaninish Island	14-21 Jan	3	62	136	0.46	HE/Vol/Dorst
Clayoquot	Cox Bay	9 Jan	3	12	40	0.30	HE/Vol
Acous	Battle Bay	16-17 Jan	3L	6	45	0.13	HE/OSF Sea Otter group
Bunsby	Gull Islet	22-24 Jan	4	5	40	0.13	HE/Rodway
Grant	Grant Bay	24 Jan	4L	5	15	0.33	HE/Swanston
Side	Side Bay	20-24 Jan	3	50	80	0.63	Rodway/OSF
Mean						0.42	
Std. Dev.						0.22	

Notes: HE = Harding and Engler (1989)
OSF = Oil Spill Facts (Canadian Coast Guard)
Rodway = Rodway et al. (1989)
Vol = Tofino Volunteers' report
Other names are individuals reporting birds or bags.

Table 17. Estimated species composition of the Nestucca victims which stranded on Vancouver Island, or disappeared at sea en route to the island. Species comprising <1% of the sample have been pooled into families.

Species	% of birds identified	Estimated no. on beaches	Estimated dead at sea*	
			Inshore	Offshore
Pacific Loon	2.38	238	238	
Other loons	0.59	59	59	
Grebes	1.43	143	143	
Northern Fulmar	1.07	107		428
Shearwaters	0.12	12		48
Brandt's cormorant	0.83	83	83	
Other cormorants	0.48	48	48	
White-winged Scoter	3.09	309	309	
Surf Scoter	2.73	273	273	
Other ducks	1.43	143	143	
Sanderling	0.12	12	12	
Glaucous-winged Gull	1.90	190	190	
Other gulls	0.71	71	71	
Black-legged Kittiwake	1.07	107		428
Common Murre	42.09	4209		16836
Pigeon Guillemot	0.59	59	59	
Marbled Murrelet	1.43	143	143	
Ancient Murrelet	2.50	250		1000
Cassin's Auklet	31.99	3199		12796
Parakeet Auklet	1.78	178		712
Other alcids	1.67	167		668
Total all species	100	10000	1771	32916

* It was assumed that 100% of the inshore species and 25% of the offshore and widespread species came ashore.

Table 18. Percentage of gulls with oiled plumage reported from sites within the northern (Combers and Landfill [C&L]) and southern (Keeha and Klanawa) portions of Pacific Rim National Park following the Nestucca spill, 1989.

Date	Location	Glaucous-winged and other large gulls	Mew Gulls	Total	Observers
Jan-16	C&L	36.1 (83)	27.0 (37)	33.3 (120)	AB,DG
Jan-19	C&L	30.9 (97)	39.1 (23)	32.5 (120)	DG,KM
Jan-21	C&L	40.7 (86)	44.1 (34)	41.7 (120)	DG,KM
Jan-20	Klanawa	4.4 (46)	14.3 (14)	6.7 (60)	AEB
Jan-21	Keeha	31.0 (29)	21.4 (28)	26.3 (57)	AEB
Mean Jan 16-21		31.1 (341)	26.5 (136)	29.8 (477)	
Mar-19	Combers	-	-	0.0 (1000)	KM
Mar-23	C&L	-	-	2.4 (85)	KM

Notes:

Other large gulls include Thayer's, Herring, Glaucous and Western Gulls.

Observers: AB: Andre Breault; AEB: Alan E. Burger; DG:Don Garnier; KM: Kati Martini.

Appendix 1.

Continued on next page

Calculations to determine the total number of oiled carcasses stranded on Vancouver Island following the Nestucca spill, using the model of Ford et al. (1987). The day to day persistance of carcasses (S) is set at 0.7.

Day of stranding	Date	Daily bird count	Daily proportion of total count (Pi)	Proportion of carcasses stranded on days 1-20 still on beaches (Pi.S): 0.7 P*S day 1	0.7 P*S day 2	0.7 P*S day 3	0.7 P*S day 4	0.7 P*S day 5	0.7 P*S day 6	0.7 P*S day 7	0.7 P*S day 8	0.7 P*S day 9
1	03-Jan	339	0.238	0.238								
2	04-Jan	157	0.110	0.167	0.110							
3	05-Jan	322	0.226	0.117	0.077	0.226						
4	06-Jan	119	0.084	0.082	0.054	0.158	0.084					
5	07-Jan	6	0.004	0.057	0.038	0.111	0.059	0.004				
6	08-Jan	25	0.018	0.040	0.026	0.078	0.041	0.003	0.018			
7	09-Jan	7	0.005	0.028	0.019	0.054	0.029	0.002	0.012	0.005		
8	10-Jan	13	0.009	0.020	0.013	0.038	0.020	0.001	0.009	0.003	0.009	
9	11-Jan	10	0.007	0.014	0.009	0.027	0.014	0.001	0.006	0.002	0.006	0.007
10	12-Jan	89	0.063	0.010	0.006	0.019	0.010	0.001	0.004	0.002	0.004	0.005
11	13-Jan	85	0.060	0.007	0.004	0.013	0.007	0.000	0.003	0.001	0.003	0.003
12	14-Jan	1	0.001	0.005	0.003	0.009	0.005	0.000	0.002	0.001	0.002	0.002
13	15-Jan	23	0.016	0.003	0.002	0.006	0.003	0.000	0.001	0.001	0.002	0.002
14	16-Jan	52	0.037	0.002	0.002	0.004	0.002	0.000	0.001	0.000	0.001	0.001
15	17-Jan	52	0.037	0.002	0.001	0.003	0.002	0.000	0.001	0.000	0.001	0.001
16	18-Jan	70	0.049	0.001	0.001	0.002	0.001	0.000	0.000	0.000	0.001	0.001
17	19-Jan	11	0.008	0.001	0.001	0.002	0.001	0.000	0.000	0.000	0.000	0.000
18	20-Jan	5	0.004	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000
19	21-Jan	8	0.006	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
20	22-Jan	3	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1, continued.

Proportion of carcasses stranded on days 1-20 still on beaches (Pi.S):

0.7 P*S day 10	0.7 P*S day 11	0.7 P*S day 12	0.7 P*S day 13	0.7 P*S day 14	0.7 P*S day 15	0.7 P*S day 16	0.7 P*S day 17	0.7 P*S day 18	0.7 P*S day 19	0.7 P*S day 20	Sum of P*S Days 1-20
											0.238
											0.277
											0.420
											0.378
											0.269
											0.206
											0.149
											0.113
											0.086
0.063											0.123
0.044	0.060										0.146
0.031	0.042	0.001									0.103
0.021	0.029	0.000	0.016								0.088
0.015	0.020	0.000	0.011	0.037							0.098
0.011	0.014	0.000	0.008	0.026	0.037						0.105
0.007	0.010	0.000	0.006	0.018	0.026	0.049					0.123
0.005	0.007	0.000	0.004	0.013	0.018	0.034	0.008				0.094
0.004	0.005	0.000	0.003	0.009	0.013	0.024	0.005	0.004			0.069
0.003	0.003	0.000	0.002	0.006	0.009	0.017	0.004	0.002	0.006		0.054
0.002	0.002	0.000	0.001	0.004	0.006	0.012	0.003	0.002	0.004	0.002	0.040

APPENDIX 2.

Oiled corpses, affected shoreline and amount of oiled debris recovered off Vancouver Island.

Areas and sub-areas		No. of birds reported	Km affected shore Oiled Class 2	3-5	Total	Bags of oil reported	Comments on the amounts of oiled debris
AREA 0.							
Washington State to Cape Beale.		12			2.94	31	
(Juan de Fuca)	Sidney			0.22	0.22	?	
	Sooke		0.4	1	1.4	11	*
	Victoria			1.32	1.32	20	*
AREA 1.							
Port Renfrew to Cape Beale.		392			28.66	800	
	Carmanah		1.6	4.6	6.2	90	*
	Cullite		2	1.8	3.8	?	With Carmanah
	Darling			1.5	1.5	70	*
	Nitinat			5.76	5.76	300	
	Pachena		0.2	11.2	11.4	340	ok?
AREA 2.							
Cape Beale to Florencia Beach (excl. Florencia)		165			22.96	946	
	Barkley			11.5	11.5	440	10 t (IA notes)
	Clutus			0.25	0.25	?	With Keeha?
	Deer Is.			0.8	0.8	15	*
	Mayne			8.6	8.6	100	
	Newcombe (Maccoah)			0.2	0.2	?	
	Ucluelet			1.61	1.61	391	*
AREA 3.							
Florencia Beach to Hot Springs Cove.		2473			64.05	3111	
	Bartlett			1.6	1.6	?	heavily oiled
	Clayoquot			18	18	897	*
	Cleland			0.185	0.185	70	
	Flores			13.9	13.9	210	*
	Kutcous			0.01	0.01	5	
	Long		0.2	20.3	20.5	1649	*
	Vargas			9.855	9.855	280	*
AREA 4.							
Hot Springs Cove to Escalante Point.		33			11.23	203	
	Escalante		6	0.38	6.38	230	
	Estevan			4	4	128	+logs burnt
	Hesquiat			0.85	0.85	75	*
AREA 5.							
Escalante Point to Ferrer Point		35			8.89	1849	
	Bajo			5.23	5.23	880	20 t removed
	Nootka			3.66	3.66	969	

Appendix 2, continued

Areas and sub-areas	No. of birds reported	Km affected shore Class 2	3-5	Total	Bags oil reported	Comments on the amts. oil
AREA 6.						
Ferrer Point to Rugged Point	6			19.3	478	
Esperanza			2	2	?	heavy oiling
Grassy			0.5	0.5	7	
Gregoire			3	3	?	with Kyuquot?
Kyoquot			2.3	2.3	28	
Nuchatlitz			7.5	7.5	305	
Tatchu			4	4	138	*
AREA 7.						
Rugged Point to Cape Cook	45			28.7	912	
Acous			3.2	3.2	122	ok
Brooks			14.42	14.42	241	low?
Bunsbys			1.62	1.62	151	
Lookout (Mission Is)			1.5	1.5	26	
McLean			1.9	1.9	265	
Mission Is.			2.96	2.96	25	*
Thomas (Chekleset Bay)			2.2	2.2	?	
Thornton			0.9	0.9	82	
AREA 8.						
Cape Cook to Cape Scott	65			13.33	331	
Cape Scott		2	3.5	5.5	46	
Grant			0.4	0.4	15	
Heater			1.5	1.5	?	
Kwakiutl		0.7	0.3	1	6	
Lawn Point			0.51	0.51	30	
Raft (S of SanJosef)		0.2	2	2.2	61	
San Josef			0.51	0.51	15	
Scott Islands			0.1	0.1	6	
Sea Otter Cove			0.8	0.8	72	
Side Bay			0.81	0.81	80	
AREA 9.						
North of Cape Scott						
QCS (Goose Is.)			0.01	0.01	1	ok.
All areas combined.	3226	15.3	186.8	202.1	8662 (197 tonnes)	

Notes:

* The numbers of bags of debris recorded here do not reflect the asctual quantities of oiled debris removed.

Areas follow the Canadian Coast Guard (Stewart et al. 1989), sub-areas the EPS report (Harding and Engler 1989).

Number of birds from Rodway et al. (1989).

Distance of affected shore from Harding and Engler (1989), supplemented by data from Oil Spill Facts (CCG daily reports) and field maps made available by D. Swanston. Many shores were repeatedly oiled, but the distance was counted once.