ESTIMATING POPULATIONS OF MARINE RIVER OTTERS IN PRINCE WILLIAM SOUND, ALASKA, USING RADIOTRACER IMPLANTS

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One year after the spillage of oil from the *Exxon Valdez* in spring 1989, we used radiotransmitters and radiotracer labels to mark river otters (*Lutra canadensis*) at Knight Island (oiled) and Esther Passage (unoiled) in Prince William Sound, Alaska. Feces recovered from latrines of animals were used as "recaptures" in mark-recapture experiments to estimate the density of river otters in the two coastal study areas. Our methods were evaluated for sources of bias in estimating and comparing population sizes. There was no evidence that densities of river otters at Knight Island (oiled) were less than those at Esther Passage (unoiled) in summer 1990 or that density of river otters at Knight Island was declining. Estimates of river otters in Prince William Sound ranged from 0.28 to 0.80 animals per km of coastline. Our estimates are similar to those for marine river otters in southeastern Alaska, but bias in the different methods should be considered.

Key words: river otter, *Lutra canadensis, Exxon Valdez,* Bayesian, mark-recapture, oil spill, population estimates, radioisotopes, Prince William Sound, Alaska

Use of radiotracer labels to estimate population size has been explored with several species of carnivores (Conner and Labisky, 1985; Crabtree et al., 1989; Kruuk et al., 1980), including river otters (*Lutra canadensis*—Knaus et al., 1983). The labels can be detected in animal scats (feces) weeks or months after being injected in liquid form or implanted as a slow-release tablet (Crabtree et al., 1989). If the number of animals with such labels is known, then a representative sample of labeled and unlabeled scats can be used for mark-recapture analysis (Kruuk et al., 1980). River otters are extremely difficult to census in traditional ways (Melquist and Hornocker, 1979). Use of marking methods that differ from those used to resight the animals may avoid important behavioral sources of bias that may be present in more traditional experiments using mark-recapture. We used a combination of radiotelemetry and recovery of scats of river otters with radiotracer labels as the basis for a series of mark-recapture experiments in summer 1990, a year after the *Exxon Valdez* oil spill in Prince William Sound. Our objectives were to compare densities of river otters in oiled and unoiled areas of Prince William Sound and to assess bias inherent in using radiotracer-labeled scats as the basis for mark-recapture estimation of populations of river otters.

MATERIALS AND METHODS

Study area.—Following heavy contamination of shores along Knight Island by crude oil from the *Exxon Valdez* in spring 1989, biologists from the Alaska Department of Fish and Game selected two areas to serve as comparative sites in a study of marine river otters in April 1989 (Fig. 1). The oiled study area at Knight Island (60°30'N, 147°40'W) included the northwestern shore of Knight Island, the southwestern part of Ingot Island, and all of Disc Island. The unoiled study area in Esther Passage (60°53'N, 147°55'W) included both shores of Esther Passage and several kilometers of coast in Port Wells on either side of the western end of the pass. The length of linear coastline including islands was 89.6 km at Knight Island and 81.4 km at Esther Passage. Vegetation in both areas included mature stands of Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*), while the understory and scattered open areas typically included blueberry (*Vaccinium*), alder (*Ulnus*), and willows (*Salix*—Eck, 1983). The terrain is mountainous with rocky shorelines.

Both study areas were closed to hunting and trapping after the oil spill, although some evidence was found that trapping may have occurred at Esther Passage in previous years. Otter skins are required to be sealed by Alaska Department of Fish and Game. No otters from Knight Island were reported in the harvest in recent years. Some otters were reportedly taken from "Esther Island" (11 in 1987–1988, 2 in 1988–1989, and 5 in 1989–1990), possibly including the western part of the Esther Passage study area, in years preceding the study. There also are some differences in habitat in the areas being compared (Bowyer et al., in press, in litt.). Therefore, we cannot exclude the possibility that densities of river otters prior to the oil spill may have been somewhat different in the two areas.

Preparation of radiotracer implants.—Implants were prepared with methods similar to those outlined by Crabtree et al. (1989). We selected radiotracers by considering their availability, photon energy, and physical half-life as well as the rating given by Crabtree et al. (1989). The five radiotracers selected were ^{109}Cd, ^{54}Mn, ^{57}Co, ^{60}Co, and ^{65}Zn, which can be separated using gamma spectrometry. All of these tracers have physical half-lives sufficiently long (from 270 to 1,920 days) so that physical decay during the period of study did not present a significant problem. Four of the five radiotracers were used by Crabtree et al. (1989) and subjectively rated as fair to excellent in effectiveness. Those selected were commercially available in the chloride form (NEN Research Products, Boston, MA). Polylactic-acid (PLA) material (poly(DL-lactide)-co-glycollide 80:20) for carrying the radiotracers (Crabtree et al., 1989) was obtained from Polysciences Inc., Warrington, PA.

Each implant was labeled with a radiotracer at a concentration of 30 microcuries for ^{109}Cd, 10 microcuries for ^{60}Co, or 20 microcuries for the other radiotracers. A slurry of polylactic-acid material and radiotracer was prepared to uniformly distribute the tracer, then allowed to dry. Aliquots of ca. 0.1 g of the labeled mixture were placed into individual indentations in an embedding mold of silicone rubber. The mold was heated on a hot plate until the mixture melted into a clear liquid (ca. 80°C). As the mold cooled, the radiolabeled material was temporarily malleable and could be reshaped into a tablet with a stainless steel spatula. Once cool, the lens-shaped implants were removed from the mold and placed in marked vials ready for implanting.

Handling of river otters.—We set Hancock livetraps (modified after Melquist and Hornocker, 1979) at heavily used latrine sites at Knight Island in December 1989 and in both study areas during May–June 1990. Traps were examined at intervals of <12 h in the morning and evening. Captured river otters were immobilized with intramuscular injection of ketamine hydrochloride (22 mg/kg of body weight—Melquist and Hornocker, 1979), transferred to a holding box, and transported to a 15-m boat that served as a logistic center. Surgeries were conducted within 24 h (usually within <3 h) by a licensed veterinarian using procedures outlined by Melquist and Hornocker (1979). In December 1989, the veterinarian employed midventral entry to the peritoneal cavity; thereafter, a side entry anterior to the first rib was used. Hermetically sealed radiotransmitters (150 MHz—Telonix, Mesa, AZ) and radiotracer-labeled tablets (Crabtree et al., 1989) were implanted into the peritoneal cavity. The five radiotracers were used singly or in combination such that no two animals from the same study area received the same combination of radiotracers. Calculated doses of radiation to the otters were within radiation-safety standards established by the Occupational Safety and Health Administration (OSHA) for humans.

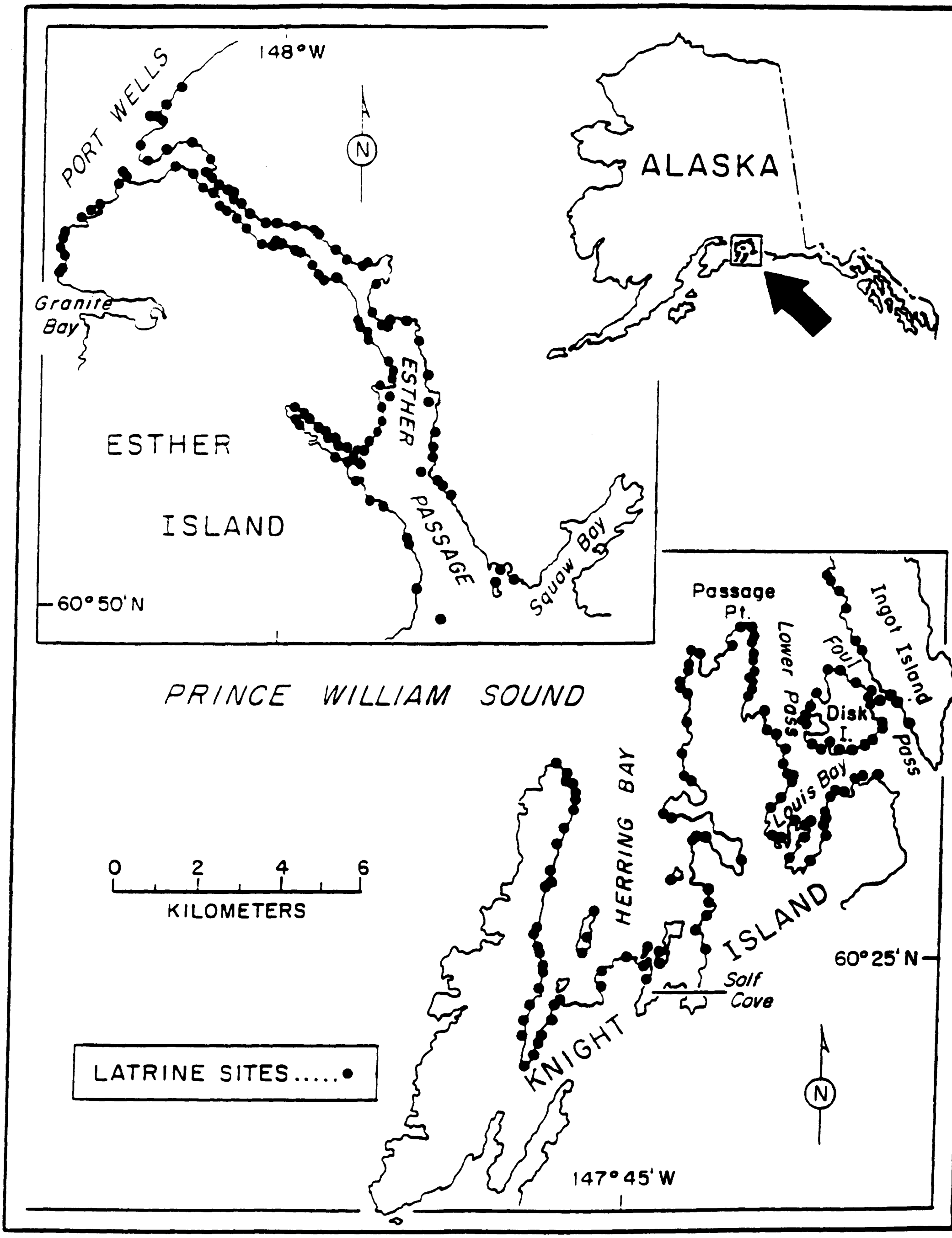

FIG. 1.—Location of latrine sites of river otters on oiled (Knight Island) and unoiled (Esther Passage) study areas in Prince William Sound, Alaska.

River otters were released near the capture site as soon as they recovered from anesthesia.

Use of radiotracers in this study was approved by a Radiation Safety Committee at the University of Alaska Fairbanks and was consistent with the provisions of the Nuclear Regulatory Commission license held by University of Alaska Fairbanks. All other procedures involving otters were approved by an Institutional Animal Care and Use Committee at the University of Alaska Fairbanks.

Assaying radiotracers.—Scat samples were returned to the University of Alaska Fairbanks in individual whirl-packs labeled with the date of collection, site, and a unique identification code. Samples were analyzed using a multichannel analyzer coupled with a high-purity germanium (HpGe) detection crystal (model GEM-15200; EG&G Ortec, Oak Ridge, TN). The detector was shielded by lead walls of 10-cm thickness. Samples were analyzed for presence or absence of radiotracers, and no attempt was made to quantify radiotracers. Affirmation of the presence of a particular radiotracer in a sample was the existence of a photopeak in the spectrum that corresponded to the gamma energy of that radiotracer. Energies used for the individual radiotracers were: 88 KeV for ^{109}Cd; 121 and 136 KeV for ^{57}Co; 835 KeV for ^{54}Mn; 1,173 and 1,333 KeV for ^{60}Co; and 1,114 KeV for ^{65}Zn. These energy regions were identified on the energy spectrum of the multichannel analyzer by assaying standards prepared from the original radiotracer solutions. When the presence of a particular radiotracer was in question even after a long assay, the sample spectrum was compared with a background spectrum in the appropriate energy region.

The assay procedure consisted of placing a sample of scats in the detector shield, assaying for ca. 10 min, and inspecting the gamma-energy spectrum for the presence or absence of each tracer. If there was doubt about the presence of a radiotracer, the sample was assayed for a longer period of time. Following this initial radioassay, samples with the same radiotracer were pooled and assayed for 8–12 h to confirm that no other radiotracers were present in any of the samples.

Location of latrine sites.—We intensively searched the shores of both study areas for signs of use by otters using small boats during spring 1989. All latrines that could be detected were physically marked, and their locations were mapped. This process was repeated over a larger area in late June 1990, so that the study areas were more likely to enclose the entire home ranges of tagged river otters and to increase the number of latrines that were sampled. Sections of the coast on both study areas were walked during the summer, which confirmed that searches from boats had detected nearly all latrine sites present.

Census.—We conducted a preliminary collection of scats from latrines of river otters in both areas on 5–6 June 1990 to assess the effectiveness of the radiotracers. Scats from river otters were distinguished from other mustelids in the area (*Mustela vison* and *Enhydra lutris*) by size, consistency, contents, and distance from the shore. Only fresh scats (estimated to be <4 days old based on cohesiveness and the amount of internal moisture) were individually collected, labeled, and wrapped in plastic bags.

We conducted more rigorous, systematic censuses of the latrines on both study areas on 12–15 July, 12–14 August, and 5–9 September 1990. These were done in conjuction with surveys by airplane and boat to detect radiosignals from instrumented otters. In experiments during July–September, the latrines were cleared of all scats at the start of each census. Two to three people searched each site systematically such that every part of the site was examined independently by at least two people. Sites were cleared twice by two different field crews before the start of the experiments in July to verify that no fresh scats were missed by single crews. Thereafter, one clearance was made at the start of each experiment. All latrines were cleared of scats in a single day and left undisturbed for 2–3 days to accumulate fresh scats. The collection process was then repeated, with each scat individually collected, labeled, and packaged for later analysis of isotopes. In September, scat recoveries were low, and scats were collected 2 and 4 days after the start of each experiment. Because river otters sometimes defecate on top of the scats of other otters, scats were discarded from the analysis if observers were unsure, judging either by volume or variation in consistency of scats, whether they were from a single otter.

Population estimates.—We designed the study to provide a precise determination of marks at risk (M) during each experimental period by using the number of radiotagged otters known to be present during the 2 or 3-day period of scat deposition. It was assumed that radio-equipped otters had recovered from surgery and were as likely to use latrines as were unmarked otters. Movements by radioequipped river otters appeared normal by the time of these experiments, and several were seen in groups with unmarked otters (Bowyer et al., in press). The labeled scats were our "recaptures" (R) from the total number of "captured" scats (C). Because the time interval was short and the number of marked animals was known, a closed model was used to estimate population size. A binomial distribution, appropriate for sampling with replacement, was assumed.

We used a Bayesian mark-recapture procedure (Gazey and Staley, 1986) because of its robust and accurate behavior with small sample sizes and its ability to estimate asymmetric confidence limits. Also, Bayesian confidence intervals have a simpler intuitive interpretation compared with more traditional approaches (Howson and Urbach, 1991). The Bayesian estimate is a numerical computation, with the probability of each possible population size (N) being calculated across the range of plausible values:

$$P(N) = (M/N)^{R} \cdot (1 - M/N)^{C-R} \cdot P'(N),$$

where P′(N) and P(N) are the probabilities of population size N being the true population size a priori and a posteriori to sampling. The a priori distribution was assumed to be uniform, but the method is robust enough to accommodate departures from this assumption (Gazey and Staley, 1986). The Bayesian method provides the complete probability distribution (the a posteriori distribution) for population size based on the captures (C), recaptures (R), and marks at risk (M) observed for each mark-recapture experiment. To compare population estimates from areas of slightly different sizes (length of the coastline at Knight Island exceeded that at Esther Passage by 10%), the individual distributions of population size were scaled to otters per 100 km of coastline by dividing estimates of population size by coastline length/100.

If radiotelemetry is used to determine which otters are present during the period of scat collection, recaptures (labeled scats) should include only those combinations of isotopes belonging to the radiotracked animals. To avoid bias, any isotope combination that occurred in the sample and was not from a radiotracked animal was considered "unmarked." Including scats belonging to the missing animals as recaptures and incrementing the number "marked" could bias the population estimates. Bias results because it is impossible to include otters that were present in the area, but were missed by both detection methods (i.e., marks at risk could be undercounted). If the number of river otters present but undetected is small, the bias that results from including the labeled scats from such animals also should be small.

During some sample periods, not all radio-equipped river otters were detected by radiosignals even though their scats were numerous. This lack of detection resulted in low numbers of marked animals during the experiment and high variances in population estimates. The total number of otters unaccounted for by either method at those times was usually low. Population estimates (N′) also were made using all the otters detected by either radiosignal or labeled scats as marks at risk (M′). The potential bias in these estimates was evaluated by determining the number of marked otters known to be alive but undetected by both methods and by comparing the difference distribution (Gazey and Staley, 1986) between the two estimates based on M versus M′ as if there were two different populations being compared. No adjustment for length of coastline was made for these comparisons. If M′ tends to undercount otters actually at risk, $N - N'$ will tend to be >0.

Joint probability distributions from the two study areas were used to calculate the probability that density of river otters at Knight Island was less than or equal to that at Esther Passage. This value was calculated by summing the joint probability distribution across all possible population sizes in which density of river otters at Esther Passage was greater than the density at Knight Island ($N_{EP} > N_{KI}$—Gazey and Staley, 1986):

$$P(N_{EP} > N_{KI}) = \sum_{N_{KI}=0}^{\infty} \left\{ P(N_{KI}) \sum_{N_{EP}>N_{KI}}^{\infty} P(N_{KI} \mid N_{EP}) \right\}.$$

This method also was used to test for changes in population density between censuses of the same area.

RESULTS

River otters alive at the time of each census at Knight Island and Esther Passage are

TABLE 1.—*River otters available for "recapture" via scat censuses at Knight Island, Prince William Sound, Alaska. Presence during the census in the month shown is indicated by "R" for radio and the number of scats bearing that combination of radiotracers.*

Sex	Release	Radiotracer	Census month			
			June	July	August	September
Male[a]	5 December	^{109}Cd	R?	1	R?	
Male[a]	10 December	^{109}Cd, ^{54}Mn	?	?	R?	?
Male[a]	11 December	^{109}Cd, ^{57}Co	?	R?	R?	R?
Male[a]	12 May	^{109}Cd, ^{60}Co	1	R2	2	
Male[a]	10 May	^{109}Cd, ^{65}Zn	3	R8	7	R8
Male	13 May	^{60}Co, ^{54}Mn	3	R2	1	R1
Male	15 May	^{54}Mn	8	R33	R11	R19
Male[a]	16 May	^{109}Cd, ^{60}Co, ^{54}Mn	?	R?	?	R?
Male	17 May	^{57}Co, ^{60}Co	9	R6	R3	R7
Male[a]	17 June	^{109}Cd, ^{65}Zn, ^{54}Mn	?	R?	?	R?
Female	9 December	^{54}Mn, ^{65}Zn	6	R8	R13	R5
Female	9 December	^{57}Co, ^{65}Zn	5	R0		R1
Female[b]	10 December	^{57}Co, ^{54}Mn		2		
Female	12 December	^{57}Co	7	R1	R2	R2

[a] The isotope ^{109}Cd could not be reliably detected. A "?" indicates that the isotope ^{109}Cd was not detected, but other tracers associated with that otter were detected in at least one scat.

[b] Radiotransmitter never detected after release; probably failed.

listed in Tables 1 and 2 with their respective radiotracer implants, radiotracking histories and scat recoveries. Six otters died at Knight Island, and one died at Esther Passage during or shortly after handling. Information from Tables 1 and 2 was used to compile the capture-recapture data from which densities of river otters were estimated (Table 3). The number of otters known to be alive, but unaccounted for by either radiosignals or radiotracer-labeled scats (Table 3), is shown to indicate the potential for negative bias in estimates of density based on using both radiotelemetry and presence of scats containing radiotracers to determine marked animals at risk (M′).

The estimated densities of river otters at Knight Island and Esther Passage broadly overlapped from June through August using either of the described methods for determining marks at risk to recapture (M and M′; Fig. 2). There was a 93% probability

TABLE 2.—*River otters available for "recapture" via scat censuses in Esther Passage, Prince William Sound, Alaska. Presence during the census in the month shown is indicated by "R" for radio and the number of scats bearing that isotope combination.*

Sex	Release	Radiotracer	Census month			
			June	July	August	September
Male	23 May	^{54}Mn	7	5	9	R8
Male	23 May	^{65}Zn	9	9	2	R9
Male	25 May	^{60}Co	1	R3	R5	R2
Male	26 May	^{54}Mn, ^{65}Zn		R2	R5	R3
Male	31 May	^{57}Co	2	R1	R4	R0
Male	2 June	^{60}Co, ^{65}Zn	8	9	2	
Male	8 June	^{65}Zn, ^{57}Co		2	1	
Female[a]	6 June	^{109}Cd	?	R2	R?	R?
Female	12 June	^{54}Mn, ^{60}Co	R3	R2	R2	

[a] The isotope ^{109}Cd was not reliably detectable. Scats from the single otter carrying this radiotracer probably are undercounted.

TABLE 3.—*Summary of marked river otters (M), captures (C), and recaptures (R) via scat recoveries from otter latrines at Knight Island and Esther Passage, Prince William Sound, Alaska, during summer 1990. M and R are number of marked river otters and "recaptured" scats when only the radiolocation of river otters was used to confirm an animal's presence in a study area. M′ and R′ are number of marked river otters and "recaptured" scats when both radiolocation of river otters and presence of scats were used to confirm an animal's presence in a study area. U′ is the number of river otters for which no accounting could be made by either method and, therefore, may have been "at risk" to scat recapture, but was not detected. U′ represents the potential for bias in population estimates that employed M′ and R′.*

Study area and month	C	M	R	M′	R′	U′
Knight Island						
June[a]	129			12	42	
July	187	9	25	11	58	2
August	113	6	18	11	40	2
September	138	9	24	12	45	1
Esther Passage						
June[a]	143			6	27	
July	134	4	9	7	32	1
August	135	4	16	8	31	0
September	88	6	24	7	25	1

[a] All river otters released and known to be alive at the start of the experiment in June were considered "at risk" in that month, but no telemetry searches were conducted.

that density of river otters at Esther Passage declined, either by emigration or mortality, between the August and September censuses, and 99% probability of a decline between July and September (Fig. 2b). None of the density estimates from Knight Island was significantly different over the summer. The probability that density of river otters at Esther Passage was higher than at Knight Island was never >0.86 and approached 0.00 in September (Table 4).

Substantial differences were present between estimates of density based on radiolocated otters alone and those based on otters detected by either radiosignals or radiotracer-labeled scats in July ($P > 0.99$) and September ($P = 0.945$) at Knight Island, and in July ($P = 0.99$) at Esther Passage (Fig. 3). Probability values are given to illustrate the likely bias in N′, but the data used in the comparison are not independent. Although using scats labeled with radiotracers to augment marks at risk (M′) and recaptured scats (R′) increases the precision of the estimates, these comparisons (Fig. 3) suggest that the density estimates (N′) can be negatively biased. Nonetheless, comparisons between Knight Island and Esther Passage still may be valid if the bias is the same at both areas.

Problems arose in the interpretation of isotope combinations in scats. Isotope ^{109}Cd was almost undetectable; it occurred only rarely by itself or in combination with other isotopes even though several otters with ^{109}Cd were active, especially at Knight Island (Tables 1 and 2). Scats labeled with ^{54}Mn were recovered at opposite ends of the study area at Knight Island, recoveries consistent with the home ranges of two otters labeled with ^{54}Mn and with ^{54}Mn + ^{109}Cd. Similar separation of home ranges was evident for animals with ^{65}Zn + ^{54}Mn, and ^{65}Zn + ^{54}Mn + ^{109}Cd. In instances where two animals differed only by their ^{109}Cd isotope label, and one or both could not be accounted for, scats with these questionable labels were considered "unmarked." These conflicts only occurred at Knight Island, where ^{109}Cd was used commonly in combination with other isotopes. Otters containing only ^{109}Cd were excluded from the analysis on both areas.

There also was evidence of cross contamination of scats, but at a low level. Of 299 scats that contained radiotracers, 7.7% included trace amounts of one isotope in combination with high amounts of one or two others. In these cases, the label occurring at low levels was considered to be a contaminant. In three cases, a combination of isotopes was found that did not occur in any experimental animal. In those instances, the volume of scat usually was above the noted average, and the combi-

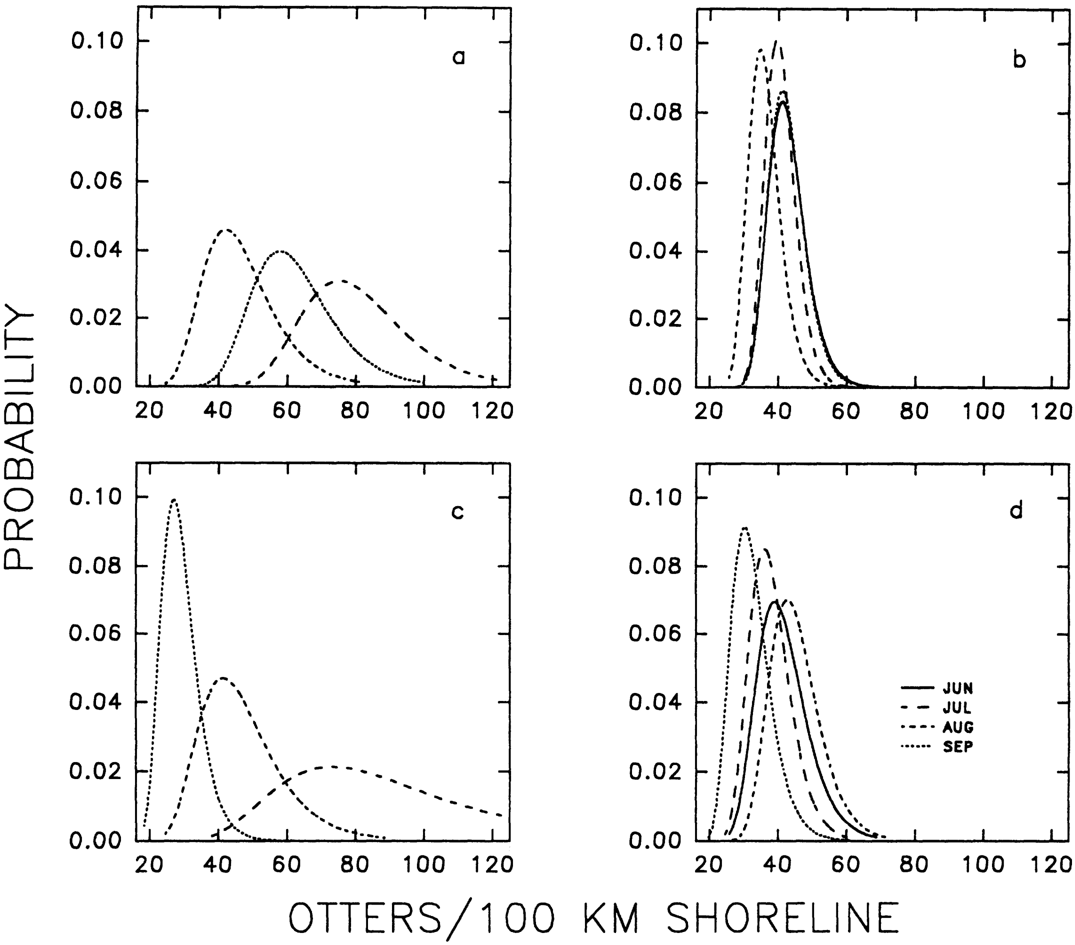

FIG. 2.—Probability distributions of density of river otters at Knight Island (a and b) and Esther Passage (c and d). Parts a and c are based solely on animals located by VHF radiosignal to estimate marks at risk to recapture (M) and are considered relatively unbiased. Estimates using both VHF signal and presence of radiolabeled scats to determine marks at risk (M′) are shown in b and d.

TABLE 4.—*Estimated mean density of river otters per 100 km coastline (with 95% confidence intervals) and estimated probabilities that density of river otters is greater at Esther Passage (unoiled) than at Knight Island (oiled), Prince William Sound, Alaska, 1990. Estimates based solely on the presence of radiolocated river otters as marks at risk to recapture (N) are contrasted to estimates based on using both the radiolocated river otters plus river otters whose presence was determined by detection of radiotracers in recovered scats (N′).*

	Knight Island		Esther Passage		*P* ($N_{EP} > N_{KI}$)	
Month	N	N′	N	N′	N	N′
June		42 (32–56)		41 (28–60)		0.44
July	79 (53–113)	40 (32–51)	80 (44–124)	37 (27–53)	0.52	0.35
August	45 (29–74)	36 (27–47)	45 (28–76)	44 (32–63)	0.500	0.86
September	61 (42–92)	42 (32–55)	28 (20–42)	32 (22–47)	0.002	0.10

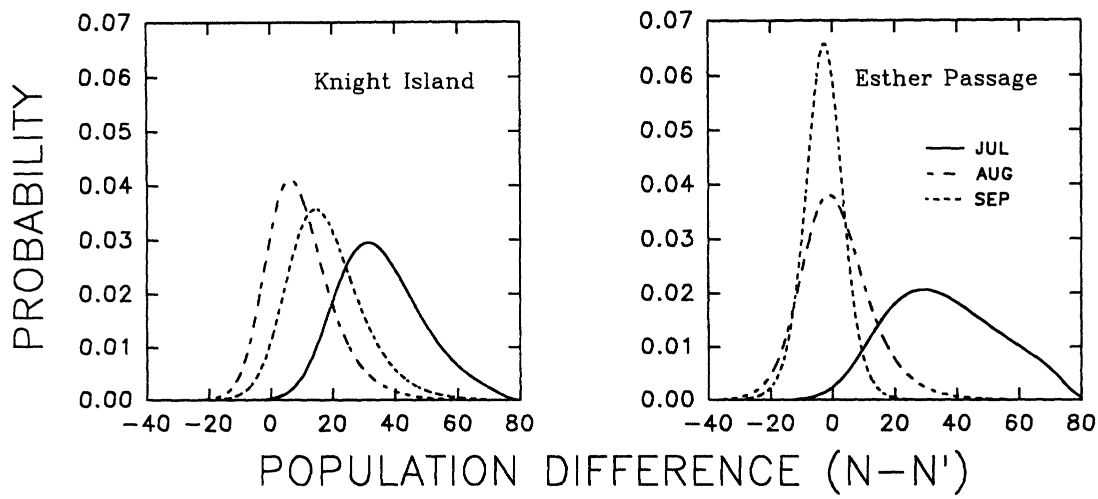

FIG. 3.—Probability distribution of differences between population estimates (N − N′) determined using VHF radiotelemetry (N) or a combination of radiotelemetry and presence of radiolabeled scats (N′) to determine marks at risk to recapture (M and M′) at Knight Island and Esther Passage.

nation was consistent with the presence of scats from two otters known to frequent those latrines. The bias resulting from excluding such scats from the analysis was considered more serious than miscounting the scat as one or two labeled scats; these samples were considered two scats.

DISCUSSION

The impetus for this study was the need to assess the effects of oil from the *Exxon Valdez* on populations of marine river otters, a species heavily dependent on the intertidal and subtidal environment that was contaminated on Knight Island. In principle, an assessment of impact based solely on an assessment of these two populations of river otter would be flawed by lack of replication and lack of prior estimates of the population size of river otters in the two areas (Skalski and Robson, 1992). Due to the cost of deploying such a remote field operation and the large home ranges of individual otters, these problems could not be avoided. A large difference in population size in the two areas would support evidence from other studies (Duffy et al., 1993, in press; Bowyer et al., in press) for effects of the oil spill on populations of river otters, but this was not found.

A continued impact from July to September 1990 might have been detected as a decline at Knight Island while the population at Esther Passage remained stable. Because the statistical power of our comparisons is relatively low, effects capable of causing a detectable decline in density in only 2 months, over 1 year after the oil spill, probably would have decimated the population before the study began. That there was no measurable decline at Knight Island is not strong evidence against an oil-related decline at Knight Island, particularly if initial effects were short-lived or if long-term effects of the oil spill were too subtle to cause a dramatic decline in the population during summer 1990. Subtle effects of the oil spill have been detected on the condition and health of otters (Duffy et al., 1993, in press), on their diet (Bowyer et al., in press), and on their use of habitats (R. T. Bowyer et al., in litt.). However, long-term study of trends in density of river otters would be needed to complement those findings.

As in previous studies of densities of river otters in marine environments, our estimates were subject to several possible sources of bias. Unlike previous studies, however, some assessment of bias is possible. Violations of mark-recapture assumptions fall broadly into two categories; recognition of marks and differences in catchability among marked and unmarked animals. In this application, the assumption that the population was closed to migration also could be questioned. Nonetheless, for the purpose of comparing two areas, our primary concern was that whatever bias was present be similar on both areas.

One source of negative bias in these mark-recapture estimates, related to recognition of marks, is the possible contamination of unlabeled scats. This possibility was indicated by three scats that contained combinations of radiotracers that were not implanted in any otter and the 7.7% of labeled scats that contained low amounts of one or more radiotracers in combination with high amounts of one or more others. This suggests that some unlabeled scats could acquire traces of a radiotracer either from the ground where another labeled scat had been removed or possibly from urine or anal-gel marking by another labeled otter. The bias from this source is probably low, if the cross-contamination rate of 7.7% is considered a good estimate. Detailed quantitative analysis of the specific energy levels per unit volume of each scat might allow discrimination of contaminant isotopes from those present in the otter depositing a scat, but this analysis would be time-consuming given the low levels of radioactivity being measured. Because the proportion of marked to unmarked otters in both populations was similar, the bias from this source is expected to be similar between study areas and should not affect the comparison of densities of river otters.

The use of radiolocations alone to determine presence of marked river otters provides the most unbiased method of determining marks at risk (M), because the scat-recovery methods should have no effect on the likelihood of finding scats of radioimplanted otters relative to those of otters without transmitters. Hence, marked and unmarked animals should be equally "catchable" in the scat collections. The transmitters, however, were not always detectable, either because otters were in dens or other locations that attenuated radiosignals or because of temporary movements outside our study areas during telemetry surveys. Such temporary movements were considered unlikely in July and August; aerial surveys that encompassed areas well outside the study areas failed to locate all otters subsequently known to be alive. Using all otters detectable by either radios or radiotracers greatly enhanced the precision of the estimates. The resulting bias from undetected otters that were actually at risk to recapture in the scat censuses is a function of the number of otters not detected, which ranged from one to two at Knight Island and from zero to one at Esther Passage, or 8–17% and 0–12%, respectively, of the total possible marks in the two areas. The estimates of density based on use of both detection methods could be biased downward by these amounts. Differences between results from the two methods (Fig. 3, Table 4) show that lower estimates resulted from using the augmented value of marks (M′) on both areas in July and at Knight Island in September. The potential for bias, as indicated by the number of missing otters, was similar in both areas, being slightly greater in the dataset from Knight Island.

Home ranges of several river otters extended beyond the boundaries of the study areas, and the total range of marked animals in the period of each population census could not be determined from one or two telemetry surveys. Effects of this extension on estimated size of the population depend on the extent to which the marked animals (M) used areas outside the study area during the census period. These animals would be at less risk of depositing scat on the censused latrines and lower the number of recaptures (R) and captures (C) by the same amount. This would cause a positive bias in the population estimate. Similar movements by unmarked otters would have little or no effect when the population estimate is considered as density. Otters are represented in captured scats (C) in proportion to the number of total scats that were deposited on the study area, effectively adding up fractional animals according to their use of the study area.

The difference in bias between study areas caused by migration may depend on differences in the shapes of the coastlines as well as the locations and relative sizes of home ranges of otters in the two areas. We believe that the potential for positive bias is higher in Esther Passage. A higher proportion of marked animals in Esther Passage occupied home ranges near the border of the study areas, and several were known to move outside the boundary of the study area, particularly at the Port Wells end of Esther Passage. Also, deposition of scats in the central part of Esther Passage was lower than at more peripheral sites, indicating movement of otters out of the central area and probably movement beyond the boundaries of this study area.

Females may be underrepresented in our marked population (Table 1) and, if females deposit scats in latrines less often than do males, females may be underestimated by our mark-recapture analysis. Use of latrines may differ between sexes, but this would have a large effect on the population estimates only if the composition of the marked population differs substantially from that of the total population. Also, the larger size of home ranges for males (R. T. Bowyer, in litt.) may affect the degree to which the assumption of population closure is violated. The sex ratio of marked otters in both study areas was skewed toward males, and few family groups (females with young) were sighted in either area. Differences between areas in the resulting bias are likely only if sexual differences in use of latrines also differed markedly between areas.

The only significant difference in the size of populations of river otters by month or area occurred in Esther Passage during September 1990. That a real change occurred is supported by the drop in rate of scat deposition in Esther Passage in September (Table 4). No unusual mortality was evident in the marked populations in either area. Because the heaviest use of latrines occurred at the periphery of the study area at Esther Passage, movements by otters out of the study area were more likely there than at Knight Island. Several marked animals temporarily moved beyond the borders of the study area particularly at Esther Passage. Also, otters traveled together in large groups (five to 18 animals per group) in both 1990 and 1991, so that the absence of one large group could cause a significant but temporary decline in density.

Although estimates of population density presented here are likely to be biased low, there are few comparable estimates of density for *L. canadensis* in marine environments, and these contain more serious bias. Woolington (1984) used the minimum number of otters known to inhabit the range of several family groups of otters in Kelp Bay, Alaska, to estimate a density of 0.85 animals/km of shoreline. An estimate of 0.5 animals/km of shoreline, similarly based on the home ranges of radiotracked river otters on Prince of Wales Island, Alaska, was made by Larsen (1983, 1984). Both estimates contain no basis for estimating the probability of sighting or detecting individual otters; so strong negative bias is probable in those estimates. Woolington's (1984) study may not be representative of densities of river otters due to his intentional selection of a study area that included certain family groups. Kruuk et al. (1989) estimated density of *L. lutra* in Shetland based on density of dens and regression estimation of animals per den. They obtained estimates of 1.6 animals/km on coastline adjacent to peatland and 0.94 animals/km on coasts of small islands, which also were mostly peatland. The reported standard errors of these estimates were ca. 15%, but this is negatively biased because no account was taken of the regression error in estimating number of animals per den. Density of marine river otters in Prince William Sound appears to be ca. 0.28–0.80 animals/km, based on the most unbiased point estimates of Table 4 (N). These estimates are similar to estimates of marine river otters in southeastern Alaska, but the different methods used should be considered. Negative bias is likely for all of the Alaskan estimates, but estimates based on mark-recapture methods are more nearly unbiased than what are essentially enumeration methods (Pollock et al., 1990) used in the studies in southeastern Alaska (Larsen, 1983, 1984; Woolington, 1984).

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