Distribution and abundance of humpback whales (*Megaptera novaeangliae*) and other marine mammals off the northern Washington coast

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Abstract—We examined the summer distribution of marine mammals off the northern Washington coast based on six ship transect surveys conducted between 1995 and 2002, primarily from the NOAA ship *McArthur*. Additionally, small boat surveys were conducted in the same region between 1989 and 2002 to gather photographic identification data on humpback whales (*Megaptera novaeangliae*) and killer whales (*Orcinus orca*) to examine movements and population structure. In the six years of ship survey effort, 706 sightings of 15 marine mammal species were made. Humpback whales were the most common large cetacean species and were seen every year and a total of 232 sightings of 402 animals were recorded during ship surveys. Highest numbers were observed in 2002, when there were 79 sightings of 139 whales. Line-transect estimates for humpback whales indicated that about 100 humpback whales inhabited these waters each year between 1995 and 2000; in 2002, however, the estimate was 562 (CV=0.21) whales. A total of 191 unique individuals were identified photographically and mark-recapture estimates also indicated that the number of animals increased from under 100 to over 200 from 1995 to 2002. There was only limited interchange of humpback whales between this area and feeding areas off Oregon and California. Killer whales were also seen on every ship survey and represented all known ecotypes of the Pacific Northwest, including southern and northern residents, transients, and offshore-type killer whales. Dall's porpoise (*Phocoenoides dalli*) were the most frequently sighted small cetacean; abundance was estimated at 181–291 individuals, except for 2002 when we observed dramatically higher numbers (876, CV=0.30). Northern fur seals (*Callorhinus ursinus*) and elephant seals (*Mirounga angustirostris*) were the most common pinnipeds observed. There were clear habitat differences related to distance offshore and water depth for different species.

Manuscript submitted 25 September 2003 to the Scientific Editor's Office.

Manuscript approved for publication 4 June 2004 by the Scientific Editor.

Fish. Bull. 102:563–580 (2004).

Marine mammals have had an important role in the history of the Olympic Peninsula for centuries. Many species, including sea otters (*Enhydra lutris*), harbor seals (*Phoca vitulina*), humpback whales (*Megaptera novaeangliae*), and gray whales (*Eschrichtius robustus*) were hunted by the Makah tribe (Swan, 1868; Huelsbeck, 1988). Much later, modern whalers targeted humpback whales in this region from stations at Bay City, Washington (1911–25, Scheffer and Slipp, 1948), and southern Vancouver Island, British Columbia (1905–43, Gregr et al., 2000). A small aboriginal hunt for gray whales resumed in these waters in 1998, and the Makah killed one gray whale in May 1999. Since the end of commercial whaling, marine mammals have been afforded protection under the Marine Mammal Protection Act of 1972. In addition, the waters off the northern Washington coast were designated as the Olympic Coast National Marine Sanctuary in 1994.

A number of studies have documented marine mammals in this region. Some surveys of broader areas have included the waters off northern Washington (Von Saunder and Barlow, 1999; Brueggeman[1]; Green et al.[2]). Species-specific studies also

[1] Brueggeman, J. J. 1992. Oregon and Washington marine mammal and seabird surveys. Final report of OCS Study MMS 91-0093 by Ebasco Environmental, Bellevue, Washington, and Ecological Consulting, Inc., Portland, Oregon, for the Minerals Management Service (MMS), 445 p. MMS, Pacific OCS Region, U.S. Dept. of Interior, 770 Paseo Camarillo, Camarillo, CA 93010.

[2] Green, G. A., M. A. Smultea, C. E. Bowlby, and R. A. Rowlett. 1993. Delphinid aerial surveys in Oregon and Washington offshore waters. Final report for contract 50ABNF200058 to the National Marine Mammal Laboratory, National Marine Fisheries Service, 100 p. Nat. Mar. Mamm. Lab., NMFS, 7600 Sand Point Way NE F/AKC3, Seattle, WA 98115.]

have been conducted on harbor porpoise (*Phocoena phocoena;* Barlow et al., 1988; Osmek et al., 1996; Calambokidis et al.[3]) and, to a limited degree, on humpback whales (Calambokidis et al., 1996, 2000) and gray whales (Darling, 1984; Green et al., 1995; Shelden et al., 2000; Calambokidis et al., 2002). Studies on pinnipeds and sea otters have also been conducted in this region (Jeffries et al., 2003; Jameson et al., 1982, 1986; Kvitek et al., 1992, 1998; Bowlby et al.[4]).

Information on humpback whales is of particular interest because they were the primary species hunted by whalers off Washington in the early 1900s. Since then, little has been known about their movements and distribution in this region. Photo-identification research has helped define the movements and stock structure of the humpback whales feeding off California (Calambokidis et al., 1990, 1996, 2000). Calambokidis et al. (1996) suggested that a demographic boundary exists between humpback whales that feed off the coasts of California, Oregon, and Washington and humpback whales feeding farther north off British Columbia and Alaska. The identity and degree of interchange of the whales that feed in this boundary area have been unclear.

Similarly for killer whales, photo-identification studies have revealed much about whale groups that frequent the inland waters of Washington and British Columbia (Bigg et al., 1990; Ford et al., 1994). Very little is known about their occurrence off the coast, in particular, about the "offshore" groups that are believed to be a distinct race (Ford et al., 1994) that are seen primarily offshore but occasionally also enter inland waterways.

We report here on the summer distribution of marine mammals off the northern Washington coast based on six ship line-transect surveys conducted between 1995 and 2002. These surveys were initiated to understand marine mammal distribution and abundance in the newly designated Olympic Coast National Marine Sanctuary, as well as to collect information on seabirds, oceanographic conditions, and juvenile fish. Each ship survey was conducted between mid-June and late July. Density estimates were made for the two most common species: humpback whales and Dall's porpoise. In addition, photo-identification data gathered during these ship surveys and from supplemental small boat surveys within the same area between 1989 and 2002 provided information on humpback and killer whale movements and stock structure.

Materials and methods

Ship surveys

Generally, ship surveys covered the area between the 20-m isobath and the landward margin of the continental shelf (200-m isobath) from the entrance to Strait of Juan de Fuca to the mouth of the Copalis River to include the boundaries of the Olympic Coast National Marine Sanctuary (Fig. 1). Although the northern extent of these waters is off southern British Columbia (Vancouver Island), the entire overlapping region will be referred to as northern Washington.

Fourteen east-west tracklines were selected, following permanent tracklines established by the NOAA ship *Miller Freeman* in 1989. Tracklines were spaced at 5-nmi intervals and were surveyed each year except in 2002, when only ten lines were surveyed (four southernmost lines were not included). Extra ship time allowed for replicate surveys of the northern survey legs in 1995, a short offshore extension of two lines in 1996 and 2000 (up to 17 nmi in 1986), the addition of three short east-west lines off southern Vancouver Island around La Perouse Bank in 1997, and one additional line that was surveyed south of the study area in 2000 (Fig. 1).

Ship surveys were conducted over a two-week period in late-June and July 1995, 1996, 1997, 1998, and 2000 (Table 1). In 2002, a shorter, one-week survey was done in mid-June. The marine mammal ship surveys were conducted by a single primary observer from the vessel's flying bridge (the sighting platform) with a viewing height of 10 m above the water level. All surveys were conducted from the NOAA ship *McArthur* (55 m) except during 2000, when the naval ship *Agate Passage* (33 m) was used. From these platforms, the primary observer scanned a 180-degree arc encompassing the area ahead of the ship and abeam to either side. Observers used reticle binoculars when possible and obtained measurements of distance to a sighting derived from the angle below the horizon (measured with graded reticles in the binoculars) and the known platform height. For sightings where the species could not be determined by the observer, animals were identified to a general taxonomic level (e.g., unidentified pinniped).

Photo-identification surveys

In addition, photo-identification data were examined that had been gathered within the survey area. Researchers took photographs directly from the survey ship, or from a *Zodiac* rigid-hulled inflatable that was launched when animals were sighted. In 1996, the last two days of vessel time on the *McArthur* were used to photograph whales for identification.

[3] Calambokidis, J., J. C. Cubbage, J. R. Evenson, S. D. Osmek, J. L. Laake, P. J. Gearin, B. J. Turnock, S. J. Jeffries, and R. F. Brown. 1993. Abundance estimates of harbor porpoise in Washington and Oregon waters. Report to the National Marine Mammal Laboratory, National Marine Fisheries Service, 55 p. Nat. Mar. Mamm. Lab., NMFS, 7600 Sand Point Way NE F/AKC3, Seattle, WA 98115.

[4] Bowlby, C. E., B. L. Troutman, and S. J. Jeffries. 1988. Sea otters in Washington: distribution, abundance, and activity patterns. Final report to National Coastal Resources Research and Development Institute, Hatfield Marine Science Center, 2030 S. Marine Dr., Newport, Oregon 97365, 131 p. Cascadia Research Collective, Wash. State Dept. of Wildlife, Olympia, WA.

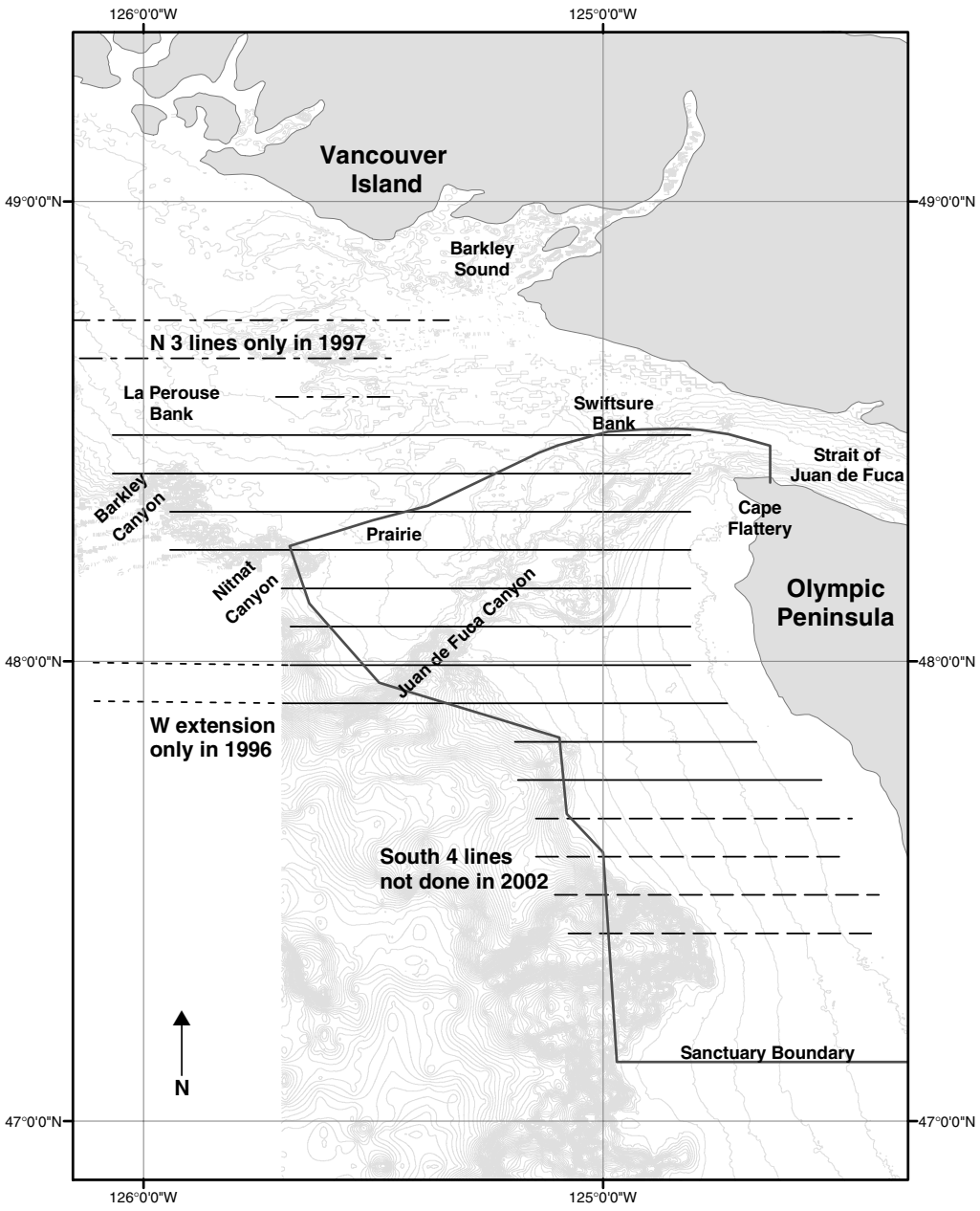

Figure 1

On-effort ship survey tracklines (horizontal lines) off the northern coast of Washington between 1995 and 2002. The Olympic Coast National Marine Sanctuary boundary is delineated and labeled. Dashed and dotted lines show three northern lines surveyed only in 1997, the western extension of two lines surveyed only in 1996, and the southern four lines missed in 2002.

In addition, dedicated photo-identification surveys were conducted by Cascadia Research scientists using a 5.3-m *Novurania* rigid-hulled inflatable that was launched from nearby ports and operated in areas where whales were concentrated. Photo-identification data in the present study includes data collected off the northern Washington coast between 1989 and 2002 (Table 2). It also includes photographs contributed by other researchers and boat operators taken in the area during this time (Table 2).

Generally, photographs were taken with Nikon 8008 35-mm cameras equipped with 300-mm Nikkor telephoto lenses. High-speed black-and-white film (Ilford HP 5+) was pushed 1½ stops so that exposure times were generally 1/1000 or 1/2000 of a second. Identification photographs were taken with standard procedures used

Table 1

Summary of ship survey effort off northern Washington (does not include small boat surveys).

Year	Dates of effort		No. of legs	Effort (h)	nmi on effort	Ship	Observers
	Start	End					
1995	21 Jul	27 Jul	10	46	546	*McArthur*	Troutman, Ellifrit
1996	28 Jun	5 Jul	14	46	540	*McArthur*	Troutman, Ellifrit
1997	9 Jul	18 Jul	17	52	513	*McArthur*	Troutman, Ellifrit
1998	25 Jun	4 Jul	14	55	572	*McArthur*	Troutman, Quan
2000	16 Jun	24 Jun	14	60	589	*Agate Passage*	Rowlett, Nelson
2002	12 Jun	18 Jun	10	32	315	*McArthur*	Troutman, Douglas
All years				291	3075		

Table 2

Photo-identification effort off the coast of northern Washington between 1989 and 2002. These data include whales identified from the ship or small boats launched from the ship, dedicated small boat surveys, and opportunistic photographs taken by others. Unique = number of different animals.

Year	Days IDs obtained			Humpback whales identified				Other sources of photographs
	No.	First	Last	No.	Unique	No. of mothers	No. of calves	
1989	1	1 Oct	1 Oct	1	1	0	0	
1990	3	25 Aug	6 Sep	10	10	1	1	Balcomb/Bloedel[1]
1991	4	23 Aug	4 Sep	14	13	0	0	Balcomb/Bloedel[1]
1993	1	15 Jul	15 Jul	3	3	0	0	
1994	3	25 Jun	15 Jul	20	16	0	0	G. Ellis,[2] R. Baird
1995	7	14 Jul	25 Jul	50	35	4	2	S. Mizroch[3]
1996	9	29 Jun	6 Oct	55	34	1	0	
1997	9	13 Jul	18 Oct	25	23	2	0	
1998	19	28 May	16 Oct	71	48	1	1	V. Deeke, B. Gisborne
1999	28	20 May	20 Oct	103	60	2	0	B. Gisborne
2000	12	2 Jun	4 Oct	56	40	2	1	B. Gisborne
2001	15	8 Jun	5 Oct	59	41	2	1	SWFSC,[4] B. Gisborne
2002	9	13 Jun	5 Sep	41	32	0	0	
Total	120			508	356	15	6	
Unique					191			

[1] Center for Whale Research, P.O. Box 1577, Friday Harbor, WA 98250.
[2] Dept. of Fisheries and Oceans, Pacific Biological Station, Nanaimo, BC, V9T 6N7, Canada.
[3] National Marine Mammal Laboratory, NMFS, 7600 Sand Point Way NE, Seattle, WA 98115.
[4] Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, CA 92037.

in past research (Calambokidis et al., 1990). For humpback whales, photographs were taken of the ventral side of the tail flukes. For killer whales, the dorsal fin and surrounding saddle-patch area were photographed from both sides.

Photographs of individuals were first compared to those identified in the same region. To analyze interchange with other regions, we compared these individuals with existing catalogs to obtain sighting histories. For humpback whales, a catalog was used of over 1000 humpback whales identified since 1986 along the West Coast. The regions used for comparison were Oregon, northern California (Oregon-California border to Pt. Arena), northern central California (Pt. Arena to north of Monterey Bay), southern central California (north of Monterey Bay to Pt. Conception) and southern California (southern California Bight). For killer whales, whales were matched to existing catalogs (Bigg et al., 1987; Ford et al., 1994; Black et al., 1997). All identifications and group determinations were confirmed by one of the authors (DKE) or Graeme Ellis (Dept. of Fisheries and Oceans, Nanaimo, British Columbia).

Data analysis

For ship surveys between 1995 and 2000, position and oceanographic data (including depth, sea surface temperature) logged by the ship's computer were later reconciled with the sighting and effort data recorded by the observers. Sighting positions were analyzed for each species for water depth, distance from shore, distance from shelf edge (200-m depth contour) and sea surface temperature. Data analysis and mapping were conducted by using a geographic information system (GIS) with ArcInfo software (ESRI, Redlands, CA). Data from the shorter 2002 ship survey were included in the summary of sightings but were not available for the analyses of sightings related to oceanographic features.

Line-transect analysis to determine density and abundance was conducted for the two species with more than 30 sightings (humpback whales and Dall's porpoise). We used the program (Distance, version 3.5, Research Unit for Wildlife Population Assessment, University of St. Andrews, St. Andrews, UK) to conduct analyses. For these analyses, we used only effort and sightings from the regular east-west transect lines and did not include on-effort data from opportunistic lines or cross-tracks. We included sightings made by secondary as well as the primary observer. Although whales were reportedly seen out to 6 nmi, we truncated the sightings at 3 nmi for humpback whales and 2.5 nmi for Dall's porpoise. For humpback whales we included 16 sightings of unidentified whales (unidentified mainly because of distance). These were probably humpback whales because the only other large whales that were seen in the surveys were a few gray whales seen close to shore. Distance position data were incomplete for 13 of the 188 whale sightings and 14 of 82 Dall's porpoise sightings; for these the missing value was randomly selected from the observed measurements.

The Distance program was used to select the best model for sighting probability in relation to distance off the transect. We allowed the program to select among models (half-normal, uniform, hazard-rate, and negative exponential) and varying numbers of adjustment terms (cosine and simple polynomials) based on lowest Akaike's information criterion (AIC) score. All years were pooled for the model of sighting probability, but encounter rate and group size were calculated by year. An adjustment to group size was calculated if there was a significant group size bias with distance from the track line, which was not the case for humpback whales but was present in some years (1996 and 1997) for Dall's porpoise.

Area was calculated for abundance estimation based on the zone covered by the regularly scheduled transect lines covered in most years (study area was considered to encompass waters 2.5 nmi north of the northernmost line and 2.5 nmi south of the southernmost line). The only annual adjustment for area was for humpback whales in 2002. Surveys in that year did not cover the southern end of the study area (because of limited ship time), an area with a typically lower abundance of whales. To avoid extrapolating the higher density of whales from the northern portion of the study area to this region, we excluded this missed area from the abundance estimates.

Estimates of abundance for humpback whales were also calculated by using capture-recapture models (Seber, 1982; Hammond, 1986). We used identifications obtained in pairs of adjacent years taken from 1994 to 2002 to generate Petersen capture-recapture estimates. The Chapman modification of the Petersen estimate (Seber, 1982) was used because it was appropriate for sampling without replacement (Hammond, 1986).

Results

In total, there were 706 sightings of 2467 animals over the six ship surveys combined (Table 3). Fifteen different marine mammal species were seen: nine cetacean species, five pinniped species, and the sea otter were identified. Each year, 9 to 12 different species were seen, except in 2002 when only six species were observed. This 2002 survey, although shorter than those of the other years, showed a dramatic change in the species diversity and numbers of animals. We saw many more humpback and Dall's porpoise than in previous years. We also noted the absence of six regularly observed species: harbor porpoise, gray whales, Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), Risso's dolphin (*Grampus griseus*), harbor seals, and California sea lions (*Zalophus californianus*).

Humpback whales

Of the large cetaceans, humpback whales were the most common species seen; there were 232 sightings of 402 animals during ship surveys (Table 3). Largest numbers of humpback whales were seen in 2002, when there were 79 sightings of 139 individuals during the one-week survey. Group sizes ranged from 1 to 8 animals (mean=1.7, SD=1.1). Only six calves were recorded from the ship surveys—probably because it was difficult to identify calves at the distance at which most sightings were made. Of these six sightings of mothers with calves, four sightings were outside the primary areas where other humpback whale groups were seen.

Sightings were concentrated in the northern part of the study area between Juan de Fuca Canyon and the outer edge of the continental shelf, an area known as "the Prairie" (Fig. 2). A small area east of the mouth of Barkley Canyon and north of the Nitnat Canyon where the water depth was 125–145 m had a high density of sightings in all years. A smaller number of humpback whales were also seen on Swiftsure Bank. Sightings in 2002 were not only more numerous but more broadly distributed; sightings were recorded in the areas described above and also farther south and closer to shore than those seen in previous years.

Line-transect estimates for humpback whales were very consistent in the first five surveys (1995 to

Erratum

Erratum: Fishery Bulletin 102(4): p. 568.
Calambokidis, John, Gretchen H. Steiger, David K. Ellifrit, Barry L. Troutman, and C. Edward Bowlby
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Correction: Table 3 should read as follows

Table 3

Summary of marine mammal sightings by year during ship surveys off northern Washington. Opportunistic sightings (nontransect) are included.

	1995		1996		1997		1998		2000		2002		All years	
Species	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals
Baleen whales														
Humpback whale	25	40	54	86	23	44	27	36	24	57	79	139	232	402
Gray whale			1	1	2	3	2	3					5	7
Minke whale	3	3									1	1	4	4
Unidentified whale	4	8	3	3	11	12	1	1	3	3	4	6	26	33
Odeontocetes														
Dall's porpoise	27	72	20	64	16	43	13	46	14	48	25	133	115	406
Harbor porpoise	4	10	11	20	2	5	14	43	7	11			38	89
Pacific white-sided dolphin	4	596	16	149					4	369	4	19	28	1133
Northern right-whale dolphin									1	6			1	6
Risso's dolphin			5	57	1	5	2	11	1	6			9	79
Killer whale	3	16	2	38	2	21	2	5	3	36	2	8	14	124
Unidentified delphinid	6	9	8	56	2	4	3	5			4	18	23	92
Pinnipeds and otters														
Harbor seal	2	2	3	3	2	3	7	7	1	1			15	16
Elephant seal	6	6	10	10	2	2			2	2			20	20
California sea lion							1	1	3	3			4	4
Steller sea lion							3	5	1	1			4	6
Northern fur seal	6	6	5	5	1	2	9	9	1	1	6	6	28	29
Sea otter							3	3					3	3
Unidentified pinniped	4	4	3	3	1	2	4	4	1	1			13	14
Total sightings	94	772	141	495	65	146	91	179	66	545	125	330	582	2467

Table 3

Summary of marine mammal sightings by year during ship surveys off northern Washington. Opportunistic sightings (non-transect) are included.

	1995		1996		1997		1998		2000		2002		All years	
Species	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals	No. of sightings	No. of animals
Baleen whales														
Humpback whale	25	40	54	86	23	44	27	36	24	57	79	139	232	402
Gray whale	1	1	2	3	2	3					5	7		
Minke whale	3	3	1	1	4	4								
Unidentified whale	4	8	3	3	11	12	1	1	3	3	4	6	26	33
Odontocetes														
Dall's porpoise	27	72	20	64	16	43	13	46	14	48	25	133	115	406
Harbor porpoise	4	10	11	20	2	5	14	43	7	11		38	89	
Pacific white-sided dolphin	4	596	16	149					4	369	4	19	28	1133
Northern right-whale dolphin					1	6		1	6					
Risso's dolphin	5	57	1	5	2	11	1	6		9	79			
Killer whale	3	16	2	38	2	21	2	5	3	36	2	8	14	124
Unidentified delphinid	6	9	8	56	2	4	3	5			4	18	23	92
Pinnipeds and otters														
Harbor seal	2	2	3	3	2	3	7	7	1	1			15	16
Elephant seal	6	6	10	10	2	2	2	2			20	20		
California sea lion	1	1	3	3			4	4						
Steller sea lion	3	5	1	1			4	6						
Northern fur seal	6	6	5	5	1	2	9	9	1	1	6	6	28	29
Sea otter	3	3	3	3										
Unidentified pinniped	4	4	3	3	1	2	4	4	1	1			13	14
Total sightings	94	772	141	495	65	146	91	179	66	545	125	330	706	2467

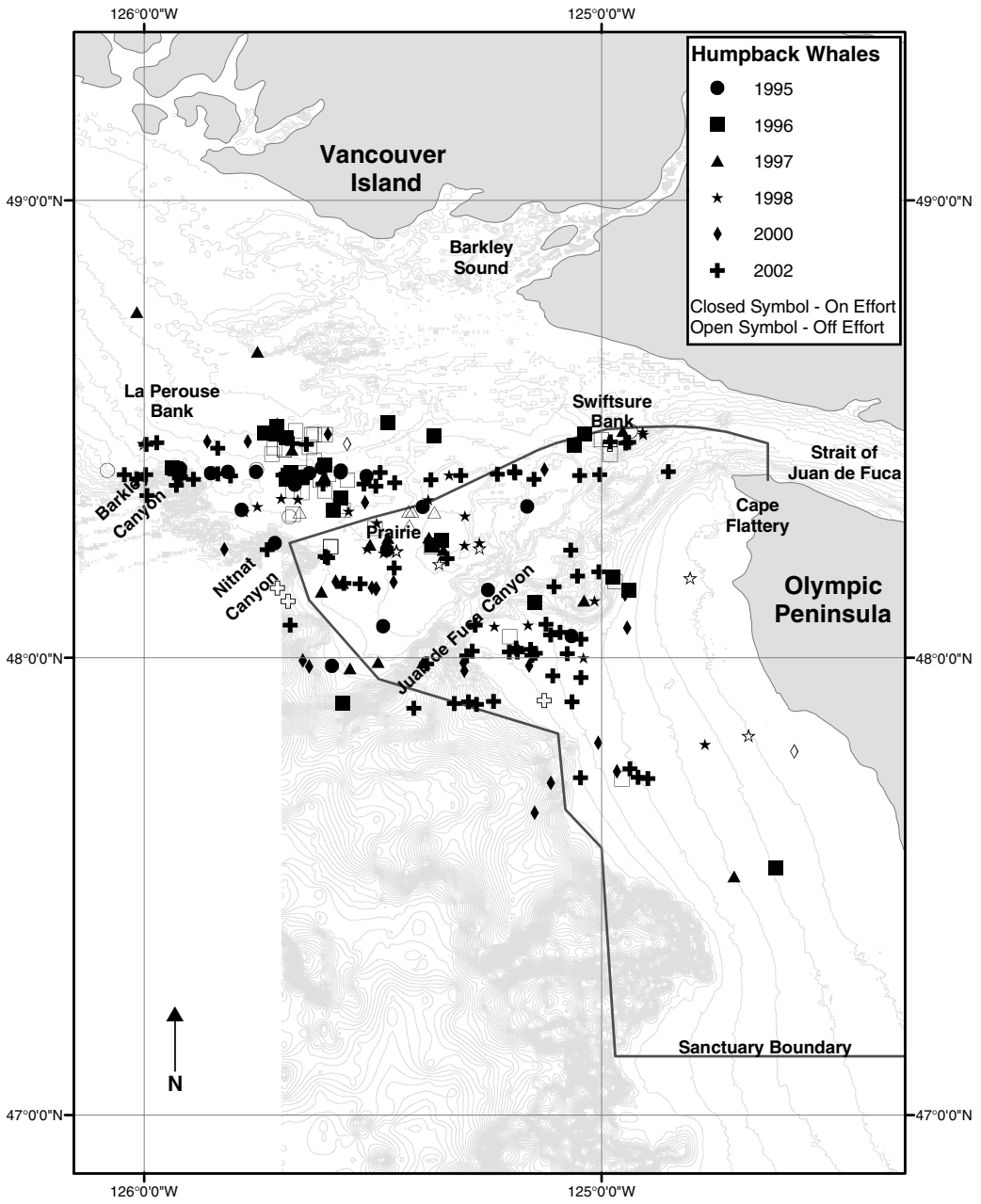

Figure 2

Locations (by year) for humpback whales (*Megaptera novaeangliae*) seen during ship surveys off the northern Washington coast between 1995 and 2002.

2000, Table 4, Fig. 3). The encounter rate of groups (0.046–0.053 sightings per nmi), density (0.034–0.050 whales per nmi^2), and abundance (85–125 individuals) were similar among these years. These data indicate that about 100 humpback whales used the study area during this period.

The sighting rate of humpback whales was dramatically higher in 2002 than in all previous years and was reflected in the line-transect estimates (Fig. 3). Estimated density (0.23 whales per nmi^2) was more than four times higher than any previous year. Applying this density to only the reduced area surveyed in 2002 (1953 instead of 2505 nmi^2) still yielded much higher estimates of abundance (562, CV=0.21) than in any previous year. These higher abundance estimates could not have been an artifact of random variation; the lower bound of the 95% confidence interval for the 2002 estimates was well above the upper confidence interval of any of the previous years (Table 4).

Of the humpback whales photographed during small boat surveys off the northern Washington-BC border between 1989 and 2002, 508 individuals were success-

Table 4

Results of line-transect analysis for humpback whales off northern Washington. On-effort sightings of humpback and unidentified large whales made during regular transects (not including deadheads [areas between transect lines] and opportunistic sightings) within 3 nmi of ship were used. Best detection model fit (AIC scores) was a negative exponential with 1 cosine adjustment yielding $f(0)=1.05$. Effective strip width was 0.95 nmi with CV=0.09.

Year	Sightings n	Survey effort		Encounter rate	Group size	Density (per nmi^2)	Area (nmi^2)	Estimated abundance	CV	95% Conf. int.	
		lines	nmi							lower	upper
1995	23	58	438	0.053	1.48	0.041	2505	102	0.33	54	193
1996	24	59	474	0.051	1.54	0.041	2505	103	0.33	55	193
1997	26	92	493	0.053	1.62	0.045	2505	112	0.3	63	199
1998	20	62	432	0.046	1.40	0.034	2505	85	0.31	47	155
2000	23	70	504	0.046	2.09	0.050	2505	125	0.32	67	234
2002	72	43	305	0.236	1.81	0.224	1953	562	0.21	375	841
Total	188	384	2646								

fully identified of which 191 were unique individuals (Table 2). Of these 191, 83 (44%) had been seen in this area in more than one year within this time period. The proportion of animals seen more than one year changed over the course of the study (Fig. 4). The proportion of whales identified each year that had been seen in others years decreased annually (Fig. 4, regression $r^2=0.63$, $P=0.002$); the most dramatic drop occurred between 1998 and 1999.

Photographs of humpback whales documented animal movements within the study area and provided some insight into possible reasons for the high sighting rates during the 2002 ship surveys. On two occasions, the same humpback whale was identified on different days in a slightly different area and represented a duplicate sighting of this animal from the ship survey. It is possible that shifting humpback whale distribution during the course of the 2002 survey could have occurred in a manner that resulted in the same animals being encountered multiple times and that elevated the sighting rate and line-transect abundance estimate (Fig. 3). We cannot test this hypothesis because other animals may have shifted in a manner that they avoided being detected at all.

Abundance of humpback whales from capture-recapture models yielded estimates of 89 to 343 whales (Table 5, Fig. 3). These estimates tended to increase over the course of the study from a low of 89 whales for 1994–95 to a high of 343 for 2000–2001 and 230 for 2001–2002 (regression $r^2=0.60$, $P=0.02$). There was fairly good agreement between the capture-recapture and line-transect estimates until 2002 (Fig. 3).

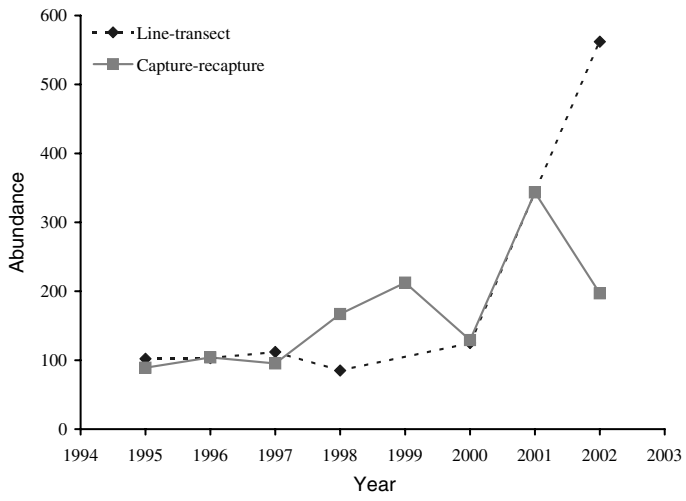

Figure 3

Line-transect (dashed line) and capture-recapture (solid line) estimates for humpback whale (*M. novaeangliae*) abundance between 1995 and 2002.

A total of 17 of the 191 (9%) whales that we identified off northern Washington had also been photographed off California and Oregon (Table 6). Interchange of whales seen off northern Washington and other feeding areas to the south decreased as distance among feeding areas increased. About 10% (10 of 105) of the whales that were identified off Oregon were also photographed off northern Washington. This rate of matching dropped below 3% (8 of 313) off northern California and continued to decrease to no interchange seen for whales photographed off southern California.

The proportion of whales that were seen in areas to the south appeared to change over the course of the study. From 1989 to 1998, when resighting rates between years within our study area were highest, we also had a higher proportion of interchange with feeding areas to the south (13 of 109 whales or 12%). From 1999 to 2002, after resightings within our region decreased, there was also a decrease

Table 5

Estimates of humpback whale abundance (Est.) off northern Washington obtained with the Petersen capture-recapture model. Each estimate was based on the identifications obtained (n) in each of two adjacent years.

	Sample 1		Sample 2				
Period	Year	n	Year	n	Match	Est.	CV
1994–95	1994	14	1995	35	5	89	0.27
1995–96	1995	35	1996	34	11	104	0.19
1996–97	1996	34	1997	21	7	95	0.24
1997–98	1997	23	1998	48	6	167	0.28
1998–99	1998	48	1999	60	13	213	0.19
1999–2000	1999	60	2000	31	14	129	0.16
2000–01	2000	40	2001	41	4	343	0.36
2001–02	2001	41	2002	32	5	230	0.32

in the proportion of these whales that had also been seen off California and Oregon (7 of 136 whales or 5%). This difference falls just short of statistical significance (χ^2=3.71, P<0.10) but is in the reverse direction from what would be expected if immigration from the south were to increase over time.

Between 1989 and 2002, 15 different mothers were seen with 16 calves (one mother seen with a calf in two different years). Mothers with calves represented 4.2% of the individual whales identified each year (15 of 356 unique annual identifications, Table 2). For each year only a small proportion of the calves were identified because calves raise their flukes less often.

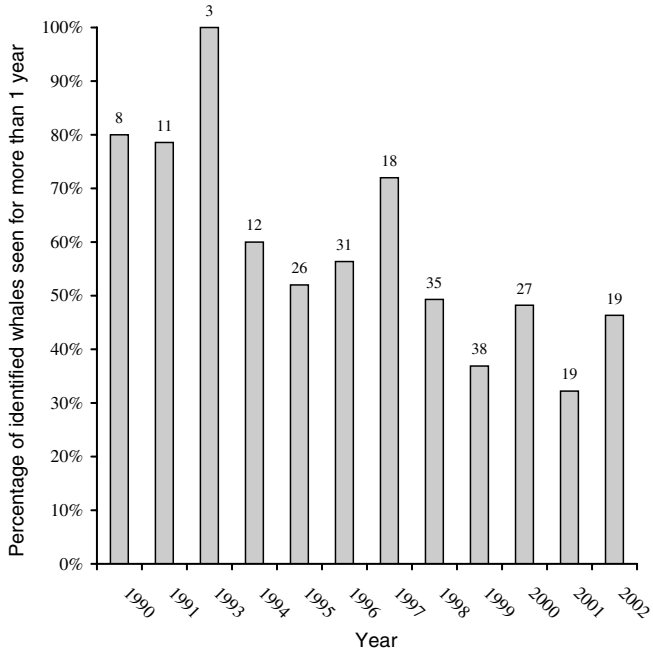

Figure 4

The proportion of humpback whales (*M. novaeangliae*) seen in more than one year during annual surveys off northern Washington from 1989 to 2002.

Killer whales

One other large cetacean species (killer whales) was also seen every year; there were a total of 14 sightings of 124 animals from ship surveys (Table 3). Three of these sightings were of large groups between 20 and 35 animals, and the rest were in groups fewer than ten (14 sightings, mean=8.9, SD=11.2). Killer whales were widely distributed across different habitats; there were sightings of animals both close to and far from shore and in fairly shallow and deep water (Fig. 5).

All three ecotypes of killer whales (namely, 1) southern and northern residents, 2) transients, and 3) offshore residents) were observed off the northern Washington coast. Of the 15 groups identified photographically between 1989 and 2002, there were sightings of animals from the southern resident (2 groups), northern resident (3), transient (5) and offshore (3) groupings (Table 7). Other sightings appeared to be northern residents (1) and offshore (1) animals but the quality of the photographs were too poor for us to be certain. Large groups of killer whales (20–40 animals) were seen on five occasions during small boat surveys.

Dall's porpoises

Dall's porpoises were the most frequently sighted small cetacean; there were 115 sightings of 406 animals and Dall's porpoises were observed every year (Table 3). No

Table 6

Number of humpback whales identified in different regions along the U.S. west coast and the number and percentage of these that matched with northern Washington. For northern Washington, we report the number of whales that were seen in that region in more than one year.

Region	No. of individuals	No. of matches with N. Wash.	% of whales that match with those in N. Wash.
Northern Washington	191	83	43.5%
Oregon	105	10	9.5%
N. California	313	8	2.6%
N. Central California	921	13	1.4%
S. Central California	666	3	0.5%
S. California	303	0	0.0%

Table 7

Summary of killer whale sightings off northern Washington between 1989 and 2002 where identifiable photographs were taken.

Date	No. of animals estimated	Lat. °N	Long. °W	Community	Pod or ID	Comments
13 Sep 89	3	48 23.0	124 48.5	Resident—southern	L10, L28,L41	
15 Jul 94	4	48 20.9	125 20.0	Transient	CA195	
25 Jul 95	7	47 49.8	124 59.5	Transient	CA195	
26 Jul 95	8	47 53.7	125 03.3	Transient	CA20,CA27	
17 Mar 96	6	46 58.2	124 15.7	Resident—southern	L26, L83	outside Grays Harbor
31 Mar 96	7	46 55.0	124 09.7	Transient—probably	T50?	Grays Harbor entrance
5 Jul 96	3	48 13.1	124 55.0	Transient	T185	
6 Jul 96	40	48 26.7	125 43.2	Resident—northern	C, D, G1s, G12s	
15 Jul 97	30	48 19.4	125 09.5	Offshore		
18 Jul 97	10	48 18.3	125 23.6	Offshore	CA105	
10 Aug 97	8	48 21.0	125 34.6	Transient	T36, T99, T36A?, T137?	
27 Aug 98	40	48 28.0	125 17.0	Offshore	O44,O30, O31,O172, O14, O158, O218	
10 Oct 99	30	48 22.0	125 38.1	Resident—northern	I11	
18 Jun 00	20	48 03.8	125 04.3	Probably resident—northern		not southern residents
6 Sep 01	12	47 01.8	124 46.6	Resident—northern	G12s, G17s, G29s	

Table 8

Results of line-transect analysis for Dall's porpoise off northern Washington. All on-effort sightings during regular transects (not including deadheads [areas between transect lines] and opportunistic sightings) within 2.5 nmi of the ship were included. The best detection model fit (AIC scores) was the hazard rate with no cosine adjustment, yielding $f(0)=2.60$. Effective strip width of 0.38 nmi with CV=0.12. The group size for 96–97 was adjusted to account for a significant group size bias with distance from the trackline.

Year	Sightings n	Survey effort lines	Survey effort nmi	Encounter rate	Group size	Density (per nmi^2)	Area (nmi^2)	Estimated abundance	CV	95% Conf. int. lower	95% Conf. int. upper
1995	16	58	438	0.037	2.25	0.100	2505	268	0.32	143	501
1996	14	59	474	0.030	2.65	0.102	2505	255	0.32	138	472
1997	13	92	493	0.026	2.28	0.078	2505	197	0.38	95	405
1998	9	62	432	0.021	2.67	0.072	2505	181	0.49	72	453
2000	13	70	504	0.026	3.46	0.116	2505	291	0.42	132	644
2002	17	43	305	0.056	4.82	0.350	2505	876	0.3	487	1576
Total	82	384	2646								

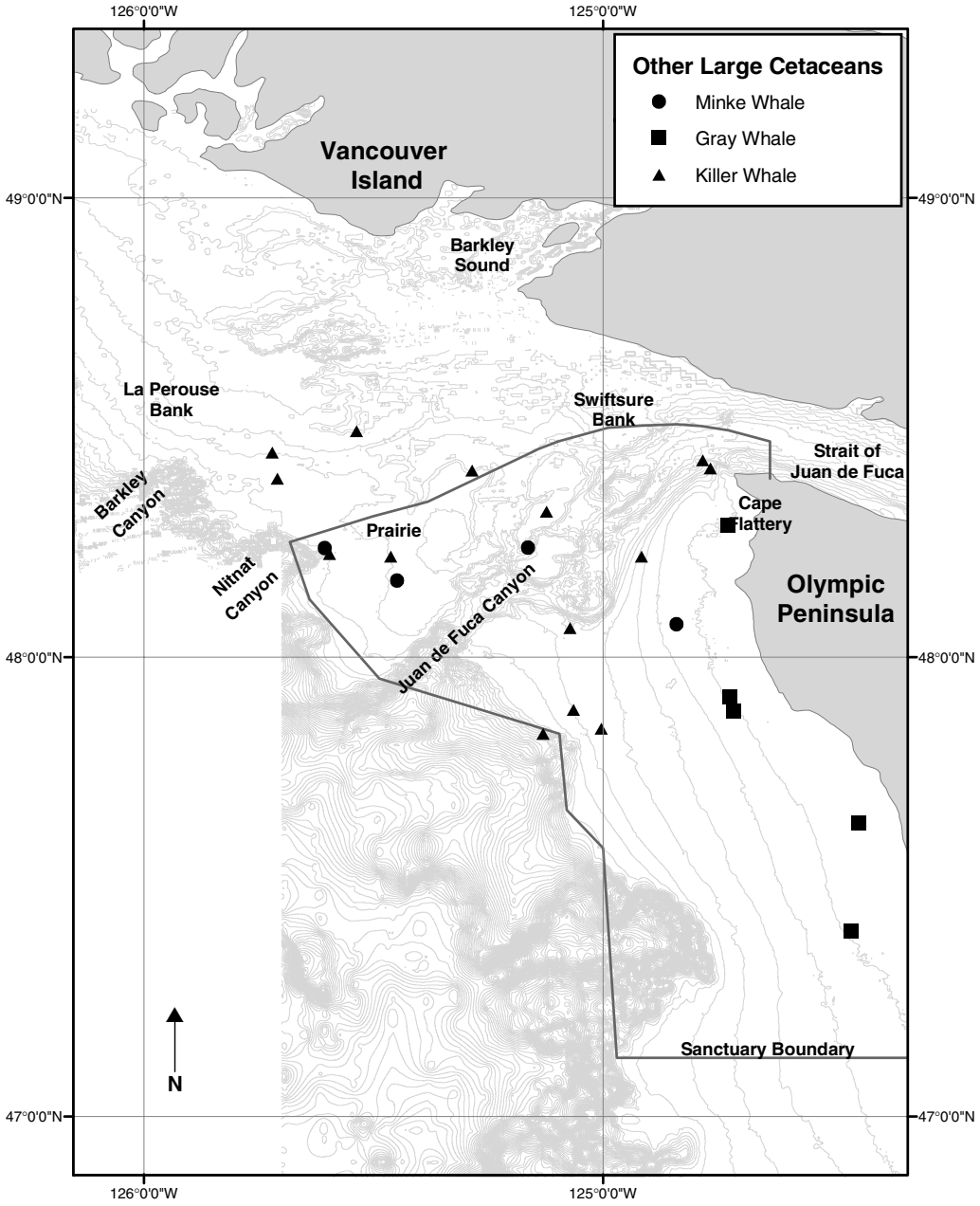

Figure 5

Locations of other large cetaceans seen during ship surveys off the northern Washington coast between 1995 and 2002.

calves were recorded during the surveys. Dall's porpoises were widely distributed in the study area but were not as commonly seen in more shallow coastal waters or in the southern portion of the study area (Fig. 6). Group size ranged between 1 and 12 individuals (mean=3.5, SD=2.2). Harbor porpoises were observed each year (except 2002) and there were a total of 38 sightings for the entire study period. Group size ranged between 1 and 6 individuals except for one sighting of a group of 20 animals (mean=2.3, SD=3.1). The distribution range for harbor porpoises was more restricted to coastal waters and showed only a small overlap with the distribution range for Dall's porpoises (Fig. 6).

Line-transect analysis allowed estimation of Dall's porpoise density and abundance (Table 8). Similar to those for humpback whales, results for Dall's porpoises were fairly consistent for the first five surveys (1995 to 2000): annual abundances were estimated between 181 and 291. For 2002, the encounter rate and corresponding density and abundances increased dramati-

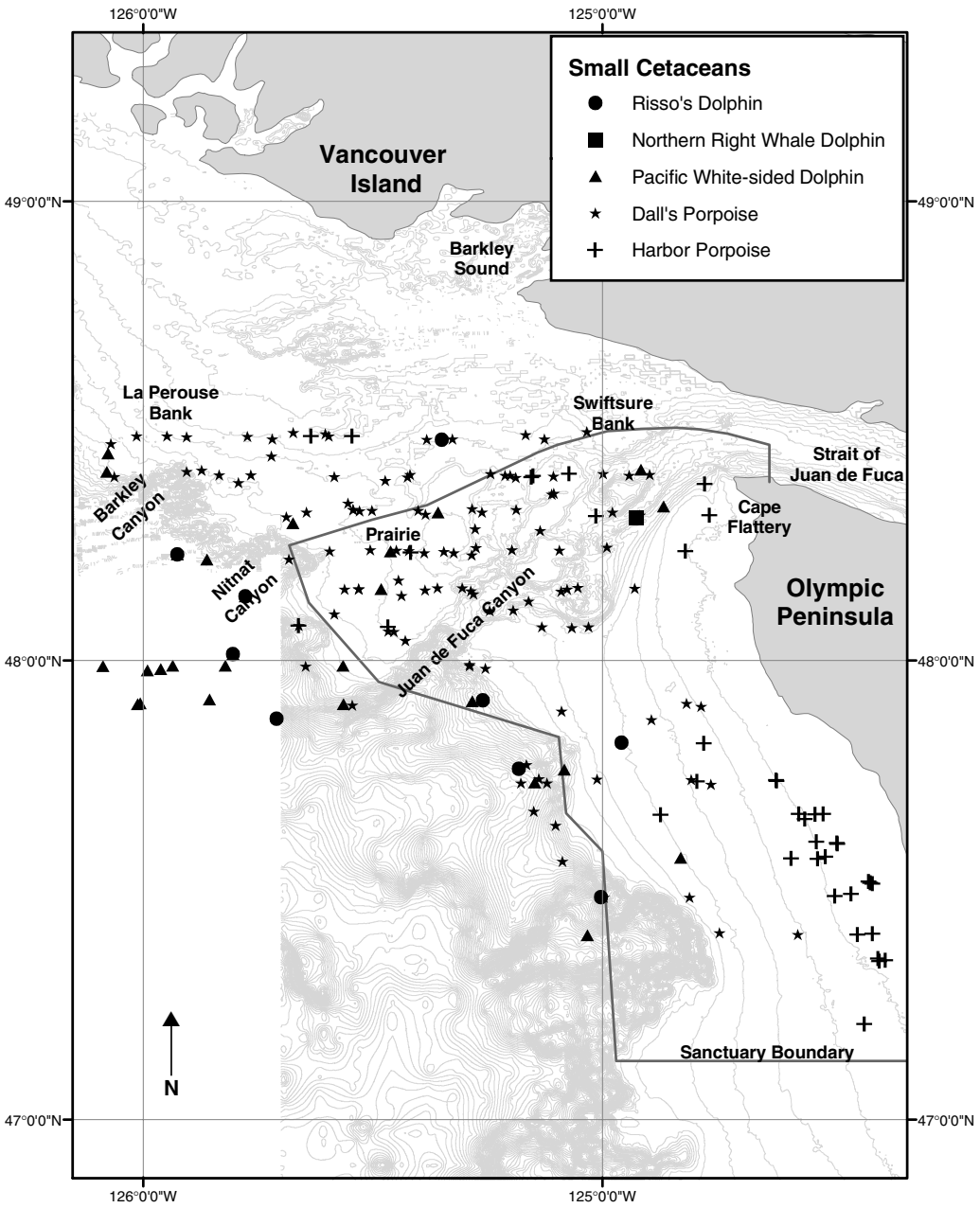

Figure 6

Locations of small cetaceans seen during ship surveys off the northern Washington coast between 1995 and 2002.

cally yielding an estimated abundance of 876 porpoises (CV=0.30, Table 8). Confidence intervals for some of the annual estimates overlapped among years.

Pinnipeds

Pinnipeds were not as frequently observed as cetaceans (Table 3, Fig. 7). The two most pelagic species observed in this region, northern fur seals and elephant seals, were the most commonly seen pinnipeds. Northern fur seals were observed every year except 2002 on a total of 28 occasions. All but one of these sightings were of a single animal. Elephant seals were seen in all years except 1998 and 2002.

Habitat differences

A number of broad habitat patterns emerged for different groups of species based on their association with water depth and distance from shore during the ship surveys from 1995 to 2000 (Table 9, data were not available for 2002). Five species were seen in shallow waters

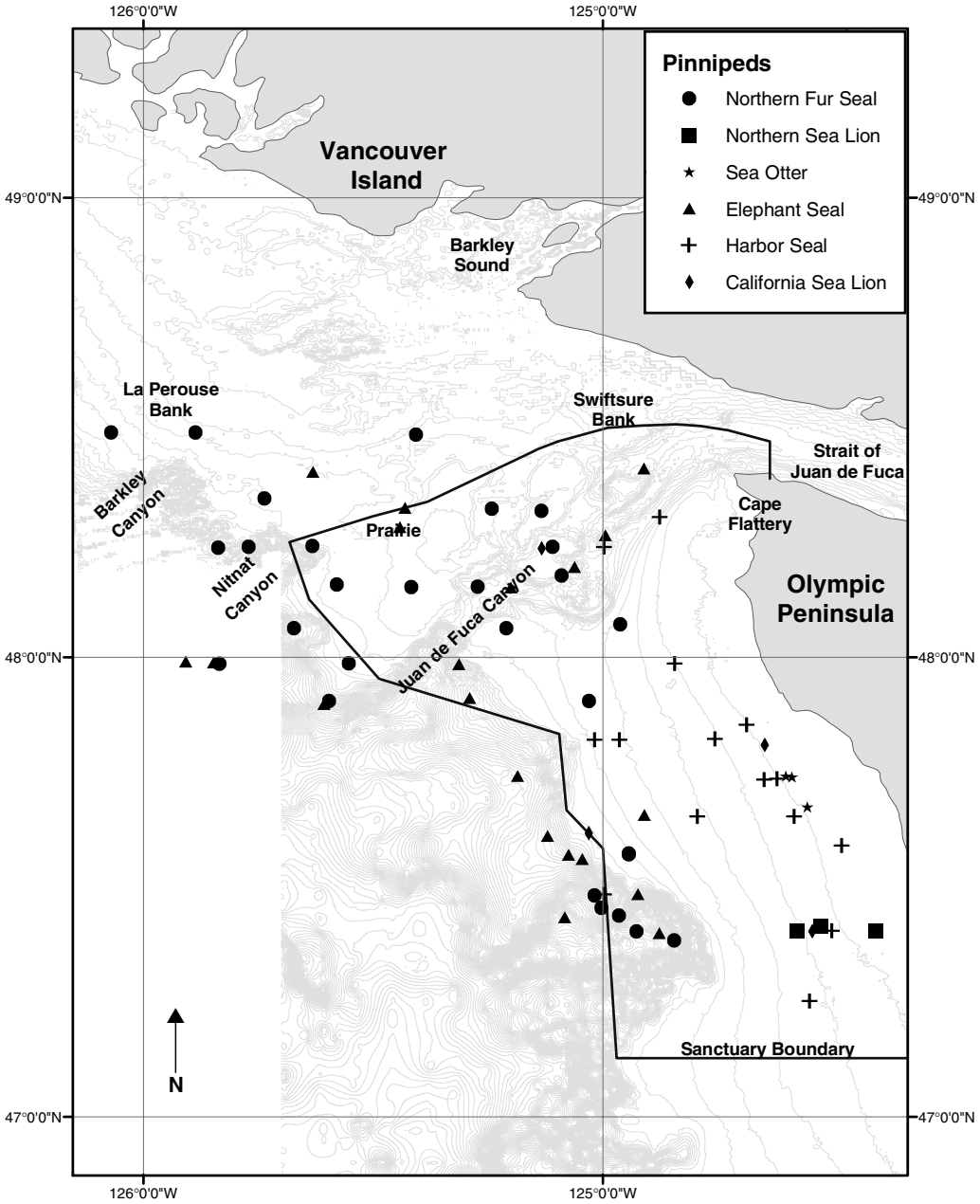

Figure 7

Locations of pinnipeds and sea otters (*Enhydra lutris*) seen during ship surveys off the northern Washington coast between 1995 and 2002.

(<100 m). Gray whales and sea otters were seen in the shallowest water of all species with average water depths of just 20 and 22 m, respectively; they also were the only two species for which sightings averaged less than 10 km from shore. The three other species—harbor porpoise, California sea lions, and northern sea lions (*Eumetopias jubatus*)—were seen in slightly deeper waters (averaging 34 to 91 m) and farther from shore (averaging 11 to 23 km). The five species that were predominantly found at mid-shelf depths (mean depths at 100–200 m) were humpback whales, killer whales, Dall's porpoises, harbor seals, and minke whales (*Balaenoptera acutorostrata*). Species seen far from shore (>40 km) and also in deepest waters (>200 m) included Pacific white-sided dolphins, Risso's dolphins, elephant seals, and northern fur seals. All of these species are known to feed along the continental slope or off the shelf.

Distances from the shelf break for different species did not fall into as clear a pattern as water depth and distance from shore (Table 9). This disparity may be the result of the varied habitat (with canyons cutting through the study area) and the lack of much effort off

Table 9

Summary of habitat and oceanographic parameters for sightings of different species during ship surveys from 1995 to 2000.

	Water depth (m)			Distance from shore (km)			Distance from shelf (km)			Sea surface temp. (°C)		
Species	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
Baleen whales												
Humpback whale	153	144	87	153	43.8	14.9	153	8.4	6.7	101	13.9	1.6
Gray whale	5	20	8	5	5.0	2.0	5	26.1	8.1	5	14.4	1.9
Minke whale	3	106	67	3	41.2	27.7	3	8.0	6.5	3	16.1	0.9
Unidentified large whale	21	189	280	21	40.5	18.4	21	8.0	7.3	18	15.4	1.3
Unidentified whale	1	197	—	1	36.3	—	1	0.1	—	1	13.0	—
Odontocetes												
Dall's porpoise	90	167	118	90	40.1	14.9	90	5.6	5.5	72	14.3	1.7
Harbor porpoise	38	58	70	38	16.3	15.6	38	17.2	11.6	29	13.9	1.7
Pacific white-sided dolphin	24	689	505	24	65.6	25.7	24	8.3	8.7	20	15.0	0.8
Northern right-whale dolphin	1	259	—	1	16.2	—	1	0.7	—			
Risso's dolphin	9	552	310	9	55.4	21.4	9	4.9	5.2	8	14.4	1.3
Killer whale	12	148	58	12	28.8	15.0	12	5.9	4.7	7	14.1	1.1
Unidentified delphinid	19	219	253	19	37.4	17.4	19	5.7	6.7	19	14.5	1.5
Pinnipeds and otters												
Harbor seal	15	102	154	15	17.3	11.0	15	15.5	12.0	14	14.2	1.4
Elephant seal	20	466	370	20	46.2	18.5	20	3.8	5.0	16	14.7	1.8
California sea lion	4	91	74	4	22.8	15.2	4	9.3	14.2	1	13.9	—
Steller sea lion	4	34	18	4	11.3	5.4	4	18.5	6.6	3	13.6	0.4
Northern fur seal	22	382	349	22	47.1	17.1	22	3.1	3.7	21	14.3	1.4
Sea otter	3	22	1	3	8.9	0.5	3	25.5	18.1	3	12.6	0.4
Unidentified pinniped	13	170	144	13	30.5	18.4	13	8.0	8.1	11	14.5	1.9
All sightings	457	205	251	457	39.1	20.1	457	8.4	8.4	352	14.3	1.6

the continental shelf. Despite most of our effort being on the continental shelf, the presence of several deep canyons in addition to the shelf edge, resulted in all species being an average of less than 11 km from the 200 m depth contour. The average surface water temperature for species that were seen also varied and was likely both a function of distance from shore and association with upwelling areas (Table 9). Sea otters were seen in the coldest waters (12.6°C) where they are predominantly found. Among the more offshore species, humpback whales, tended to be seen in colder waters (13.9°C) than most other offshore species, probably because of their association with offshore upwelling areas.

Discussion

Although humpback whales were the most abundant large cetacean seen in our study, their numbers of a few hundred still appear to be substantially lower than numbers found prior to whaling. Commercial hunting of humpback whales occurred in the 1900s from coastal whaling stations in northern California, Washington, and British Columbia. In these areas, thousands of humpback whales were killed over a relatively short time period (less than 10 years) before catches dropped precipitously with the depletion of the population. At the south end of our study area, 1933 humpback whales were taken from a station at Bay City (in Grays Harbor), Washington, from 1911 to 1925 (Scheffer and Slipp, 1948). To the north, 5638 humpback whales were taken from British Columbia stations from 1908 to 1967, of which 60% (3393) were taken from 1908 to 1917 from the two southernmost whaling stations on Vancouver Island closest to our study area (Gregr et al., 2000; Nichol et al., 2002). Additionally, 1871 humpback whales were taken from two stations in northern California from 1919 to 1926 (Clapham et al., 1997). Although these hunts encompassed areas larger than our study area, the number killed in short periods dwarfs even the sum of our abundance estimates for Washington and British Columbia and the estimate of under 1000 whales estimated in the 1990s for California, Oregon, and Washington (Calambokidis and Barlow, 2004). Moreover, humpback whales have not returned to some of the areas where they were once found prior to commercial

whaling; humpback whales were commonly observed in the inside waters of Washington and British Columbia (Scheffer and Slipp, 1948; Webb, 1988) and have not returned to these areas in any numbers (Calambokidis and Steiger, 1990).

The distribution of humpback whales within our study area was not uniform and indicated that some specific areas were important feeding habitat for this recovering species. The region between the Juan de Fuca Canyon and the shelf edge (the Prairie)—the mouth of Barkley Canyon and Swiftsure Bank—was the area where humpback whales were concentrated. In monthly aerial surveys in 1989–90 by Green et al.,[5] there were only a total of 13 sightings of 25 humpback whales along the entire Washington coast between July and September. Over half of those sightings were in the Prairie area.

Our line-transect estimates revealed that about 100 humpback whales inhabit the northern Washington coast waters each summer; substantially more (over 500), however, were present in 2002. Although this is a small number compared to estimates of just under 1000 humpback whales for California, Oregon, and Washington (Calambokidis and Barlow, 2004), our study area encompasses a relatively small area and reflects a high density of animals. Additionally our line-transect estimates were not corrected for any missed animals; therefore they are probably biased slightly downward.

Despite the relatively high density of humpback whales in this region, the photographic identification data indicated that a relatively small number of individuals use the area consistently. Both the line-transect and the photographic identification data (increasing capture-recapture estimates, as well as decreased proportions of animals sighted multiple years) showed that the number of whales using this region has increased in recent years. The growing number of whales in this region could be either the result of births or immigration into this area. Births alone could not account for this increase, especially because the proportion of whales that were mothers with calves seen in this region was not high. There did not appear to be a shift in distribution of animals from areas to the south because interchange with those areas dropped from 1999 to 2002. The most likely explanation for these changes is that there was a shift of animals from feeding areas from the north into this region beginning in the late 1990s.

This interchange of humpback whales with feeding areas to the south provides new insight into the structure of humpback whale feeding aggregations. In a study that examined interchange rates of humpback whales along the west coast, Calambokidis et al. (1996) identified northern Washington as a demographic boundary between the whales feeding area along California, Oregon, and Washington and those to the north. The larger sample reported here shows the same general pattern of decreasing interchange with distance from a feeding area as that reported previously for whales off California (Calambokidis et al., 1996). The decreasing rate of interchange with distance among feeding areas does not allow for a clear demarcation between feeding areas, however, as suggested by Calambokidis et al. (1996). Although humpback whales demonstrate site fidelity to specific feeding locations, their feeding aggregations may not have clear boundaries and may occupy overlapping ranges.

The commercial whaling data also tended to support the existence of somewhat discrete feeding areas off the west coast of the United States and British Columbia. Commercial whaling resulted in the depletion of humpback whales off British Columbia by 1917, whereas the numbers taken off Washington and California did not decline until the mid-1920s (Scheffer and Slipp, 1948; Clapham et al., 1997; Gregr et al., 2000).

The relatively small proportion of mothers with calves identified in our study is consistent with findings off California and Oregon (Steiger and Calambokidis, 2000). Steiger and Calambokidis reported reproductive rates along the California, Oregon, and Washington coasts that are lower than those reported for other regions in southeastern Alaska and the North Atlantic (Clapham and Mayo, 1987, 1990; Baker et al., 1992; von Ziegesar et al., 1994). In aerial transect surveys, no humpback whale calves were seen among the 68 humpbacks observed off the Oregon and Washington coasts in 1989–90 (Green et al.[5]). If geographic segregation is occurring by humpback mothers and calves, as was suggested by Steiger and Calambokidis (2000), this northern region is not the area where mothers and calves are congregated. It is interesting to note, however, that mothers and calves were distributed around the periphery of the main feeding region—a finding that suggests that a more local segregation may be occurring. A bias in sampling would occur if large concentrations of whales are targeted and mother with calves feeding on the perimeter of these groups were underrepresented.

In contrast to humpback whales, no other large rorquals (blue, fin, or sei whales) were observed during any of our ship or small boat surveys. Likewise, these species were absent in other recent surveys of Washington waters (Wahl, 1977; Von Saunder and Barlow, 1999; Shelden et al., 2000; Green et al.[5]), although they were seen in surveys farther offshore in surveys in July 1994 (Thomason et al.[6]). Fin whales were common

[5] Green, G. A., J. J. Brueggeman, R. A. Grotefendt, and C. E. Bowlby. 1992. Cetacean distribution and abundance off Oregon and Washington, 1989–1990. *In* Oregon and Washington marine mammal and seabird surveys (J. J. Brueggeman, ed.), 100 p. Final report of OCS Study MMS 91-0093 by Ebasco Environmental, Bellevue, Washington, and Ecological Consulting, Inc., Portland, Oregon, for the Minerals Management Service, Pacific OCS Region, U.S. Dept. of Interior, 770 Paseo Camarillo, Camarillo, CA 93010.

[6] Thomason, J., M. Dahlheim, S. E. Moore, J. Braham, K. Stafford, and C. Fox. 1997. Acoustic investigations of large cetaceans off Oregon and Washington: NOAA ship *Surveyor* (21 July–1 August 1994), 27 p. Final report by the National Marine Mammal Laboratory, 7600 Sand Point Way NE F/AKC3, Seattle, WA 98115.

in Washington waters in the early 1900s when they were the second most commonly killed species by Bay City whalers (Scheffer and Slipp, 1948). Blue and sei whales were less common, although they were present historically (Scheffer and Slipp, 1948). Although Bay City whaling stations (in Grays Harbor, Washington) were closed after humpback whales were depleted, serial depletion of whale populations continued off British Columbia waters, beginning with humpback and blue whales, then with fin and sperm whales, and finally with sei whales (Gregr et al., 2000).

No sperm whales or beaked whales were seen during our surveys, although our study area did not include the deeper waters where we would expect to find these species. Most of the sperm whales (90%) seen by Green et al.[5] off Washington and Oregon were present in deeper offshore waters outside of our study area.

The other cetacean species not seen in our surveys that have been reported to occur off Washington historically included northern right whale (*Eubalaena japonica*), pygmy sperm whale (*Kogia breviceps*), false killer whale (*Pseudorca crassidens*), short-finned pilot whale (*Globicephala macrorhynchus*), and striped dolphin (*Stenella coeruleoalba*) (Scheffer and Slipp, 1948). Sightings of northern right whales throughout the eastern North Pacific are scarce; there have been only a small number of sightings since the 1960s (Brownell et al., 2001). Several of these sightings, however, have been off the northern Washington coast (Fiscus and Niggol, 1965; Osborne et al., 1988; Rowlett et al., 1994). The primary reason for the paucity of sightings in the eastern North Pacific in recent decades is due to the illegal take of 372 right whales in the early to mid-1960s by the USSR (Brownell et al., 2001; Doroshenko[7]).

Although some small cetacean species such as Pacific white-sided dolphins and Risso's dolphins were sighted frequently on our surveys, they were not as common as in some previous surveys (Green et al.[5]), probably because our coverage was concentrated in shallower waters inside the shelf break. In contrast to our findings of a number of species seen near the shelf edge, Wahl (1977) reported that most marine mammal species off central Washington tended to be in either inshore or in deeper offshore waters and only killer whales and Dall's porpoises regularly used the slope waters (13–45 km offshore).

It is difficult to make abundance estimates of Dall's porpoise because of their proclivity to approach ships (Buckland and Turnock, 1992). If they begin to approach the ship before the observer sights them, the estimate is biased upwards, which would be the case with our estimate. Our estimate would also have a downward bias because we did not attempt to adjust for animals missed even if they were on the track line.

All three types of killer whales (residents [both northern and southern], transients, and offshore type) were identified in the waters off northern Washington. These sightings are interesting because of concerns about killer whale populations, especially the southern resident community that has declined in recent years. Although killer whales have been intensely studied in inside waters of the Pacific Northwest, little has been known about their use of outside waters, where they may spend large portions of their lives. Little is known about the offshore type of killer whales, which is believed to be a distinct race of killer whale that has only recently been described. These whales are believed to be found usually in large groups along the continental shelf but also have been seen in inland waters (Ford et al., 1994; Dahlheim et al., 1997). All three sightings of the offshore form were just west of the Juan de Fuca canyon on the Prairie; the closest sighting to shore was 37 km (30 animals on 15 July 1997).

Acknowledgments

We are grateful to those who assisted with this study. This work was supported by the Olympic Coast National Marine Sanctuary and Southwest Fisheries Science Center (Jay Barlow, COTR). Many people contributed to this study. Jennifer Quan, Richard Rowlett, Anne Nelson, and Annie Douglas worked on the ship surveys. We thank the ship personnel on board the *McArthur* and *Agate Passage*. Researchers who helped with small boat work included Joe Evenson and Todd Chandler. Photographs of whales from this area were also contributed by L. Baraff, R. Baird, P. Bloedel, V. Deeke, P. Ellifrit, G. Ellis, J. Evenson, B. Gisborne, B. Halliday, H. Hunt, S. Mizroch, K. Rasmussen, J. Wilson and SWFSC researchers. Permission to survey in Canadian waters was given by the Dept. of Fisheries and Oceans. Lisa Schlender, Kristin Rasmussen, and Annie Douglas organized and conducted the photographic matching with the help of many interns at Cascadia Research. DKE and Graeme Ellis identified the killer whales; Oscar Torres assisted with the photographic matching. Data analyses and mapping were conducted with the help of Scot McQueen at ESRI and Tom Williams.

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