Distribution and movement patterns of gray whales off central Oregon: Shore-based observations from Yaquina Head during the 2007/2008 migration.

Report submitted to the Oregon Wave Energy Trust

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Introduction

The growing demand for energy, the rising oil prices, and the need to curb carbon emissions have stimulated a search for alternative (*i.e.* non-fossil fuel) sources of energy. The quest for "clean" energy has resulted in development of technology to produce electricity by harnessing wind, wave, and solar radiation. The Oregon coast has been identified as an area with great potential for production of electricity from wave energy. In 2007 the state legislature appropriated funding to create the Oregon Wave Energy Trust (OWET), a non-profit organization composed of stakeholders including representatives from the wave energy industry, fishing, environmental, government and community groups. OWET has the mission of building and sharing expertise needed to support and accelerate the responsible development of the wave energy industry in the State of Oregon. Within the last couple of years, applications have been filed for permits to develop wave energy facilities in several locations along the Oregon coast. Recent plans to develop wave energy facilities along the Oregon coast raise the priority of assessing any potential environmental effects (Boehlert *et al.* 2008). Assessment of ecological risk (as defined in US Environmental Protection Agency 1998) of wave energy facilities requires an estimation of the magnitudes of both exposure and effects on species, species assemblages or habitats.

Gray whales are a protected species under the U.S. Marine Mammal Protection Act. Two extant distinct populations are recognized for this species: the Eastern North Pacific stock, which lives along the west coast of North America, and the Western North Pacific stock, which lives along the coast of eastern Asia (Rice *et al.* 1984, Swartz *et al.* 2006, Angliss and Outlaw 2008). The majority of the Eastern North Pacific population spends the summer feeding in the northern Bering and Chukchi Seas, although some gray whales have been observed feeding in the summer in waters off of Southeast Alaska, British Columbia, Washington, Oregon, and California (Rice and Wolman 1971, Darling 1984, Nerini 1984, Rice *et al.* 1984, Newell and Cowles 2006). Whales observed foraging in

these more southern locations during several summers are referred as “residents” (*e.g.* Newell and Cowles 2006). Resident whales have been observed off the Oregon coast from May through October and 28 individuals were observed near Depoe Bay for at least three successive summers (Newell and Cowles 2006).

Every year, a significant part of the population of eastern gray whales migrates from their summer feeding grounds towards the calving lagoons in Baja California, Mexico and back (Rice and Wolman 1971). Segregation has been observed in the migration timing of whales of different sex, age and reproductive status. The sequence during the southward migration is: females in late pregnancy, followed by females that recently ovulated, adult males, immature females, and immature males (Rice and Wolman 1971, Rice *et al.* 1984). Although it is difficult to define an exact date for the start of the southbound migration, most whales are migrating out of the northern seas between mid October and November (Rugh *et al.* 2001). A series of observations of gray whale migration collected since 1967 at Granite Canyon, in central California, shows a one-week delay in the southbound migration after 1980 (Rugh *et al.* 2001). Calves are born in the Baja lagoons from early January to mid-February (Rice *et al.* 1981). The northbound migration begins in mid-February. Newly pregnant females are the first to leave Baja, followed by anestrous females, adult males, and immature males and females (Rice *et al.* 1984). This first wave is known as “phase A” of the northbound migration. Cows with calves are the last to leave the lagoons 4-6 weeks later and constitute “phase B” (Poole 1984). Mother/calf pairs have been observed in San Ignacio Lagoon up into April (Rice *et al.* 1981).

Previous observations indicated that southbound whales pass by Yaquina Head between early December and mid February (Herzing and Mate 1984). Peak dates for the southbound migrations along Yaquina Head were 28 December 1978, 6 January 1980, 1 January 1981 (Herzing and Mate 1984) and 7 January 1999 (Mate and Poff 1999). Phase A of the northbound migration starts the last week of February and peaks in mid March while Phase B begins in late April and peaks in mid May (Herzing and Mate 1984).

Gray whale migration along Oregon is primarily coastal. The average distance from shore for sightings recorded during aerial surveys off the Oregon coast was 9.2 km and the farthest sighting occurred 23 km offshore (Green *et al.* 1995). Because of their coastal path, gray whales are well known and appreciated by the public and by visitors to the Oregon coast. Whale-watching is one of the main attractions offered by tour boat operators in Depoe Bay and Newport. Whale-watching is also an important attraction at visitor centers along the Oregon coast (*e.g.* Yaquina Head Outstanding Natural Area, Whale Watching Center in Depoe Bay, etc.). However, the coastal migratory path of gray whales crosses areas where wave energy parks have been proposed.

The objective of this study is to generate accurate, up to date data on distribution (distance to shore, travel path) and behavior (travel speed, migration timing) of gray whales migrating along the central Oregon coast. Results from this study will help estimate potential exposure of migrating gray whales to wave energy facilities in the Oregon territorial sea. Moreover, the baseline information reported here, combined with further observations to monitor gray whale behavior after wave energy facilities are installed, can be used to determine potential effects and to evaluate the need for and effectiveness of mitigation measures.

Methods

From December 10th, 2007 through May 30th 2008 a team of three observers surveyed for marine mammals from an observation station next to Yaquina Head lighthouse, Oregon. The station was located at 44.67675º latitude north and 124.07956º longitude west, 25.395 m above mean sea level. Average eye-height was 1.572 m. Therefore, total height of the theodolite eye-piece was 26.967 m above sea level and distance to the horizon was approximately 10 nautical miles (18.65 km).

Observations took place during daylight hours, whenever environmental conditions were favorable to search for whales: no rain, no fog, wind less than 12 miles per hour and white caps, if present, not numerous (*i.e.,* Beaufort wind force scale < 4).

The observation team consisted of at least three members: one person searching with 70×50 handheld binoculars (Fujinon FMTRC-SX), one person handling a digital theodolite with a 30× scope (Sokkia DT210, 2 seconds of arc resolution), and one person recording data into a portable computer. Observers rotated every 30 minutes between the three positions.

We determined that magnetic declination at the station was 15.199º (east) for the binoculars' compass during our study. A reference point (antenna) coincident with zero in the binoculars' magnetic compass was used as reference azimuth for the theodolite so that horizontal angles were equivalent between the two instruments.

Whenever a whale was sighted, observers recorded azimuth (horizontal) and declination (vertical) angles with the theodolite to estimate distance from the station following the approximation described by Lerczak and Hobbs (1998). The theodolite was connected to a computer running the software package *Pythagoras* (Gailey and Ortega-Ortiz 2002) which recorded angle measurements, estimated distance to the whale and calculated the whale's geographic location. Alternatively, if it was not possible to acquire a theodolite fix, azimuth and declination angles were measured with a compass and reticle etched into the eyepiece of the handheld binoculars, applying the conversion factors described by Kinzey and Gerrodette (2001). Binocular angle measurements were manually entered into *Pythagoras* to estimate whale's location. Magnetic declination was entered into *Pythagoras* station set up and accounted for in all location calculations.

Scan sampling

Observers surveyed the area of the ocean included in the sector from 160º to 360º, clockwise, in the magnetic compass (175.199º to 15.199º degrees true) and from Yaquina Head to either the horizon or shore line (Figure 1). As part of the sampling protocol, hereafter referred to as "scan," all three observers focused in a 5º arc segment for 30 seconds, searching for whales or whale cues such as water splash and spouts or blows. To prevent duplicate counts, during the southbound migration the survey was conducted clockwise, starting at the south end of the scan sector (160º magnetic) and ending in the north end (360º magnetic). Conversely, during the northbound migration scan surveys were conducted counterclockwise, from 360º to 160º magnetic.

Behavioral Observations

In addition to scan sampling, the observers conducted focal follow behavioral observations. During focal follow observations, also referred as "tracking," observers followed individual whales and obtained multiple theodolite fixes to determine speed and path of whales as they passed by Yaquina Head. Duration of focal follows was variable but an effort was made to track the whales for as long as possible.

Scans and focal follows were not conducted concurrently. Scan sampling events were conducted every two hours if weather conditions were favorable and no focal follow was being performed. An effort was made to conduct at least one scan sampling event and one focal follow on each observation day.

Whale location data were imported into a geographic information system (GIS) created with the computer software package *ArcMap*. The GIS included a bathymetry raster layer with 500m pixel size and a vector map of Oregon's coastline scale 1:75,000. A vector line map of the Oregon territorial sea, defined as 3 nautical miles (5.556 km) off land and islands, was derived from the coastline map. Bottom depth, distance to shore and

occurrence inside/outside Oregon's territorial sea were determined for each whale location.

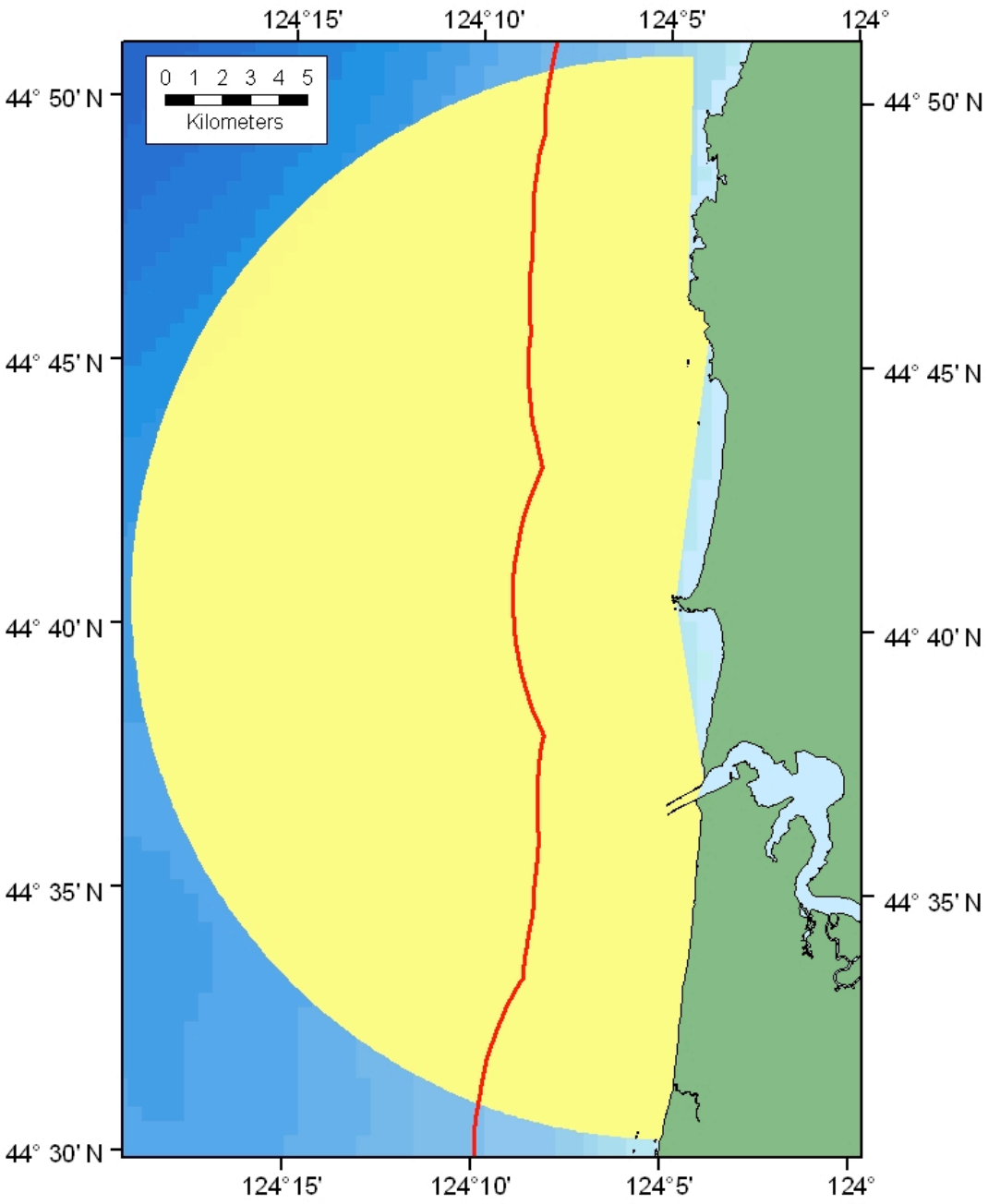

Figure 1. Map of Yaquina Head indicating the area covered during scan surveys (yellow highlight). Distance to the horizon was approximately 10 nautical miles (18.52 km) from the observation station. Red line indicates the State of Oregon territorial waters (3 nautical miles or 5.556 km offshore).

Results

Observations were possible on 78 days during the period of this study. A total of 256 scan sampling events were completed during 106.3 hours of scan effort (Table 1). Focal follows were conducted on 120 individual whales during 103.2 hours of tracking effort (Table 2). A total of 2416 gray whale locations were recorded: 460 locations during scan sampling and 1956 locations during focal follows.

Scan Sampling

Scan sampling began on December 11, 2007 and continued for four days, after which bad weather precluded further observations until January 11, 2008. The first whale was observed on January 11, and the peak of the southbound migration was January 23. . The first northbound whale was observed on February 26 and the first cow/calf pair was sighted on April 10. The peak of northbound migration phases A and B was March 30 and April 16, respectively (Fig. 2). The last northbound whale was recorded on May 29. No whales were observed on May 30, the last day of fieldwork.

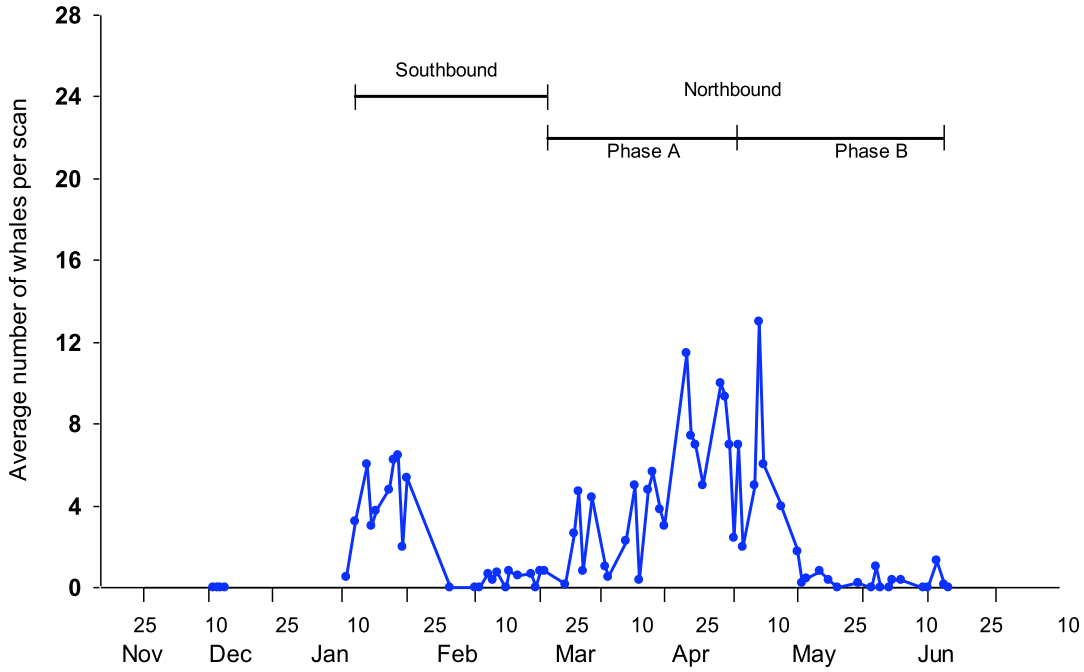

Figure 2. Migration timing, determined from average number of whales per scan surveys conducted at Yaquina Head, Oregon, from December 2007 to May 2008.

Table 1. Scan sampling events, number of whales observed, and wind speed during observations.

Scan	Date	Start time	End time	Duration (hours)	Number of whale groups	Total number of whales	Wind speed (km/h)
1	11-Dec-07	13:57	16:33	2.59	0	0	12.9
2	12-Dec-07	12:00	12:53	0.88	0	0	8.0
4	12-Dec-07	13:57	14:30	0.56	0	0	5.0
5	12-Dec-07	14:41	14:57	0.26	0	0	5.0
7	13-Dec-07	10:46	11:06	0.34	0	0	6.6
8	14-Dec-07	10:51	11:25	0.57	0	0	5.3
9	14-Dec-07	12:30	12:55	0.42	0	0	4.0
10	11-Jan-08	08:59	09:21	0.36	0	0	14.0
11	11-Jan-08	10:55	11:48	0.88	1	1	11.3
12	13-Jan-08	08:48	09:23	0.58	4	4	10.1
13	13-Jan-08	11:01	12:08	1.13	3	3	7.0
14	13-Jan-08	13:05	13:49	0.73	0	0	1.2
15	13-Jan-08	14:54	15:25	0.51	3	4	4.8
16	13-Jan-08	15:52	16:19	0.45	3	5	3.7
17	16-Jan-08	08:56	09:20	0.39	3	4	6.9
18	16-Jan-08	10:42	11:22	0.67	7	12	7.3
19	16-Jan-08	13:21	13:46	0.42	2	2	3.4
20	17-Jan-08	08:43	09:13	0.50	2	2	7.0
21	17-Jan-08	10:24	10:57	0.56	4	4	7.0
22	17-Jan-08	11:56	12:27	0.50	1	3	6.2
23	18-Jan-08	08:53	09:21	0.47	2	2	7.1
24	18-Jan-08	10:06	10:36	0.50	4	4	9.4
25	18-Jan-08	12:51	13:20	0.48	2	5	8.1
26	18-Jan-08	14:15	14:41	0.43	2	4	5.9
27	21-Jan-08	08:54	09:17	0.38	6	6	13.2
28	21-Jan-08	11:01	11:25	0.39	3	3	13.1
29	21-Jan-08	14:21	14:39	0.29	5	5	23.7
30	21-Jan-08	15:18	15:45	0.45	5	5	23.8
31	22-Jan-08	08:38	09:01	0.39	4	4	11.2
32	22-Jan-08	10:02	10:31	0.49	7	7	9.8
33	22-Jan-08	12:56	13:21	0.41	4	5	13.1
34	22-Jan-08	14:43	15:13	0.49	8	9	9.3
35	23-Jan-08	08:42	09:10	0.48	3	6	19.8
36	23-Jan-08	11:41	12:11	0.50	7	9	16.4
37	23-Jan-08	13:26	13:48	0.37	3	3	13.5
38	23-Jan-08	15:07	15:36	0.47	5	8	14.3
39	24-Jan-08	08:33	08:57	0.40	0	0	12.3
40	24-Jan-08	09:08	09:40	0.54	2	3	11.7
41	24-Jan-08	10:18	10:47	0.50	3	3	15.7
42	25-Jan-08	09:57	10:32	0.58	9	10	14.0

43	25-Jan-08	14:22	14:43	0.35	0	0	14.2
44	25-Jan-08	15:56	16:23	0.45	6	6	13.0
45	04-Feb-08	15:06	15:31	0.43	0	0	7.9

Table 1. Continued.

Scan	Date	Start time	End time	Duration (hours)	Number of whale groups	Total number of whales	Wind speed (km/h)
41	10-Feb-08	15:28	15:47	0.33	0	0	6.5
42	11-Feb-08	13:01	13:23	0.36	0	0	8.9
44	11-Feb-08	14:54	15:19	0.41	0	0	8.1
45	11-Feb-08	16:01	16:20	0.32	0	0	10.0
46	13-Feb-08	13:23	13:47	0.39	0	0	8.4
47	13-Feb-08	14:20	14:43	0.37	0	0	9.2
48	13-Feb-08	15:43	16:09	0.43	2	2	11.5
49	14-Feb-08	10:52	11:15	0.38	0	0	6.1
50	14-Feb-08	11:16	11:41	0.42	1	1	6.0
51	14-Feb-08	13:59	14:20	0.35	0	0	8.0
52	15-Feb-08	10:00	10:20	0.34	0	0	9.9
54	15-Feb-08	13:10	13:33	0.39	1	1	6.2
55	15-Feb-08	14:16	14:36	0.34	1	1	8.4
56	15-Feb-08	15:04	15:26	0.37	1	1	11.6
57	17-Feb-08	08:44	09:07	0.38	0	0	8.1
58	17-Feb-08	09:53	10:19	0.44	0	0	7.0
59	17-Feb-08	11:18	11:42	0.40	0	0	6.3
60	17-Feb-08	12:25	12:46	0.35	0	0	8.7
61	17-Feb-08	13:35	13:56	0.35	0	0	8.7
62	17-Feb-08	14:42	15:03	0.35	0	0	10.6
63	17-Feb-08	15:41	16:01	0.33	0	0	11.4
64	18-Feb-08	10:01	10:23	0.37	0	0	7.0
65	18-Feb-08	10:59	11:25	0.43	1	1	6.0
66	18-Feb-08	12:07	12:31	0.39	1	4	7.2
67	18-Feb-08	13:15	13:37	0.36	0	0	9.5
68	18-Feb-08	14:13	14:35	0.37	0	0	10.6
69	18-Feb-08	14:58	15:21	0.39	0	0	9.0
70	20-Feb-08	11:06	11:29	0.37	0	0	5.0
71	20-Feb-08	12:13	12:35	0.37	0	0	4.1
72	20-Feb-08	13:20	13:40	0.33	0	0	4.1
73	20-Feb-08	14:24	14:46	0.37	1	3	3.6
74	20-Feb-08	15:26	15:48	0.35	0	0	4.3
75	23-Feb-08	12:22	12:42	0.33	0	0	13.6
76	23-Feb-08	13:27	13:51	0.40	0	0	10.7
77	23-Feb-08	14:31	14:55	0.41	1	2	8.5
78	24-Feb-08	08:26	08:48	0.36	0	0	11.5
79	24-Feb-08	09:38	10:01	0.39	0	0	10.7
80	24-Feb-08	11:18	11:41	0.39	0	0	8.0
81	24-Feb-08	11:45	12:08	0.39	0	0	8.0

82	25-Feb-08	09:00	09:26	0.43	0	0	7.0
83	25-Feb-08	10:33	10:57	0.40	0	0	8.2
85	25-Feb-08	11:59	12:22	0.38	2	4	5.1

Table 1. Continued.

Scan	Date	Start time	End time	Duration (hours)	Number of whale groups	Total number of whales	Wind speed (km/h)
86	25-Feb-08	14:20	14:43	0.38	0	0	4.4
87	25-Feb-08	15:23	15:46	0.38	0	0	4.7
88	26-Feb-08	08:25	08:50	0.41	0	0	7.2
89	26-Feb-08	09:43	10:09	0.43	2	3	8.2
90	26-Feb-08	10:47	11:11	0.41	0	0	3.2
91	26-Feb-08	13:27	13:50	0.37	0	0	4.6
92	26-Feb-08	14:38	14:56	0.29	2	2	2.9
93	26-Feb-08	16:05	16:31	0.43	0	0	4.8
94	02-Mar-08	09:11	09:29	0.29	1	1	7.4
95	02-Mar-08	09:40	10:03	0.38	0	0	6.4
96	02-Mar-08	11:27	11:48	0.35	0	0	6.0
97	02-Mar-08	12:58	13:23	0.41	0	0	9.4
98	02-Mar-08	14:04	14:26	0.37	0	0	8.9
99	02-Mar-08	15:11	15:32	0.35	0	0	11.8
100	04-Mar-08	09:53	10:18	0.41	1	1	3.9
101	04-Mar-08	11:03	11:28	0.42	2	7	6.0
102	04-Mar-08	14:20	14:42	0.36	0	0	10.6
103	05-Mar-08	09:29	09:54	0.41	0	0	8.9
104	05-Mar-08	10:33	10:56	0.39	0	0	9.5
105	05-Mar-08	11:34	11:59	0.42	2	14	8.8
106	06-Mar-08	09:34	09:58	0.39	0	0	6.0
107	06-Mar-08	10:34	11:00	0.43	1	1	6.6
108	06-Mar-08	12:46	13:08	0.37	0	0	9.6
109	06-Mar-08	14:20	14:43	0.38	0	0	6.0
110	06-Mar-08	16:10	16:33	0.39	3	3	5.7
111	08-Mar-08	08:25	08:48	0.38	2	2	0.0
112	08-Mar-08	10:13	10:38	0.41	4	8	2.4
113	08-Mar-08	11:39	12:04	0.41	2	3	3.3
115	08-Mar-08	14:34	14:57	0.38	3	3	9.1
116	08-Mar-08	15:32	15:58	0.43	4	6	10.6
117	11-Mar-08	14:27	14:46	0.32	1	1	6.0
118	11-Mar-08	15:29	15:50	0.35	1	2	7.9
119	11-Mar-08	16:35	16:55	0.33	0	0	10.6
120	12-Mar-08	09:25	09:48	0.38	1	1	4.2
121	12-Mar-08	10:33	10:56	0.38	0	0	5.8
123	16-Mar-08	09:34	10:00	0.43	1	1	1.0
124	16-Mar-08	13:56	14:21	0.41	1	1	7.1
125	16-Mar-08	15:01	15:24	0.38	2	2	5.1
126	16-Mar-08	16:08	16:35	0.44	3	5	3.9
127	18-Mar-08	15:21	15:45	0.39	3	5	7.0

128	19-Mar-08	10:16	10:40	0.41	1	1	7.5
129	19-Mar-08	11:46	12:09	0.39	0	0	12.1
130	19-Mar-08	12:33	12:55	0.36	0	0	15.9

Table 1. Continued.

Scan	Date	Start time	End time	Duration (hours)	Number of whale groups	Total number of whales	Wind speed (km/h)
131	21-Mar-08	11:11	11:34	0.37	0	0	9.1
132	21-Mar-08	12:05	12:31	0.43	4	5	9.8
133	21-Mar-08	14:41	15:05	0.40	3	4	6.0
134	21-Mar-08	16:30	16:50	0.34	7	10	4.1
135	22-Mar-08	10:19	10:44	0.41	6	7	9.3
136	22-Mar-08	13:10	13:36	0.44	6	7	9.4
137	22-Mar-08	15:31	15:55	0.41	2	3	5.6
138	24-Mar-08	09:25	09:48	0.39	1	2	3.8
139	24-Mar-08	10:44	11:09	0.41	1	1	5.7
140	24-Mar-08	11:38	12:01	0.37	1	1	6.4
141	24-Mar-08	15:08	15:32	0.40	6	9	4.8
142	24-Mar-08	16:46	17:07	0.37	5	6	2.9
143	25-Mar-08	09:05	09:29	0.40	3	3	5.4
144	30-Mar-08	10:28	10:54	0.43	8	13	6.5
145	30-Mar-08	12:31	12:56	0.42	8	10	6.5
146	30-Mar-08	14:41	15:03	0.36	5	5	7.7
147	30-Mar-08	16:08	16:31	0.39	11	18	8.1
148	31-Mar-08	09:33	09:58	0.41	3	6	4.9
149	31-Mar-08	10:39	11:05	0.42	4	5	4.8
150	31-Mar-08	11:36	12:02	0.43	7	10	5.6
151	31-Mar-08	15:22	15:41	0.32	5	7	15.3
152	31-Mar-08	15:46	16:07	0.35	8	9	15.7
153	01-Apr-08	08:26	08:49	0.39	3	5	7.6
154	01-Apr-08	10:44	11:08	0.40	4	9	11.3
155	03-Apr-08	08:27	08:51	0.40	4	6	2.7
156	03-Apr-08	11:28	11:56	0.46	3	4	10.9
157	07-Apr-08	14:06	14:30	0.39	5	8	8.2
158	07-Apr-08	15:21	15:49	0.46	9	9	9.5
159	07-Apr-08	16:34	16:57	0.39	10	13	7.8
160	08-Apr-08	11:10	11:35	0.42	7	9	9.1
161	08-Apr-08	13:48	14:13	0.41	6	8	11.7
162	08-Apr-08	16:27	16:53	0.44	10	11	9.7
163	09-Apr-08	08:30	09:00	0.50	7	10	8.0
164	09-Apr-08	12:16	12:40	0.39	4	6	10.5
165	09-Apr-08	14:19	14:43	0.41	5	5	10.9
166	10-Apr-08	09:36	09:59	0.40	2	2	11.1
167	10-Apr-08	11:35	11:58	0.39	3	3	9.5
168	10-Apr-08	13:14	13:38	0.41	2	2	9.7
169	10-Apr-08	15:22	15:46	0.40	1	2	8.1
170	10-Apr-08	16:21	16:42	0.35	2	3	10.3

171	11-Apr-08	08:31	08:55	0.41	5	6	9.0
172	11-Apr-08	11:24	11:51	0.44	3	8	8.7
173	12-Apr-08	10:23	10:49	0.43	1	1	8.4

Table 1. Continued.

Scan	Date	Start time	End time	Duration (hours)	Number of whale groups	Total number of whales	Wind speed (km/h)
174	12-Apr-08	11:24	11:48	0.41	3	3	10.2
175	12-Apr-08	12:23	12:52	0.48	5	5	10.8
176	12-Apr-08	14:07	14:29	0.37	0	0	13.0
177	12-Apr-08	15:04	15:24	0.33	1	1	12.7
179	15-Apr-08	12:14	12:39	0.41	3	5	11.8
180	16-Apr-08	10:48	11:15	0.45	9	16	3.1
181	16-Apr-08	12:16	12:40	0.41	8	8	5.1
182	16-Apr-08	14:52	15:17	0.41	10	20	13.5
183	16-Apr-08	15:54	16:17	0.39	6	8	14.9
184	17-Apr-08	08:30	08:54	0.39	4	4	9.6
185	17-Apr-08	11:15	11:41	0.43	6	8	15.8
186	21-Apr-08	08:49	09:11	0.38	4	4	8.2
187	25-Apr-08	08:25	08:48	0.39	1	1	6.0
188	25-Apr-08	08:52	09:19	0.44	1	2	6.0
190	25-Apr-08	10:33	10:58	0.42	2	3	6.8
191	25-Apr-08	12:01	12:25	0.40	1	1	8.8
192	26-Apr-08	10:13	10:38	0.40	0	0	6.6
193	26-Apr-08	10:40	11:04	0.41	0	0	5.7
194	26-Apr-08	12:27	12:52	0.41	0	0	4.8
195	26-Apr-08	14:04	14:28	0.40	1	1	4.5
196	26-Apr-08	16:16	16:39	0.39	0	0	4.1
197	27-Apr-08	08:35	08:58	0.38	0	0	4.5
198	27-Apr-08	09:44	10:08	0.39	1	1	5.5
199	27-Apr-08	11:25	11:48	0.39	0	0	6.0
200	27-Apr-08	13:02	13:26	0.41	1	1	6.2
201	27-Apr-08	14:15	14:37	0.37	1	1	6.3
202	27-Apr-08	15:18	15:43	0.40	0	0	6.4
203	27-Apr-08	16:25	16:47	0.37	0	0	6.5
204	30-Apr-08	08:25	08:48	0.39	0	0	5.5
205	30-Apr-08	11:02	11:25	0.37	0	0	2.9
206	30-Apr-08	12:15	12:39	0.40	1	2	2.9
207	30-Apr-08	14:29	14:52	0.39	2	3	2.8
208	30-Apr-08	15:30	15:51	0.36	0	0	2.8
209	30-Apr-08	16:20	16:39	0.33	0	0	2.8
210	02-May-08	08:38	09:02	0.40	0	0	4.0
211	02-May-08	09:40	10:04	0.40	1	1	7.0
212	02-May-08	11:01	11:22	0.35	0	0	5.1
213	02-May-08	12:11	12:38	0.44	1	1	5.4
214	02-May-08	13:44	14:08	0.40	0	0	5.8
215	02-May-08	15:53	16:17	0.40	0	0	6.3

216	04-May-08	08:45	09:07	0.38	0	0	8.0
217	04-May-08	09:43	10:06	0.38	0	0	14.0
218	09-May-08	08:31	08:55	0.39	0	0	5.5

Table 1. Continued.

Scan	Date	Start time	End time	Duration (hours)	Number of whale groups	Total number of whales	Wind speed (km/h)
219	09-May-08	10:01	10:24	0.39	0	0	8.0
220	09-May-08	11:12	11:30	0.30	0	0	8.4
221	09-May-08	12:30	12:53	0.40	1	1	9.9
222	12-May-08	11:08	11:31	0.38	0	0	7.0
223	12-May-08	12:14	12:36	0.37	0	0	7.5
224	12-May-08	13:19	13:43	0.39	0	0	8.9
225	13-May-08	10:57	11:19	0.38	0	0	10.9
226	13-May-08	11:52	12:14	0.38	0	0	9.2
227	13-May-08	12:58	13:20	0.36	1	3	9.9
228	14-May-08	10:50	11:12	0.38	0	0	6.7
229	14-May-08	13:20	13:43	0.38	0	0	11.6
230	14-May-08	14:42	15:05	0.38	0	0	7.3
231	14-May-08	16:03	16:25	0.36	0	0	18.1
232	16-May-08	13:45	14:09	0.39	0	0	3.6
233	16-May-08	14:57	15:19	0.36	0	0	7.8
234	16-May-08	16:05	16:28	0.39	0	0	6.7
235	17-May-08	10:32	10:54	0.38	0	0	8.8
236	17-May-08	12:00	12:23	0.39	1	1	7.0
237	17-May-08	13:11	13:34	0.38	0	0	5.3
238	19-May-08	11:58	12:23	0.42	0	0	4.1
239	19-May-08	13:13	13:37	0.40	0	0	2.7
240	19-May-08	14:34	14:58	0.39	1	1	3.2
241	24-May-08	14:33	14:57	0.40	0	0	4.9
242	24-May-08	15:57	16:19	0.37	0	0	5.9
243	25-May-08	14:48	15:11	0.37	0	0	8.9
244	25-May-08	16:04	16:27	0.38	0	0	12.8
245	27-May-08	11:26	11:48	0.36	0	0	5.9
246	27-May-08	12:30	12:52	0.37	1	1	7.5
247	27-May-08	15:18	15:42	0.39	3	3	11.7
248	29-May-08	09:15	09:39	0.41	1	1	1.9
249	29-May-08	09:41	10:05	0.41	0	0	1.9
250	29-May-08	11:38	12:03	0.42	0	0	7.0
251	29-May-08	12:55	13:18	0.38	0	0	8.0
252	29-May-08	14:02	14:23	0.35	0	0	7.0
253	29-May-08	15:19	15:42	0.38	0	0	7.0
254	29-May-08	16:30	16:54	0.40	0	0	7.0
255	29-May-08	17:28	17:50	0.38	0	0	7.0
256	30-May-08	08:28	08:52	0.39	0	0	4.8
257	30-May-08	09:37	10:01	0.40	0	0	9.2
258	30-May-08	10:48	11:12	0.40	0	0	10.9

259	30-May-08	12:02	12:23	0.35	0	0	11.2
260	30-May-08	12:59	13:21	0.38	0	0	14.0

Table 2. List of focal behavioral observations of migrating whales recorded from Yaquina Head.

Track Num.	Start Date-Time	Group size	Duration (hours)	Track Length (km)	Num. of Fixes	Average Speed (km/h)	Average Distance to shore (km)	Average Depth (m)	Notes	Migration phase
1	2008-01-13 12:29	3	0.42	5.53	10	75.9	9.3	63		Southbound
2	2008-01-16 09:22	1	0.25	6.48	3	30.6	2.3	28		Southbound
3	2008-01-16 09:57	2	0.57	4.75	6	8.5	7.0	57		Southbound
4	2008-01-16 11:30	1	0.68	4.89	3	8.7	7.0	59		Southbound
5	2008-01-16 12:14	3	0.07	0.55	4	8.3	11.1	64		Southbound
6	2008-01-16 12:35	6	0.64	4.77	8	7.8	9.5	67		Southbound
7	2008-01-17 09:48	2	0.41	1.54	4	6.7	4.8	42		Southbound
8	2008-01-17 11:06	2	0.81	13.97	9	53.3	8.2	63		Southbound
9	2008-01-17 14:03	1	0.43	4.04	3	9.7	5.2	47		Southbound
10	2008-01-18 11:07	1	0.89	5.20	9	6.1	3.8	41		Southbound
11	2008-01-18 13:37	5	0.35	1.38	4	5.4	9.8	57		Southbound
12	2008-01-18 13:59	1	0.06	0.87	2	13.5	10.5	59		Southbound
13	2008-01-18 14:45	3	0.43	4.16	10	10.1	9.7	64		Southbound
14	2008-01-18 15:24	5	0.39	2.43	8	6.6	6.7	50		Southbound
15	2008-01-21 09:35	3	0.56	3.35	4	5.5	4.4	42		Southbound
16	2008-01-21 10:13	3	0.43	3.45	8	8.2	5.4	52		Southbound
17	2008-01-21 11:41	2	0.67	3.70	11	7.2	4.1	44		Southbound
18	2008-01-21 14:53	3	0.18	1.31	7	6.9	7.4	50		Southbound
19	2008-01-21 15:04	2	0.21	0.95	3	3.8	5.3	46		Southbound

20	2008-01-21 15:48	4	0.48	3.92	7	8.2	6.2	55		Southbound
21	2008-01-22 10:38	2	0.67	3.66	9	6.1	7.8	62		Southbound
22	2008-01-22 11:28	3	0.50	4.14	6	8.2	8.2	61		Southbound
23	2008-01-22 13:32	2	0.47	3.73	14	8.1	5.9	53		Southbound
24	2008-01-22 14:04	1	0.39	2.62	10	6.5	7.7	52		Southbound
25	2008-01-22 15:25	1	0.09	2.71	2	31.5	9.4	60		Southbound
26	2008-01-22 15:57	1	0.93	6.65	23	7.1	4.9	46		Southbound
27	2008-01-23 09:11	5	0.53	3.29	9	6.5	7.8	52		Southbound

Table 2. Continued

Track Num.	Start Date-Time	Group size	Duration (hours)	Track Length (km)	Num. of Fixes	Average Speed (km/h)	Average Distance to shore (km)	Average Depth (m)	Notes	Migration phase
28	2008-01-23 10:18	3	1.16	7.14	23	6.5	5.2	48		Southbound
29	2008-01-23 13:49	1	0.01	0.46	3	50.8	6.1	60		Southbound
30	2008-01-23 13:55	1	0.00	0.00	1		6.4	60		Southbound
31	2008-01-23 13:57	1	0.39	3.13	4	7.4	7.4	61		Southbound
32	2008-01-23 14:26	2	0.52	3.92	19	7.8	7.8	61		Southbound
33	2008-01-23 15:36	1	0.06	8.57	3	192.3	5.6	49		Southbound
34	2008-01-24 11:34	1	0.65	5.16	4	7.8	6.3	53		Southbound
35	2008-01-25 08:46	4	1.10	6.15	20	5.3	1.9	24		Southbound
36	2008-01-25 10:33	1	0.28	1.55	3	3.2	1.3	20	Resident	
37	2008-01-25 10:57	3	2.26	15.24	32	6.8	7.2	56		Southbound
38	2008-01-25 15:19	3	0.62	2.49	7	5.7	3.2	40		Southbound

39	2008-01-25 16:24	4	0.66	4.76	21	6.9	3.5	34		Southbound
40	2008-02-04 15:31	1	0.15	1.07	5	6.6	1.0	20	Resident	
41	2008-02-23 15:05	2	1.89	12.97	32	6.2	4.9	47		Southbound
42	2008-02-24 10:25	2	0.56	3.17	8	4.6	5.4	45		Southbound
43	2008-02-24 13:00	1	1.14	5.64	15	5.2	3.0	38		Southbound
44	2008-02-24 15:11	3	1.10	7.86	25	7.1	6.4	54		Southbound
45	2008-02-25 12:31	2	1.04	6.95	11	6.9	8.5	63		Southbound
46	2008-02-26 11:51	1	0.99	5.56	9	5.3	6.7	49		Southbound
47	2008-02-26 15:01	2	1.00	5.71	21	6.0	3.2	40		Northbound-A
48	2008-03-04 11:38	4	0.22	1.24	9	5.8	8.1	52		Northbound-A
49	2008-03-04 12:04	1	1.09	7.08	20	5.3	1.9	23		Northbound-A
50	2008-03-04 14:50	1	0.28	1.08	2	3.8	3.0	35		Northbound-A
51	2008-03-05 12:05	3	1.27	6.55	76	5.4	3.7	42		Northbound-A
52	2008-03-06 11:09	3	1.55	10.07	40	6.5	4.0	40		Northbound-A
53	2008-03-06 14:51	2	1.22	7.97	23	6.6	2.5	30		Northbound-A
54	2008-03-06 16:50	1	0.18	1.26	9	6.7	2.6	35		Northbound-A

Table 2. Continued

Track Num.	Start Date-Time	Group size	Duration (hours)	Track Length (km)	Num. of Fixes	Average Speed (km/h)	Average Distance to shore (km)	Average Depth (m)	Notes	Migration phase
55	2008-03-08 08:57	3	1.23	7.79	22	6.5	3.0	33		Northbound-A
56	2008-03-08 10:46	2	0.79	3.84	8	5.6	4.3	47		Northbound-A
57	2008-03-08 13:28	2	0.84	6.13	15	7.0	4.9	48		Northbound-A

58	2008-03-08 15:00	7	0.45	2.99	25	6.9	8.2	63	Northbound-A
59	2008-03-08 16:02	3	0.39	2.36	11	5.9	4.2	37	Northbound-A
60	2008-03-11 15:00	2	0.39	1.84	4	5.4	2.5	30	Northbound-A
61	2008-03-11 15:59	2	0.59	4.05	6	7.9	2.8	28	Northbound-A
62	2008-03-12 12:04	3	0.69	4.34	22	6.2	5.0	44	Northbound-A
63	2008-03-16 10:12	3	1.90	10.27	37	6.1	5.1	48	Northbound-A
64	2008-03-16 16:43	3	1.14	4.83	22	4.6	4.6	41	Northbound-A
65	2008-03-18 16:05	3	0.88	4.70	12	6.1	3.8	43	Northbound-A
66	2008-03-19 10:49	1	0.28	1.34	5	6.5	2.2	29	Northbound-A
67	2008-03-19 11:09	1	0.56	2.75	9	6.7	1.7	24	Northbound-A
68	2008-03-21 12:46	3	0.31	0.92	3	4.7	3.3	40	Northbound-A
69	2008-03-21 13:07	1	0.25	0.38	2	1.5	1.8	31	Northbound-A
70	2008-03-21 13:34	3	0.68	5.29	8	7.3	3.7	37	Northbound-A
71	2008-03-21 15:12	1	0.64	4.66	8	7.1	2.5	34	Northbound-A
72	2008-03-21 15:55	1	0.55	3.59	9	6.9	4.1	46	Northbound-A
73	2008-03-22 10:49	3	2.04	12.67	24	6.8	5.2	49	Northbound-A
74	2008-03-22 13:46	4	1.69	11.29	62	6.3	6.3	51	Northbound-A
75	2008-03-24 10:01	2	0.66	4.26	8	6.9	5.3	52	Northbound-A
76	2008-03-24 12:07	3	1.46	10.44	46	7.6	5.9	51	Northbound-A
77	2008-03-24 15:40	3	1.05	6.54	27	6.1	3.5	37	Northbound-A
78	2008-03-24 17:20	2	0.40	2.38	13	6.1	4.2	41	Northbound-A
79	2008-03-25 09:39	2	0.70	3.80	11	6.3	5.6	51	Northbound-A

80	2008-03-30 13:59	1	0.49	2.65	8	5.2	2.4	34		Northbound-A
81	2008-03-30 15:07	2	0.94	5.24	26	6.1	5.6	51		Northbound-A

Table 2. Continued

Track Num.	Start Date-Time	Group size	Duration (hours)	Track Length (km)	Num. of Fixes	Average Speed (km/h)	Average Distance to shore (km)	Average Depth (m)	Notes	Migration phase
82	2008-03-31 10:01	3	0.55	2.86	7	6.5	7.4	61		Northbound-A
83	2008-03-31 12:12	2	2.07	12.04	24	6.2	5.8	53		Northbound-A
84	2008-04-01 08:55	5	1.61	8.58	72	5.9	7.0	58		Northbound-A
85	2008-04-01 11:19	1	1.01	4.57	11	4.7	1.2	19		Northbound-A
86	2008-04-03 08:55	2	2.17	15.92	19	7.2	3.2	37		Northbound-A
87	2008-04-03 12:06	2	1.42	10.98	19	7.1	4.3	45		Northbound-A
88	2008-04-07 13:31	2	1.78	3.46	4	4.3	5.9	54		Northbound-A
89	2008-04-08 11:46	2	1.95	12.59	34	6.4	5.8	52		Northbound-A
90	2008-04-08 14:24	3	1.96	12.44	47	6.4	6.3	54		Northbound-A
91	2008-04-09 12:49	3	1.46	8.47	37	6.0	3.8	42		Northbound-A
92	2008-04-10 10:15	1	0.94	6.03	13	6.2	2.2	24		Northbound-A
93	2008-04-10 13:44	3	1.57	7.97	47	5.0	3.4	34		Northbound-A
94	2008-04-10 16:59	2	1.11	5.14	26	5.3	1.3	18	Cow/calf	Northbound-B
95	2008-04-11 09:34	3	1.62	8.21	26	5.6	7.2	59		Northbound-B
96	2008-04-11 12:03	1	1.39	5.77	19	4.2	3.0	38		Northbound-B
97	2008-04-12 12:58	1	0.98	4.53	12	5.2	3.6	43		Northbound-B
98	2008-04-15 10:44	3	1.47	7.09	28	5.9	6.8	58		Northbound-B

99	2008-04-15 12:53	1	0.11	1.17	3	10.0	3.2	29		Northbound-B
100	2008-04-16 11:26	1	0.77	4.16	4	5.8	4.5	42		Northbound-B
101	2008-04-16 12:44	3	2.05	14.54	58	6.7	3.3	36		Northbound-B
102	2008-04-17 09:13	2	1.99	9.64	48	4.7	4.0	43		Northbound-B
103	2008-04-25 10:02	3	0.29	1.19	3	4.1	2.0	17		Northbound-B
104	2008-04-25 10:28	1	0.06	1.43	7	28.4	2.0	17		Northbound-B
105	2008-04-26 14:33	2	1.45	8.05	20	5.8	1.4	18	Cow/calf	Northbound-B
106	2008-04-27 10:15	1	0.83	6.60	5	7.4	1.5	14	Resident	
107	2008-04-25 11:02	1	0.97	3.02	19	2.6	0.4	14	Resident	
108	2008-04-30 12:47	2	0.32	2.22	7	6.8	2.7	35	Cow/calf	Northbound-B

Table 2. Continued

Track Num.	Start Date-Time	Group size	Duration (hours)	Track Length (km)	Num. of Fixes	Average Speed (km/h)	Average Distance to shore (km)	Average Depth (m)	Notes	Migration phase
109	2008-04-30 14:44	1	1.55	3.50	9	3.3	0.8	16	Resident	
110	2008-05-02 10:20	2	0.45	1.79	4	5.3	1.9	16		Northbound-B
111	2008-05-02 14:58	1	0.56	2.89	11	5.4	0.7	15		Northbound-B
112	2008-05-09 12:59	1	2.01	9.90	27	4.7	2.4	28		Northbound-B
113	2008-05-12 14:04	1	1.49	6.17	8	4.2	1.3	15		Northbound-B
114	2008-05-13 13:24	2	0.26	1.87	4	7.8	1.4	12		Northbound-B
115	2008-05-14 11:40	2	1.29	5.72	12	5.0	0.8	14	Cow/calf	Northbound-B
116	2008-05-14 15:19	2	0.53	2.14	12	4.9	0.8	16	Cow/calf	Northbound-B
117	2008-05-17 10:56	3	1.03	6.26	19	5.8	0.9	15		Northbound-B

118	2008-05-19 12:27	1	0.46	2.66	13	6.1	0.7	17	Northbound-B
119	2008-05-19 15:08	1	1.65	8.27	13	4.8	2.3	28	Northbound-B
120	2008-05-27 12:58	1	2.10	7.01	111	3.4	1.1	14	Resident

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Distance from the observation station to location of whales sighted during scan surveys ranged from 0.23 to 17.29 km ($\bar{x}$ = 6.81 km, n = 460). Significant differences (F = 33.92, $p < 0.01$) were observed in the average distance to shore of whale locations recorded during the different migration phases (Figures 3-6). Average distance from shore during the southbound migration was 6.59 km (S.D. = 2.526, n = 139). During phase A of the northbound migration, whales were sighted at an average of 5.08 km from shore (S.D. = 2.135, n = 230), while during phase B the average distance from shore was 4.08 km (S.D. = 2.618, n = 91).

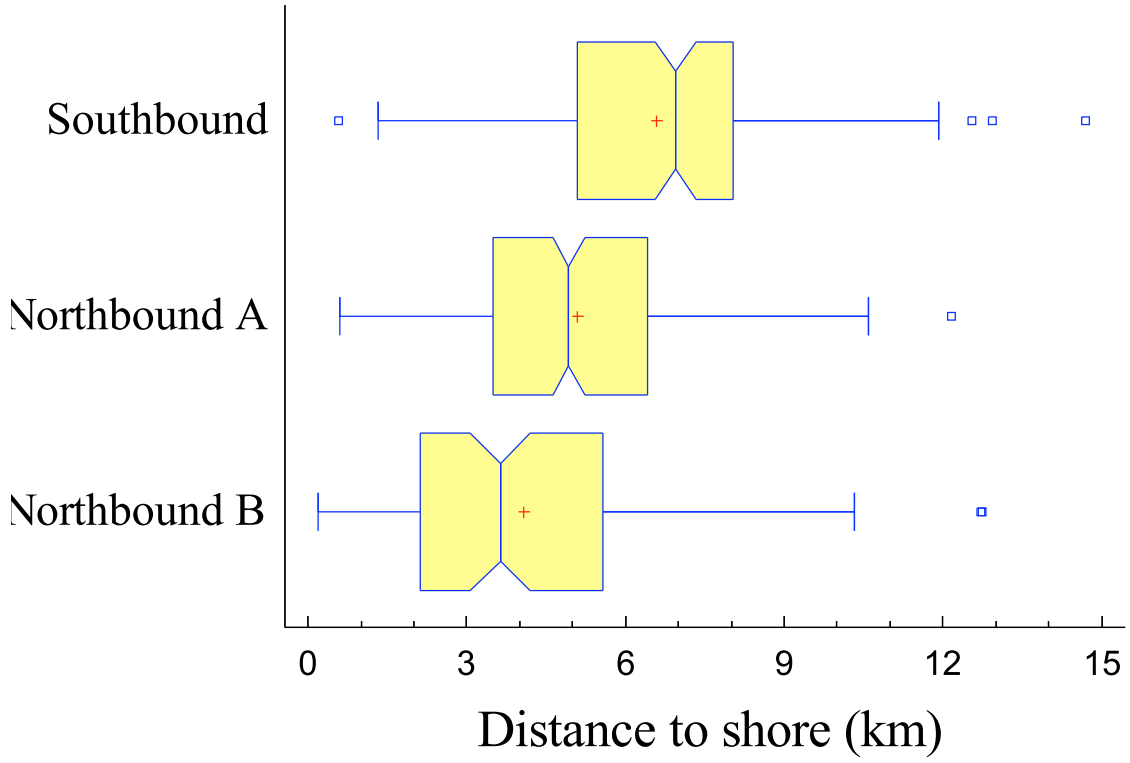

Figure 3. Box plot of distance from shore for gray whale locations recorded during the different migration phases. Average values are indicated by a cross. Boxes

represent the interquartile range, the notch indicates the median value. Outlier values are indicated by squares.

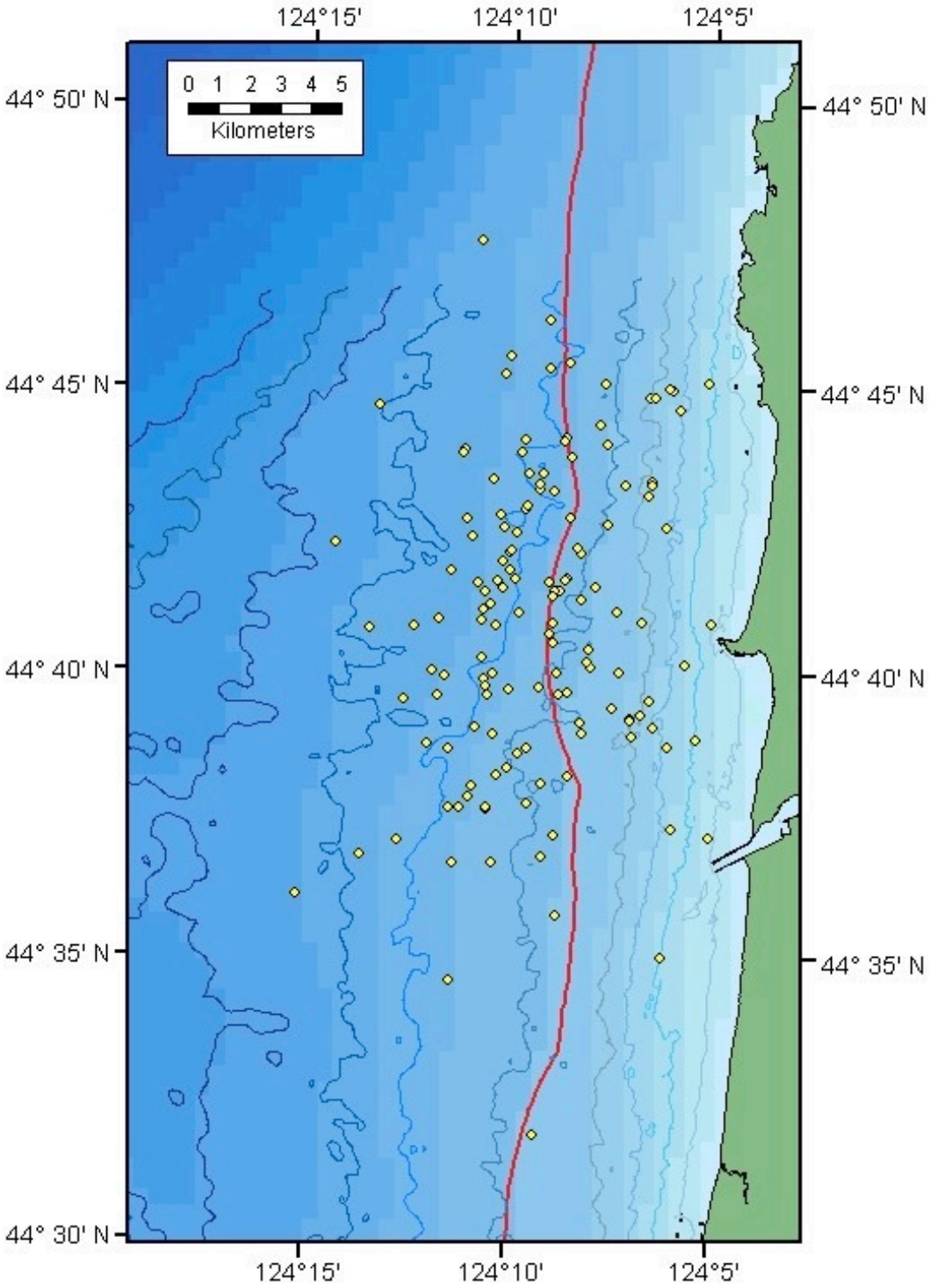

Figure 4. Locations of gray whale groups (yellow circles) observed on scan surveys off Yaquina Head during the southbound migration (December 2007 – February

25, 2008). Contours indicate 10-80 meter isobaths (every 10 meters). The red line is the boundary of the State of Oregon territorial sea.

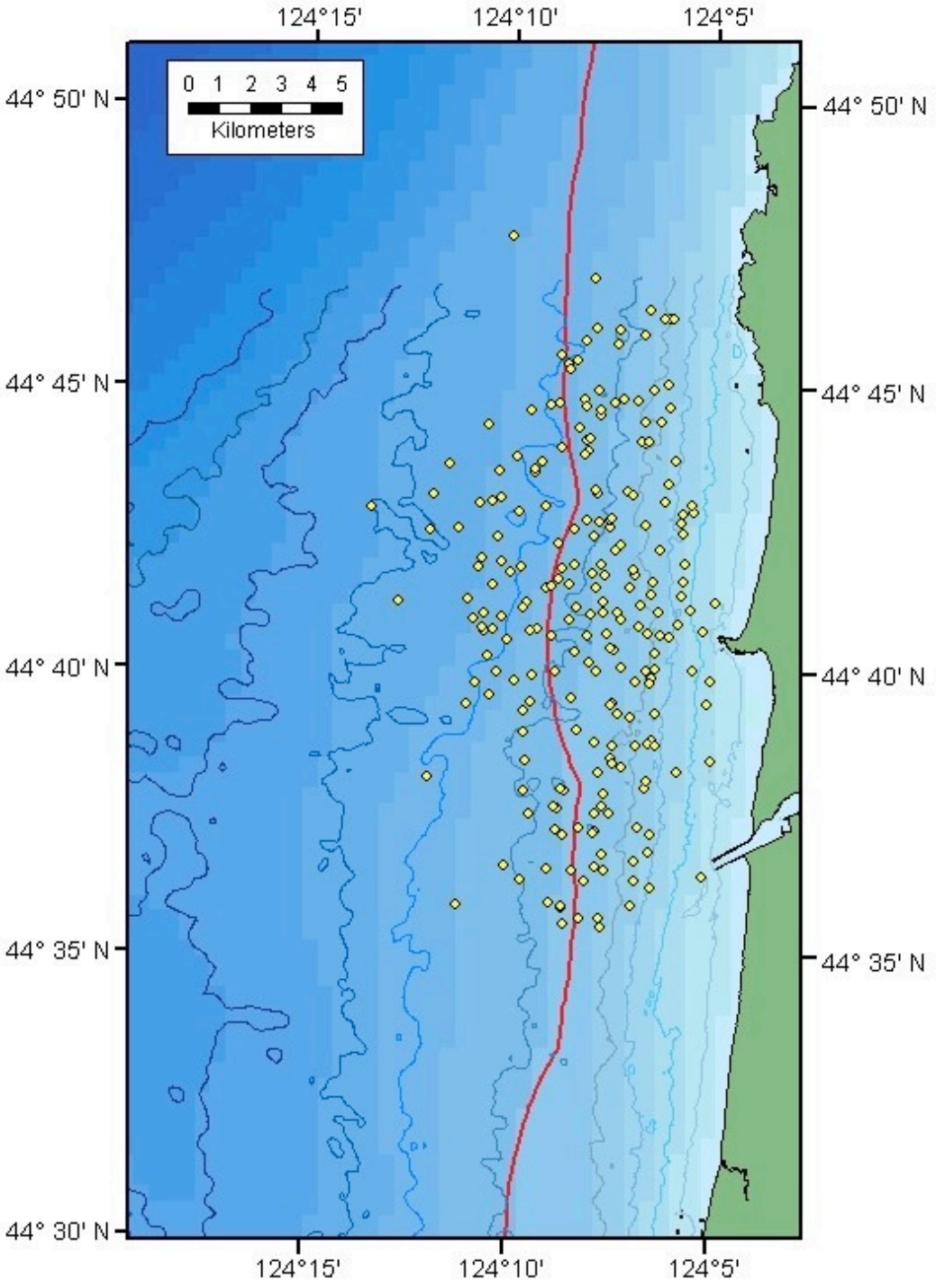

Figure 5. Locations of gray whale groups (yellow circles) observed on scan surveys off Yaquina Head during phase A of the northbound migration (February 26 –

April 9, 2008). Contours indicate 10-80 meter isobaths (every 10 meters). The red line is the boundary of the State of Oregon territorial sea.

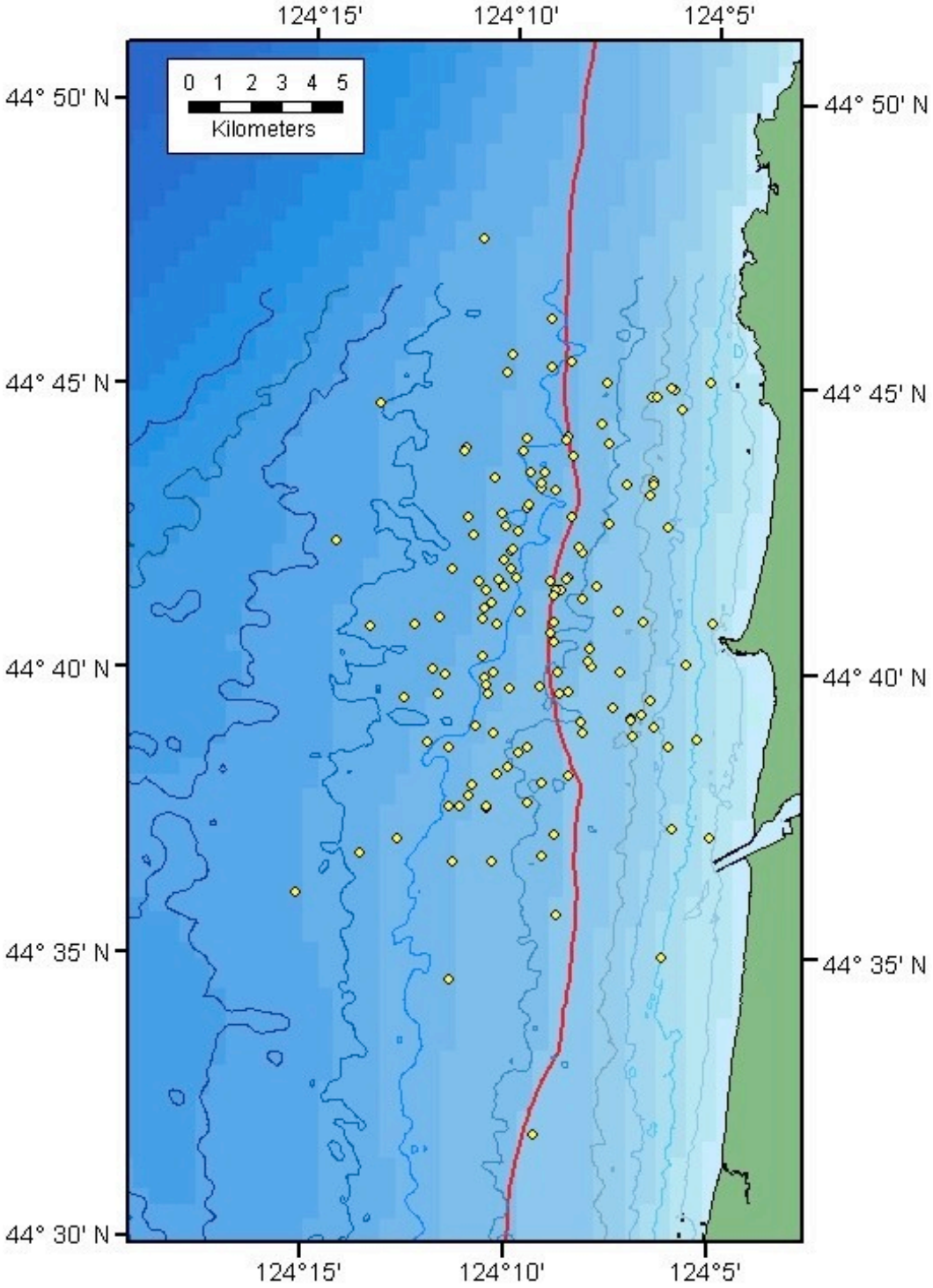

Figure 6. Locations of gray whale groups (yellow circles) observed on scan surveys off Yaquina Head during phase B of the northbound migration (April 10-May 29,

2008). Contours indicate 10-80 meter isobaths (every 10 meters). The red line is the boundary of the State of Oregon territorial sea.

Gray whale locations recorded during scan sampling events occurred in a bottom depth range of 12 – 75 meters. Average bottom depth at location of whale sightings was 46.3 m (S.D. 13.73). Similar to the differences in distance to shore, significant differences (Kruskal-Wallis Test statistic = 61.3, p = 0.0) were observed in median bottom depth of whale sighting location between the three migration phases (Fig. 7).

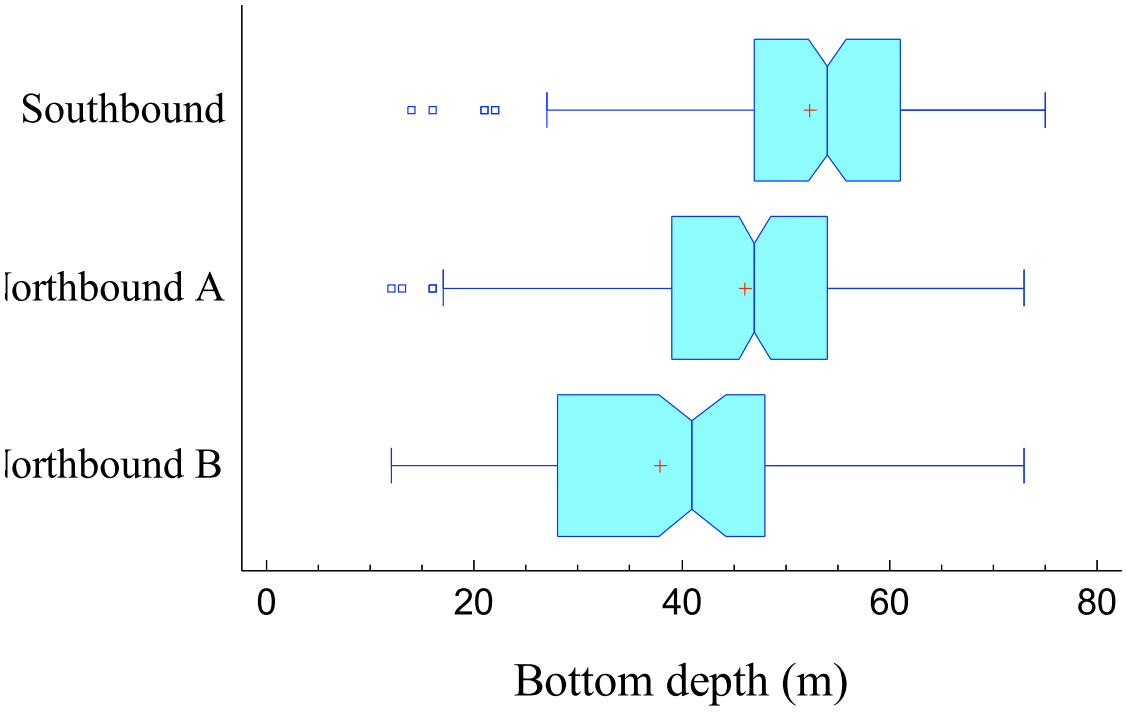

Figure 7. Box plot of bottom depth at gray whale locations recorded during the different migration phases. Average values are indicated by a cross. Boxes represent the interquartile range, the notch indicates the median value. Outlier values are indicated by squares.

Gray whales observed during this study migrate within the Oregon territorial sea, particularly during the northbound migration (Table 3). Migratory paths of some, but not all whales, pass through areas of currently proposed wave energy development.

Table 3. Proportion of whale locations (scan survey data) inside and outside the Oregon territorial sea (OTS) during the different migration phases.

Migration phase	**Number of locations**	**Inside OTS**		**Outside OTS**	
Southbound	139	57	41.0%	82	59.0%
Northbound - Phase A	230	155	67.4%	75	32.6%
Northbound - Phase B	91	71	78.0%	20	22.0%
Total	460	283	61.5%	177	38.5%

Behavioral observations

Distance from the observation station to tracked whales ranged from 0.28 to 13.56 km ($\bar{x}$ = 5.02 km, n = 1956). Out of the 120 focal observations, only 110 tracked whales had enough data to conduct further behavior analysis. Significant differences were observed in the average speed of gray whales tracked during the different migration phases (F = 8.04, p = 0.0006, Fig. 8). Average speed of tracked whales was 6.74 km/h (S.D.= 1.382, n = 37) during the southbound migration, 6.05 km/h (S.D.= 1.094, n = 47) during phase A of the northbound migration, and 5.42 km/h (S.D.= 1.529, n = 26) during phase B. The migration paths of tracked whales are shown in figures 9-11.

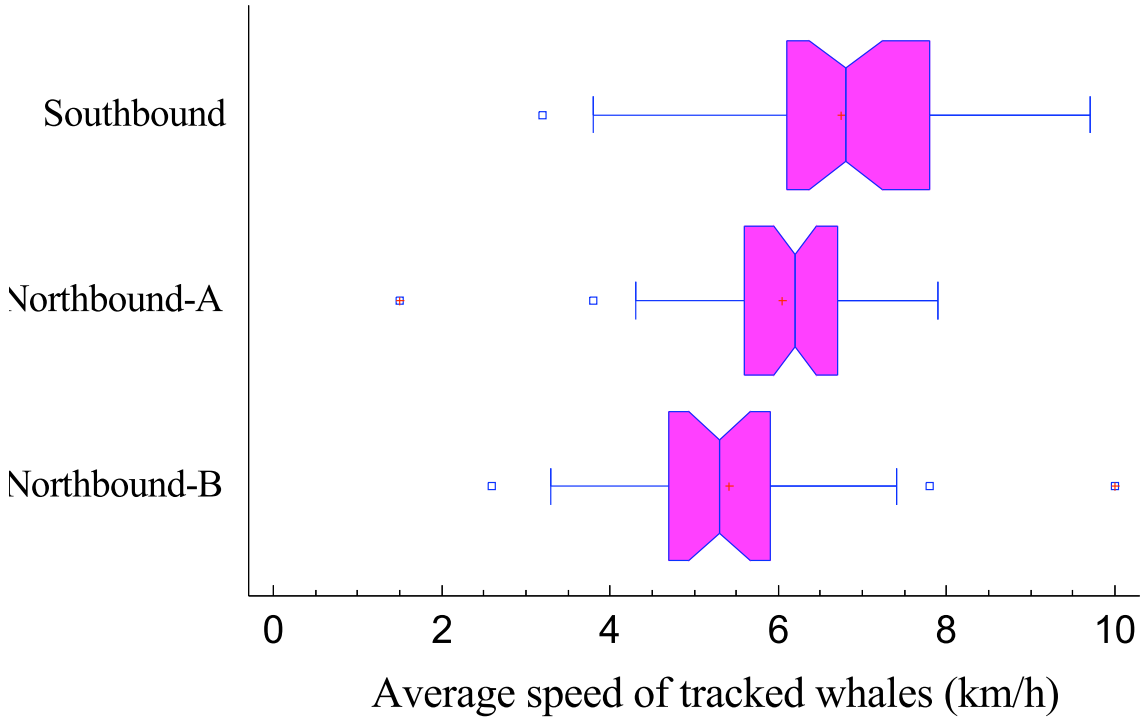

Figure 8. Box plot of speed of gray whales tracked during the different migration phases. Average values are indicated by a cross. Boxes represent the interquartile

range, the notch indicates the median value. Outlier values are indicated by squares.

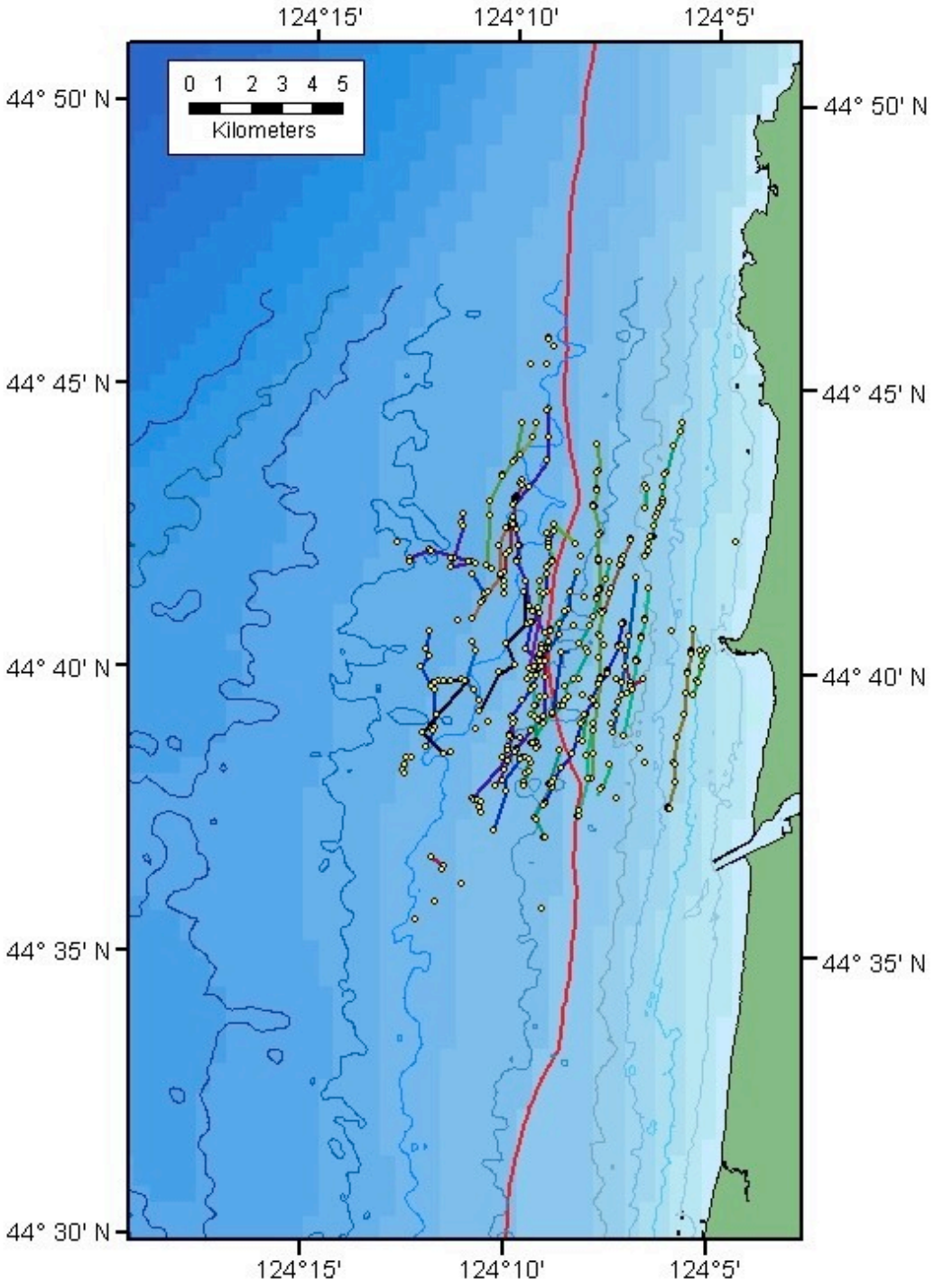

Figure 9. Migration path of gray whales tracked off Yaquina Head during the southbound migration (January 13-February 25, 2008). Contours indicate 10-80 meter

isobaths (every 10 meters). The red line is the boundary of the State of Oregon territorial sea.

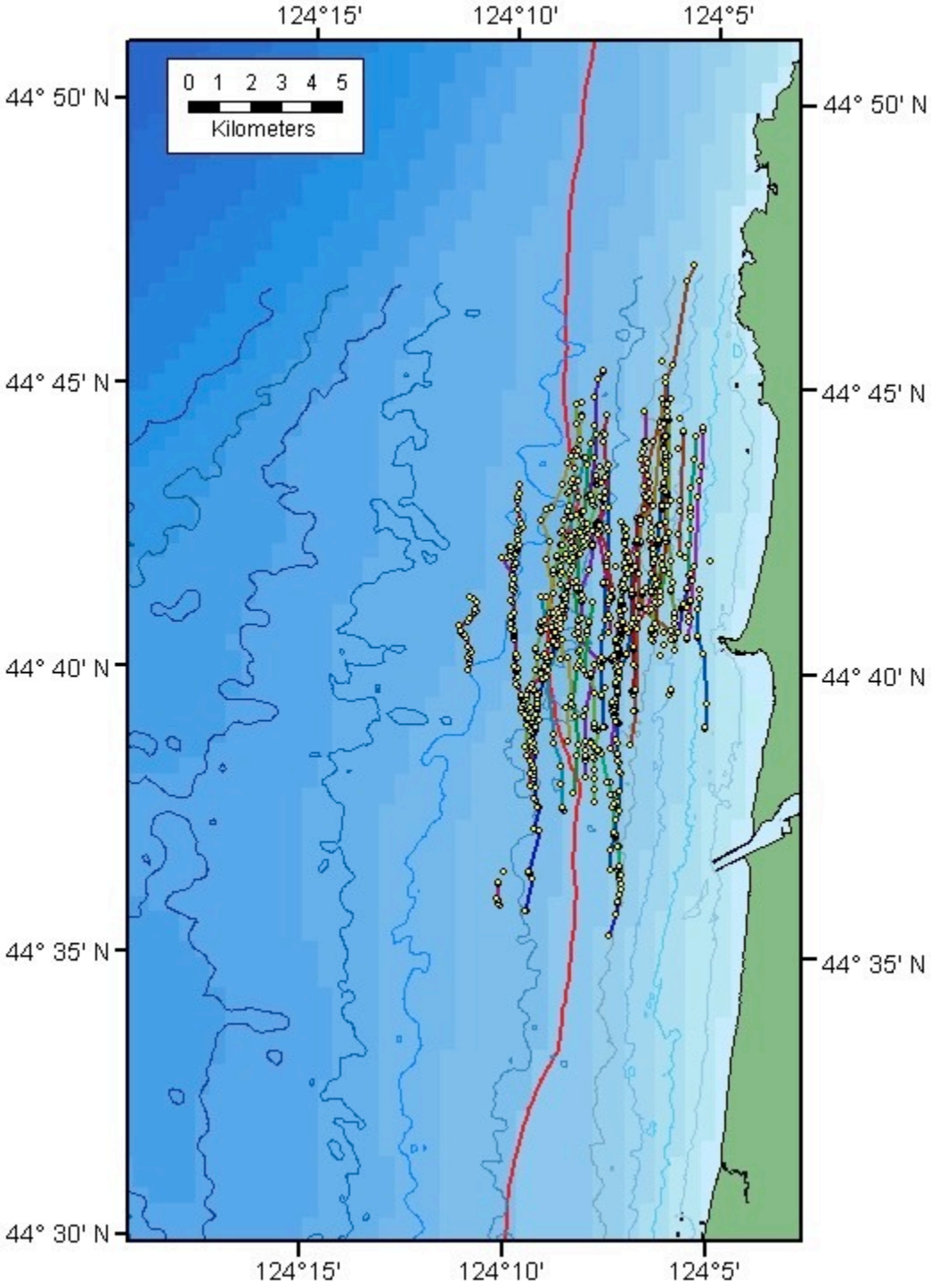

Figure 10. Migration path of gray whales tracked off Yaquina Head during the phase A of the northbound migration (February 26-April 9, 2008). Contours indicate 10-80 meter isobaths (every 10 meters). The red line is the boundary of the State of Oregon territorial sea.

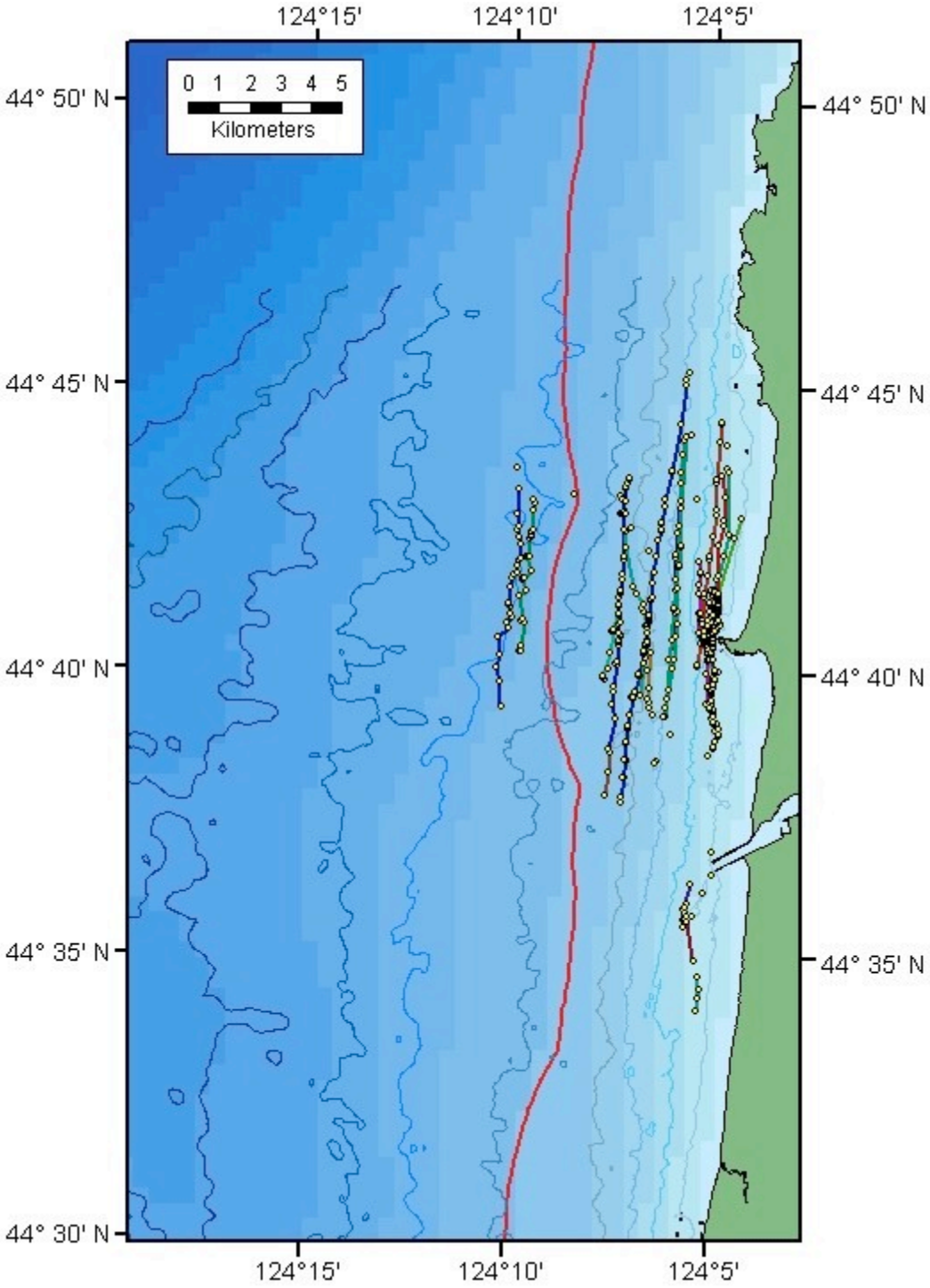

Figure 11. Migration path of gray whales tracked off Yaquina Head during phase B of the northbound migration (April 10-May 29, 2008). Contours indicate 10-80 meter isobaths (every 10 meters). The red line is the boundary of the State of Oregon territorial sea.

Discussion

This study presents up-to-date results on the migratory behavior of gray whales along the central Oregon coast. These results are in accordance with previous studies (e.g. Herzing and Mate 1984, Green *et al.* 1995) and add quantitative measurements of behavior that can be used as a baseline for future monitoring studies.

Shore-based observations are limited to the field of view, which is determined by distance to the horizon and obstructions in the area. The observation station at Yaquina head has an acceptable 180º field of view, with no obstructions and horizon estimated to be approximately 18 km (10 nautical miles). Gailey *et al.* (2007) limited their behavioral observations to within 4 km of their observation platforms which had a maximum height above sea level of 16 m. We conducted calibration tests by fixing a boat with the theodolite and comparing the location estimated by Pythagoras to the boat's GPS reading. At a distance of 7.6 km, the difference between the theodolite fix and the GPS was 232 m. Therefore, we consider that the elevation at Yaquina Head (26.9 m above mean sea level) allow reliable observations up to 8 km away from the station. Details about theodolite fixing related errors are discussed in Würsig *et al.* (1991). While limitations of the field of view at Yaquina Head are relevant for census studies (Green *et al.* 1995), we think that the coverage is appropriate for behavioral studies within the Oregon territorial sea. The 8 km from the station criterion was applied when choosing whales to be tracked and is reflected in a lower number of tracks further offshore, particularly during the northbound migration. The bias to track whales closer to the station must be considered before drawing conclusions from tracking location data. That is the reason why distance

to shore, depth and percentage of locations within the Oregon territorial sea are only analyzed for scan sampling locations.

Some tracklines had very high speed estimates which were likely the result of theodolite fix errors. This problem was more prevalent during the first two months of the study as observers became familiar with the method. Nevertheless, the majority of the tracking data during the northward migration produced speed estimates well within the range of values reported in previous studies (*e.g.* Harvey and Mate 1984, Mate and Urban-Ramirez 2003).

The migration paths of tracked whales seem to follow a constant depth (isobath) rather that following exactly the shoreline. For example, some whales that we started tracking more than 3 kilometers away from the observation point maintained a straight path even as they approached Yaquina Head. Linearity of their path continued as they moved away from the Head. Nevertheless, we observed variability in the isobath followed by different whales within the same migration phase. Green *et al.* (1995) also observed this variability and mention that the migration corridor off the Oregon and Washington coasts is seasonally and annually "elastic".

Our results indicate that, as expected, the migration paths of some gray whales cross through areas of proposed wave energy development. Deployment of structures for wave energy facilities (buoys, cables, mooring systems, etc.) in the migratory path of gray whales raises the possibility of collision, entanglement or displacement of the whales (Boehlert *et al.* 2008). Future observations can use the data presented here as a baseline to determine potential effects of wave energy facilities on the migratory path of gray whales off the Oregon coast.

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