

## Historic and current habitat use by North Pacific right whales *Eubalaena japonica* in the Bering Sea and Gulf of Alaska

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### ABSTRACT

1. To help define areas and ecological parameters critical to the survival and recovery of the remnant population of North Pacific right whales, habitat use was investigated by examining all available sighting and catch records in the south-eastern Bering Sea (SEBS) and Gulf of Alaska (GOA) over the past two centuries.

2. Based on re-analyses of commercial whaling records, search effort, and resultant catches and sightings, waters of the: (i) SEBS slope and shelf, (ii) eastern Aleutian Islands and (iii) GOA slope and abyssal plain were important habitat for North Pacific right whales through the late 1960s.

3. Since 1980, the only area where right whales have been seen consistently is on the SEBS middle shelf. However, acoustic detections and single sightings have been reported in all other regions except the SEBS slope and oceanic GOA (areas where little, if any, acoustic and visual effort has occurred).

4. Sightings since 1979 were in waters <200 m deep which may simply reflect the paucity of search effort elsewhere. From the commercial whaling era to the late 1960s, right whales were commonly seen in waters >2000 m deep, indicating that their distribution is not restricted to shallow continental shelves.

5. North Pacific right whale sightings through the centuries have been associated with a variety of oceanic features, and there is little in common in the bathymetry of these regions. These whales appear to have a greater pelagic distribution than that observed in the North Atlantic, which may be related to the availability of larger copepods across the SEBS and GOA.

*Keywords:* cetacean, distribution, endangered, marine mammal, oceanography, prey

### INTRODUCTION

Prior to 1840, North Pacific right whales *Eubalaena japonica* were abundant during the summer months throughout the waters of the south-eastern Bering Sea (SEBS) and Gulf of Alaska (GOA) (Webb, 1988; Scarff, 1991). Two areas of intense commercial whaling during the 19th century were the 'Bristol Bay Ground' in the SEBS and the 'Kodiak Ground' or 'Northwest Ground' in the GOA (Maury, 1852, 1853; Townsend, 1935) (Fig. 1). Within 14 years of the discovery of the Northwest Ground in 1835, commercial whalers had greatly reduced the North Pacific right whale population such that many whalers switched to the newly established bowhead whale *Balaena mysticetus* fishery in the Arctic (Scarff, 2001). The prohibition on the catching of right whales established in 1935 provided some protection for

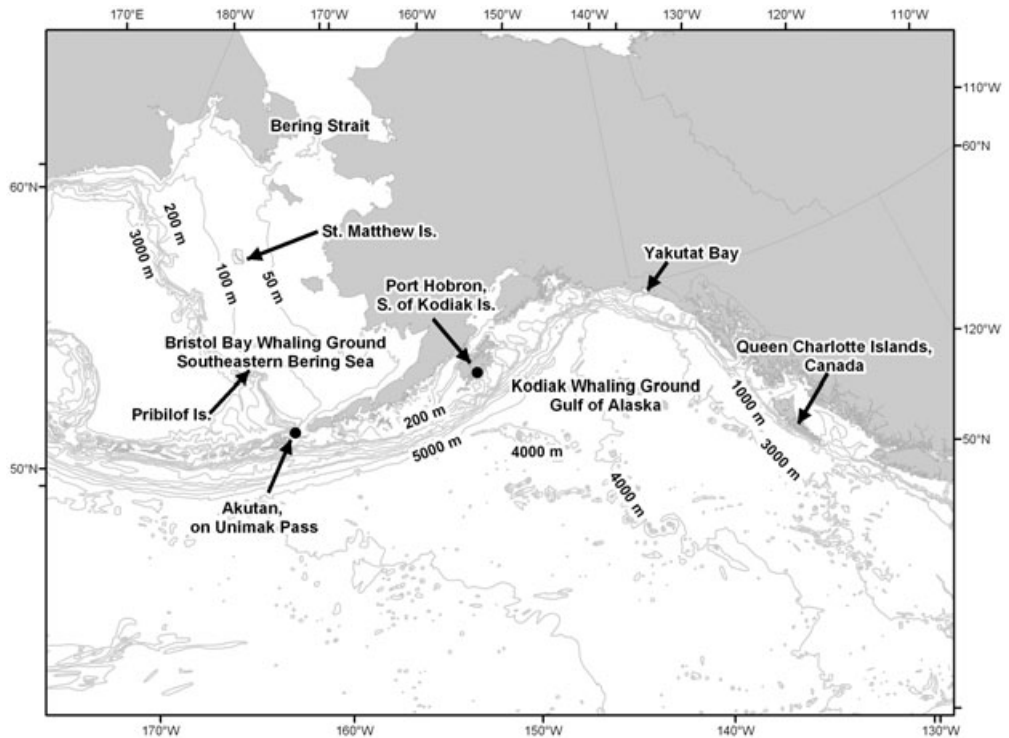


Fig. 1. Place names mentioned in the text.

the species until the Soviet Union began widespread illegal whaling of right whales in the post-war period (Doroshenko, 2000).

In 2000, North Pacific right whales were recognized as a species separate from right whales in the North Atlantic *Eubalaena glacialis* (Rosenbaum *et al.* 2000). Brownell *et al.* (2001) recently reviewed the conservation status of North Pacific right whales and concluded that available data support the hypothesis that at least two stocks of right whales exist in the North Pacific: a western population that is found in summer in the Okhotsk Sea and north-western North Pacific, and an eastern population that includes whales found in the Bering Sea and Gulf of Alaska. The reviewed data further suggested that by 1960, North Pacific right whales were showing signs of recovery following the 1935 prohibition on catches. However, Soviet pelagic whalers illegally killed at least 508 right whales in the North Pacific; this total included at least 251 animals from the GOA and 121 in the SEBS from 1963 to 1967 (Doroshenko, 2000). In recent years, very few right whales have been seen and photographed in these regions (LeDuc *et al.*, 2001; Waite, Wynne & Mellinger, 2003). Brownell *et al.* (2001) suggest the Soviet catches severely reduced the long-term prospect for recovery of the eastern population.

On 2 June 1970, right whales were added to the list of species threatened with extinction under the US Endangered Species Conservation Act of 1969, and were subsequently listed as endangered under the US Endangered Species Act of 1973. Defining habitat critical to the survival of North Pacific right whales is difficult, given the paucity of life history information. Migration patterns have been surmised based on seasonal sighting records (see Clapham *et al.*, 2004), but calving and nursery areas have never been documented (Scarff, 1991; Brownell *et al.*, 2001) unlike for some other right whale populations (e.g. Kraus *et al.*, 1986;

Payne, 1986). Biological sampling of eastern North Pacific right whales has been limited to nine scientific research catches by Japan in the early 1960s, including three whales in the GOA and six in the SEBS (Omura *et al.*, 1969).

Observations of a group of right whales in the SEBS middle shelf in 1996 (Goddard & Rugh, 1998) led to dedicated photo-identification and genetics studies in 1997 (Perryman, LeDuc & Brownell, 1999; LeDuc *et al.*, 2001; Tynan, DeMaster & Peterson, 2001), and were augmented by shipboard acoustic monitoring in 1999 (McDonald & Moore, 2002; Munger *et al.*, in press). Deployment of autonomous acoustic recorders to detect right whale calls year-round was initiated in the SEBS middle shelf and GOA in 2000 (Moore, 2003; Mellinger *et al.*, 2004). Provisional results of these acoustic data indicate that at least a few right whales continue to occupy both of these areas, at least in summer months (Waite *et al.*, 2003; Mellinger *et al.*, 2004; Munger *et al.*, 2003).

Part of the difficulty in determining what habitat is important to the survival and recovery of rare species is that we cannot obtain sufficient sample sizes for critical variables, such as seasonal distribution and abundance, calving areas or foraging areas. Furthermore, we cannot assume that the remaining population will allow us to identify the full range of habitat that is important to the species. Scarff (1986, 1991) examined the distribution of 19th century right whale encounters using the compilation provided by Maury (1852 *et seq.*). Clapham *et al.* (2004) created monthly plots that included these data. These plots suggest that right whales had an extensive offshore distribution in the 19th century, and were common in areas where few right whales are seen today, such as the GOA. The monthly plots indicated that right whales migrated northward in spring and were found in major concentrations north of 40°N in summer. Clapham *et al.* (2004) concluded that the eastern population currently exists as a remnant and does not fully occupy its former range from the 19th century.

Here we re-examine all available sighting and catch records in or near the SEBS and GOA over the past two centuries to help define areas and ecological parameters critical to the survival of the remnant eastern population of North Pacific right whales.

## METHODS

We created maps comparing the distribution of catches and sightings in the 19th, 20th and early 21st centuries in the SEBS and GOA. We relied heavily on the 20th century data set that Brownell *et al.* (2001) tabulated from multiple sources. Clapham *et al.* (2004) kindly provided these data in electronic format. Additional data sets presented in Townsend (1935), Omura (1958), Reeves *et al.* (1985), Brueggeman, Newby & Grotefendt (1986), Scarff (1991), Miyashita, Kato & Kasuya (1995), LeDuc *et al.* (2001), and LeDuc (2004) are described in greater detail below.

Maps were created using ArcView geographical information system software. Plots that show sightings per unit effort within 5-degree blocks were projected using the GCS North American 1983 coordinate system. This projection displays each 5-degree block as a perfect square. Symbols in each sector were positioned so all months of the year could be displayed (i.e. the first row in each 5-degree block begins with January and ends with April, the middle row depicts May to August, and the last row September to December). Effort maps were restricted to the area east of 180°W and north of 40°N to encompass the commercial whaling grounds in the SEBS and GOA. The southern extent of each map reflects where sightings diminished during the summer months, May to August (see Clapham *et al.*, 2004).

Plots showing sighting locations were projected using the Alaska Albers Equal Area Conic coordinate system which provides a more accurate depiction of positional data. Maps include all available data collected north of 40°N. Separate plots were created for data

collected west of 160°W and east of 180°W (primarily in the SEBS) and east of 160°W (primarily in the GOA) to show whale locations in each area in greater detail. Depth contours and grids (5 × 5 degrees) were included on all maps. Where possible, whale distribution was compared to bathymetry. Each sighting record reported within these sections represents a sighting location not total number of whales seen. The data sets presented in these plots are described below.

### **Commercial whaling 1835–1906**

Scarff (1991) analysed the whaling charts presented in Maury (1852 *et seq.*) by creating a table based on histograms depicting right whale distribution (Series F, Chart no. 1). This table (Scarff, 1991: Table 3) provides the number of days right whales were observed and number of days of whaling effort per month within each sector (a 5-degree latitude by 5-degree longitude box) from 1835 to 1851. Data were entered into a Microsoft Excel spreadsheet (provided by Clapham *et al.*, 2004). We then staggered the monthly data symbols within each 5-degree block in order to view all months on one map. Because Maury included whaling effort, these encounter data are particularly useful for documenting where right whales were and were not found during this era; however, discrepancies exist among his whaling charts, and Maury did not include some sightings in his Chart no. 1 (Scarff, 1991). Biases and errors within the Maury data sets are discussed in detail by Scarff (1991) and Reeves, Josephson & Smith (2004). For example, examination of original logs from whaling ships in the North Atlantic revealed that the apparent offshore distribution previously shown in this ocean basin was largely the result of errors in how the source data were extracted and transcribed (Reeves *et al.*, 2004).

Townsend (1935: Chart C) plotted the locations of American whaleships on days when right whales were taken between 1785 and 1913. Whaling in waters north of 40°N occurred between 1839 and 1906 (Scarff, 1991). We recreated Chart C by scanning the portion of the chart north of 40°N and east of 180°W and saving the digital image as a JPEG file. This file was imported into ArcMap 8.2 as a raster data set layer and saved as a georeferenced map. Whaling locations were redrawn as graphics then converted to a shapefile. The shapefile was edited to include coordinates and month, linked to nearest isobath feature for each location. These positional data were then plotted on two maps (divided along 160°W). It should be noted that in the more densely plotted areas, such as that shown in the GOA, Townsend (1935, p.15) may have omitted 10–20% of the available records. Best (1987) checked for possible errors in the Townsend (1935) data set (his charts and table) by examining a subsample of logbook abstracts. He found some North Pacific right whales were omitted or plotted in error as other species, though this under-reporting error was very small ( $n = 8$  more North Pacific right whales) (P. Best, personal communication). Because Townsend only examined a sample of logbooks, his plots within the SEBS and GOA may only partially represent the distribution of whaling activity that occurred between 1839 and 1906.

### **Sightings and catches 1924–68**

Right whale sightings and catches for which locations were available were plotted west and east of 160°W, similar to the maps created for the Townsend (1935) data. Specific data sets are described below.

#### *Shore whaling and sightings 1924–39*

Shore whaling took place in the GOA, SEBS and offshore British Columbia from 1911 to 1939 with a total of 28 right whales taken (Tomilin, 1957; Reeves *et al.*, 1985). Locations of

kills and unsuccessful chases were only reported for some of the whales that were seen between 1924 and 1939 (Reeves *et al.*, 1985). Descriptions of 17 kill locations in Alaskan waters (1924–35) in Reeves *et al.* (1985) were converted to latitudes and longitudes by Brueggeman *et al.* (1986). Of the six catches in Canadian waters, only three catches (two in 1924 and one in 1926) included location data (Reeves *et al.*, 1985). Eight sightings of right whales (in most cases unsuccessful chases) were reported from 1928 to 1939 (table 8 in Reeves *et al.*, 1985), seven of which included descriptive locations that Clapham *et al.* (2004) converted to latitudes and longitudes.

#### *Japanese sightings and scouting cruises 1941–68*

Of 129 right whales observed between 1941 and 1958, the specific latitude and longitude location was provided for only one sighting and none included the year observed (Omura, 1958; Brownell *et al.*, 2001). Year was provided for all sightings from 1959 to 1963, and 77% of the records (40 out of 52 total) also included month and day. Locations were provided for 94% of these sightings (Brownell *et al.*, 2001). Additional sightings collected up until 1968 were only available in figures in Omura *et al.* (1969), which also included all prior sightings back to 1941. To avoid including duplicate sightings from these three published data sets, we plotted only the sightings and scientific catches found in Omura *et al.* (1969: fig. 13(2–7) and table 1) that covered the entire time period from 1941 to 1968 and occurred east of 180°W, using the same technique we applied to Townsend's (1935) Chart C. The sightings by Soviet whalers (1951–57), also shown on these figures, all occurred west of 180°W (Klumov, 1962) and were not plotted.

#### *Additional sightings during the 1950s*

Additional records for the 1950s included opportunistic sightings from weather ships ( $n = 2$ ) (Pike & McAskie, 1969) and Dutch vessels ( $n = 4$ ) (Slijper, van Utrecht & Naaktgeboren, 1964) in the GOA. Sightings from the Dutch vessels occurred over a 4-year period (1955–58) within a 10-degree block between 40–50°N and 170–180°W, and are not shown on any map as exact locations were not available and species identification was uncertain.

#### *Soviet whaling in the 1960s*

The illegal catch of North Pacific right whales by Soviet whalers occurred from 1963 to 1966 in the GOA, and in 1964 and 1967 in the SEBS. Exact locations were available for only two kills in the GOA west of 160°W. Areas where Soviet whalers likely caught large numbers of right whales are shown as shaded regions (recreated from fig. 1 in Doroshenko, 2000).

#### **Japanese effort and sightings 1964–90**

Miyashita *et al.* (1995) mapped vessel effort and whale sighting data collected during Japanese whale scouting (1964–88) and sighting cruises (1972–90). Sightings were displayed as a density index of number of animals per 10 000 nautical miles (nmi) of effort within 5 degree squares by month. Because sighting effort occurred throughout most of the North Pacific north of 40°N, these data provide critical information on the distribution of right whales during this time period. We created an Excel file similar to that used to plot Scarff's (1991) data set. Comparisons were made between the Miyashita *et al.* (1995) data and Japanese Whaling Association sightings reported from 1965 to 1979 (Wada, 1975 *et seq.*; Anonymous, 1976, 1980, 1981). Wada (1975 *et seq.*) and Anonymous (1976, 1980, 1981) assigned sightings to 5 × 5, 5 × 10, or 10 × 20 degree squares (Table 1). Clapham *et al.* (2004) selected the mid-point of each block to represent these sighting locations. We opted to create shaded regions

covering the areas where the sightings were reported each year. Many of these regions represent sightings of only 1–3 whales (Table 1).

### Effort and sightings post-whaling 1979–2002

Sightings of North Pacific right whales in the last two decades of the 20th century were exceedingly rare, particularly in the GOA. Since 1979, a number of research efforts and literature reviews have focused on cetacean distribution and abundance in Alaskan waters (e.g. Rice & Wolman, 1980; Brueggeman, Grotefendt & Erickson, 1984; Turnock, Buckland & Boucher, 1995; Forney & Brownell, 1996; Laidre *et al.*, 2000; Waite, Friday & Moore, 2002). Some right whale sightings were made opportunistically during research cruises [e.g. Goddard & Rugh, 1998; Platforms of Opportunity Program (POP) database (The POP database is maintained by the National Marine Mammal Laboratory, NMFS, Seattle, WA., USA)], but most of the sightings were from dedicated surveys to document cetacean distribution (e.g. Moore *et al.*, 2000, 2002; Waite *et al.*, 2003), particularly surveys focused on right whales (e.g. Tynan, 1998; Perryman *et al.*, 1999; LeDuc *et al.*, 2001; Tynan *et al.*, 2001). Tracklines from a number of these studies, in addition to the positional data presented west and east of 160°W, were included to show where searches for cetaceans have taken place.

**Table 1.** Japanese survey sectors where North Pacific right whales were observed 1965–79

Year	From latitude	To latitude	From longitude	To longitude	Location	Number of whales	Source
1965	45	50	170	180	South of Aleutians	1	Wada (1975)
"	50	55	160	170	Aleutians, Pacific side	1	"
"	55	60	140	150	Gulf of Alaska	1	"
1966	50	55	150	160	South of Alaska Peninsula	3	"
"	50	55	170	180	Aleutians, Pacific side	1	"
"	55	60	140	150	Gulf of Alaska	1	"
1967	50	55	150	160	South of Alaska Peninsula	1	"
"	55	60	160	170	Eastern Bering Sea	1	"
1969	45	50	170	180	South of Aleutians	1	"
"	50	55	160	170	Aleutians, Pacific side	1	"
1973	45	50	140	150	NE Pacific, south of GOA	1	"
"	50	55	160	170	Aleutians, Pacific side	1	"
1974	40	50	140	160	NE Pacific	1	Anonymous (1976)
1975	40	45	140	150	NE Pacific, south of GOA	2	Wada (1977)
1976	45	50	150	155	NE Pacific, south of AK Pen.	1	Wada (1978)
"	50	55	155	160	Kodiak Island	1	"
1977	45	50	135	140	NE Pacific, south of GOA	2	Wada (1979)
"	45	50	140	145	NE Pacific, south of GOA	1	"
"	45	50	150	155	NE Pacific, south of AK Pen.	1	"
1978	50	60	140	160	Alaska Peninsula region	2	Anonymous (1980)
1979	40	45	145	150	NE Pacific	1	Wada (1981)
"	40	50	140	160	NE Pacific	1	Anonymous (1981)

NE, north-eastern; GOA, Gulf of Alaska; AK Pen., Alaska Peninsula.

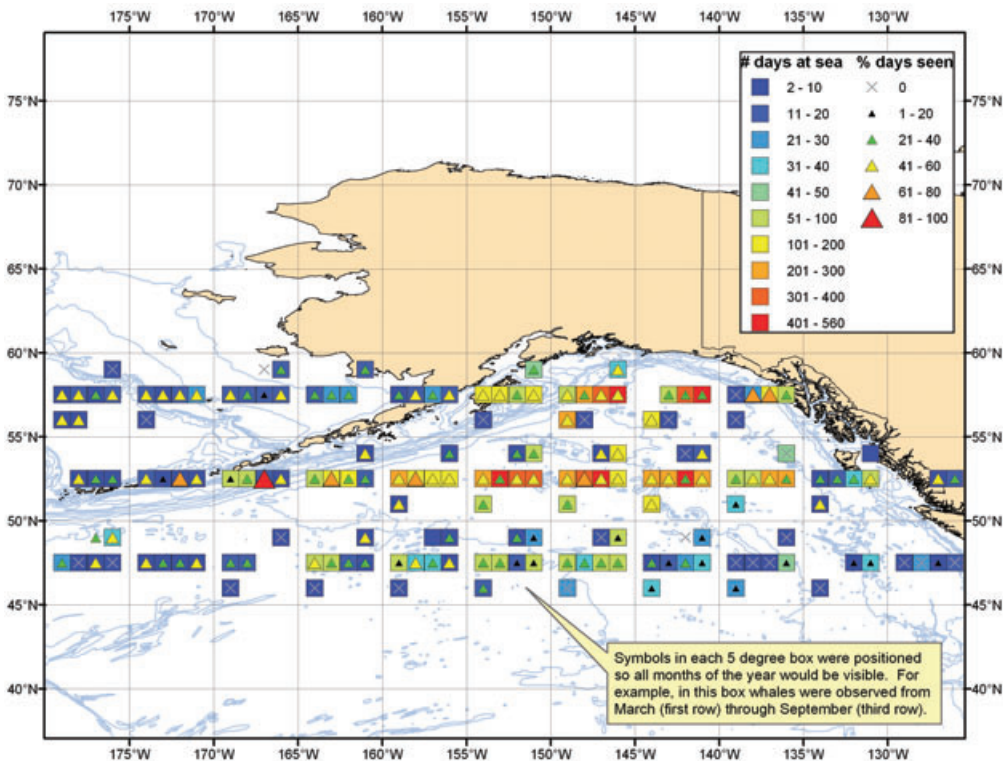


## RESULTS

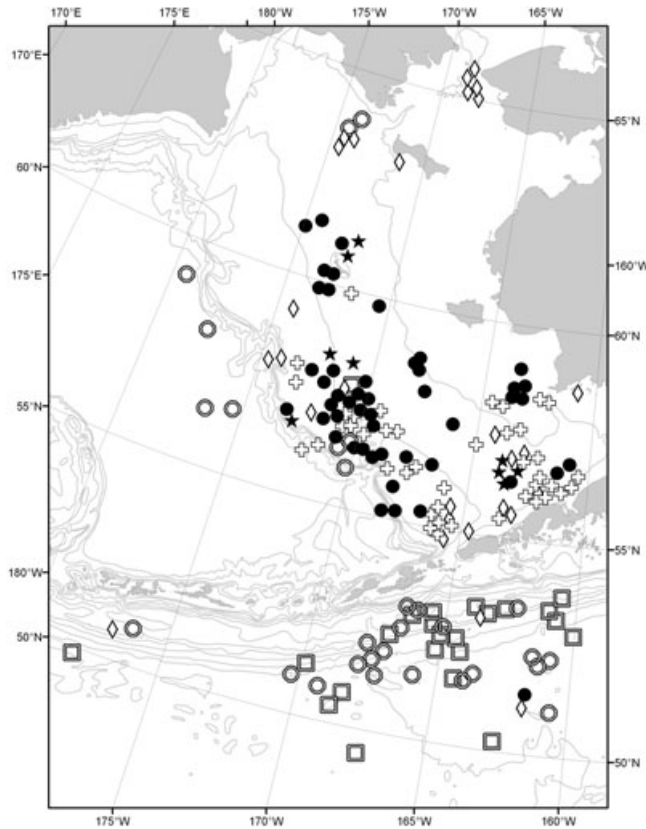
### Commercial whaling 1835–1906

According to Maury (1852 *et seq.*), commercial whaling from 1835 to 1851 occurred as early as March and continued into October (Fig. 2). Symbol colours were scaled such that the warmer the colour, the greater the number of days at sea and percentage of days right whales were seen. Based on these data, commercial whaling was concentrated between 50°N and 60°N in the GOA and in the Bristol Bay Ground in the SEBS (Fig. 2). Scarff's interpretation of the Maury data was that no whaling activity for right whales was reported north of 60°N (Clapham *et al.*, 2004), at least not prior to 1851. However, Townsend (1935: Chart C) does show whaling for right whales as far north as the Bering Strait (Fig. 3). Although these northernmost whales might be misidentifications of bowhead whales (Scarff, 1986, p. 47), Bockstoce (1986) concluded that the two species were easily differentiated from one another both physically and behaviourally by whalers. Examination of some of the original logbooks upon which the Maury and Townsend charts were based is currently underway and should resolve some of the discrepancies found in these data sets (e.g. Reeves & Mitchell, 1990; Reeves *et al.*, 2004).

Townsend's (1935) Chart C included locations of whaleships that killed 2118 right whales north of 40°N in the North Pacific between 1839 and 1906. About 72% of those catches occurred by 1851 and 97% by 1875 (Townsend, 1935, pp. 19–50). A total of 1018 catch records were recreated from Townsend, (1935) Chart C for whales taken north of 40°N and east of



**Fig. 2.** Commercial whaling effort and sighting data from the right whale fishery 1835–51. The warmer the colour of the symbol, the greater the number of survey days and percentage of days right whales were observed (see text for references).



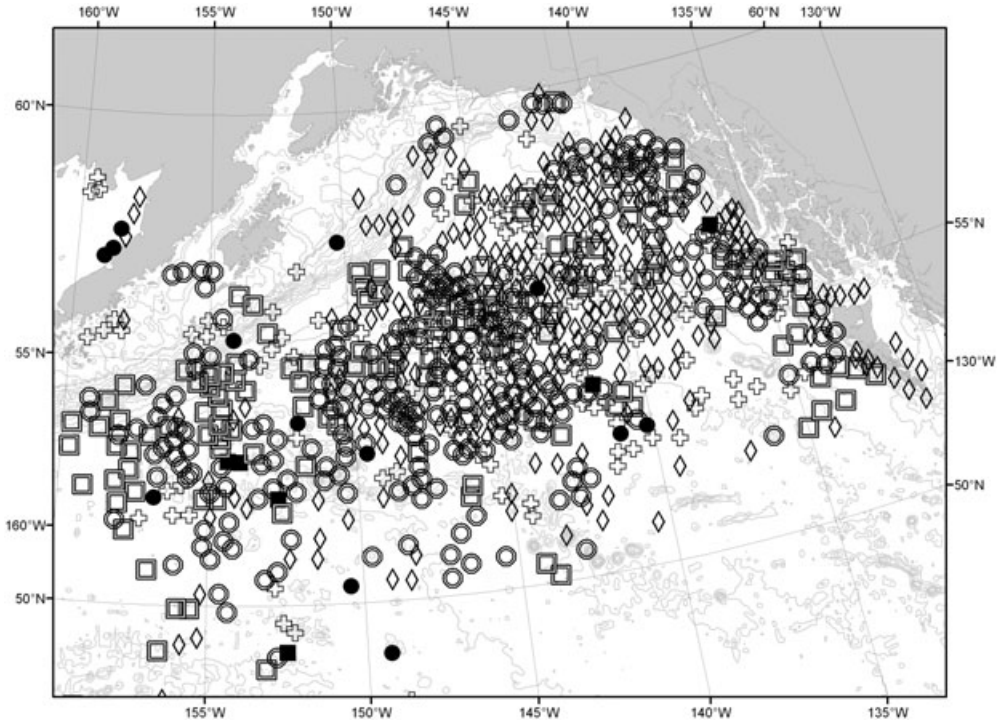
**Fig. 3.** Locations of American whaleships 1839–1904 on days when North Pacific right whales were taken in waters west of 160°W and east of 180°W. Symbol shape denotes month: January (closed triangles), May (open squares), June (open circles), July (open diamonds), August (open crosses), September (closed circles) and October (closed stars) (see text for references).

180°W (Figs 3 and 4). It should be noted that only five catches were reported south of 40°N (and therefore were not digitized): four in May and one in November, and all were north of 37°N. Figure 3 shows 180 of the digitized records for catches west of 160°W, of which 133 occurred in the Bering Sea and 47 were recorded south of the Aleutian Islands. Whaling occurred in the Bering Sea from May to October with the majority of catches occurring during August (32%) and September (35%). South of the Aleutian Islands, whaling occurred from May to July and in September, with the majority of catches occurring in May (47%) and June (43%). During this period, nearly all of the whaling activity in the Bering Sea (91%) took place in shallow (< 200 m deep) continental shelf waters. Conversely, south of the Aleutian Islands, right whales were caught along the steep continental slope (200–2000 m deep) and basin (> 2500 m deep) habitats (Fig. 3).

American whalers also caught right whales in Bristol Bay and throughout the GOA east of 160°W. Figure 4 shows 825 records recreated from Townsend's (1935) Chart C: nine in Bristol Bay and 816 in the GOA. Whaling in the GOA occurred from April to October and in December, with the majority of catches occurring in June (33%) and July (34%). At least 80% of right whales killed in GOA waters east of 160°W were in waters deeper than 2500 m (Fig. 4). No seasonal change in depth at catch location was evident from May to August for whales taken in the GOA ( $\chi^2 = 4.2$ ,  $P = 0.65$ ; Table 2).

There appeared to be some errors in stamping on Townsend's Chart C near the Bering Strait where January symbols ( $n = 5$ ) partially obscured July symbols (Fig. 3). Stray symbols [January ( $n = 5$ ) and December ( $n = 3$ )] also partially obscured summer symbols in Bristol





**Fig. 4.** Locations of American whaleships 1839–1904 on days when North Pacific right whales were taken in waters east of 160°W. Symbol shape denotes month: January (closed triangles), April (closed squares), May (open squares), June (open circles), July (open diamonds), August (open crosses), September (closed circles), October (closed stars) and December (closed diamonds) (see text for references).

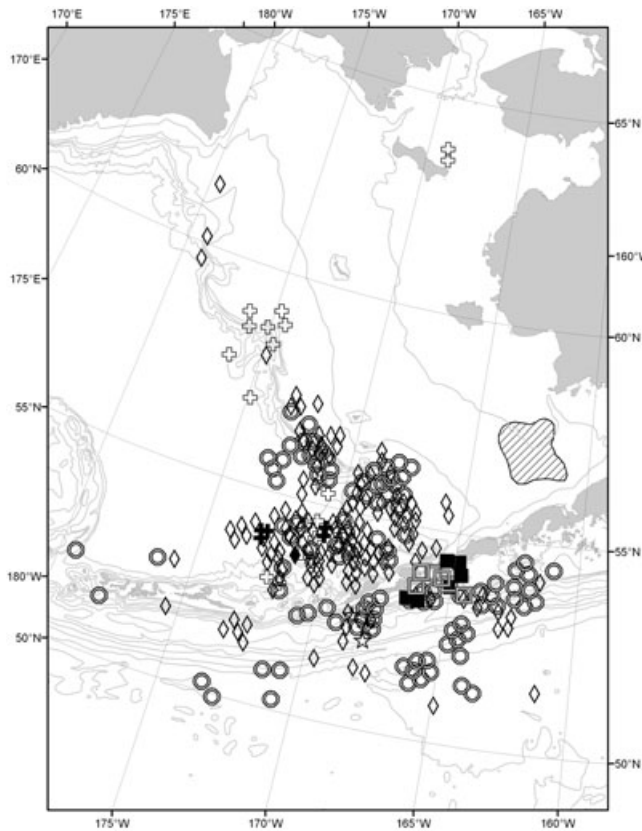
**Table 2.** Gulf of Alaska depths east of 160°W where North Pacific right whales were caught by American whaleships. Depths were binned and compared across months from the Townsend (1935) data

	April	May	June	July	August	September	October	December
< 1000 m		8	23	31	12			
1000–2500 m	1	16	29	29	10	1		
> 2500 m	6	119	216	219	84	10	1	1

Bay east of 160°W (Fig. 4). Townsend (1935, p. 11) clearly states that ‘the whalers were *not there in winter* . . . [referring to the Bering Sea]’ nor was winter whaling (November–February) reported by Maury (Fig. 2). We included these winter symbols in the comprehensive data set (noting Townsend’s statement), but did not map them or use them in any analyses.

### Sightings and catches 1924–68

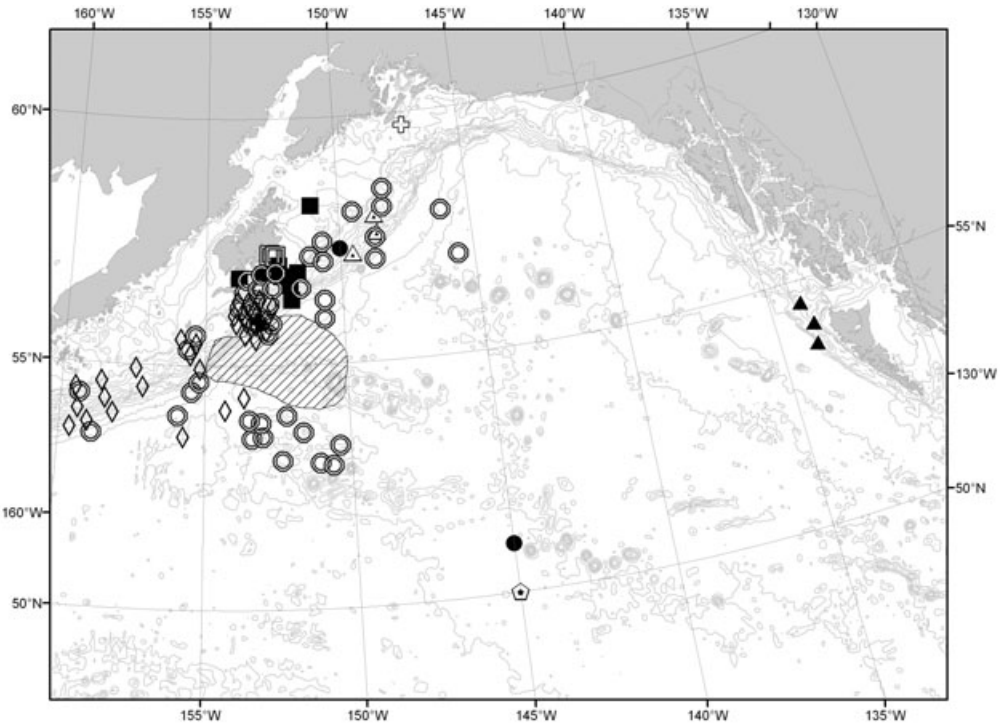
The shore whaling station at Akutan (1924–39) reported right whales in the vicinity of Unimak Pass and south of the Pass within 150 km of the station (Fig. 5). Catches occurred in June ( $n = 4$ ) and July ( $n = 2$ ), and unsuccessful chases were reported in June ( $n = 2$ ), August ( $n = 3$ ) and September ( $n = 1$ ). A total of 351 sighting records were recreated from the figures in Omura *et al.* (1969) for right whales observed by Japanese catcher-boats between 1941 and 1968. There were 81 records south of the Aleutian Islands and west of 160°W in June ( $n = 53$ ),



**Fig. 5.** Sightings of North Pacific right whales in waters west of 160°W and east of 180°W from 1924 to 1968. Symbols denote data sets: shore whaling station at Akutan & Alaska 1924–39 [catches = closed squares, sightings/unsuccessful chases = open squares], Japanese catcher-boats 1941–68 (catches by month = July (closed diamonds), August (closed crosses); sightings by month = June (open circles), July (open diamonds), August (open crosses) and September (open stars)], and Soviet whaling 1963 and 1967 (hatched polygon) (see text for references).

July ( $n = 25$ ), and September ( $n = 3$ ) (Fig. 5). Japanese catcher-boats operating in the SEBS reported right whales concentrated along the steep continental slope from June ( $n = 50$ ) to August ( $n = 23$ ), with the majority of records occurring in July ( $n = 120$ ) (Fig. 5). The six right whales taken under scientific permit in 1962 and 1963 were killed in the SEBS from late July to early August (Fig. 5). Soviet whalers caught 121 right whales in the shallow shelf waters just west of Bristol Bay in 1964 and 1967 (Fig. 5). Month of capture was not provided for these illegal catches.

Whalers at the Port Hobron shore station reported right whales in the steep slope waters south of Kodiak Island from 1924 to 1937 (Fig. 6). Catches occurred from June to September ( $n = 11$ ), with two unsuccessful chases reported in May. In Canadian waters, catches occurred near the Queen Charlotte Islands during June in 1924 ( $n = 2$ ) and 1926 ( $n = 1$ ). In the early 1960s, three right whales were taken in August south of Kodiak Island during Japanese scientific research cruises (Fig. 6), and sightings from 1941 to 1968 occurred in May ( $n = 3$ ), June ( $n = 43$ ), July ( $n = 30$ ) and August ( $n = 1$ ) in slope and oceanic waters east and west of the island (Fig. 6). Soviet whalers killed 251 right whales between 1963 and 1966 south-west of Kodiak Island. These whales were near seamounts that are 500–1000 m below the surface in areas where the seafloor is 5000–6000 m deep (Fig. 6). Two sightings by weather ships and ‘a sighting’ of roughly 200 right whales by Soviet vessels were reported as far south as 50°N (Fig. 6). However, according to Brownell *et al.* (2001), there is some confusion as to whether this is a single sighting of 200 animals or the total number of right whales seen by Soviet research vessels operating in the eastern North Pacific in 1963.



**Fig. 6.** Sightings of North Pacific right whales in waters east of 160°W from 1924 to 1968. Symbols denote data sets: shore whaling station at Port Hobron 1924–37 (catches = closed squares, sightings/unsuccessful chases = open squares) and Naden Harbour, Canada (June catches = closed triangles), weather ships post 1958 (open pentagon), Japanese catcher-boats 1941–61 [catches by month = August (closed crosses), sightings by month = May (open triangles), June (open circles), July (open diamonds) and August (open crosses)], and Soviet whaling 1963–64 (closed circles) and 1963–66 (hatched polygon) (see text for references).

### Japanese effort and sightings 1964–90

Despite considerable effort in the SEBS and GOA, right whales were observed in only 15 of 43 sectors surveyed north of 40°N and east of 180°W from 1964 to 1990 (Fig. 7). In the SEBS, right whales were found in only one sector (55–60°N, 165–170°W) in June over the shelf west of Bristol Bay, although sightings in sectors that overlap the Aleutian Islands (e.g. 50–55°N, 165–170°W and 50–55°N, 175–180°W) may have occurred north or south of the archipelago. For example, Fig. 7 shows Japanese sighting data collected from 1965 to 1979 where a general description of sighting location was provided for each effort block (Table 1). In at least one block (50–55°N, 160–170°W), sightings occurred on both sides of the Aleutians (Fig. 8).

The large number of right whales observed in August near the Queen Charlotte Islands, Canada (Fig. 7; 50–55°N, 130–135°W) is particularly noteworthy. The Maury data (Fig. 2) indicate that right whales were found within this sector from May to September during the 1800s, and that small numbers were caught by shore whalers in the 1920s (Fig. 6). Sightings were not reported in this region in the Japanese catcher-boat literature (e.g. Omura *et al.*, 1969; Wada, 1975 *et seq.*) prior to 1980 (Figs 5 and 7), suggesting this sighting occurred sometime between 1980 and 1990. Such a large number certainly warrants further investigation, particularly given the possibility of transcription errors and known discrepancies between the Japanese data sets.

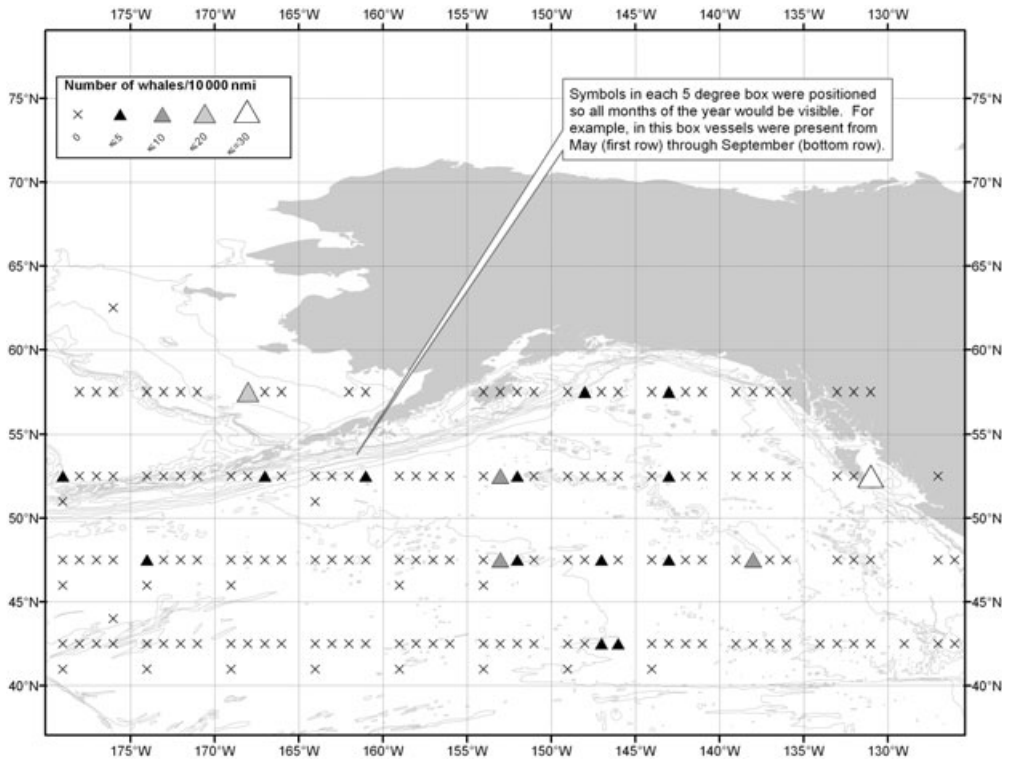


Fig. 7. Number of whales per 10 000 nautical miles from Japanese sighting and scouting cruises 1964–90 (see text for references).

A few discrepancies were noted among the data sets provided by Miyashita *et al.* (1995), Wada (1975 *et seq.*) and Anonymous (1980, 1981). This may be due to the way sightings were reported (i.e. differences in block sizes used by Wada and Anonymous, Table 1, Fig. 8). Also some of the sightings reported in Miyashita *et al.* (1995) may have occurred after 1979. Even so, a sighting was reported by Wada (1978) in 1976 in a 5-degree block near Kodiak Island (Fig. 8; 50–55°N, 155–160°W) where Miyashita *et al.* (1995) showed effort but no sightings (Fig. 7). This discrepancy has not yet been resolved.

#### Effort and sightings post-whaling 1979–2002

Since the 1980s, survey effort directed at detecting cetaceans during spring and summer has primarily been confined to the shelf and slope waters in both the SEBS (Fig. 9) and the GOA (Fig. 10). One of the earliest surveys for endangered whales in the Bering Sea during the ice-free period occurred in 1982 in the Navarin Basin west of St. Matthew Island (Brueggeman *et al.*, 1984). Subsequently, vessel surveys were conducted over parts of the shelf from the Alaska Peninsula to waters north of St. Matthew Island and west to the shelf break in 1997, 1999, 2000 and 2002 (Tynan, 1998, 2004; Moore *et al.*, 2002; NMFS, unpublished data) (Fig. 8). Aerial surveys in 1984 near the whaling station at Akutan (Stewart *et al.*, 1987) and vessel surveys in 1994 south of the Aleutians out over the abyssal plain (Forney & Brownell, 1996) occurred in August (Fig. 10). In 2001–03, vessel surveys for cetaceans were conducted along the eastern Aleutian Islands within 55–80 km of shore (Sinclair *et al.* in press; A.N. Zerbini, P.R. Wade & J.M. Waite, unpublished data). Aerial and vessel surveys and passive



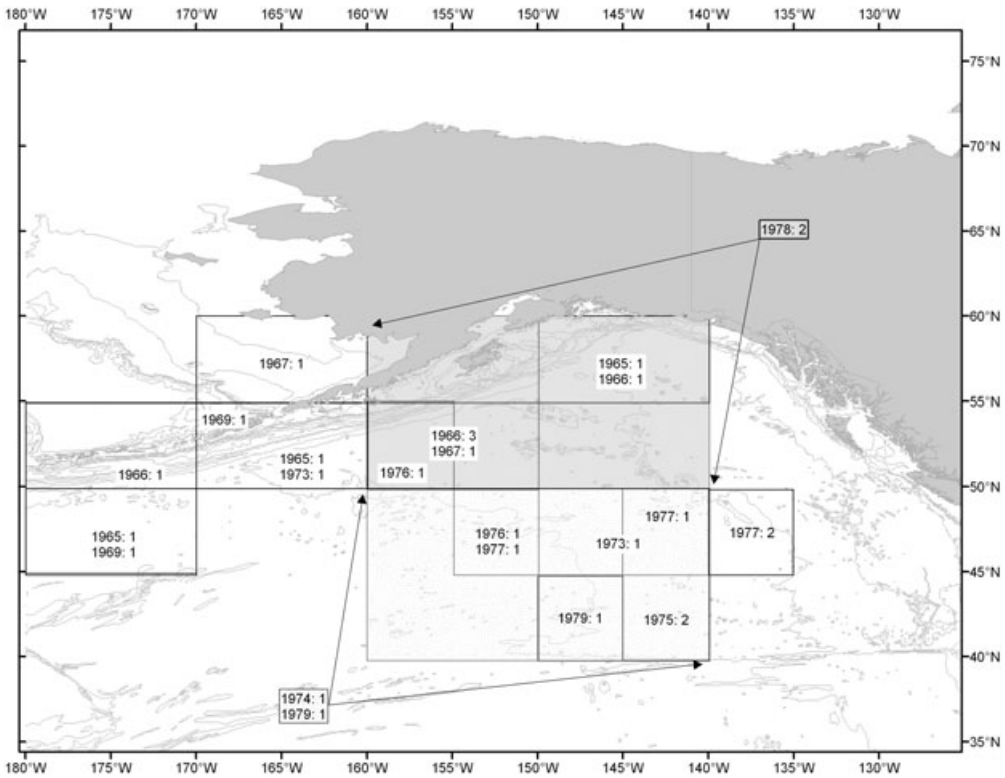


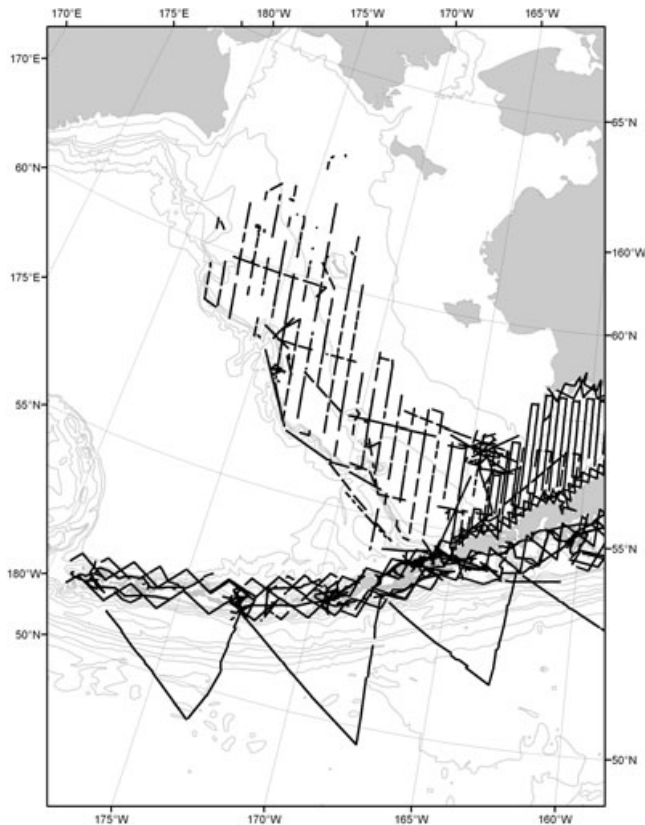
Fig. 8. Number of whales observed per year per region by Japanese sighting and scouting cruises from 1965 to 1979 (see text for references).

acoustic monitoring targeting right whales began in the SEBS middle shelf in 1998 and 2000, respectively (LeDuc *et al.*, 2001; McDonald & Moore, 2002; Moore, 2003; Munger *et al.*, 2003), after an opportunistic sighting there of right whales in July 1996 (Goddard & Rugh, 1998).

The majority of survey effort in the GOA (Fig. 10) has occurred over shelf and slope waters (Laidre *et al.*, 2000). Only two surveys extended beyond the continental slope: the June–August 1980 vessel survey between Cape Fairweather (138°W) and Chirikof Island (156°W) (Rice & Wolman, 1980), and the August 1994 Aleutian Island vessel survey south of Kodiak Island (Forney & Brownell, 1996). Aerial surveys of eastern Bristol Bay and shelf and slope waters of the GOA (Fig. 10) took place during the summers of 1991–93 (Dahlheim *et al.*, 2000) and 1997–99 (Hobbs & Waite, in press). Summer vessel surveys of coastal waters from the Kenai Fjords to the central Aleutian Islands took place in 2001–03 (Sinclair *et al.* in press; A.N. Zerbini, P.R. Wade & J.M. Waite, unpublished data; NMFS, unpublished data).

The POP database contains sightings and survey effort from 1973 to 1991, much of which was collected opportunistically from sources such as Japanese salmon research vessels and catcher-boats, National Oceanic and Atmospheric Administration (NOAA) research vessels, US Coast Guard vessels and commercial fishing vessels. While some of this effort was systematic and random and occurred over the abyssal plain in the SEBS and GOA, these surveys were designed to sample the distribution of fish and not cetaceans (Turnock *et al.*, 1995).



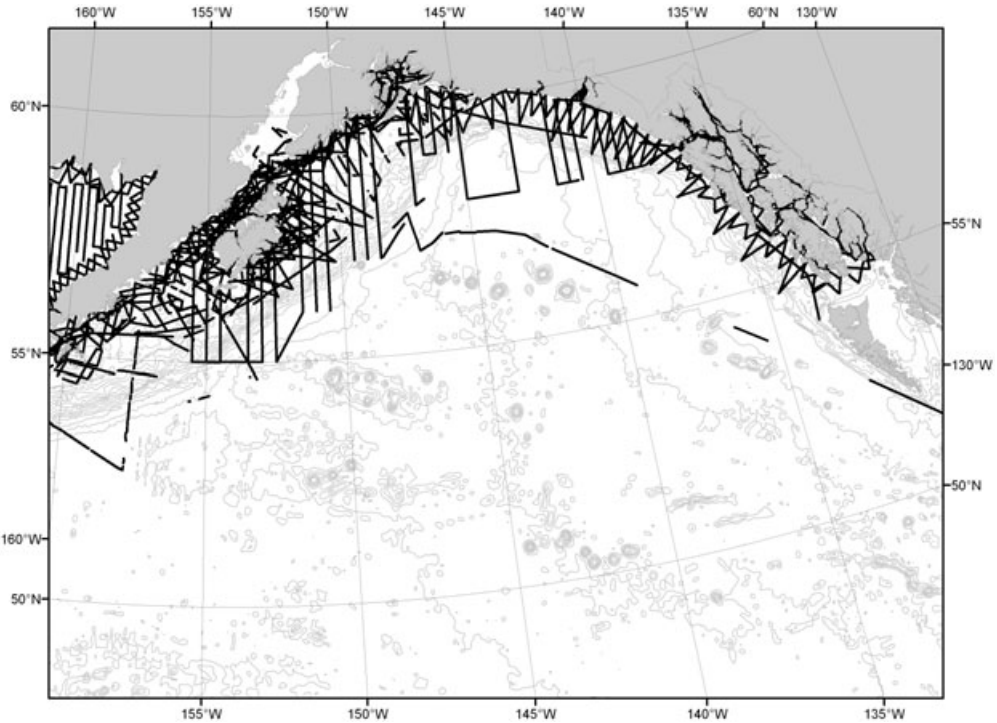


**Fig. 9.** Tracklines represent effort from multiple cetacean surveys conducted between 1982 and 2003 in the south-eastern Bering Sea and south of the Aleutian Island archipelago west of 160°W (see text for references).

Many of the sightings reported since 1982 have occurred within a small region on the middle shelf of the SEBS (Fig. 11). The northernmost sighting was of two right whales near St. Matthew Island in July 1982 (Brueggeman *et al.*, 1984). Right whales were seen in April 1993 near Unimak Pass (POP database) and from June to October over the SEBS middle shelf west of Bristol Bay (Moore *et al.*, 2000; LeDuc *et al.*, 2001; Tynan *et al.*, 2001; POP database). In the SEBS middle-shelf region, the first sighting occurred in September 1985 (POP database); 8 years passed before another sighting was reported there in August 1993 (Goddard & Rugh, 1998). Since 1996, 86% of the sightings ( $n = 28$ ) in western Bristol Bay have been recorded in July; the other sightings were reported in June ( $n = 1$ ), September ( $n = 1$ ) and October ( $n = 2$ ). In the GOA, the sightings in March 1979 (POP database) and July 1998 (Waite *et al.*, 2003) occurred in shelf waters less than 100 m deep near Yakutat Bay and Kodiak Island, respectively (Fig. 12).

## DISCUSSION

Based on re-analyses of commercial whaling activities, available survey effort, and resulting catches and sightings, we conclude that waters of the: (i) SEBS slope and shelf, (ii) eastern Aleutian Islands and (iii) central GOA were important habitat for North Pacific right whales. While the remnant population of right whales probably does not occupy the breadth of these waters today, a review of habitat features can be informative with regard to efforts to conserve this critically endangered species. Here, we review the general pattern of right whale distri-



**Fig. 10.** Tracklines represent effort from multiple cetacean surveys conducted between 1980 and 2003 in Bristol Bay and the Gulf of Alaska east of 160°W (see text for references).

bution in each of these areas (*Right whale habitats*) and relate that to oceanographic features and potential prey associations (*Food and feeding*).

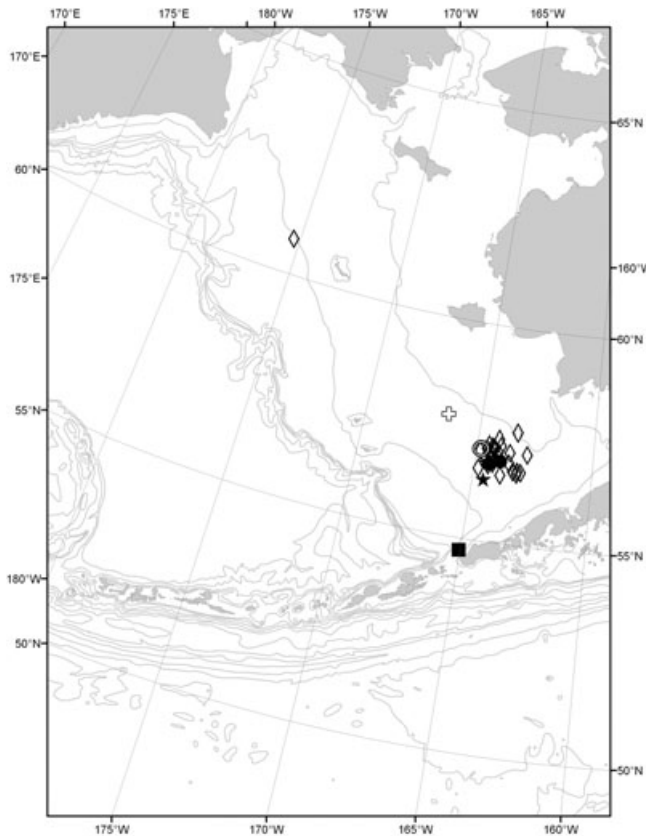
### Right whale habitats

#### *South-eastern Bering Sea*

Right whales were taken in summer along the edge of the continental slope and over the adjacent middle-shelf area of the SEBS in the 19th century. Large numbers were seen along the continental slope during the 1940s–60s, while most of the sightings made between 1964 and 2002 occurred on the middle shelf. These records suggest that the SEBS slope and middle shelf were, and remain, important habitats for right whales.

*Slope waters.* There have been no sightings of right whales in Bering Sea slope waters since the 1960s, though this may simply reflect the paucity of survey effort (e.g. Brueggeman *et al.*, 1984; Moore *et al.*, 2002) as well as commercial fishing effort (Perez, 2003) compared to that over middle-shelf waters. Three acoustic recorders were deployed along the Bering slope in April 2004. This marks the first attempt to monitor this region for right whales over the course of a year.

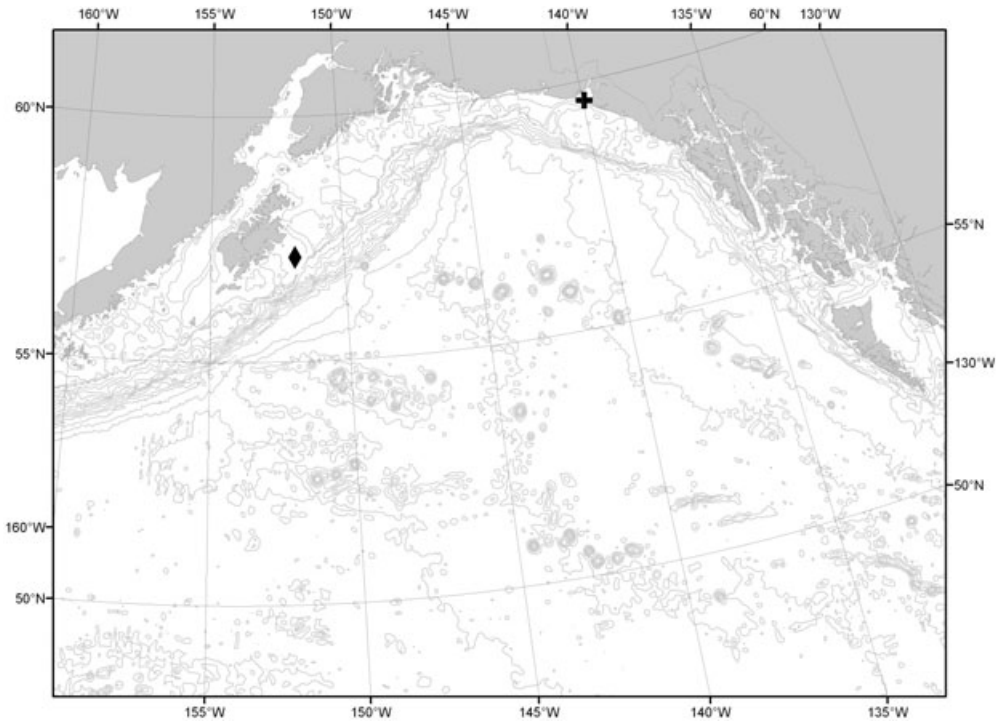
*Middle shelf.* During the late 1990s and early 2000s, a few right whales were found in the middle-shelf region of the SEBS in summer, usually in July when most surveys occurred (Goddard & Rugh, 1998; LeDuc *et al.*, 2001; Tynan *et al.*, 2001; Moore *et al.*, 2002). Calls obtained from year-long deployments of autonomous recorders confirmed the presence of right whales in this region from late May to early November (Munger *et al.*, 2003). Although



**Fig. 11.** Sightings of North Pacific right whales in waters west of 160°W and east of 180°W from 1982 to 2002. Symbol shape denotes month: April (closed square), June (open circles), July (open diamonds), August (open crosses), September (closed circles) and October (closed stars) (see text for references).

right whales have been seen consistently in the SEBS middle shelf since 1996, sightings have been confined to a small area on the western edge of Bristol Bay (Fig. 11) where dedicated survey effort has been focused (LeDuc *et al.*, 2001; LeDuc, 2004). There were no opportunistic reports of right whales in the western Bristol Bay region prior to the observation in 1985, and despite considerable commercial fishing activity in that region and throughout the entire middle shelf (Perez, 2003), it was 8 years before another opportunistic sighting was documented (Goddard & Rugh, 1998). Notably, in eastern Bristol Bay, near the Alaska coastline, sightings were reported only in the 19th century (Townsend, 1935). Extensive cetacean surveys of eastern Bristol Bay in the 1990s have not produced a single right whale sighting (Dahlheim *et al.*, 2000; Hobbs & Waite, in press).

Tynan *et al.* (2001) concluded that a 'habitat shift' has occurred whereby right whales that formerly occupied deep continental slope waters during the 1940s–60s now occupy 'a different habitat' on the middle shelf of the SEBS. However, at least three lines of evidence refute the proposed 'habitat shift' idea. First, Townsend (1935) shows that right whales were caught from July to October in middle-shelf waters, as well as slope waters, during the 19th century. After 1964, the majority of sightings made from Japanese vessels were over the SEBS middle shelf (Miyashita *et al.*, 1995). Finally, Soviet whalers removed over 100 right whales from the middle shelf during the 1960s (Doroshenko, 2000). Given that right whales have been seen in middle-shelf waters from the 19th century to the present, it appears that the SEBS middle-shelf does not represent 'a different habitat' for right whales; rather it was and continues to be important habitat for this species. Perhaps more perplexing is the conspicuous absence of



**Fig. 12.** Sightings of North Pacific right whales in waters east of 160°W from March 1979 (closed cross) and July 1998 (closed diamond) (see text for references).

right whale sightings from the outer shelf and slope habitat in recent years. Again, this may be due, at least in part, to a lack of survey effort there. Results of the acoustic recorder deployments along the slope are much anticipated.

#### *Eastern Aleutian Islands*

Right whales were caught or seen in the 19th and early 20th centuries south of the eastern Aleutians, including the vicinity of Unimak Pass. Catches during the 19th century occurred in offshore waters south of the continental shelf break. In contrast, early 20th century catches occurred closer to shore along the continental shelf. Although there is little overlap between 20th and 19th century catches, the nearshore distribution during the 20th century may simply reflect the operating range of shore-based catcher-boats, as the vessels departed from and returned to Akutan. The Akutan whaling station primarily landed blue, fin, sperm and humpback whales (Reeves *et al.*, 1985), so the relatively small number of right whales caught there suggests that the whales may have been transiting the area. Because many of the right whale catches, or sightings, were in June and the one recent sighting just north of Unimak Pass was in April, we suggest that right whales may move through this area in spring and early summer on their way north to the Bering Sea. There have been no recent sightings of right whales along the eastern Aleutian Islands, despite six summer-focused surveys there over the past 5 years (A.N. Zerbini, P.R. Wade, J.M. Waite, unpublished data; Hobbs & Waite, in press; Sinclair *et al.* in press) and one in the mid-1980s (Stewart *et al.*, 1987). In waters over the continental slope and abyssal plain, the majority of historical right whale catches occurred in May and June during the 19th century (Townsend, 1935) and in June during the

1940s–60s, much earlier in the season than the only survey that occurred there in August 1994 (Forney & Brownell, 1996).

### *Gulf of Alaska*

The Townsend (1935) data indicate that right whales were caught across a broad offshore region in the GOA, and these catches extended all the way to the coastline of south-east Alaska and the Queen Charlotte Islands. Most of these catches occurred from June to September. Very few of these 19th century catches occurred on the continental shelf in nearshore waters. In the early 20th century, right whales were caught from the Port Hobron shore whaling station south of Kodiak, but mainly over the continental shelf or adjacent shelf break area. Again, there is little overlap between the 19th and 20th century catch locations, likely due to the nearshore operating range of shore-based catcher-boats.

Illegal catches by Soviet whalers in the 1960s occurred directly south of Kodiak Island, from the shelf edge break south over the Patton Seamount to about 54°N. Catches during the 19th century took place in this same area. The occurrence of right whales' near features such as seamounts was supported by the discovery of a complete right whale skeleton on the Patton Seamount in 1999 (Hoff, in press), within the area where Soviet whaling occurred. In addition, there were a number of Japanese sightings from the 1940s to the 1960s along the shelf edge and slope and oceanic waters in the vicinity of Kodiak. A small number of right whales were caught in the early 20th century from two shore whaling stations in the Queen Charlotte Islands (Reeves *et al.*, 1985). Right whales were also found in the vicinity of the Queen Charlottes, probably sometime between 1980 and 1990 (Miyashita *et al.*, 1995). Recent sightings in the GOA include a single right whale among humpback whales south of Kodiak at the shelf edge, and four right whales just inside Yakutat Bay (Waite *et al.*, 2003). There has been very little survey effort south of the shelf break (e.g. Rice & Wolman, 1980; Forney & Brownell, 1996) where the majority of whales were observed in the 19th and 20th century. However, right whale calls have been recorded from instruments deployed near the 1998 sighting location (Waite *et al.*, 2003), as well as waters south-west of there (c. 53°N, 157°W) in a region where right whales have not been encountered since the 19th century (Mellinger *et al.*, 2004).

### **Food and feeding**

#### *Oceanography and prey*

Habitat selection is often associated with features that influence abundance and availability of a predator's prey. Right whales in the North Pacific are known to prey on a variety of zooplankton species including *Calanus marshallae*, *Euphausia pacifica*, *Metridia* spp. and copepods of the genus *Neocalanus* (Omura, 1986). *C. marshallae* was only recently recognized as a species distinct from *C. glacialis* (Frost, 1974), and the species names are used interchangeably in the literature. Both of these species were once referred to as *C. finmarchicus*, the principal prey of North Atlantic right whales (Baumgartner & Mate, 2003; Baumgartner *et al.*, 2003a,b). North Atlantic right whales require dense prey aggregations (prey patch concentrations >3000 copepods m<sup>-3</sup>) to forage efficiently (Baumgartner & Mate, 2003), and it is likely that availability of prey greatly influences the distribution of the small North Pacific population on their feeding grounds in the SEBS and GOA.

*SEBS slope waters.* The Bering Sea slope is a very productive zone, sometimes referred to as the 'Greenbelt', where annual primary production can exceed that on the adjacent shelf and basin by 60% and 270%, respectively (Springer, McRoy & Flint, 1996). Physical processes at



the shelf edge, such as intensive tidal mixing, eddies and up-canyon flow, bring nutrients to the surface thereby supporting enhanced productivity and elevated biomass of phytoplankton, zooplankton and fish. This elevated productivity appears to influence whale distribution as well. For example, fin whales aggregate to feed along the Bering Sea slope, with densities an order of magnitude higher than on the adjacent middle shelf (Moore *et al.*, 2002). Recent studies of this dynamic habitat reveal the importance of cyclonic (anticlockwise) and anticyclonic (clockwise) eddies to nutrient transport and patterns of meso-scale productivity (Okkonen, 2001; Mizobata *et al.*, 2002). These features are roughly 100–150 km in diameter and can pump nutrients to the surface from depths of 100–500 m. Specifically, very high chlorophyll concentrations develop in the centre of cyclonic and around the periphery of anticyclonic eddies, features that typically form at the intersection of the slope with the eastern Aleutian Islands and propagate north-westward along the Bering slope current (Okkonen, 2001; Mizobata *et al.*, 2002). In the North Atlantic, right whales were associated with thermal fronts (Brown & Winn, 1989), areas of upwelling along the continental shelf, and at least one satellite-tagged right whale fed along the edge of a warm-core eddy (Mate, Nieu Kirk & Kraus, 1997). Western North Pacific right whales have also been observed in association with oceanic frontal zones that produce eddies south-east of Hokkaido Island, Japan, and south-east of Cape Patience (Mys Terpeniya), Sakhalin Island, in the Okhotsk Sea (Omura *et al.*, 1969). Whether or not the Bering Slope Current (BSC), or eddies shed from the BSC (Fig. 13), support production or entrain right whale prey is unknown, but should be the focus of future study.

From August to October in 1955 and 1956, Soviet scientists observed aggregations of *Calanus* between the Pribilof Islands and the Aleutian Islands (around 170°W) that were

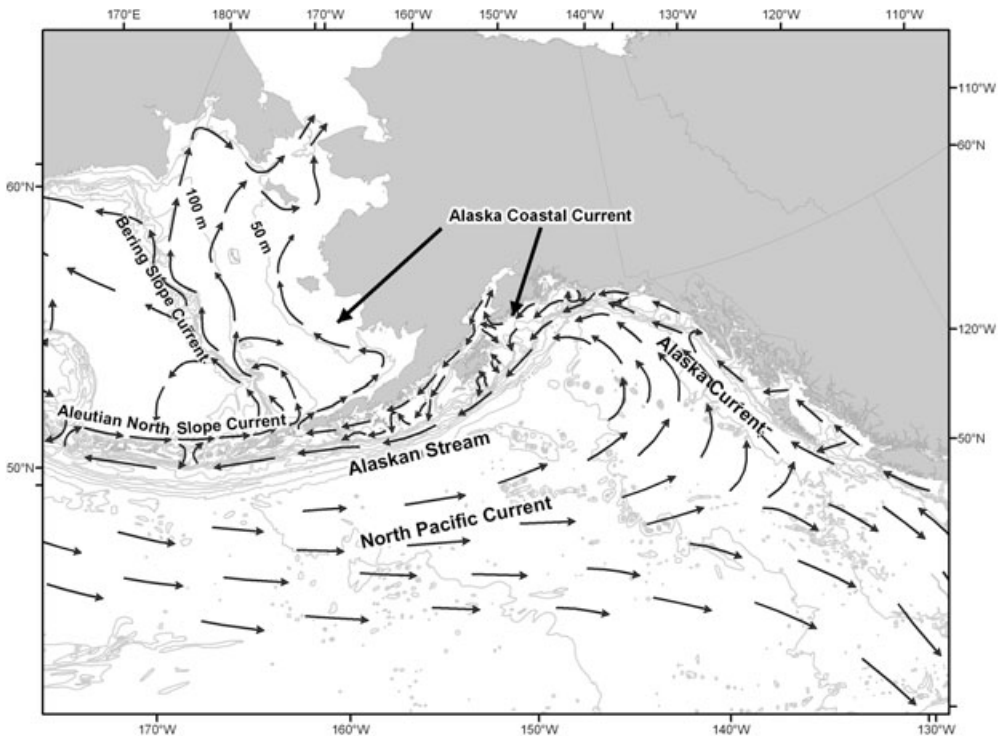


Fig. 13. Major currents of the south-eastern Bering Sea and Gulf of Alaska.

**Table 3.** Right whales caught in Alaska waters during Japanese scientific research cruises

Date	Location	Depth (m)	Gender	Body length (m)	Prey	Quantity
22 August 1961	South Kodiak Island	2500	M	17.1	<i>N. plumchrus</i>	'r'
22 August 1961	South Kodiak Island	2500	M	17.0	<i>N. plumchrus</i>	'r'
22 August 1961	South Kodiak Island	2500	M	15.1	<i>N. plumchrus</i>	'rr'
30 July 1962	SEBS slope	3000	F	14.1	<i>N. cristatus</i>	'rrr'
10 August 1962	SEBS slope	2000	M	14.7	<i>N. cristatus</i>	'r'
10 August 1962	SEBS slope	2000	M	16.1	<i>N. cristatus</i>	'rr'
5 August 1963	SEBS plain	> 3000	F*	16.1	<i>N. cristatus</i>	'rr'
5 August 1963	SEBS plain	> 3000	F*	15.4	<i>N. cristatus</i>	'rr'
5 August 1963	SEBS plain	> 3000	M	16.4	<i>N. cristatus</i>	'rrr'

Omura *et al.* (1969) did not define Quantity levels in their table 17 but did note that the intestines of the whales caught in 1963 were 'filled with faeces of red copepods' and were labelled Quantity 'rr' and 'rrr', while other right whales caught in the Okhotsk Sea in 1968 were described as having only a 'trace of food in stomach and fecal contents in their intestine' and were labelled with a Quantity 'r'. SEBS, south-eastern Bering Sea; M, male; F, female.

\*pregnant.

identified as *C. finmarchicus*, though, as mentioned above, were probably *C. marshallae* (Klunov, 1963). Flint *et al.* (2002) also report high concentrations of *C. marshallae* at frontal zones near the Pribilof Islands, with especially high biomass noted for the subthermohaline layer. This oceanographic front effectively separates slope and outer shelf *Neocalanus* spp. from the inshore middle-shelf community of *C. marshallae* (Vidal & Smith, 1986). Right whales were found on both sides of this frontal zone (that coincides with the shelf break at 170 m) during both the 19th and 20th centuries (Figs 2 and 4). This is similar to the habitat described by Baumgartner *et al.* (2003a) for right whales feeding in the North Atlantic. The six right whales that were caught under scientific permit in late July–early August 1962–63 in Bering Sea slope waters (Fig. 5, Table 3) had exclusively consumed *Neocalanus cristatus* (*Calanus cristatus*: Omura *et al.*, 1969). Although oceanic species such as *Neocalanus* usually enter diapause and migrate to depths greater than 200 m by late summer in the slope waters of the Bering Sea (Vidal & Smith, 1986), right whales may still be able to use these resources by targeting regions where the bottom-mixed layer forces the zooplankton into shallower, discrete layers (e.g. Baumgartner *et al.*, 2003a).

*SEBS middle-shelf waters.* The SEBS shelf has been the focus of intense oceanographic study since the late 1970s (e.g. Schumacher *et al.*, 1979; Coachman, 1986; Napp, Kendall & Schumacher, 2000; Hunt, Baduini & Jahncke, 2002a; Hunt *et al.*, 2002b), largely due to the enormous commercial fishing effort in the area (National Research Council, 1996). Coachman (1986) described the now well-established hydrographic domains of the inner-, middle- and outer-shelf, each separated by a front or transition zone at roughly the 50 m (inner front) and 100 m (outer front) isobaths (Fig. 13). During the 1990s, research focused on these domains demonstrated dynamic advection of nutrient-rich Bering slope water onto the shelf in both winter and summer, via eddies, meanders and up-canyon flow (Schumacher & Stabeno, 1998; Stabeno & Hunt, 2002). These intrusions of nutrient-rich water, physical factors related to water column stratification, and long summer day length results in a very productive food web over the SEBS shelf (e.g. Livingston, Low & Marasco, 1999; Coyle & Pinchuk, 2002; Napp *et al.*, 2002; Schumacher *et al.*, 2003). Specifically, copepod species upon which right whales feed (e.g. *Calanus marshallae*, *Pseudocalanus* spp. and *Neocalanus* spp.) are among the most abundant of the zooplankton sampled over the middle shelf (Cooney &

Coyle, 1982; Smith & Vidal, 1986). Small, dense patches (to  $>500 \text{ mg/m}^{-3}$ ) of euphausiids (*Thysanoessa raschii*, *T. inermis*), potential right whale prey, have also been reported in waters near the SEBS inner front (Coyle & Pinchuk, 2002).

Zooplankton sampled near right whales seen in the SEBS in July 1997, included *C. marshallae*, *Pseudocalanus newmani* and *Acartia longiremis* (Tynan, 1998). *C. marshallae* was the dominant copepod found in these samples as well as the samples collected near right whales in the same region in 1999 (Tynan *et al.*, 2001). *C. marshallae* is the only 'large' calanoid species found over the SEBS middle shelf (Cooney & Coyle, 1982; Smith & Vidal, 1986). Concentrations of copepods were significantly higher in 1994–98 than in 1980–81 by at least an order of magnitude (Napp *et al.*, 2002), and Tynan *et al.* (2001) suggest that this increased production may explain the presence of right whales in middle-shelf waters. However, at least three right whales were observed in 1985 in the same location as the middle-shelf sightings reported in the late 1990s (Goddard & Rugh, 1998), and right whales have been present in middle-shelf waters during all the time periods reviewed within this document. Therefore, the middle shelf is not a new habitat for right whales, and consumption of *C. marshallae* does not constitute a change in prey selection.

*Eastern Aleutian Islands.* The area around the eastern Aleutians is an oceanographically dynamic zone. The primary currents run parallel to the coast and include the Alaska Coastal Current (ACC), the Alaskan Stream (AS), the Aleutian North Slope Current (ANSC) and the BSC (Fig. 13). The ACC is dominated by freshwater discharge and flows south-westward between 20 and 50 km of shore along the Alaska Peninsula and Aleutian archipelago, turning northward at passes between Unimak and Samalga Island (Royer, Hansen & Pashinski, 1979; Ladd *et al.* in press). The AS also flows south-westward along the shelf break, approaching the archipelago as the shelf narrows west of Samalga Pass. Both the ANSC and BSC flow eastward, north of the islands, the latter continuing northward (Fig. 13). Flow through the passes of the eastern and central Aleutian Islands was the focus of an interdisciplinary study in 2001–02 (e.g. Ladd *et al.* in press; Stabeno *et al.* in press). Although right whales were not seen during these cruises (Sinclair *et al.* in press), results indicate that the eastern Aleutians are dynamic and productive, with dense patches of both copepod and euphausiid zooplankton reported within and at the margins of the passes (Coyle, in press). The importance of such passes as a source of *Neocalanus* spp. has been documented for western North Pacific right whales taken in waters adjacent to the Kuril Islands, Russia (Klumov, 1962).

*Gulf of Alaska.* The central GOA is dominated by the Alaskan gyre, a cyclonic feature that is demarcated to the south by the eastward flowing North Pacific Current and to the north by the AS and ACC, which flow westward near the shelf break (Fig. 13). The bottom topography of this region is rugged and includes seamounts, ridges and submarine canyons along with the abyssal plain. Strong semidiurnal tides and current flow generate numerous eddies and meanders (Okkonen *et al.*, 2001) that influence the distribution of zooplankton.

Copepods are the dominant taxa of mesozooplankton found in the GOA and are patchily distributed across all water depths. Three large herbivorous species comprise more than 70% of the biomass: *N. cristatus*, *N. plumchrus* and *Eucalanus bungii* (Cooney, 1986, 1987). In northern GOA shelf waters, the late winter and spring zooplankton is dominated by calanoid copepods (*Neocalanus* spp.), with a production peak in May, a cycle that appears resistant to environmental variability associated with El Niño/Southern Oscillation (ENSO) (Coyle & Pinchuk, 2003). In oceanic waters (50°N, 145°W), *N. plumchrus* dominate (Miller & Nielsen, 1988; Miller & Clemons, 1988) and have demonstrated dramatic shifts in the timing of annual peak biomass from early May to late July (Mackas, Goldblatt & Lewis,

1998). From late summer to autumn, *N. plumchrus* migrate to deep water ranging from 200 to 2000 m, depending on location within the GOA (Mackas *et al.*, 1998). The three right whales caught under scientific permit on 22 August 1961 south of Kodiak Island (Fig. 6, Table 3) had all consumed *N. plumchrus* (*Calanus plumchrus*: Omura *et al.*, 1969), potentially by targeting areas where adult copepods remained above 200 m (e.g. Baumgartner *et al.*, 2003a).

#### *Summary and conclusions*

We have identified shelf, slope and oceanic areas within the Bering Sea and Gulf of Alaska where North Pacific right whales were observed in the 19th and 20th centuries. Although there are concerns about the 19th century depictions of right whale occurrence (Reeves *et al.*, 2004), we do know that right whales were still seen in all of these areas as recently as the late 1960s. Sightings were especially prevalent along the Bering Sea slope, in the eastern Bering Sea middle shelf, and over the GOA slope and oceanic waters. Since 1980, right whales have been seen singly or in small groups or detected acoustically in Bering Sea middle-shelf waters, in GOA shelf and slope waters, and near Unimak Pass in the Aleutian Islands. Parts of the eastern North Pacific currently lacking sightings or acoustic detections include the Bering Sea slope and the oceanic GOA, though this also reflects a paucity of survey effort in these regions. The winter distribution of North Pacific right whales is not well known. Although single animals have been reported off Mexico, California and Hawaii since the late 1970s (Brownell *et al.*, 2001), large concentrations of right whales were not observed in these waters during the 19th century.

Larger calanoid copepods appear to be the preferred prey of right whales in the SEBS and GOA, similar to that observed in North Atlantic and western North Pacific right whales. Through the past two centuries, eastern North Pacific right whales have been associated with a variety of oceanic features, with little in common in the bathymetry of these regions. These whales appear to have a greater pelagic distribution than that observed in the North Atlantic, perhaps related to a wider distribution of larger copepods across shelf, slope and oceanic regions of the SEBS and GOA. Therefore, there is no single, distinct, oceanographic habitat to which North Pacific right whales are limited, but their distribution is probably driven by availability of concentrations of their preferred prey.

In order better to understand habitat requirements of eastern North Pacific right whales, given current gaps in the data, we feel that future research and funding should focus on three currently applicable techniques: (i) satellite tagging, (ii) acoustic monitoring and (iii) mapping of the primary prey species. The first technique, satellite tagging, should be applied to right whales in middle-shelf waters of the SEBS in late summer. This will be optimal for gaining information about migratory routes and winter areas. If the tags last 8 months, they will cover essentially the entire fall migration south, the winter distribution and the spring migration north. The second technique, acoustic monitoring, will provide location and occupancy times that will be invaluable during research cruises on both real-time and long-term bases. Real-time acoustic monitoring using sonobuoys has been used to track right whale calls to their source (LeDuc, 2004). Three acoustic recorders were moored along the Bering Sea slope in April 2004. This marks the first attempt to monitor this region for right whales over the course of a year. Additional arrays have been proposed for deployment along passes in the Aleutian Islands, as well as continued monitoring of middle-shelf waters in the SEBS (e.g. Munger *et al.*, in press) and oceanic waters of the GOA (e.g. Mellinger *et al.*, 2004). Third, density maps for calanoid copepods and euphausiids are needed for the SEBS and GOA. Currently, the National Marine Mammal Laboratory (NMML) in association with the Auke

Bay Laboratory and NOAA's Fisheries Oceanography Coordinated Investigations (FOCI) group are proposing to develop these maps and compare them to historic and current distributions of North Pacific right whales in these regions. This study would use zooplankton samples collected on previous surveys to help identify factors that affect the distribution of the zooplankton and thus the right whales. With better understanding of the zooplankton frequenting the areas where eastern North Pacific right whales occur, we will be in a better position to determine what habitat may be important and to predict other areas where surveying for North Pacific right whales could be particularly productive.

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Caroline Good and Phil Clapham (NOAA, Northeast Fisheries Science Center) created databases from the tables in Brownell *et al.* (2001) that included much of the 20th century positional data used to create these maps. Technical assistance was provided by Keri Lodge (NMML) and Jan Benson (AFSC, Office of Fisheries Information Systems) during the ArcMap georeferencing of the Townsend (1935) data. Sonja Kromann (NMML Library) proved invaluable in tracking down obscure literature. Gary Duker and James Lee (AFSC, Publications Unit) provided technical reviews of the manuscript. We are indebted to Phil Clapham (NEFSC), Nancy Friday (NMML), Jeff Napp (AFSC, Fisheries Oceanography Coordinated Investigations), Randall Reeves (Okapi Wildlife Associates) and an anonymous reviewer for scientific reviews that greatly improved this paper.

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