Aerial Surveys of Large Whales in the Northeastern Chukchi Sea, 2008-2009, with Review of 1982-1991 Data

JANET T. CLARKE[1] AND MEGAN C. FERGUSON[2]
Contact e-mail: janet.clarke@saic.com

ABSTRACT
Broad-scale aerial surveys of the northeastern Chukchi Sea off Alaska were conducted from June-October 2008-2009, after a hiatus since 1991. These surveys are now known as the Chukchi Offshore Monitoring In Drilling Area (COMIDA) project. Climatic changes in the Arctic between the early 1990s and the present have been well-documented, including (but not limited to) the dramatic reduction in summer sea ice cover in the Chukchi Sea. The 17-year lag between surveys in this region allowed for comparisons of large cetacean relative abundance and distribution over time, although comparisons were impacted due to the temporal and spatial variability of surveys in any single year. Results from the current study are still preliminary since only one partial season (2008) and one full season of data (2009) have been collected in recent years and the data have not been corrected for sighting and availability bias. In 1982-1991 and 2008-2009, 107 bowhead whales, 533 gray whales, 1 humpback whale (in 2009) and 1 fin whale (in 2008) were seen during 113,758 transect kilometers flown. Bowhead whales were observed in all months of the survey and were distributed mainly west and southwest of Pt Barrow, including sightings within the Chukchi Sea Planning Area. Bowhead distribution in light ice years remained similar between the 1980s and 2008-2009. Bowhead whale sighting rates (whales per unit effort) were highest in the 50-200m depth zone. Bowhead whales were observed feeding in the Chukchi Sea in October 1983 and in June, July and September 2009. Gray whales were observed in all months of the survey; they were distributed in nearshore, shallow water areas and offshore over Hanna Shoal. Most gray whales (73%) were feeding. The majority of the gray whale calves were seen in three years, 1982, 1985 and 2009, mainly in July of each year.

KEYWORDS: ARCTIC; NORTHERN ALASKA; CHUKCHI SEA; BOWHEAD WHALE; GRAY WHALE; FIN WHALE; HUMPBACK WHALE; HABITAT; SURVEY-AERIAL; FEEDING; OCEANOGRAPHY

INTRODUCTION

The U.S. Bureau of Land Management (BLM) commenced funding of aerial surveys of endangered whales in oil and gas lease areas offshore of Alaska in 1979. The U.S. Minerals Management Service (MMS) assumed these responsibilities in 1982. From 1979-1991, surveys in the northeastern Chukchi (68°-73°N, 157°-169°W) were conducted through a series of Interagency Agreements (IA) between MMS and the Naval Oceans Systems Center (Ljungblad *et al*., 1987) and directly with contractors (Moore and Clarke, 1992). No surveys were conducted in this broad area from 1992-2007, although localized surveys nearshore were conducted in 2006-2008 (Thomas *et al*., 2010). In 2008, MMS initiated an IA with the National Marine Mammal Laboratory (NMML) of the U.S. National Marine Fisheries Service (NMFS) to conduct broadscale aerial surveys in the Chukchi Sea Planning Area (CSPA), which encompasses the northeastern Chukchi Sea (68°-72°N, 157°-169°W). These aerial surveys are part of the Chukchi Offshore Monitoring In Drilling Area, or COMIDA, program, and they were designed to document distribution and abundance of cetaceans and pinnipeds and to monitor areas of importance for specific behaviors such as calving, pupping, feeding, hauling out and migrating. COMIDA surveys are of particular relevance now because there is renewed interest in offshore oil and gas activity in the Chukchi Sea, as evidenced by the record-breaking Lease Sale 193, which occurred in February 2008 (MMS, 2008).

[1] *Science Applications International Corporation, 14620 268th Ave E, Buckley, WA 98321, USA*
[2] *Cetacean Assessment and Ecology Program, National Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA Fisheries, 7600 Sand Point Way NE, Seattle, WA 98115, USA*

The spring migration of the Bering-Chukchi-Beaufort Sea stock of bowhead whales (*Balaena mysticetus*) in the northeastern Chukchi Sea passes through nearshore leads in the ice between Pt Hope and Pt Barrow (Moore and Reeves, 1993). Most of the stock migrates offshore to summer feeding areas in the Canadian Beaufort Sea. Although bowheads have been documented in the Chukchi Sea throughout summer (Moore, 1992; Moore *et al*., 2010), their presence there is thought to be low (Dahlheim *et al*., 1980; Miller *et al*., 1986). The return migration across the Alaskan Beaufort Sea in autumn is nearshore (Clarke and Ferguson, 2010), and commences at least as early as August (Rugh, 2010). The autumn migration of bowhead whales across the northeastern Chukchi Sea appears to follow both a west-northwesterly route along the ice edge (Quakenbush *et al*., 2010) and a broad southwesterly route towards the Chukotka coast, but autumn migration patterns are not well understood in this area (Moore and Clarke, 1993).

The Eastern North Pacific stock of gray whales (*Eschrichtius robustus*) undergoes one of the longest migrations of any mammal, from winter grounds near Baja California to summer feeding areas in the Bering and Chukchi seas. Recent evidence indicates that the Chukchi Sea has replaced the northern Bering Sea as the preferred feeding area for gray whales because amphipod biomass has decreased in the latter area (Bluhm *et al*., 2007; Coyle *et al*., 2007; Moore *et al*., 2003). Gray whales were reliably sighted in the northeastern Chukchi Sea during surveys conducted from 1982-1991 (Moore *et al*., 2000), when ice cover in summer and autumn was greater than at present.

Sightings of large whale species other than bowhead and gray whales are becoming more frequent in the northeastern Chukchi Sea (e.g., Haley *et al*., 2010). Therefore, we include a review of sightings of other large whales in the COMIDA database.

METHODS AND RESULTS

The study area was the northeastern Chukchi Sea from 68°N to 72°N latitude and from 157°W to 169°W, an area totaling 122,500 km^2, which was subdivided into 10 survey blocks (Figure 1). The historical data (1982-1991) incorporated results from four additional survey blocks located from 72° to 73°N latitude between 157° and 169°W, which were flown regularly from 1989-1991. Surveys were flown from 16 June to 31 October from 1982-1991 and 2008-2009, although effort varied temporally among years. Surveys were flown in a Grumman Turbo Goose from 1982-1991, deHavilland Twin Otter aircraft in 2008-2009 and an Aero Commander in 2009. Line transect aerial surveys were flown at 305 to 460 m altitude, maintaining a speed of 220 to 300 km/h. During the early period (1982-1991), the transects tended north/south and were located between randomly determined start and end points anchored to the survey block boundaries, The survey design changed dramatically in 2009 to transects oriented perpendicular to shore, thereby cutting across isobaths, prevailing currents, and expected gradients in marine mammal density. In 2009, a coastal transect was flown 1 km offshore and parallel to the coast between Pt Barrow and Pt. Hope. Two primary observers maintained a continuous watch for marine mammals, one on each side of the aircraft, while a third observer/data recorder entered data into a laptop computer for each sighting, whenever survey conditions changed or every five to ten minutes. The aircraft occasionally made brief (less than 10 minutes) diversions from the transect to investigate sightings for species verification, to determine group size and to confirm presence or absence of calves. Flightlines were considered to be "on effort" if the data were logged as on transect. In contrast, "off effort" flightlines included data collected while on search mode or when circling, connecting tracklines or deadheading to a location. Data routinely logged when cetaceans were seen included time, altitude, position, sea state, ice cover, visibility conditions, species, inclinometer angle (to determine distance from the trackline), number of whales, initial heading and behavior. Sea state was classified according to the Beaufort scale (Chapman, 1977), and ice cover estimated as a percentage of the sea surface. Additional details of survey protocol are provided elsewhere (e.g., Moore and Clarke, 1992; National Marine Mammal Laboratory, NMFS, NOAA, 2010).

Total transect distance (km) per survey block or depth zone for “on effort” flightlines only was calculated by clipping the transects to polygons (defined by either survey block boundaries or isobaths) using R version 2.10.1 (R Development Core Team, 2009) and packages *sp* (Pebesma and Bivand, 2005), *maptools* (Lewin-Koh *et al*., 2009), *rgdal* (Keitt *et al*., 2010), *gpclib* (Peng *et al*., 2009), and *PBSmapping* (Schnute *et al*., 2008). Transect distances differ slightly among the effort-by-year, effort-by-block, and effort-by-depth analyses due to slight differences in the region within which effort was summarized. Sighting rate (whales per unit effort) was calculated as the number of whales per transect kilometer (Tr-km) surveyed for survey blocks and depth zones. Sighting rates were not corrected for availability or perception bias. Sighting rates for survey blocks were calculated only for the current study area; sighting rate per depth zone was calculated for the extended survey area, spanning 68°N to 73°N.

Depths at sightings were taken from the International Bathymetric Chart of the Arctic Ocean (IBCAO; http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html).

Over 113,000 km of transect surveys were flown from 1982-1991 and 2008-2009 (Figure 1). Effort varied greatly among years and months (Table 1). The most annual effort was in 2009 (greater than 21,000 Tr-km), when the survey period extended almost nonstop from mid-June through the end of October. The least annual effort (approximately 3,000 Tr-km) was in 1990 and 1982, when effort in the study area occurred only in October. Monthly effort was highest in October (over 56,000 Tr-km) and lowest in June (approximately 4,000 Tr-km). Survey Block 13 had twice as much survey effort as any other block (27,425 Tr-km; Table 2), and Blocks 13, 14, 17 and 18 were surveyed the most frequently over all years combined (Figure 2).

Comparison of ice cover among years is difficult to assess from the survey data alone because effort was not evenly distributed. However, ice cover in autumn (September-October) was considered heavy in 1983 and 1988, moderate in 1984, 1985, 1987 and 1991, and light in 1982, 1986, 1989, 1990, 2008 and 2009 (Moore and Clarke, 1992; National Snow and Ice Data Center, 2008, 2009).

There were 77 on-effort sightings of 107 bowhead whales in the Chukchi Sea from 1982-1991 and 2008-2009 (Table 3). Bowhead whales were seen in all survey months in the Chukchi Sea (Figure 3), with the greatest number of sightings in October. Most whales were seen west and southwest of Pt Barrow, with a few sightings northwest. Bowhead sightings were within the CSPA and close to active leases. Highest sighting rates per block for all years combined were in Blocks 13 (WPUE=0.0023) and 18 (WPUE=0.0020; Table 2); sighting rates were highest in Block 13 in June through September and in Block 18 in October. Most of the whales (13 whales) observed in Block 18 were seen in October 1983 and 1988, both heavy ice years, but the other five whales in Block 18 were seen in ice-free water in 1989 and 2009. The highest bowhead sighting rate per depth zone for all months combined was in the 50-200m zone (WPUE=0.0012; Table 4). Bowhead whale sighting rate in June was highest in the shallowest depth zone (0-35m), but the highest sighting rates in all other months (considered individually) were either in 35-50m or 50-200m depth zones. Bowheads were not seen in waters >200m deep, but this depth zone was underrepresented in the study area (only a small area north of Block 13). In light ice years (1982, 1986, 1989, 1990, 2008 and 2009), surveys were consistently conducted in September and October only (i.e., there was no summer effort in most years). During light ice years, the distribution of bowhead whales was similar between the 1982-1991 period and the 2008-2009 period (Figure 4). There were no bowhead whale sightings in 2008 or 2009 north of 72°N because the recent survey area did not extend that far north.

Most bowhead whales were recorded as engaged in directional swimming (59%). Feeding behavior was rarely recorded on-effort and is likely underrepresented in the database due to the difficulty of identifying this behavior in the brief periods of time allowed during transects. Bowhead whale feeding behavior was recorded off-effort (while on search or circling) in two years during this study, under very different circumstances. In 1983, a heavy ice year, nine bowheads were observed feeding on 17 and 18 October (Figure 5) in 70-80% ice cover. In 2009, a light ice year, bowhead whales were observed feeding from 30 June to 11 July near Pt Franklin, and at least one easily re-identifiable whale was present during this 13-day period. Ice cover at this time ranged from 5% to 80%. A group of at least 12 bowheads was also observed feeding southwest of Pt Barrow on 19 September 2009 when no ice was present.

There were 254 on-effort sightings of 533 gray whales in the Chukchi Sea from 1982-1991 and 2008-2009 (Table 3). Gray whales were seen in all months in the Chukchi Sea (Figure 6), with the greatest number of sightings in September. Most whales were seen nearshore between Pt Barrow and Pt Lay, with an additional area of concentration in offshore shoal areas. Few gray whales were seen in the deeper water areas between the shallow nearshore continental shelf and Hanna Shoal (northern half of Block 14), except during August. Gray whales were seen offshore (in Block 14 and farther north) in autumn 1989-1991, but few were seen in that area in autumn 2008-2009, and few gray whales were seen within the CSPA or near active leases. The highest sighting rate per block for all years combined was in Block 22 (WPUE=0.0230; Table 2), where relatively high numbers of gray whales were seen in September and October during relatively little survey effort. Sighting rates were also high in Blocks 13 (WPUE=0.0096) and 17 (WPUE=0.0090; Table 2). In 2009, when survey effort was nearly nonstop from mid-June through the end of October, gray whale sighting rates were twice as high in August (WPUE=0.0154) as in July (WPUE=0.0078), and dropped off considerably in September (WPUE=0.0026) and October (WPUE=0.0033). The highest sighting rate per depth zone for all years combined was in 0-35m category (WPUE=0.0063; Table 5). Gray

whale sighting rate in all months except August was highest in the shallowest depth zone (0-35 m). In August, the sighting rate was highest in the 50-200m depth zone.

Most gray whales were recorded as feeding (73%) in all survey months. Feeding was evidenced by the presence of conspicuous mud plumes streaming out of the mouths of surfacing whales. Gray whale calves were often undetected during initial on-effort sighting events, and many would likely have remained undetected if brief diversions off-effort (in search or circling mode) were not initiated. Including all on-effort and off-effort sightings, a total of 50 gray whale calves were seen (Figure 7). Calves were seen mainly in nearshore areas, and most (n=34) were seen in Block 13, where the majority of survey effort was conducted. Most calves were observed in July of 1982 (n=18, all off-effort), 1985 (n=15) and 2009 (n=10). One calf was seen in August 2008, and six calves were seen in September. All calf sightings were in 0-10% ice cover. One cow-calf pair observed in July 2009 was in close proximity to feeding bowhead whales near Pt Franklin. That cow-calf pair exhibited protection of the calf wherein the calf moved under the cow so that only the calf's flukes could be seen.

One fin whale (*Balaenoptera physalus*) was seen on 2 July 2008 at 69.228°N, 165.675°W, in survey Block 20. The whale was swimming alone, and no other marine mammals were in the immediate area.

One humpback whale (*Megaptera novaeangliae*) was seen on 25 July 2009 at 70.384°N, 160.837°W, in survey Block 17. The whale was feeding very near shore and close to four gray whales.

DISCUSSION

Although bowhead whale sightings are still far fewer in the northeastern Chukchi Sea than in the Beaufort Sea, data collected in 2008-2009 corroborated data collected on bowheads from 1982-1991. Bowhead whale distribution in 2008-2009 suggested a southwesterly migration route across the northeastern Chukchi Sea, particularly in October. Results from satellite-tagged bowhead whales in 2006-2009 also confirmed a southwesterly migration route, as suggested in Moore and Clarke (1990), in addition to a more westerly route for whales presumably heading towards Wrangel Island and the Chukotka coast (Quakenbush *et al*., 2010). Bowhead distribution can also be inferred by the presence of bowhead whale calls on hydrophones deployed throughout the northeastern Chukchi Sea (Delarue *et al*., 2009).

The distribution of bowhead sightings from June to October is unexpected. Most of the summer bowhead sightings and the highest sighting rates occurred in Block 13, closest to the Beaufort Sea. Bowhead whales observed in the northeastern Chukchi Sea during summer may be late migrants to or early returnees from summer feeding areas in the Canadian Beaufort Sea. Conversely, some of the bowheads observed in the summer in the Chukchi Sea may not undergo a complete migration, similar to gray whales that do not migrate the entire distance from the Bering/Chukchi Sea to Mexico (Rugh *et al*. 2008). Summer observations of bowhead whales nearshore in the Chukchi Sea near Pt Franklin were recorded in July 2003 (Moore *et al*., 2010), and four bowhead whales were seen during nearshore surveys in 2008 (Thomas *et al*., 2010). Surveys conducted in summer 1984 (Moore *et al*., 1986), 1985 and 2008 (this study), and oil industry-sponsored aerial surveys in July 2006 and 2007, did not yield any bowhead whale sightings. Moore (1992) summarized summer records of bowhead whale sightings in the northeastern Chukchi Sea from 1975-1991 and listed only three sightings west of Pt Barrow in June or July. The sightings of bowheads feeding near Pt Franklin over a 13-day period in late June through mid July 2009 may be some of the first reported for this area during this time period and indicates that this area may sometimes be important to bowhead whales in the summer. Bowheads have been previously identified as feeding in September near the area in which they were seen feeding in 2009, although far fewer in number (Moore, 1992). Bowheads feeding nearshore in the northeastern Chukchi Sea may be taking advantage of euphausiids and other prey advected north in the Alaska Coastal Current. Feeding observed in 1983, a heavy ice year, was farther from shore and in deeper water. Heavier ice nearshore that year may have prevented feeding from occurring elsewhere along the bowhead whale migration route (e.g., nearer to shore east of Barrow). Alternatively, the ice might have affected the aerial marine mammal observers' ability to detect feeding whales.

Gray whale distribution in 2008-2009 remained primarily nearshore between Pt Lay and Pt Barrow, and underscores the continued importance of that area to gray whales in all months surveyed. Overall sighting rates were lowest in June, increased through August, then decreased through October, reflecting the migration timing of gray whales in Alaskan waters (Rugh *et al*., 2001). This temporal pattern in sighting rates was repeated in data

collected from 1982-1991 and also observed during oil industry-sponsored surveys in 2006-2008 (Thomas *et al*., 2010). Feeding remained the predominant behavior in 2008-2009. Mud plumes were often noted even when no whales were present at the surface. The lack of gray whale sightings in the Hanna Shoal area was unexpected. There was also no evidence of mud plumes over Hanna Shoal, which are generally seen in areas where gray whales are feeding. Feeding gray whales were regularly sighted offshore in the 1980s. Clarke *et al*. (1989) suggested that gray whales may forage along the coast as they first move into the Chukchi Sea in the summer and move to offshore areas in autumn after the ice recedes. The lack of summer sea ice cover in the Chukchi may have changed the location of high concentrations of prey or the overall density of prey. There was only one year (2009) of recent effort offshore from summer through autumn (surveys were not conducted there in September and the first half of October 2008), so it remains to be seen if the lack of offshore gray whales in 2009 was an unusual event or representative of a changing Arctic environment.

It is evident from these aerial survey data that the shallow coastal areas of the northeastern Chukchi Sea may serve as nursery habitat for gray whale calves in some years, particularly in July. Clarke *et al*. (1989) discussed the potential benefits of this habitat for cow-calf pairs, including less competition from other adults to allow the cow to feed more successfully and greater protection from potential predators, such as killer whales (*Orcinus orca*). Killer whales are occasionally observed in the Chukchi Sea (George *et al*. 1994), but their presence there may be less than in the Bering Sea. Gray whale calves have rarely been observed in offshore areas of the northeastern Chukchi Sea, and spatial segregation has also been reported for the Chukotka Peninsula (Krupnik *et al*., 1983; Yablokov and Bogoslovskaya, 1984).

Habitat partitioning between bowhead and gray whales, as described by Moore (2000) and Moore *et al*. (2000), remained evident in the 2008-2009 surveys. Bowheads showed a strong preference for outer shelf waters (50-200m) in all months except June, when results may have been biased by less survey effort and the repeated sightings of feeding bowhead whales very close to shore in 2009. Gray whales showed a strong preference for coastal/shoal areas (<35m) in all months except August, when they may move farther offshore to take advantage of newly uncovered feeding areas when the ice recedes.

While results from these analyses should be considered preliminary because they were based on raw sighting rates (uncorrected for perception or availability bias) they clearly underscore the seasonal importance of the northeastern Chukchi Sea to bowhead and gray whales. The COMIDA surveys are the only broad scale, offshore aerial survey effort underway in the northeastern Chukchi Sea, and the only effort that can reliably collect data that may be used to determine marine mammal density and abundance in areas of active oil and gas leases. Although the time series in the offshore Chukchi Sea does not benefit from the same long-term, uninterrupted surveys as the closely related BWASP study (Clarke and Ferguson, 2010), the data collected in the early years (1982-91) provide valuable insight into cetacean distribution and density patterns during more variable summer ice conditions, and provide a baseline for comparison with the current COMIDA study. Data from COMIDA, combined with information from other research efforts including physical, chemical, and biological sampling, satellite tagging, and passive acoustic monitoring, will continue to improve our understanding of the temporal and spatial nature of large cetacean distribution and density patterns in the northeastern Chukchi Sea, including documenting the impacts of climate change and anthropogenic activities.

ACKNOWLEDGEMENTS

Support and funding for aerial surveys in the northeastern Chukchi Sea were provided by the Minerals Management Service, Alaska OCS Region (formerly part of Bureau of Land Management), where we particularly appreciate the support and guidance of Charles Monnett. Don Ljungblad, formerly with the Naval Oceans Systems Center, was the Project Supervisor from 1979-1986. Sue Moore, formerly of SEACO and SAIC and currently with NOAA, was the Project Manager from 1981-1992, and continues to provide much appreciated support to this and several other Arctic studies. Since 2008, COMIDA has been managed by the National Marine Mammal Laboratory, NOAA Fisheries, where we appreciate the support and assistance of Phillip Clapham, David Rugh, Kim Shelden, Cynthia Christman, and Joanne Wejak. Mike Hay, of Resource Data Incorporated, provided invaluable and timely software support. Numerous observers, pilots, mechanics, programmers and other staff have been responsible for conducting surveys safely and effectively, collecting solid data and carrying out numerous analyses, and deserve our unmitigated appreciation. We also thank the North Slope Borough Department of Wildlife Management and

National Weather Service personnel in Barrow for their continued assistance and the villages of Barrow and Kotzebue for their annual hospitality during the field season.

REFERENCES

Bluhm, B.A., Bodil, A. and Gradinger, R. 2008. Regional variability in food availability for Arctic marine mammals. *Ecological Applications* 18(Supp):S77-S96. Arctic Marine Mammals and Climate Change.

Chapman, C.F. 1977. *Piloting, seamanship and small boat handling*. New York: Hearst Books.

Clarke, J.T. and Ferguson, M.C. 2010. Aerial Surveys for Bowhead Whales in the Alaskan Beaufort Sea: BWASP Update 2000-2009 with Comparisons to Historical Data. Paper SC/62/BRG14 presented to the IWC Scientific Committee, May 2010. 11pp.

Clarke, J.T., Moore, S.E. and Ljungblad, D.K. 1989. Observations on gray whale (*Eschrichtius robustus*) utilization patterns in the northeastern Chukchi Sea, July-October 1982-87. *Can. J. Zool*. 67: 2646-2654.

Coyle, K.O., Bluhm, B., Konar, B., Blachard, A. and Highsmith, R.C. 2007. Amphipod prey of gray whales in the northern Bering Sea: Comparison of biomass and distribution between the 1980s and 2002-2003. *Deep Sea Res. II: Topical Studies in Oceanography* 54(23-26):2906-2918. Effects of Climate Variability on Sub-Arctic Marine Ecosystems - A GLOBEC Symposium, GLOBEC-ESSAS Symposium.

Delarue, J., Laurinolli, M. and Martin, B. 2009. Bowhead whale (*Balaena mysticetus*) songs in the Chukchi Sea between October 2007 and May 2008. *J. Acous. Soc. of America* 126(6): 3319-3328.

Dahlheim, M.E., Bray, T. and Braham, H. 1980. Vessel survey for bowhead whales in the Bering and Chukchi Seas, June-July 1978. *Mar. Fish. Rev*. 42: 51–57.

George, J.C., Philo, L.M., Hazard, K., Withrow, D., Carroll, G.M. and Suydam, R. 1994. Frequency of killer whale (*Orcinus orca*) attacks and ship collisions based on scarring on bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort seas stock. *Arctic* 47(3): 246-255.

Haley, B., Beland, J. Ireland, D.S., Rodrigues, R. and Savarese, D.M. 2010. Chukchi Sea vessel-based monitoring program. p. 3-1 to 3-81 *In*: Funk, D.W, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-2, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research , Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 506 p. plus Appendices. [Available from www.shell.us/home/content/usa/aboutshell/projects_locations/alaska].

Keitt, T.H., Bivand, R., Pebesma, E. and Rowlingson, B. 2010. rgdal: Bindings for the Geospatial Data Abstraction Library. R package version 0.6-24. http://CRAN.R-project.org/package=rgdal.

Krupnik, I.I., Bogoslovskaya, L.S. and Votrogov, L.M. 1983. Gray whaling off the Chukotka Peninsula: past and present status. *Rep. int. Whal. Commn*. 33: 557-562

Lewin-Koh, N.J., Bivand, R., contributions by Pebesma, E.J., Archer, E., Baddeley, A., Bibiko, H., Dray, S., Forrest, D., Friendly, M., Giraudoux, P., Golicher, D., Rubio, V.G., Hausmann, P., Jagger, T., Luque, S.P., MacQueen, D., Niccolai, A., Short, T. and Stabler, B. 2009. maptools: Tools for reading and handling spatial objects. R package version 0.7-29. http://CRAN.R-project.org/package=maptools

Ljungblad, D.K., Moore, S.E., Clarke, J.T. and Bennett, J.C. 1987. Distribution, abundance, behavior and bioacoustics of endangered whales in the Alaskan Beaufort and eastern Chukchi Seas, 1979-86. NOSC Technical Report 1177, 187pp plus appendices.

Miller, R.V., Rugh, D.J., and Johnson, J.H. 1986. The distribution of bowhead whales, *Balaena mysticetus*, in the Chukchi Sea. *Mar. Mam. Sci*. 2, 214–222.

MMS. 2008. MMS Chukchi Sea lease sale 193 breaks energy records with $2.6 billion in high bids. Press Release 6 February 2008. [Available from www.mms.gov/alaska].

Moore, S.E. 1992. Summer records of bowhead whales in the northeastern Chukchi Sea. *Arctic* 45(4): 398-400.

Moore, S.E. 2000. Variability of cetacean distribution and habitat selection in the Alaskan arctic, autumn 1982-91. *Arctic* 53(4): 448-460.

Moore, S.E., DeMaster, D.P. and Dayton, P.K. 2000. Cetacean habitat selection in the Alaskan arctic during summer and autumn. *Arctic* 53(4): 432-447.

Moore, S.E., Stafford, K.M. and Munger, L.M.. 2010. Acoustic and visual surveys for bowhead whales in the western Beaufort and far northestern Chukchi seas. *Deep-Sea Research* II 57: 153-157.

Moore, S.E., and Clarke, J.T. 1990. Distribution, abundance and behavior of endangered whales in the Alaskan Chukchi and Western Beaufort Sea, 1989. Report by SEACO/Science Applications International Corporation to the U.S. Minerals Management Service, Alaska Outer Continental Shelf Region," NTIS Report No. PB91-105494, National Technical Information Service, Springfield, VA.

Moore, S.E. and Clarke, J.T. 1992. Patterns of bowhead whale distribution and abundance near Barrow, Alaska, in fall 1982-1989. *Marine Mammal Science* 8(1): 27-36.

Moore, S.E., Clarke, J.T. and Ljungblad, D.K. 1986. A comparison of gray whale (*Eschrichtius robustus*) and bowhead whale (*Balaena mysticetus*) distribution, abundance, habitat preference and behavior in the northeastern Chukchi Sea, 1982-84. *Rep. int. Whal. Commn*. 36: 273-279.

Moore, S.E., Grebmeier. J.M. and Davies, J.R. 2003. Gray whale distribution relative to forage habitat in the northern Bering Sea: current conditions and retrospective summary. *Can. J. Zool*. 81: 734-742.

Moore, S.E. and Clarke, J.T. 1993. Bowhead whale autumn distribution and relative abundance in relation to oil and gas lease areas in the northeastern Chukchi Sea. *Polar Record* 29(17): 209-214.

Moore, S.E. and Reeves, R.R. 1993. Distribution and movement. Pp. 313-386 *In*: , J.J. Burns, J.J. Montegue and C.J. Cowles (eds.) *The Bowhead Whale*. Special Publication No. 2, The Society for Marine Mammalogy, Lawrence, Kansas.

National Snow and Ice Data Center. 2008. Arctic sea ice down to second-lowest extent: likely record low volume. Press Release 2 October 2008. Cooperative Institute for Research in Environmental Sciences at the University of Colorado at Boulder. [Available from http://nsidc.org/].

National Snow and Ice Data Center. 2009. Arctic sea ice extent remains low: 2008 sees third lowest mark. Press Release 6 October 2009. Cooperative Institute for Research in Environmental Sciences at the University of Colorado at Boulder. [Available from http://nsidc.org/].

National Marine Mammal Laboratory, NMFS, NOAA. 2010. BWASP and COMIDA Observer Manual – 2010. (unpublished). 135pp. [Available from the author].

Pebesma, E.J. and Bivand, R.S. 2005. Classes and methods for spatial data in R. R News 5(2), http://cran.r-project.org/doc/Rnews/.

Peng, R.D., with contributions from Murdoch, D.; GPC library by Murta, A. 2009. gpclib: General Polygon Clipping Library for R. R package version 1.4-4. http://CRAN.R-project.org/package=gpclib

Quakenbush, L., Citta, J., George, J.C., Small, R., Heide-Jorgensen, N.P., Harwood, L. and Brower, Jr., H. 2010. Western Arctic bowhead whale movements throughout their migratory range, 2006-2009 satellite telemetry results. Poster presented at Alaska Marine Science Symposium, Anchorage, AK, January 2010. [Available from http://www.wildlife.alaska.gov/index.cfm?adfg=marinemammals.bowhead].

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Rugh, D.J., Shelden, K.E.W., and Schulman-Janiger, A. 2001. Timing of the southbound migration of gray whales. *J. Cetacean Res. and Manage*. 3(1):31-39.

Rugh, D., Breiwick, J., Hobbs, R., Shelden, K. and Muto, M. 2008. Eastern North Pacific gray whale abundance in the winter of 2006-2007. Paper SC/60/BRG6 presented to the IWC Scientific Committee, May 2008. 12 pp.

Rugh, D. (ed.) 2010. Bowhead Whale Feeding Ecology Study (BOWFEST) in the Western Beaufort Sea; 2009 Annual Report. MMS-4500000120. Produced through the National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way, NE Seattle, WA 98115-6349.

Schnute, J.T., Boers, N., Haigh, R. and Couture-Beil, A. 2008. PBSmapping: PBS Mapping 2.59. R package version 2.59.

Thomas, T., Koski, W.R. and Ireland, D.S. 2010. Beaufort Sea acoustic monitoring program. p. 4-1 to 4-42 *In*: Funk, D.W, Ireland, D.S., Rodrigues, R. and Koski, W.R. (eds.). Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-2, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research , Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 506 p. plus Appendices. [Available from www.shell.us/home/content/usa/aboutshell/projects_locations/alaska].

Yablokov, A.V. and Bogoslovskaya, L.S. 1984. A review of Russian research on the biology and commercial whaling of the gray whale. p. 465-486 In: Jones, M.L., Swartz, S.L. and Leatherwood, J.S. (eds.). *The gray whale*. Academic Press, Inc., San Francisco, CA.

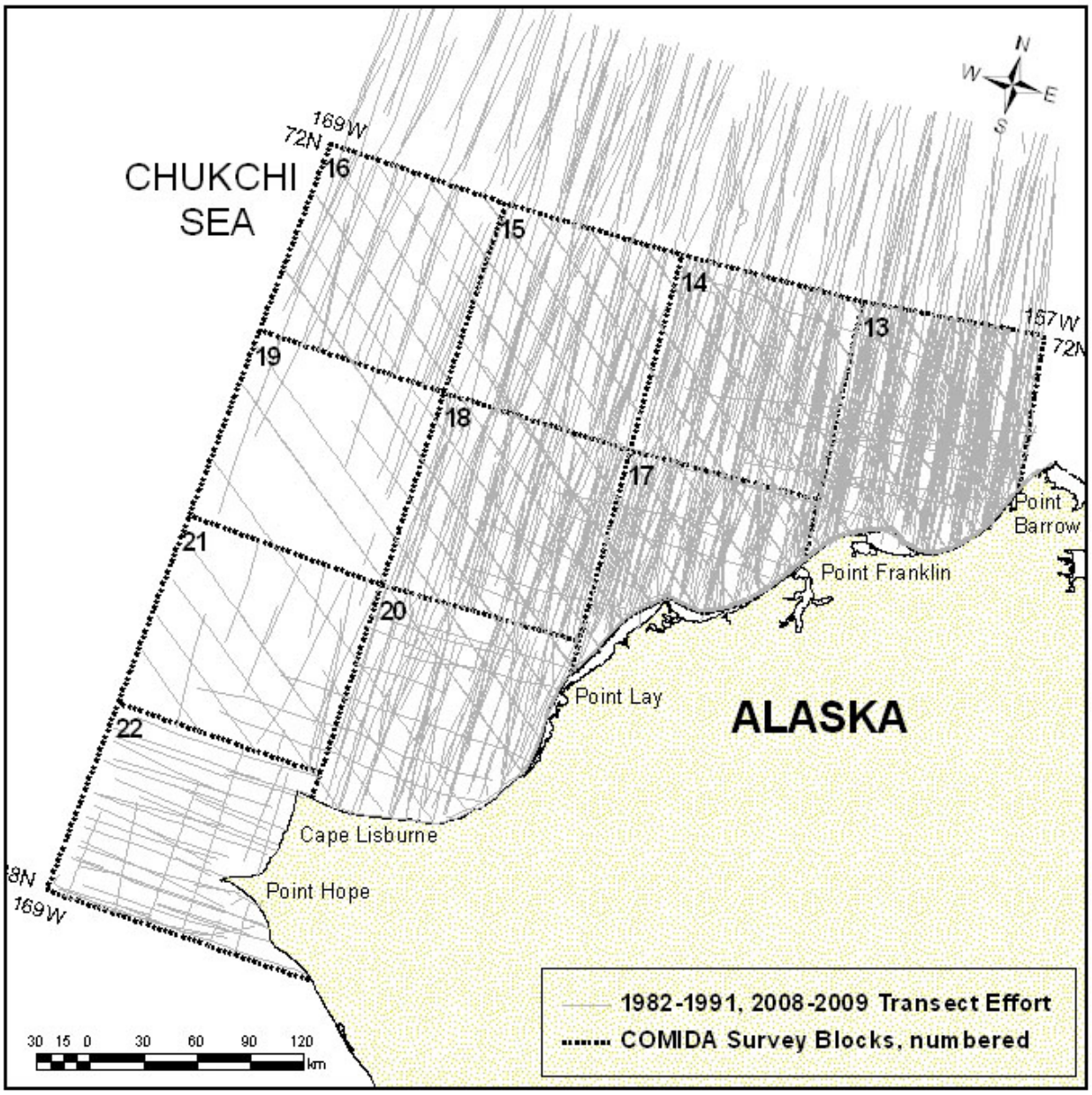

Figure 1. Chukchi Sea study area, survey blocks and aerial survey effort in 1982-1991, 2008, and 2009.

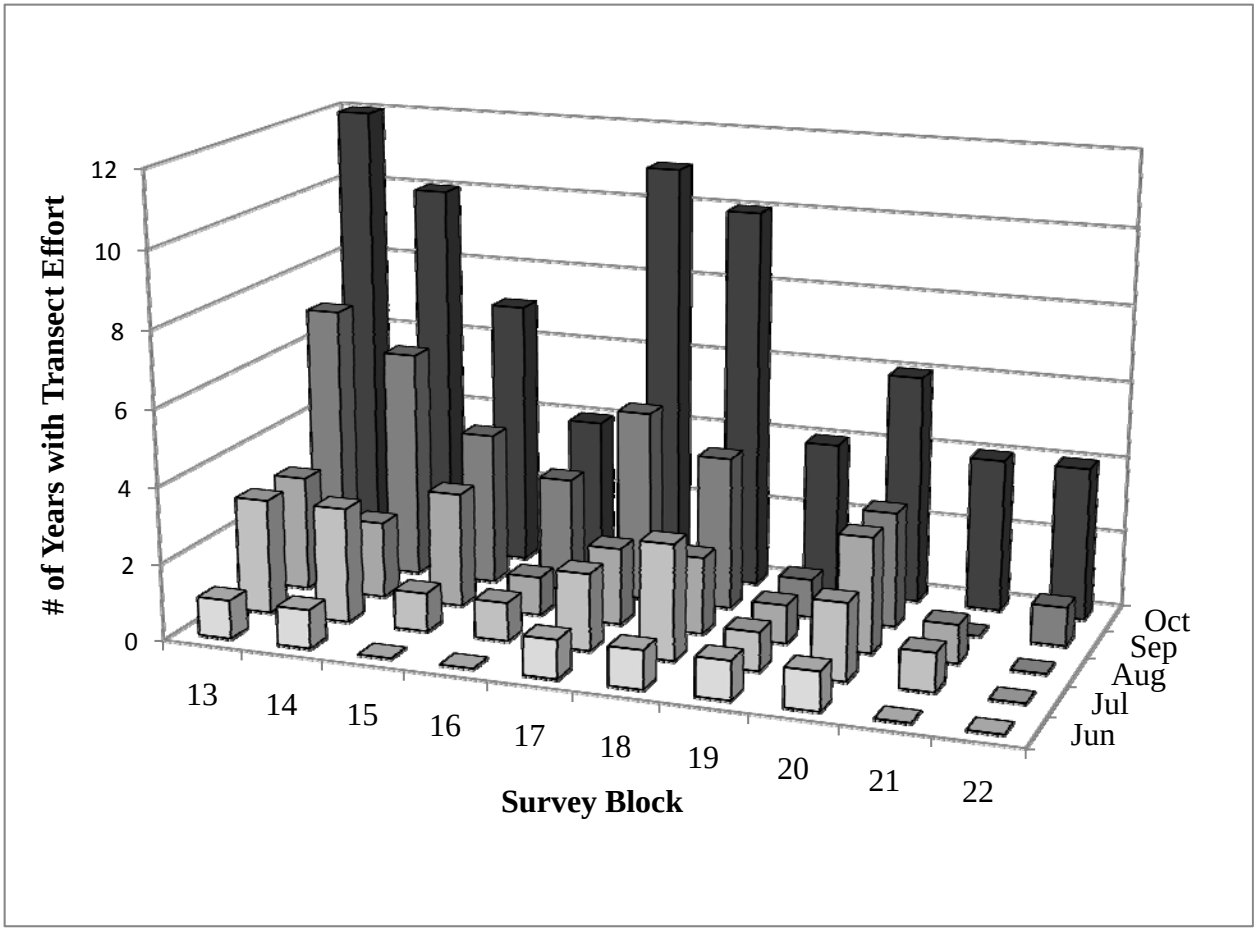

Figure 2. Distribution of transect effort in the northeastern Chukchi Sea by month, year, and survey block.

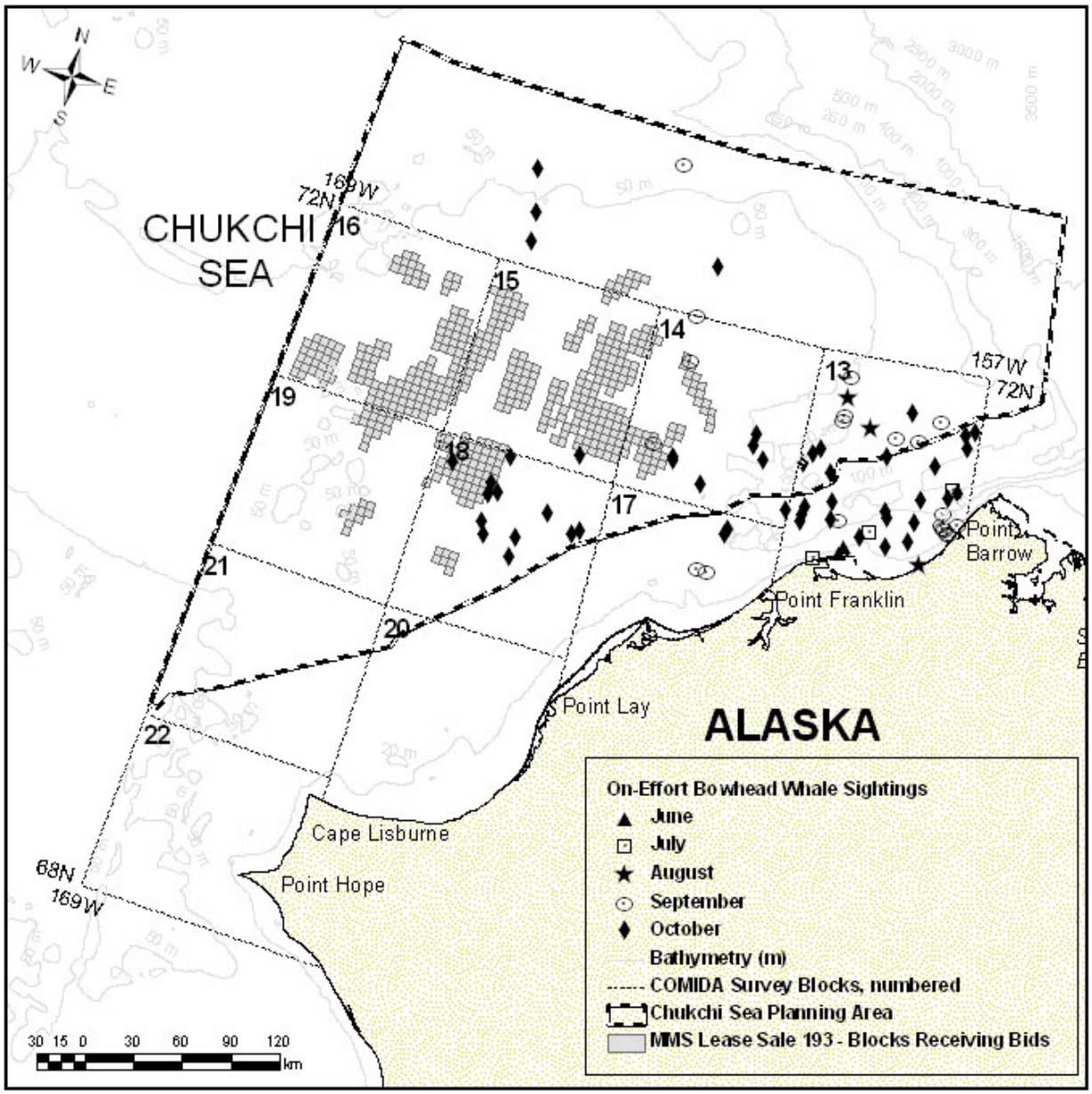

Figure 3. On-effort bowhead whale sightings per month, all years combined.

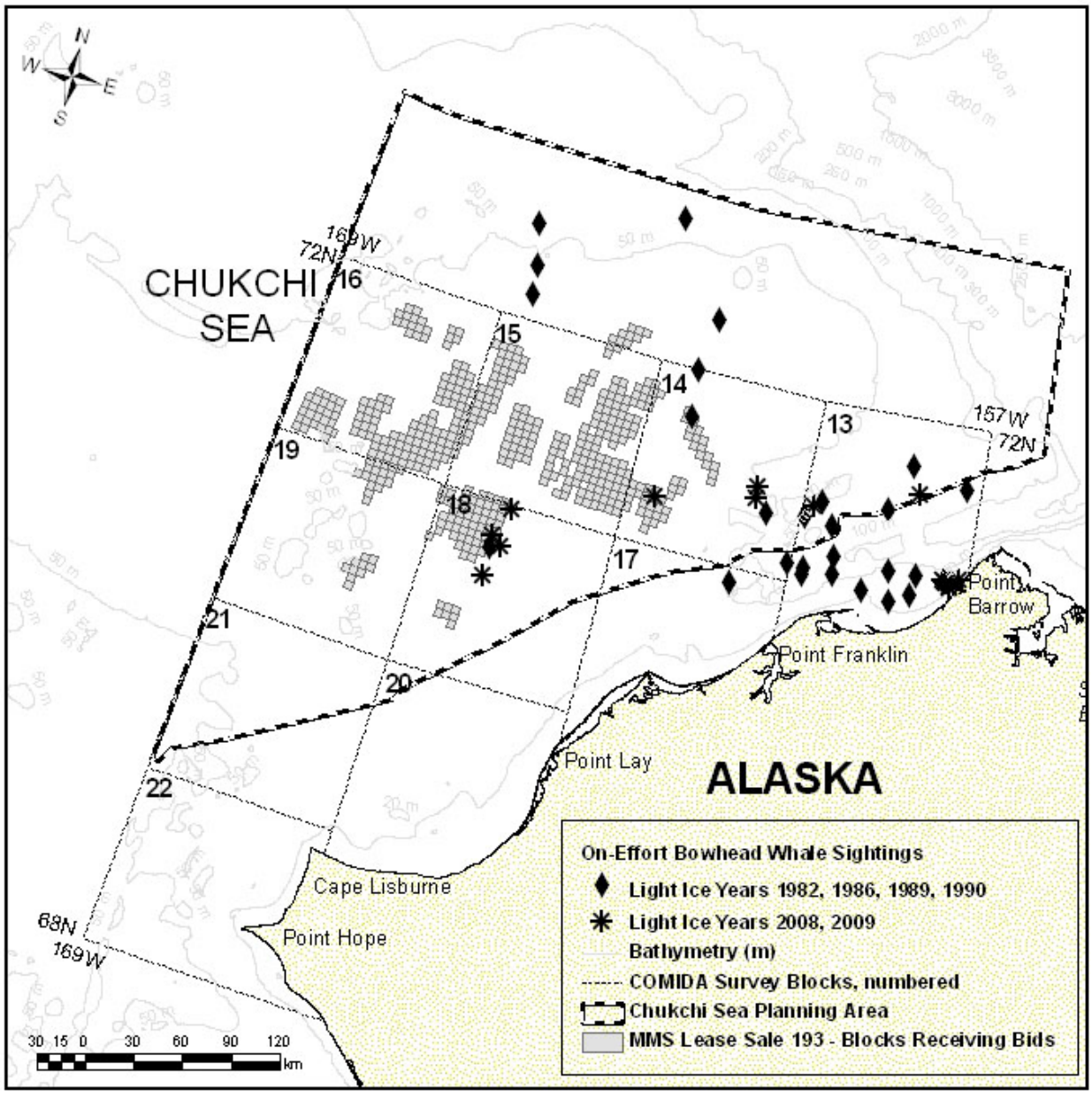

Figure 4. On-effort bowhead whale sightings in light ice years.

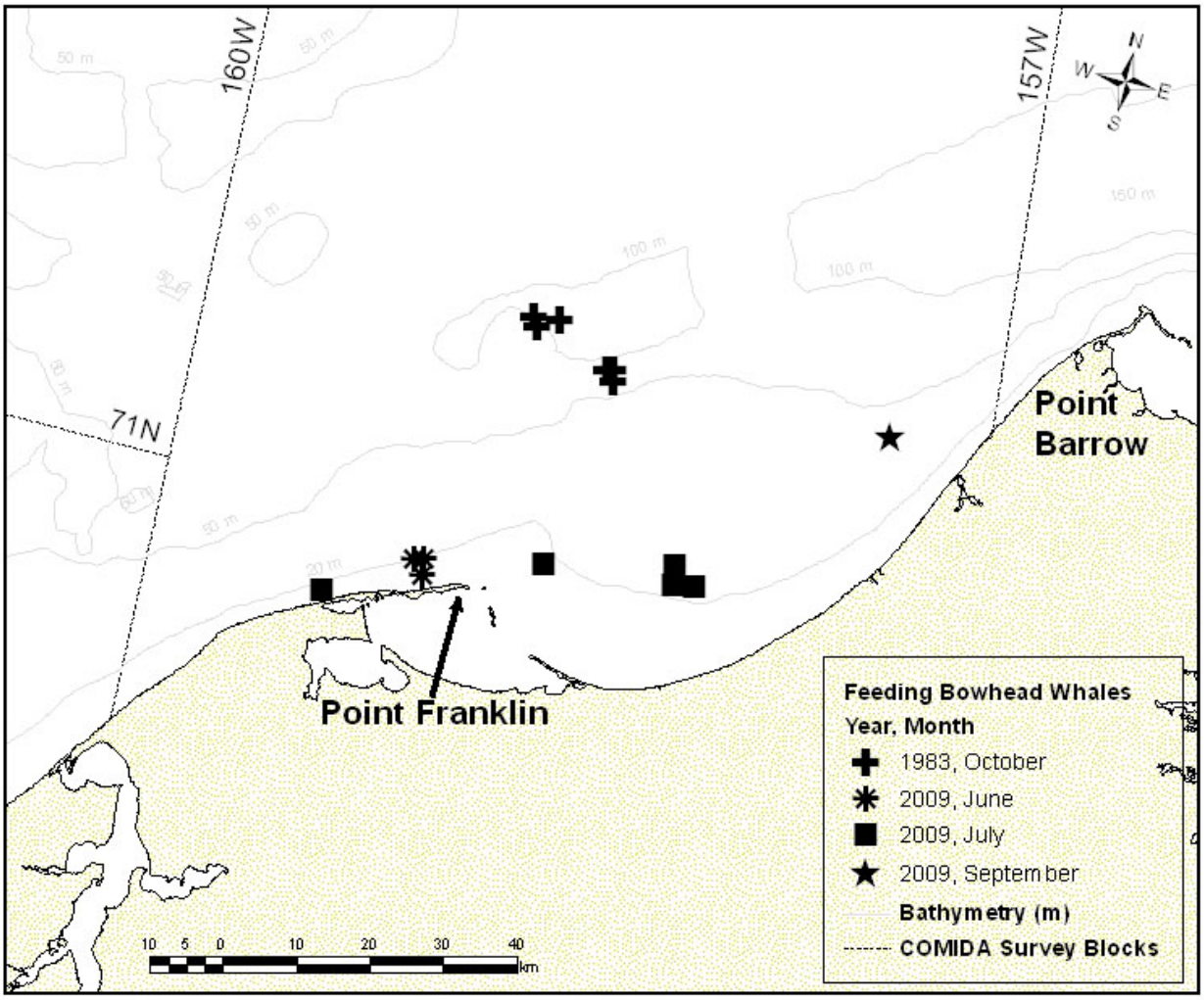

Figure 5. Locations of on- and off-effort feeding bowhead whales, 1983 and 2009.

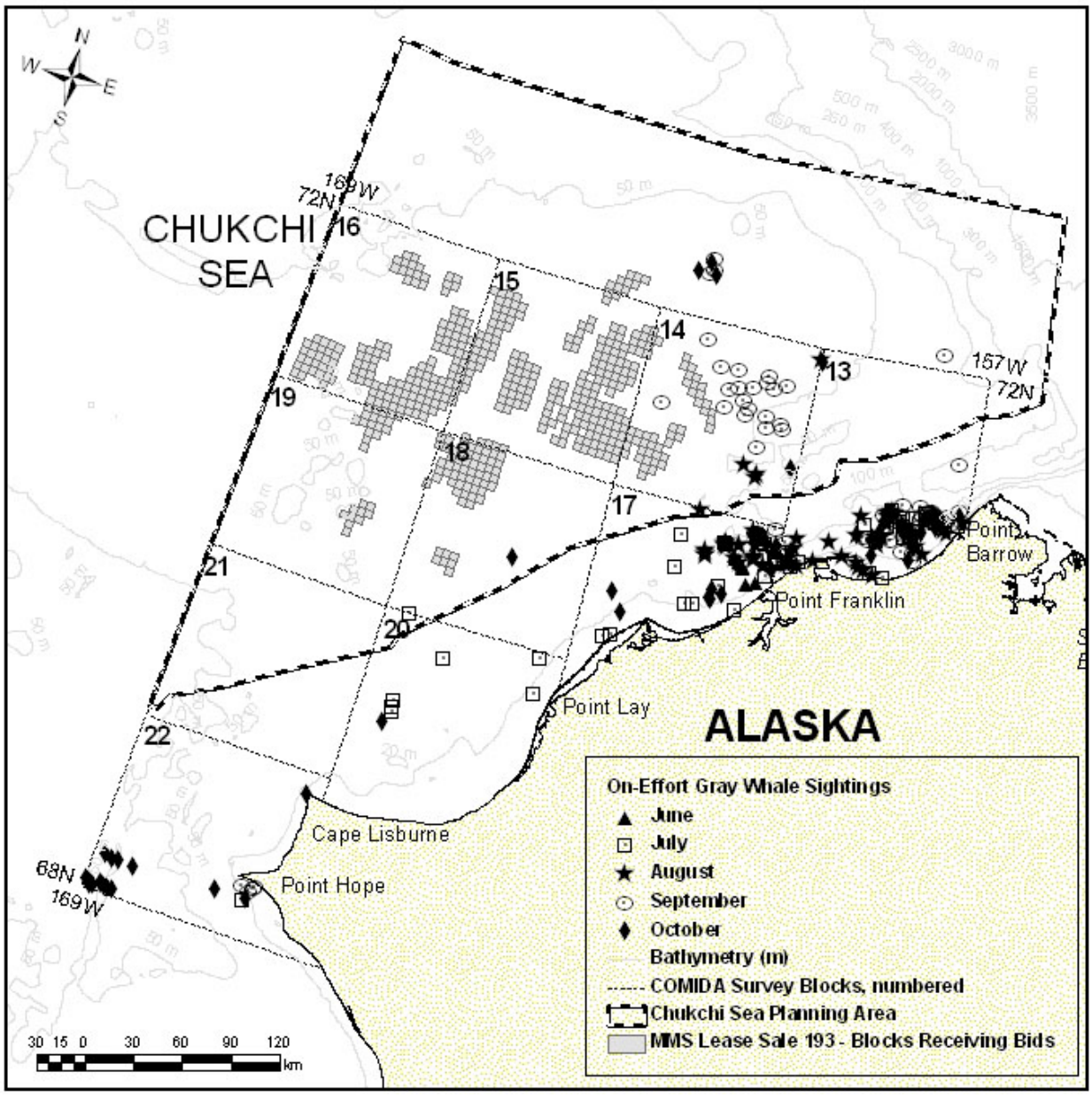

Figure 6. On-effort gray whale sightings per month, all years combined.

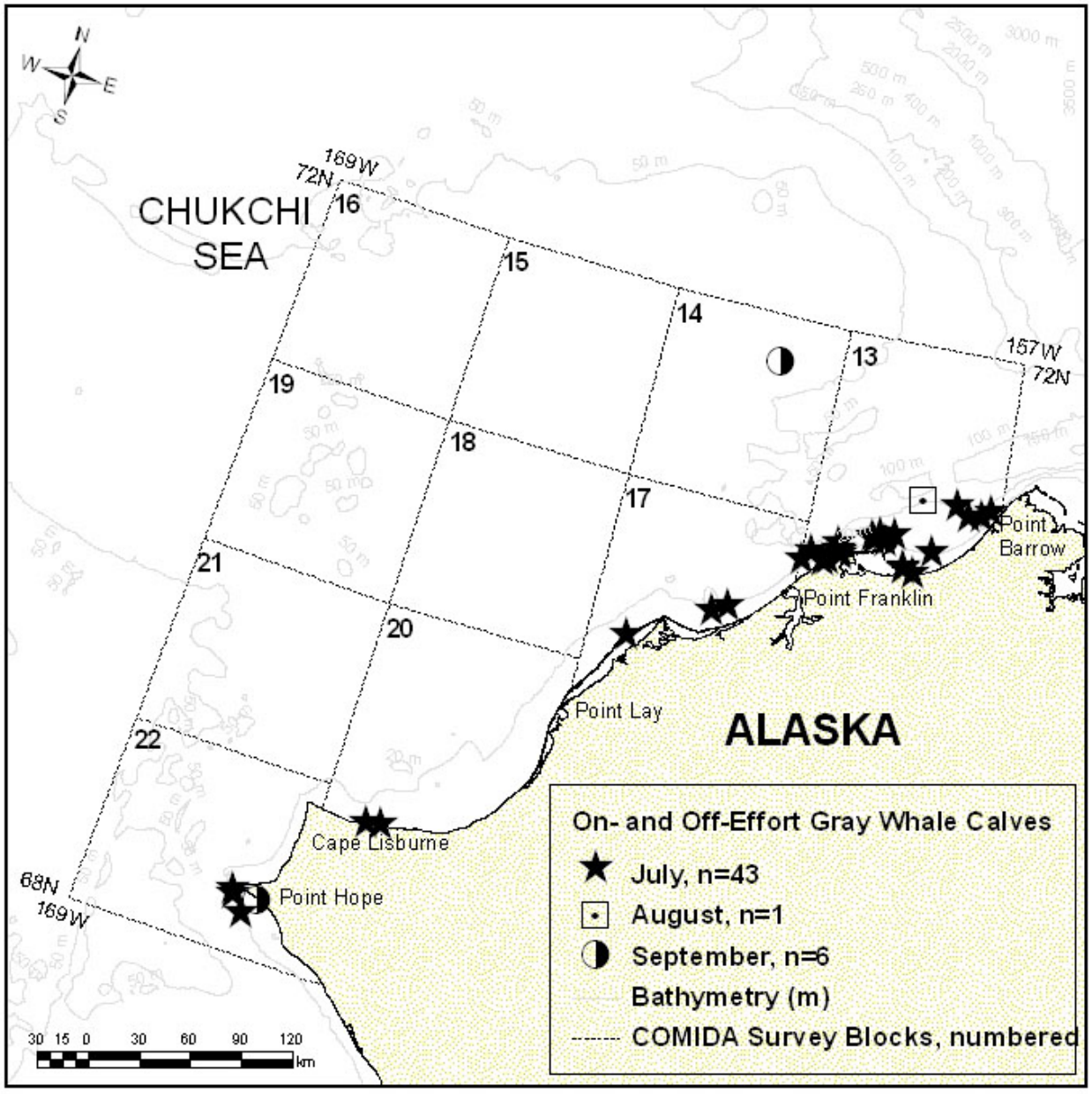

Figure 7. On- and off-effort gray whale calf sightings, by month.

Table 1. Summary of survey flights per month and year, with total kilometers flown on transect (Tr-km).

	June	July	August	September	October	Total Tr-km/Year
1982					x	3,461
1983				x	x	5,478
1984		x	x	x	x	6,713
1985		x			x	7,058
1986				x	x	11,025
1987				x	x	11,471
1988					x	6,337
1989				x	x	12,769
1990					x	3,084
1991				x	x	13,576
2008	x	x	x		x	11,647
2009	x	x	x	x	x	21,139
Total Tr-km/Month	3,998	13,275	10,675	29,123	56,686	113,758

Table 2. Bowhead and gray whale sightings (n) and sighting rate (whales per unit effort=WPUE) per survey block per month. Survey Effort (Tr-km) is included only for current survey blocks (13-22) and does not include effort between 72° and 73°N that was flown from 1989-91. Six bowheads and 16 gray whale sightings were north of 72°N and are not included here. The maximum WPUE per month and for all months combined is **bolded**.

Bowhead Whales

	JUN			JUL			AUG			SEP			OCT			TOTAL		
Block	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE
13	398	5	**0.0126**	3,713	7	**0.0019**	1,992	2	**0.0010**	9,022	15	**0.0017**	12,301	35	0.0028	27,425	64	**0.0023**
14	213	0	0.0000	2,050	0	0.0000	846	0	0.0000	5,039	2	0.0004	5,787	12	0.0021	13,936	14	0.0010
15	47	0	0.0000	1,235	0	0.0000	1,026	0	0.0000	2,668	0	0.0000	3,160	1	0.0003	8,136	1	0.0001
16	0			256	0	0.0000	1,463	0	0.0000	849	0	0.0000	2,016	0	0.0000	4,584	0	0.0000
17	318	0	0.0000	1,572	0	0.0000	925	0	0.0000	2,851	2	0.0007	5,462	2	0.0004	11,128	4	0.0004
18	225	0	0.0000	1,082	0	0.0000	112	0	0.0000	2,283	0	0.0000	5,506	18	**0.0033**	9,208	18	0.0020
19	5			298	0	0.0000	816	0	0.0000	422	0	0.0000	625	0	0.0000	2,165	0	0.0000
20	0			1,087	0	0.0000	671	0	0.0000	1,234	0	0.0000	2,753	0	0.0000	5,745	0	0.0000
21	0			568	0	0.0000	113	0	0.0000	0			908	0	0.0000	1,589	0	0.0000
22	0			611	0	0.0000	1			500	0	0.0000	2,503	0	0.0000	3,615	0	0.0000
TOTAL																**87,532**	**101**	**0.0012**

Gray Whales

	JUN			JUL			AUG			SEP			OCT			TOTAL		
Block	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE
13	398	1	0.0025	3,713	54	0.0145	1,992	65	0.0326	9,022	108	0.0120	12,301	35	0.0028	27,425	263	0.0096
14	213	0	0.0000	2,050	0	0.0000	846	4	0.0047	5,039	51	0.0101	5,787	1	0.0002	13,936	56	0.0040
15	47	0	0.0000	1,235	0	0.0000	1,026	0	0.0000	2,668	0	0.0000	3,160	0	0.0000	8,136	0	0.0000
16	0			256	0	0.0000	1,463	0	0.0000	849	0	0.0000	2,016	0	0.0000	4,584	0	0.0000
17	318	15	**0.0472**	1,572	31	**0.0197**	925	34	**0.0367**	2,851	9	0.0032	5,462	11	0.0020	11,128	100	0.0090
18	225	0	0.0000	1,082	1	0.0009	112	0	0.0000	2,283	0	0.0000	5,506	2	0.0004	9,208	3	0.0003
19	5			298	0	0.0000	816	0	0.0000	422	0	0.0000	625	0	0.0000	2,165	0	0.0000
20	0			1,087	10	0.0092	671	0	0.0000	1,234	0	0.0000	2,753	2	0.0007	5,745	12	0.0021
21	0			568	0	0.0000	113	0	0.0000	0			908	0	0.0000	1,589	0	0.0000
22	0			611	5	0.0082	1			500	23	**0.0460**	2,503	55	**0.0220**	3,615	83	**0.0230**
TOTAL																**87,532**	**517**	**0.0059**

Table 3. Summary of large whale sightings, 1982-1991 and 2008-2009.

	June	July	August	September	October	Total
Bowhead Whale	2/5	3/7	2/2	20/21	50/72	77/107
Gray Whale	9/16	51/101	75/103	68/199	51/114	254/533
Humpback Whale	0	1/1	0	0	0	1/1
Fin Whale	0	1/1	0	0	0	1/1

Table 4. Number of bowhead whale sightings (n) and sighting rate (whales per unit effort= WPUE) per depth zone. Tr-km=transect kilometer. The maximum WPUE per month and for all months combined is *italicized*.

TOTAL	**June**			**July**			**August**		
Depth Range (m)	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE
0 to 35	708	5	*0.0071*	3,723	3	0.0008	3,116	0	0.0000
35 to 50	1,736	0	0.0000	6,089	0	0.0000	4,775	0	0.0000
50 to 200	1,554	0	0.0000	3,464	4	*0.0012*	2,783	2	*0.0007*
>200	0	0		0	0		0	0	
Total	**3,998**	**5**	**0.0013**	**13,275**	**7**	**0.0005**	**10,675**	**2**	**0.0002**

TOTAL	**September**			**October**			**TOTAL**		
Depth Range (m)	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE
0 to 35	4,844	3	0.0006	9,582	5	0.0005	21,974	16	0.0007
35 to 50	13,033	8	0.0006	25,480	38	*0.0015*	51,113	46	0.0009
50 to 200	10,841	10	*0.0009*	20,253	29	*0.0014*	38,895	45	*0.0012*
>200	404	0	0.0000	1,371	0	0.0000	1,775	0	0.0000
Total	**29,123**	**21**	**0.0007**	**56,686**	**72**	**0.0013**	**113,758**	**107**	**0.0009**

Table 5. Number of gray whale sightings (n) and sighting rate (whales per unit effort= WPUE) per depth zone. Tr-km=transect kilometer. The maximum WPUE per month and for all months combined is *italicized*.

TOTAL	**June**			**July**			**August**		
Depth Range (m)	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE
0to35	708	5	*0.0071*	3,723	43	*0.0116*	3,116	27	0.0087
35to50	1,736	10	0.0058	6,089	45	0.0074	4,775	47	0.0098
50to200	1,554	1	0.0006	3,464	13	0.0038	2,783	29	*0.0104*
200+	0			0	0		0	0	
Total	**3,998**	**16**	**0.0040**	**13,275**	**101**	**0.0076**	**10,675**	**103**	**0.0096**

TOTAL	**September**			**October**			**TOTAL**		
Depth Range (m)	Tr-km	n	WPUE	Tr-km	n	WPUE	Tr-km	n	WPUE
0to35	4,844	38	*0.0078*	9,582	26	*0.0027*	21,974	139	*0.0063*
35to50	13,033	94	0.0072	25,480	38	0.0015	51,113	234	0.0046
50to200	10,841	67	0.0062	20,253	50	0.0025	38,895	160	0.0041
200+	404	0	0.0000	1,371	0	0.0000	1,775	0	0.0000
Total	**29,123**	**199**	**0.0068**	**56,686**	**114**	**0.0020**	**113,758**	**533**	**0.0047**