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Movement and Aggregation of Eastern Hudson Bay Beluga Whales (*Delphinapterus leucas*): A Comparison of Patterns Found through Satellite Telemetry and Nunavik Traditional Ecological Knowledge

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ABSTRACT. Traditional Ecological Knowledge (TEK) consists of the collective knowledge, experience, and values of subsistence communities, while Western science relies on hypothesis testing to obtain information on natural processes. Both approaches provide important ecological information, but few studies have directly compared the two. We compared information on movements and aggregation of beluga whales obtained from TEK interview records (n = 3253) and satellite telemetry records of 30 whales tagged in eastern Hudson Bay, Canada, using geographic information system (GIS) approaches that allowed common formatting of the data sets. Estuarine centres of aggregation in the summer were evident in both data sets. The intensive use of offshore areas seen in the telemetry data, where 76% of the locations were more than 15 km from mainland Quebec, was not evident in the TEK data, where only 17% of the records indicated offshore locations. Morisita's index of similarity indicated that TEK and telemetry data distributions varied with season, with the highest similarity in winter (0.74). Location and movement data from the telemetry study were limited by small sample size and short tag deployment times, while TEK data were biased by spatial coverage and coastal travel habits. Although the two data sets can provide complementary information, both suffer from weaknesses that need to be acknowledged when these data are adapted for use in resource management.

Key words: Traditional Ecological Knowledge (TEK), telemetry, beluga whales, home range, kernel, Hudson Bay, Hudson Strait, Ungava Bay, Labrador Sea, resource management

RÉSUMÉ. Les connaissances écologiques traditionnelles (CÉT) consistent en l'ensemble des connaissances, de l'expérience et des valeurs des communautés de subsistance, tandis que la science occidentale s'appuie sur la mise à l'épreuve d'hypothèses dans le but d'obtenir de l'information sur les processus naturels. Bien que ces deux démarches permettent d'obtenir d'importants renseignements sur l'écologie, peu d'études ont établi une comparaison directe entre ces deux démarches. Nous avons comparé des données sur les mouvements et le rassemblement des bélugas, données obtenues à partir de CÉT prélevées au moyen d'entrevues (n = 3253) ainsi qu'à partir de résultats de télémétrie par satellite sur 30 baleines marquées dans l'est de la baie d'Hudson, au Canada, à l'aide de systèmes d'information géographique (SIG) qui ont permis le formatage commun des ensembles de données. Pendant l'été, les centres de rassemblement en estuaire étaient évidents dans les deux ensembles de données. L'utilisation intensive des zones au large en ce qui a trait aux données de télémétrie, où 76 % des localisations se situaient à plus de 15 km du continent québécois, n'était pas évidente dans le cas des données des CÉT, où seulement 17 % des résultats indiquaient des localisations au large. L'indice de similarité de Morisita indiquait que la répartition des données obtenues par CÉT et par télémétrie variait d'une saison à l'autre, la similarité la plus grande ayant été atteinte l'hiver (0,74). Les données de localisation et de mouvement découlant de l'étude de télémétrie étaient limitées par la petite taille de l'échantillon et les courtes durées de déploiement des étiquettes, tandis que les données provenant des CÉT étaient biaisées par l'espace à couvrir et les habitudes de déplacement sur la côte. Bien que les deux ensembles de données puissent fournir de l'information complémentaire, tous deux possèdent des faiblesses qu'il y a lieu de reconnaître lorsque ces données sont adaptées à des fins de gestion des ressources.

Mots clés : connaissances écologiques traditionnelles (CÉT), télémétrie, béluga, territoire, noyau, baie d'Hudson, détroit d'Hudson, baie d'Ungava, mer du Labrador, gestion des ressources

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INTRODUCTION

TEK has been defined as the knowledge claims of persons who have a lifetime of observation and experience of a particular environment, and as a result function effectively in that environment, but are untutored in the conventional scientific paradigm (Usher, 2000). As a result of policy developments in Canada, TEK is increasingly being incorporated into environmental assessment and resource management in northern communities (Usher, 2000). Many promote the use of TEK and its integration with science because it reflects the long observational experience and resource use of local people and provides a longer historical record than scientific data in remote areas (Ferguson and Messier, 1997). However, TEK and science differ in the ecological information they provide. These differences in both observational intensity and geographic coverage may lead to different conclusions about the environment and the size of populations and thus influence management decisions. To date, few studies have attempted to compare and contrast these two data sets, or to examine critically the differences in ecological understanding of beluga whales arising from the use of TEK versus Western scientific data.

The beluga whale, *Delphinapterus leucas*, is a medium-sized, toothed whale widely distributed throughout Arctic waters (Finley et al., 1982; Smith et al., 1985; Hammill et al., 2004). Within the waters surrounding northern Quebec (Nunavik), seasonal aggregations of at least three populations of beluga whales that appear to be genetically identifiable have been defined by their summer distributions (Fig. 1) (de March, 2001, 2003). For management in this area, the most important are the Eastern Hudson Bay (EHB), the Ungava Bay (UB), and the Western Hudson Bay (WHB) populations. Beluga whales of the EHB population summer within the Hudson Bay arc, which extends from 54˚40′ N to 58˚40′ N (Kingsley et al., 2001), and frequent the Little Whale (56˚00′ N, 76˚46′ W) and Nastapoka estuaries (56˚54′ N, 76˚32′ W) (Smith, 2004). Beluga whales from UB occur in the Mucalic (58˚16′ N, 67˚23′ W), the George (58˚46′ N, 66˚8′ W), and the Whale estuaries (58˚15′ N, 67˚36′ W) (Fig. 1) (Smith, 2004). The WHB population, which could consist of more than one stock, summers in James Bay and along the Ontario, Manitoba, and Nunavut coasts of Hudson Bay, and overwinters in Hudson Strait and Ungava Bay (Richard et al., 1990). All populations are hunted by the Inuit communities in Nunavik.

Concern over the apparent low numbers of whales in the waters adjoining Nunavik (Smith and Hammill, 1987) led to harvesting limits (quotas, and seasonal and regional closures) that were imposed in 1988 to allow the stocks to recover (Reeves and Mitchell, 1989; Hammill et al., 2004). In spite of harvest restrictions, aerial surveys continue to indicate that beluga whale numbers in eastern Hudson Bay and Ungava Bay are low (Hammill et al., 2004), and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has designated the EHB and UB beluga whale populations as “endangered.”

Information on the movements and distribution of whales around Nunavik has been passed to successive generations of Inuit through traditional ecological knowledge (TEK). In contrast to the observational history of TEK, the scientific study of beluga whales has used systematic aerial surveys and satellite telemetry to examine beluga distribution and movement (Kingsley, 2000; Kingsley et al., 2001; Hammill et al., 2004).

Drawing on available data sets from both forms of knowledge, we compare the movements and aggregation patterns of beluga whales obtained from TEK interview records (n = 3253) and from the satellite telemetry records of 30 whales tagged between 1993 and 2003 at three locations in eastern Hudson Bay. Specifically, we test the hypothesis that the two data sets result in significantly different characterizations of beluga whale movement and aggregation patterns in Nunavik.

MATERIAL AND METHODS

Study Area

Fourteen Inuit communities are located north of the 55th parallel in Nunavik. Their population in 2001 was 9632 (Table 1), and 90% were of Inuit descent. The communities are spread along the coast and all border the shores of major water bodies or rivers (Fig. 1).

TEK Database

After the signing of the James Bay and Northern Quebec Agreement (JBNQA) in November 1975, the Makivik Corporation (the Inuit organization established to manage the Agreement compensation funds) established a research department with a mandate to develop a TEK database (see Kemp and Brooke, 1995). TEK was collected during interviews held in 11 Inuit communities, as well as in Chisasibi (53˚46′ N, 78˚54′ W), a Cree community with a small number of Inuit residents, and in Killiniq, a community located on Killiniq Island (60˚25′ N, 64˚39′ W) that was abandoned in 1978. Interviews, which began in the late 1970s, used one interview template for elders (the older, influential members of a community) and another for non-elders. The two interview templates facilitated the collection of both historical data (based on pre-1970 knowledge of elders) and current data (based on post-1970 observations by active hunters).

Each template consisted of a series of questions in Inuktitut about hunting practices. The responses, recorded on standard cassette tapes, were later transcribed into English and stored in ASCII text files. Both spatial and non-spatial questions were posed during the interviews. Responses to spatial questions were recorded on a mylar/map combination for later digitization. The TEK interview process is comparable to a semi-directive interview (Huntington, 1998); hunters were encouraged to expand on topics, but directed through a series of pre-determined questions. Community

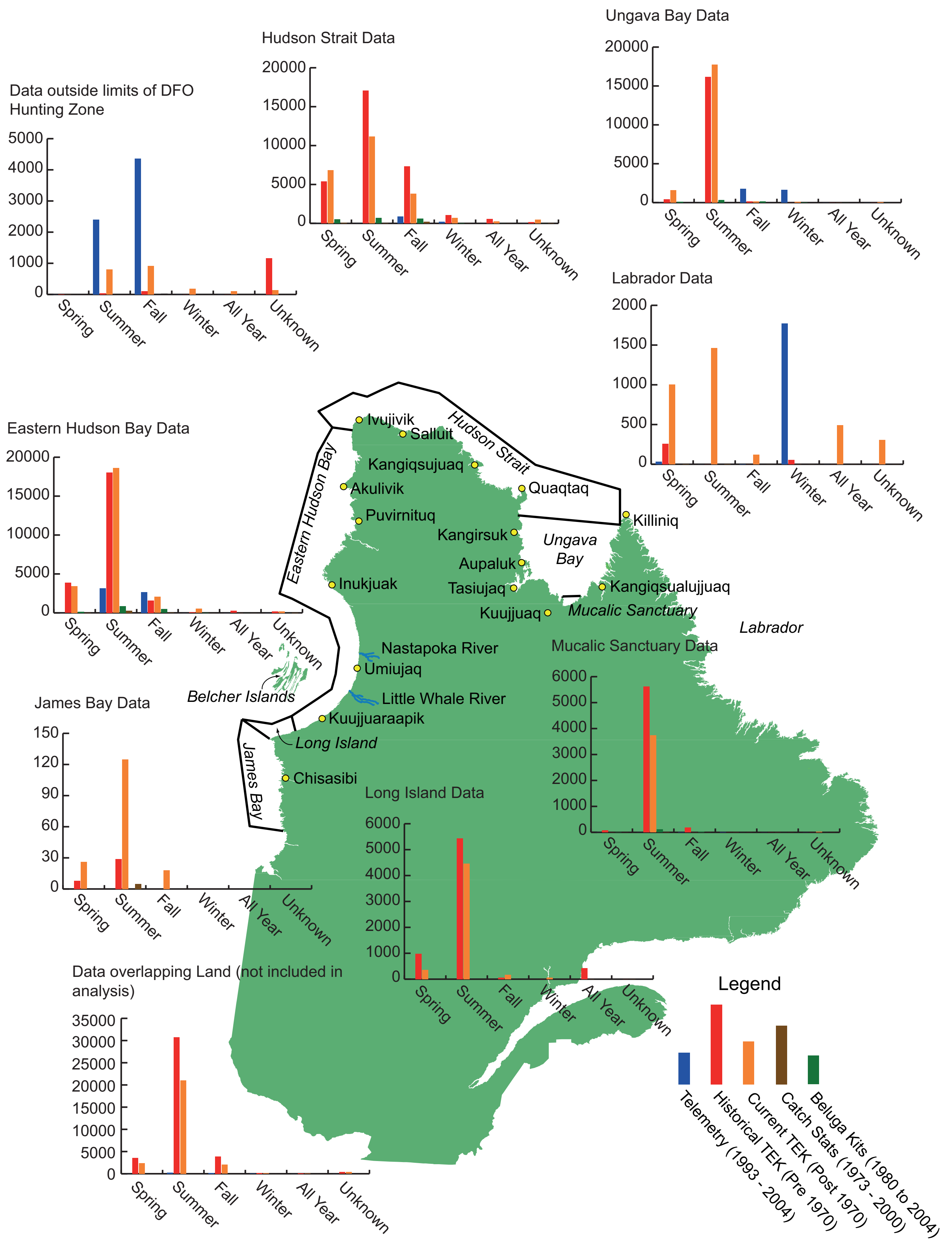

FIG. 1. Map of Nunavik (northern Quebec), showing the location of communities from which TEK data were collected and plots of data used in the analysis (by data type). Plots are sorted according to the hunting zones defined in the 2001–03 Northern Quebec Beluga Three-Year Management Plan.

TABLE 1. Population, number of Inuit hunters interviewed, and number of TEK interviews completed in Nunavik communities. Population data are from the Statistics Canada, 2001 census. Where no numbers are recorded for interviews, the data were either unavailable or not transcribed.

Community	Population 2001	# Hunters Interviewed	# Historical Interviews	# Current Interviews
Kuujjuaraapik	555	80	53	68
Inukjuak	1294	41	39	36
Akulivik	472	21	14	19
Puvirnituq	1287	4	–	–
Ivujivik	298	43	11	37
Salluit	1072	35	24	28
Kangiqsujuaq	536	25	21	18
Quaqtaq	305	14	18	11
Kangirsuk	436	33	17	28
Aupaluk	159	13	13	9
Tasiujaq	228	16	15	14
Kuujjuaq	932	33	24	29
Kangiqsualujjuaq	710	35	35	29
Killiniq	N/A	11	–	–
Chisasibi	3467	6	0	6
Umiujaq	348	17	2	14
Total	**13099**	**427**	**286**	**346**

booklets were created from the digitized data and returned to the communities for verification of accuracy and interpretation. A total of 427 hunters have been interviewed to date. Of those hunters, 205 have given both historical and current interviews, for a total of 286 historical and 346 current interviews (Table 1).

Records in the database were coded by time period (historical or current), community, type of record (see below), and season. The database contains 86 693 spatial records in the form of points and lines representing species (e.g., beluga, seal), routes, ice conditions, ecology, and sites. Of these records, 3253 (3.7%), 1702 historical, 1548 current, and 3 unknown, pertain to beluga whales.

Canadian Inuit recognize six seasons based on natural phenomena associated with weather or animal movements. The two extra seasons cannot be readily translated into English, but can be defined as pre-fall and pre-summer. In the design of the TEK database, these two extra seasons were incorporated into the four-season structure, with pre-fall reclassified as fall and pre-summer reclassified as summer. Accordingly, the seasons are not directly related to a calendar date, and can vary in length from year to year. However, to standardize data for subsequent analysis, we defined seasons as spring (April to June), summer (July and August), fall (September to November), and winter (the longest season, from December to March).

Telemetry Database

Beluga whales (n = 30) were captured using six-inch shore-anchored nets, and satellite-linked time-depth recorders were secured to the dorsal ridge (Richard et al., 1997; Kingsley et al., 2001) (See Table 2). Most animals were tagged in July or August at the Little Whale River (LWR) (n = 24) or the Nastapoka River (n = 5), while one animal was captured in October in Hudson Strait, near the community of Ivujivik (62˚25′ N, 77˚54′ W). Transmitter deployments lasted from three days to seven months, with a mean deployment of 98 days (Table 2).

Signals from the transmitters (also referred to as tags) were received by the polar orbiting satellites of the ARGOS network (Toulouse, France) and transmitted to ground stations (Fancy et al., 1988; ARGOS User's Manual Online at http://www.cls.fr/manuel). The satellite transmitter data were arranged by whale identification number, date, and time of reception. Records consisted of a location point and associated attributes, such as depth and water temperature; however, only the location data were used in the present study. ARGOS files from the SPOT and SDR-T16 tags (Wildlife Computers Ltd., Redmond, Washington, USA) were processed using SATPAK and SATPAK2003 applications provided by Wildlife Computers Ltd. The SMRU tag data are processed automatically at the Sea Mammal Research Unit (SMRU), St. Andrews, UK, and are available in a standardized database format. A total of 28 571 records were recovered from 30 tags.

The accuracy of the locations depends on the presence and position of orbiting satellites, as well as the strength and number of consecutive signals received by a satellite from a transmitter in a single pass (Goulet et al., 1999). To minimize location errors, data were filtered using a three-step method to remove questionable locations prior to comparison with the TEK data (Austin et al., 2003). The filter removed 9163 (32%) of the location records, leaving 19 408 for analysis. Reception date was then used to classify each location record according to the seasonal time structure used in analyzing the TEK database.

Verification Databases

Locations from both the catch statistics for 1974 to 2000 (Lesage et al., 2001) and tissue sampling kit data were used to cross-check and validate the locations of TEK data. These data include the number of whales hunted per community

TABLE 2. Belugas tagged (n = 30) in Nunavik in 1993, 1995, 1999, 2002, and 2003. SDR and SPOT transmitters are manufactured by Wildlife Computers, Redmond, Washington. SMRU transmitters are manufactured by the Sea Mammal Research Unit in St. Andrews, Scotland. Nose-to-tail length (NTL) is total straight-line length (cm) from the tip of the snout to the base of the fluke notch.

ID Number	Tagging Location	Deployment Date	Date of Last Reception	Tag Type	Sex	NTL	Colour
5090	Little Whale	12/08/1993	23/09/1993	SDR-T16	–	390	White
11747	Little Whale	12/08/1993	07/09/1993	SDR-T16	–	280	Grey
11748	Little Whale	15/08/1993	30/08/1993	SDR-T16	–	–	White
11750	Little Whale	15/08/1993	29/08/1993	SDR-T16	–	270	Grey
5091	Nastapoka	18/08/1993	25/08/1993	SDR-T16	–	265	Grey
11749	Nastapoka	18/08/1993	31/08/1993	SDR-T16	–	320	White
11751	Ivujivik	17/10/1995	19/11/1995	SDR-T16	F	300	–
1854	Nastapoka	29/07/1999	21/10/1999	SDR-T16	F	310	White
2014	Nastapoka	29/07/1999	06/08/1999	SDR-T16	F	330	Grey
17908	Nastapoka	29/07/1999	06/09/1999	SDR-T16	–	270	Grey
1853	Little Whale	19/07/2002	04/09/2002	SDR-T16	M	353	Light Grey
1851	Little Whale	20/07/2002	08/10/2002	SDR-T16	F	342	White
17911	Little Whale	24/07/2002	25/09/2002	SPOT	M	290	Light Grey
1852	Little Whale	24/07/2002	05/01/2003	SDR-T16	F	332	White
1855	Little Whale	24/07/2002	13/01/2003	SDR-T16	M	321	White
17906	Little Whale	28/07/2002	11/12/2002	SPOT	M	394	White
17905	Little Whale	28/07/2002	23/11/2002	SPOT	M	375	White
1852	Little Whale	11/07/2003	27/01/2004	SPOT	M	265	Grey
3022	Little Whale	11/07/2003	10/02/2004	SMRU	M	385	White
17908	Little Whale	14/07/2003	16/07/2003	SDR-T16	F	332	Grey/White
1853	Little Whale	14/07/2003	14/02/2004	SPOT	M	310	Grey
1851	Little Whale	22/07/2003	09/09/2003	SPOT	F	230	Grey
5091	Little Whale	22/07/2003	21/11/2003	SDR-T16	F	335	White
3415	Little Whale	22/07/2003	14/02/2004	SMRU	F	335	White
17905	Little Whale	22/07/2003	17/12/2003	SDR-T16	M	294	Grey
17906	Little Whale	23/07/2003	22/12/2003	SDR-T16	M	315	Grey/White
1854	Little Whale	27/07/2003	13/04/2004	SPOT	M	295	Grey
17911	Little Whale	27/07/2003	03/03/2004	SDR-T16	M	360	White
5059	Little Whale	27/07/2003	05/08/2003	SDR-T16	M	340	White
1855	Little Whale	27/07/2003	18/09/2003	SPOT	M	325	Grey

per season. Of the 9148 records in the catch statistics database, 5076 were not classifiable to month. These were not used in subsequent analysis because of the missing harvest date. The remaining 4072 data points were then also classified by season in the same way as the TEK data to allow direct comparison.

The tissue sampling kit data are from a sampling program for hunters in Nunavik started in 1980. Since participation is voluntary, the amount and quality of data obtained vary between years. The data set contains 1002 records. Of those, 863 contained month, year, and location information. The 139 remaining records, which lacked information on location or mortality date (or both), were not used for verification purposes. The complete records were organized into the same seasonal structure used for the TEK data.

ANALYSIS

We used home range analysis to compare summer and over-winter distributions of beluga whales based on TEK and on telemetry data. The telemetry data represent a series of locations that can be analyzed within the context of a home range. However, the TEK data, which were not collected in a form immediately suitable for home range analysis, were converted from lines to locational points at their vertices (the point at which the sides of an angle intersect). Attribute data such as time period and season were preserved in the resulting file. After conversion, the 3253 original TEK lines created 233 956 points (125 650 historical and 108 306 current). Historical records representing periods before the 1970s were removed from the TEK dataset; thus, only post-1970 data were used in the analyses that follow.

Summer and winter home ranges were calculated, using the Animal Movement Analysis Extension (AMAE) (Hooge et al., 1998) in ArcView (ESRI, Redlands, California) and a fixed kernel estimator. Least Squares Cross Validation (LSCV) was used as the smoothing parameter, as suggested by Seaman and Powell (1996). Probability contours of 50%, 90%, and 95% were created and exported in polygon format. Seasonal home ranges (summer and winter) were calculated for whales and communities for which there were 25 or more pieces of location information either from telemetry data or from TEK (Seaman and Powell, 1996). Locations found erroneously on land (Natural Resources Canada, 2005, 1:2 000 000 basemaps) were excluded from the calculation. Because summer data produced the large majority of points in the TEK database for each community, we selected a random number of points (n = 500) to calculate the seasonal home range for each community. Winter TEK records were not as abundant. Therefore, all winter records that existed in the original database were used in seasonal home range calculations, except for communities with fewer than 25 data points (Inukjuak, Umiujaq), where home ranges were not calculated. Limiting home range analysis to summer and winter was necessary because of the complications posed by migrations from Hudson Bay to Ungava Bay for the definition of a home range.

To identify areas of overlap between the home ranges calculated from TEK and those calculated from telemetry data, the geometric intersection of home range polygons (probability contours of 50%, 90%, and 95%) was calculated using the INTERSECT command in ArcInfo (ESRI, Redlands, California). The XTools extension in ArcView was used to calculate the equivalent in km^2 of each overlapping area (DeLaune, 2000).

Morisita's index of similarity (Morisita, 1959) and Manly's selection ratio test (Manly et al., 1993) were used to investigate distributional similarities in the TEK and telemetry data. Before the tests were applied, buffer zones were created around the coasts of mainland Quebec and the Belcher Islands, as shown in Table 3. The resulting polygon was used in a query to determine the number of points that occurred within or outside the defined buffer zones. TEK and telemetry points within each zone were tallied for each season for use in Morisita's index of similarity, calculated following Krebs (1999).

To apply Manly's selection ratio test (Manly et al., 1993) for the determination of zone selection preferences in the TEK and telemetry data, buffer zones areas were converted to proportions. These proportions were compared to proportionate-use values determined from TEK and telemetry location data by means of standardized selection indices (B_i):

$$B_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

and

$$w_i = \frac{O_i}{P_i}$$

where w_i is the selection ratio for the i^{th} zone, n is the number of zones and P_i and O_i, respectively, express the proportional availability of the zone and its use (number of points per zone) as indicated by TEK and telemetry data. Values above and below 1/n indicate relative zone preference and avoidance, and ratios of 1/n indicate no zone preference (Manly et al., 1993). Selection ratios were then tested for statistical significance under the null hypothesis that beluga select zones randomly (Manly et al., 1993). Significant differences among multiple calculated selection indices were established using Bonferroni-adjusted confidence limits (Manly et al., 1993).

The seasonal distribution of beluga whale kills from the catch records was compared with that of the seasonal TEK locations. Chi-square tests were used to test the similarity (Zar, 1999). Zero entries for winter were deleted from the seasonal analysis except for Kangiqsualujjuaq, where winter kills were reported. A chi-square test was also used to compare the seasonal distribution of home range areas.

Finally, frequencies of kill sites were counted in each buffer zone. The areas from the 50% and 90% probability home ranges were then overlaid on the buffer zones to create a new spatial file of seasonal home range areas defined as distance zones. This allowed us to use chi-square tests to compare seasonal distributions of home range areas and to determine how the distribution of recorded summer kills compared with the summer home range calculated from current TEK. We expected that the location of kill sites would have a spatial distribution similar to that of the recorded TEK.

RESULTS

Seasonal Distribution of Whales in Nunavik

For spring, there was no similarity in the spatial distribution of whales in the TEK and telemetry data (Morisita's index = 0.04); however, spring telemetry data were limited to a single EHB whale located in the Labrador Sea that indicated a preference for areas 25–75 km from the shore. TEK-based observations were mainly distributed along the coast of Nunavik (≤ 5 km), and on the basis of the TEK data, whales showed a distinct preference for the inshore 0–5 km zone ($p < 0.05$) (Fig. 2a). These coastal distributions were located in EHB, Hudson Strait near Ivujivik, and near Quaqtaq at the northwestern tip of Ungava Bay (Fig. 1). EHB communities indicate that whales arrive in spring from no particular direction. Hudson Strait hunters indicate that whales are traveling from Hudson Bay, where they overwinter.

For summer, low similarity was found between the distributions of whales in the TEK and telemetry data (Morisita's index = 0.39). The TEK data indicated that whales were distributed along the coast of Nunavik, with a preference for inshore areas (0–5 km zone, $p < 0.05$) in eastern Hudson Bay, Hudson Strait, and Ungava Bay (Fig. 2b). The telemetry locations also indicated that whales were distributed along the eastern Hudson Bay coast, between Inukjuak in the north and Kuujjuaraapik to the south. However, the telemetry data also indicated that whales occurred in offshore regions, sometimes as much as 230 km from the Quebec coast, to the west of the Belcher Islands. Thus, tagged whales showed preferences for a broad range of habitat zones (0–75 km).

Fall and winter distributions of animals in the TEK and satellite telemetry databases showed the greatest similarity (Morisita's index = 0.52 and 0.74). Fall TEK observations were more concentrated along the eastern Hudson Bay coast and near Ivujivik in Hudson Strait, with a preference for the inshore area (0–5 km zone) (Fig. 2c). TEK respondent data also indicated that beluga whales move northward along the EHB coast, east through HS, and are recorded moving both northwest and southeast from Quaqtaq. Fall telemetry observations in eastern Hudson Bay showed a distribution of offshore locations comparable to the summer distribution. Animals occurred between the mainland and the Belcher Islands, with a preference for the 0–50 km offshore zone

TABLE 3. Seasonal frequency of points per zone. Zones define distance from shore, with boundaries defining the areas in which whales were reported or found.

	# Current TEK Points					# Telemetry Points				
Zone (km)	Spring	Summer	Fall	Winter	All	Spring	Summer	Fall	Winter	All
0–5	8973	40880	4569	615	56378	0	593	1212	168	1973
5–25	4271	16257	1920	651	23521	2	1674	3943	1548	7167
25–50	28	884	8	257	1281	5	1627	2638	833	5103
50–75	0	0	212	64	329	13	1403	1319	736	3471
> 75	0	65	578	0	747	14	236	504	370	1124
Total	**13272**	**58086**	**7287**	**1587**	**82256**	**34**	**5533**	**9616**	**3655**	**18838**

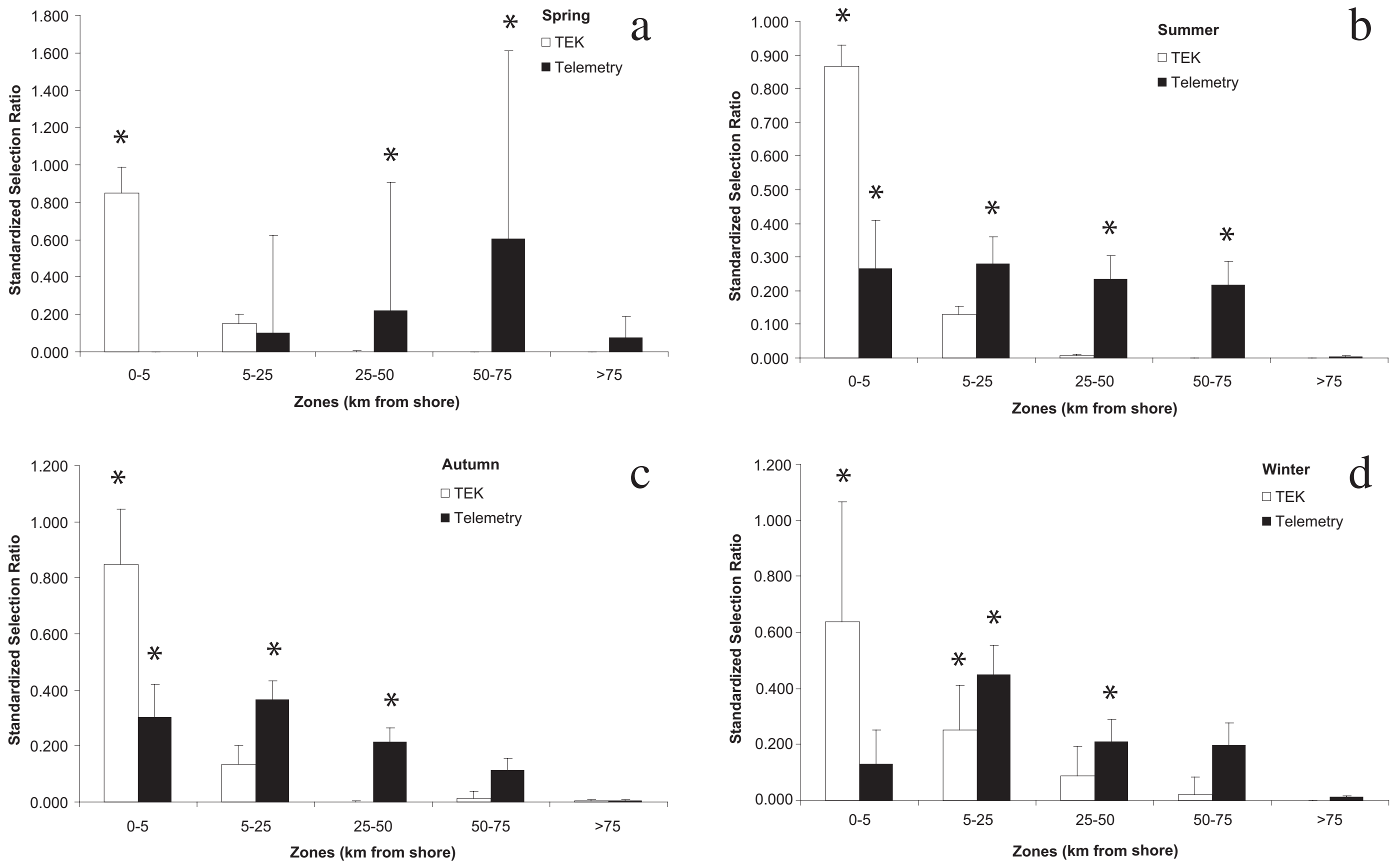

FIG. 2. Standardized selection ratios for offshore habitat zones during a) spring, b) summer, c) autumn, and d) winter, as computed using TEK (white bars) and telemetry data (black bars). An asterisk above a plot indicates preference for that zone.

(Fig. 2c). Tagged whales began migrating northward as early as September 20, and completely exited eastern Hudson Bay into Hudson Strait by early November. Animals remained in Hudson Strait for only a short period (mean 10 days, range 5–28 days). Thereafter, whales moved from Hudson Strait into Ungava Bay between late October and late November and were located along the Ungava coast to Killiniq in northeastern Ungava Bay.

TEK records indicated that whales occurred in winter along the Hudson Bay coast, with most locations near Ivujivik in Hudson Strait. The habitat preference was for the 0–25 km zone (Fig. 2d). Interviews indicate whales were often trapped in polynyas. However, TEK data showing polynyas in southern Ungava Bay (n = 10) located at the mouths of rivers such as the Koksoak (58˚32′ N, 68˚9′ W) and Dancelou (58˚53′ N, 68˚43′ W) did not overlap with TEK whale records. In contrast, telemetry locations in Ungava Bay indicated that whales did not remain along the coast, but moved offshore (with a preference for the 5–50 km zone) and traveled along the edge of the fast ice as they moved through Ungava Bay in November and December. From early to late December, whales migrated past Killiniq to deep-water troughs (> 600 m) in the Labrador Sea, where they overwintered (56˚7′ N, 59˚29′ W). Some whales, however, remained in Ungava Bay as late as February, typically at the ice edge.

Seasonal Home Ranges

Seasonal home ranges showed a large degree of overlap in summer and winter (Fig. 3d, f). The 50% probability band

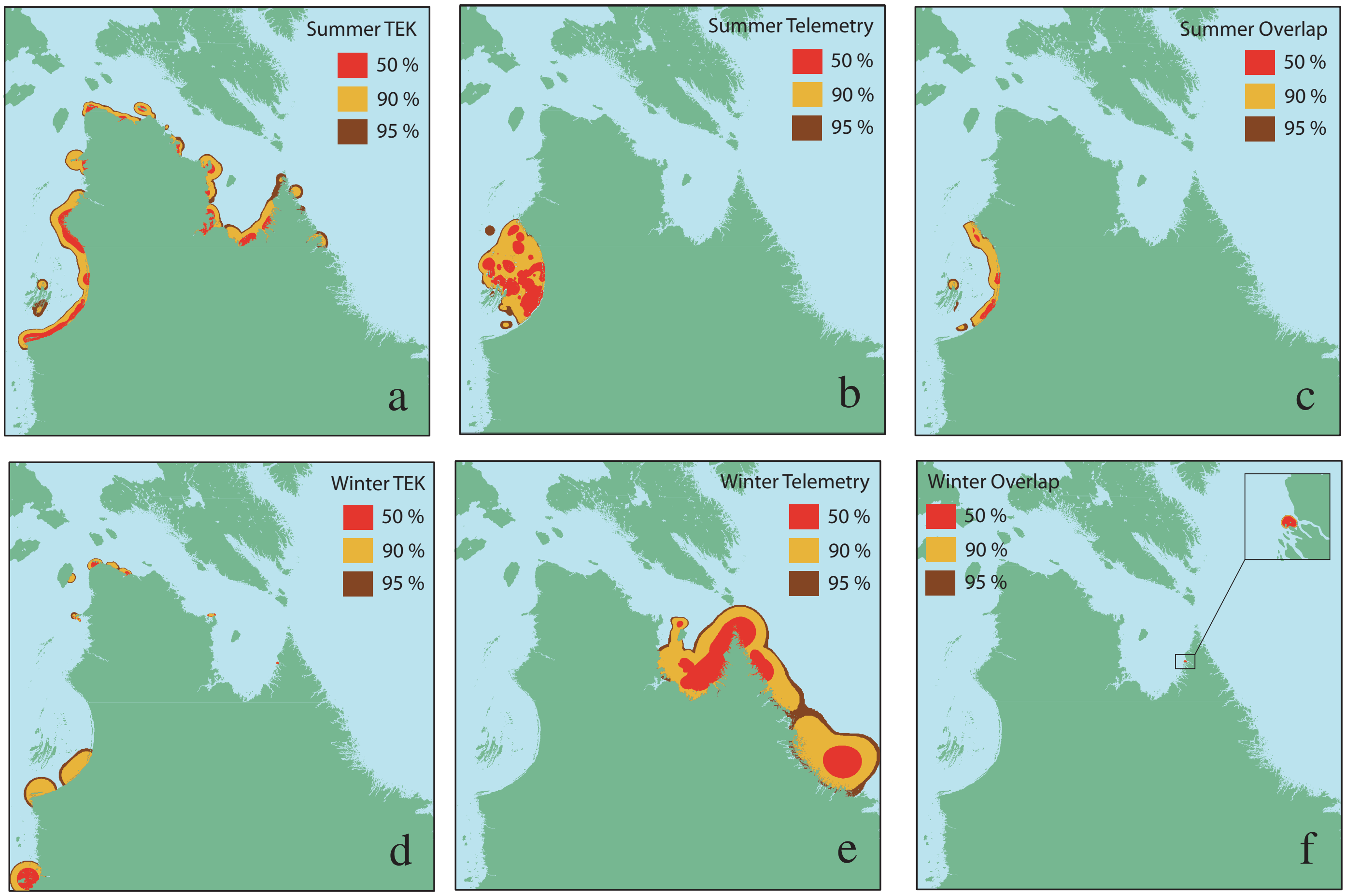

FIG. 3. Home range probabilities of 50%, 90%, and 95% calculated with TEK and telemetry data for summer (a, b) and winter (d, e). Also shown are overlaps between TEK and telemetry calculations for summer (c) and winter (f).

(home range) showed the least degree of overlap in both seasons (66.2% in summer and 53.0% in winter). The 90% and 95% probability bands showed an overlap of 84.2% or more in all seasons.

For summer, both the telemetry and TEK data sets identified coastal areas used by whales in the EHB arc as important. However, TEK data also showed areas of use outside EHB (Fig. 3a, b). Noted centers of activity (50%) were similar in summer and corresponded to known EHB stock aggregation areas in river estuaries (e.g., Little Whale and Nastapoka rivers). Low concentration areas in summer (90% and 95%) did not have a high degree of overlap (≤ 15.5%). For winter, however, the home ranges defined by TEK and telemetry were significantly different (Fig. 3d, e, f).

Statistical Analytical Results

The seasonal patterns in the beluga whale catch and TEK data differed for most communities (Table 4), i.e., the location of kills did not correlate with the distribution of TEK data. Lack of winter kill data precluded chi-square contingency table analysis for significant differences in the winter distributions of harvested whales and TEK data. Testing of summer data, however, indicated significant differences in the two data sets (Table 5), with no kills occurring outside the 0–25 km zone.

DISCUSSION

The purpose of this study was to put TEK into a framework that allowed for hypothesis testing and critical comparison with data obtained from scientific studies and harvest statistics. Our study shows that the TEK and telemetry data sets result in significantly different characterizations of beluga whale movement and aggregation patterns in Nunavik in certain seasons. Differences were found in the extent of offshore use, the preferences for near and offshore habitat use, and seasonal distribution patterns. Overlaps in the characterization of movement and aggregation patterns were greatest in summer and least in winter.

Many studies have pointed out the necessity and benefits of incorporating TEK into resource management and policy development (Wenzel, 1999; Berkes et al., 2000; Huntington, 2000, 2004; Pierotti and Wildcat, 2000; Usher, 2000; Riedlinger and Berkes, 2001; Moller et al., 2004; Nichols et al., 2004). However, little attempt has been made to subject TEK to the same level of rigorous peer review as normally

TABLE 4. Chi-square test results comparing catch statistics with current TEK data for all seasons.

Community	Chi-Square	DF[1]	*p*-value[2]
Kuujjuaraapik	2.97	3	0.396
Inukjuak	9.48	3	**0.024**
Akulivik	57.37	3	**< 0.001**
Puvirnituq	3.09	1	0.079
Ivujivik	29.79	3	**< 0.001**
Salluit	16.41	3	**0.001**
Kangiqsujuaq	3.08	3	0.379
Quaqtaq	28.38	3	**< 0.001**
Kangirsuk	1.87	2	0.393
Aupaluk	11.17	2	**0.004**
Tasiujaq	28.84	2	**< 0.001**
Kuujjuaq	15.34	2	**< 0.001**
Kangiqsualujjuaq	34.75	3	**< 0.001**
Umiujaq	19.15	3	**< 0.001**

[1] Degrees of Freedom.

[2] Bold values indicate significant differences ($\alpha = 0.05$).

occurs with Western science-based information. Such efforts are needed if TEK is to be used effectively for assessment and management purposes (Usher, 2000).

It has been argued that early studies did not formally include TEK because it was generally not considered scientifically reliable, or was difficult to access (Huntington, 2000; Nichols et al., 2004). Nonetheless, TEK has been used extensively in the development of new research directions and to improve our understanding of natural phenomena. For example, one has only to read early descriptions of the subnivean snow structures maintained by ringed seals (*Phoca hispida*) to realize that these studies are based on increased understanding of events gained through transfer of knowledge between Inuit hunters and Western researchers (McLaren, 1958; Smith and Stirling, 1975).

In remote areas, the ecological knowledge of indigenous peoples is often geographically and temporally more extensive than scientific knowledge (Ferguson and Messier, 1997). In Nunavik, the TEK database dating from the 1970s provides a longer historical record than the scientific data, which are the result of sporadic satellite tagging studies. However, limitations linked to collection methods, data type, and storage hinder the use of TEK. The use of lines on TEK maps and the unknown accuracy of these lines increase the uncertainty associated with the location and source (sampling or hunting efforts) of the data. Furthermore, it is difficult to interpret line data when minimal supporting information has been recorded. For example, the TEK data did not include any specific indications of whale movement direction, or statements as to whether a recorded line was the outer boundary of an aggregation area. Converting these line data into a form suitable for an analytical context remains a challenge. Errors occur in the calculated TEK seasonal home range after lines are converted to points. At a technical level, the density of points is a function of the number of vertices per line, and not the number of records in a given area. In one instance, the 50% probability area was significantly correlated in shape with the distribution of points created from a curved line. TEK data are also limited to the range of the hunter's experience, so the data tend to cluster around the community in which the hunter resides. Movements, aggregation areas, and ecology beyond these hunting ranges are generally not known and are therefore not reported. To obtain a more complete understanding of beluga whales, information from additional communities is needed, which increases the financial and logistical sampling effort. Although this additional sampling will extend the spatial and temporal extent of information, the quality of these observations will be limited by the cultural history of the villages involved. For example, Inuit along parts of eastern Hudson Bay and Ungava Bay have alternative food resources, including waterfowl, fish, and terrestrial mammals, which reduce their reliance on beluga. Application of management measures will also limit or alter hunter experience: some hunters may reduce their participation in beluga hunting, while others will travel to new areas to maintain access to beluga resources.

In cases where data are available about wildlife beyond the hunter's or community's hunting range, the source may be word-of-mouth reports. In some interviews, hunters reported specific areas where they had heard whales were located. Such reports can mean that a hunter may record a location well beyond his hunting range on the basis of the collective knowledge of the community. Transcription errors may also occur. In some instances, a location was mentioned during the TEK discussion but was not drawn on the map. In instances where the record was mapped, the location records were flagged when a sighting was out of the hunter's range. These observations may also be one-time sightings made while traveling. Such data may reflect an extreme event that might be useful in some analyses, but should be avoided in others. However, there is no a priori means of assessing the utility of such single observations. In

TABLE 5. Chi-square test results comparing kill sites with summer TEK home range analysis. Beluga kit indicates the number of kills per zone. The 50% and 90% probability figures refer to the area of the summer home range, and Chi 50% and Chi 90%, to the chi-square test values for the respective zones.

Zone	Beluga Kit	50% Probability (km^2)	90% Probability (km^2)	Chi 50%	Chi 90%
0–5	313	6587.225	15219.891	216.771	477.546
5–25	42	9733.471	30756.605	130.342	121.727
25–50	0	566.410	9670.586	11.974	61.866
50–75	0	0.000	157.010	0.000	1.004
> 75	2	0.000	0.000	0.000	0.000
	357	**16887.106**	**55804.092**	**359.087**	**662.143**

the present study, outliers were not omitted from the analysis as they were infrequent and they did not significantly affect analytical results (e.g., standardized selection ratios).

Individual interviews tend to be less biased than multiple-person interviews. However, group interviews are usually more cost-effective in remote areas, where travel is expensive and time-consuming. The resulting degree of bias depends on the questions asked, the interviewer's skills (which include establishing rapport with the subject), and the interviewer's biases. In some individual interviews, the subject can provide the answers he or she thinks the interviewer wants to hear. In other instances, a person might reveal more detail in an individual interview than in a group interview, either because peer pressure is absent or because there is more opportunity to talk and expand on the details. Huntington (1998) found that in group interviews, participants were able to encourage each other to recall specific events, to spur each other's memories, and to discuss the details of a particular item that led to a consensus based on their knowledge of the area and of each other. Other factors that may bias interviews include the reluctance of informants to reveal proprietary or sensitive knowledge (of particular concern in situations involving species experiencing conservation concern, such as beluga); withholding of information that the informant assumes is known or obvious to the interview team; lack of recall of specific facts during the interview; intentional deference to other informants, who may be seen as more knowledgeable; inadequate or inappropriate questioning by the interview team; and inadequate comprehension by the interview team of the information provided (Ferguson and Messier, 1997).

TEK is also often based on unusual events; out-of-the ordinary circumstances are easily remembered and recorded in Inuit cultures (Krupnik and Jolly, 2002; Moller et al., 2004). Thus the seasonal ranges in our study that do not correlate with telemetry may result from the capture of abnormal events or the lack of telemetry data. Late migration for some whales evident in the telemetry data, however, may represent the unusual events captured during some seasons in the TEK data.

The telemetry studies provided new knowledge that was unavailable through TEK, most notably from tags that recorded dive information, temperature, and salinity. Another important attribute of telemetry data is that collection was independent of the observer, and information from offshore or heavily ice-covered areas was provided for regions where hunters do not travel because of logistical or safety concerns. The transmitter data can also be linked directly to a specific population or group, whereas the TEK data tend to group all belugas together. However, telemetry results are limited by small sample size, temporal and spatial distribution of the sampling effort, and possible changes in the behaviour of animals resulting from their capture and the deployment of instruments. There is often little appreciation for the uncertainty associated with the deployment of 30 transmitters at one or two locations, over a period of several years, to describe the movement and activity patterns of a population of approximately 3000 animals (Hammill et al., 2005). For example, animals caught in eastern Hudson Bay during summer do not provide summer information on beluga in Hudson Strait. The number of transmitter deployments is typically limited by high transmitter cost and by the ability to capture animals. A data gap was also evident in the records when the tags ceased to transmit or fell off. In some areas, capturing animals was not possible. Study results were punctual, and because developments of this technology were recent, no historical record was available to help us understand how beluga movements might have changed over time. Finally, since the information was transmitted via satellite, the data can be difficult to interpret because ancillary information, such as oceanography or ice conditions, pod size, distribution of food resources, or the presence of predators, is not available.

Treatment of telemetry data is also problematic. The quality of satellite position data can be variable owing to a combination of signal strength, the number of signals received by the satellite per pass, and the location of the satellite (Goulet et al., 1999). To eliminate positions of poor quality, the data are often filtered (Austin et al., 2003). The choice of filter and data preparation may result in subjective bias in the telemetry data that is not readily quantifiable. For example, estimates of home range size are affected by autocorrelation between consecutive observations and by the total number of points used in the estimation procedure.

Differences between TEK and telemetry results increase with distance from the coast. In the EHB region, along the coast where Inuit hunt, home ranges from both datasets overlap extensively. Summer TEK and telemetry home range data show many aggregation areas. TEK indicates aggregation areas exclusively in coastal regions throughout Nunavik, while the telemetry data indicate additional aggregation areas off the coast in EHB. Aerial surveys flown in eastern Hudson Bay have also detected large numbers of animals offshore, underlining the importance of offshore areas to the population (Smith et al., 1985; Kingsley, 2000; Hammill et al., 2004).

Winter TEK and telemetry home range estimates were significantly different. Winter TEK observations were limited because of limited daylight and limited hunting activity in the broken ice areas inhabited by beluga at this time. In fact, most winter observations were associated with winter entrapments, of the sort described in Heide-Jørgenson et al. (2002). However, winter information from the satellite telemetry must also be considered as limited because transmitter failure during the winter months resulted in small sample sizes.

The catch statistics from 1974 to 2000 differed from TEK estimates, with the degree of difference varying by community. Our assumption was that the number of actual kills would correlate to the number of beluga sightings reported in a given season. Simple pair-wise comparisons showed a significant seasonal difference in 10 of 14 communities. The differences were attributed primarily to the recollective nature of the interview process; hunters were asked a question that pertained to a decade or more prior. Smith (1989) has similarly noted that many communities exhibit inconsistent data reporting in which times of sightings do not correlate with maximum harvests.

The survival of hunters and their ability to provide for the needs of their communities—food, clothing, and shelter—are evidence of the utility of their knowledge, particularly when it pertains directly to hunting success (Huntington, 1998). The frequency of kills in shallow-water areas and estuaries underlines the importance of applying this knowledge by taking advantage of beluga coastal and estuarine use to increase hunting success and minimize personal loss. However, when used alone for management decision making on a larger spatial scale, TEK is incomplete because of the coastal nature of hunter movements and the limited displacement of hunters from the community. Both TEK and telemetry approaches are subject to sampling bias, which if not taken into consideration can have serious implications for the management and policy process. Scientists must remember that the number of deployments represents only a small proportion of a population and reflects the age class, sex, and individual differences between animals in studied areas. Hunters must remember that their observations have spatial and temporal limitations, which can lead to erroneous interpretations as to the importance of habitat use. Although we have underlined the shortcomings in both approaches, we believe that management in Nunavik would benefit from the synthesis of TEK and scientific data aimed at providing a more comprehensive understanding of beluga ecology.

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