Spatial Analyses of Bowhead Whale Calls by Type of Call

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Introduction

Bowhead whales, *Balaena mysticetus*, migrate westward through the Beaufort Sea offshore of Alaska's Prudhoe Bay oil fields in the August to October timeframe each year (Moore and Reeves, 1993, Blackwell, et al., 2007). Bowhead whales are known to swim at speeds up to 5 km/h and to stop and feed or socialize. In recent years, scientists have collected long-term recordings of these calls and classify them into several distinctive types. Whale calls have been qualitatively described as clustered in time and space; however this clustering has not been described statistically for different call types.

Seven main call type classifications are used in this study (personal communication with Katherine Kim, 2012).

- Call type 1 is an upsweep, starting from a lower frequency and evolving to a higher frequency.
- Call type 2 is a downsweep, starting at a high frequency and evolving to a lower frequency.
- Call type 3 is a tone, constant in frequency.
- Call type 4 is a "U" shaped call (high frequency evolving to low then back to high).
- Call type 5 is an "n" shaped call.
- Call type 6 is a combination of "u" and "n" in frequency undulations.
- Finally, type 7 is a complex call, consisting of a combination of the above call types.

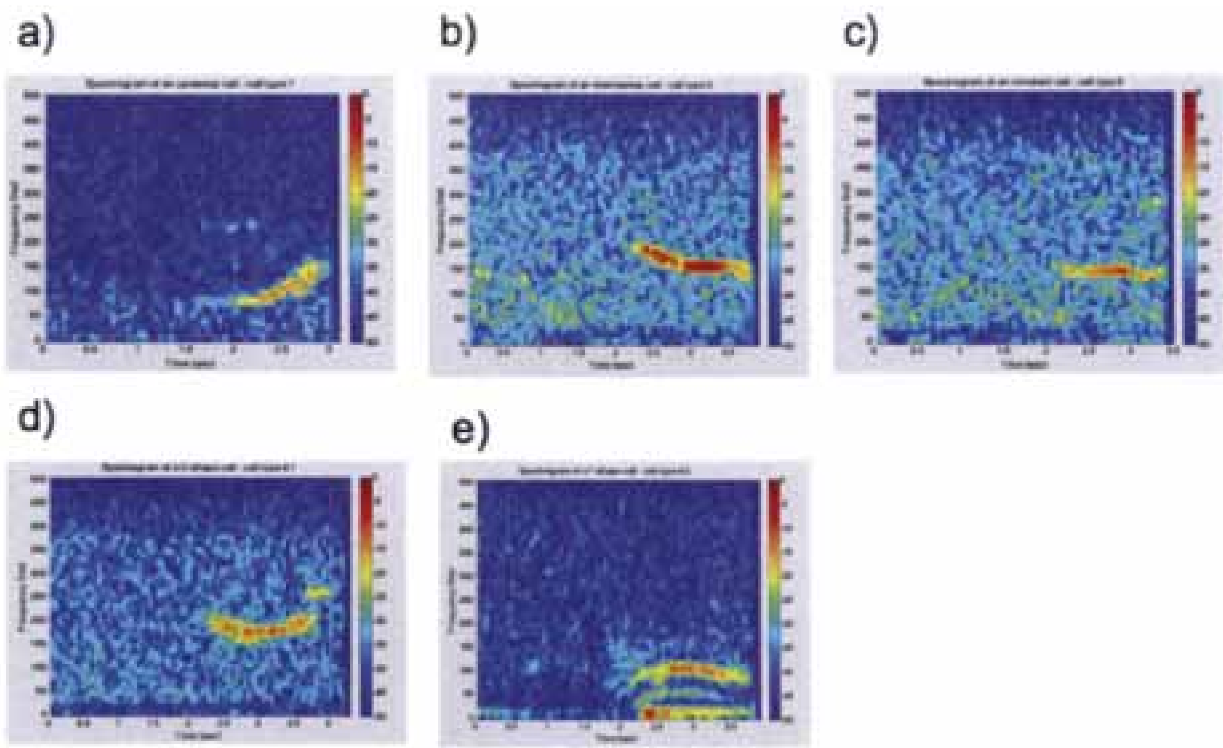

Figure 1. Spectrograms of calls of (a) type 1 "upsweep", (b) type 2 "downsweep" , (c) type 3 "constant", (d) type 4 "U-shaped", (e) type 5 "n-shaped"

From Mathias, et al., 2008

<u>Data collection and processing</u>

Acoustic data were collected from early August through the beginning of October, 2010 using a field of Directional Autonomous Seafloor Acoustic Recorders (DASARs) deployed in the Beaufort Sea (Blackwell et al. 2008, Blackwell et al. 2009a) A total of 32 DASAR packages, arranged in five clusters as shown in Figure 2, were deployed in 2010.

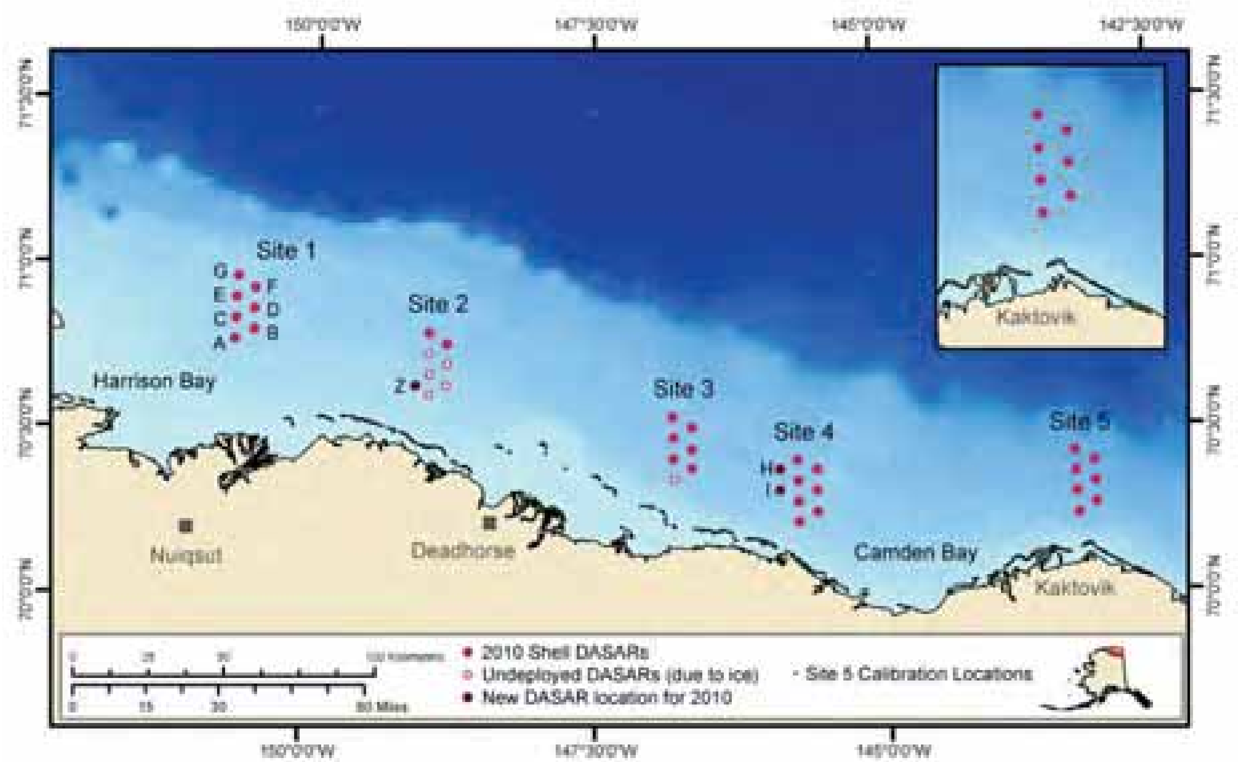

Figure 2. The DASAR deployment and study area.

From Shell 2010, Chapter 8

Each of the three channels of DASAR acoustic data were recorded at a 1 kHz sampling rate throughout the deployment. After the DASAR packages were retrieved and the data offloaded, trained Greeneridge Science staff manually analyzed spectrograms created from the acoustic data, visually identifying and classifying the bowhead whale calls. Most calls were detected on more than one DASAR; however, each call was only used once for this study.

Each call was classified by a human analyst as call type 1 through 7, followed by localization using a Huber robust triangulation location estimator (Lenth 1981; Greene et al.

2004) based on the intersection(s) of bearings from multiple DASARs. The localization results include an estimated x and y position for each call as well as an error ellipse.

Methods and Results

In this study, a 24-hour period of data recording is used for the spatial analysis of Bowhead whale call types in the Beaufort Sea. The time period 00:00:00 – 23:59:59 AKDT, September 13, 2010 was chosen from a sample of six days of processed whale call detections.

A total of 12313 whale calls were detected, classified, and localized from the data for September 13, 2010. The resulting 2D positions are plotted as gray points in Fig. 3 along with the DASAR package locations shown as green circles.

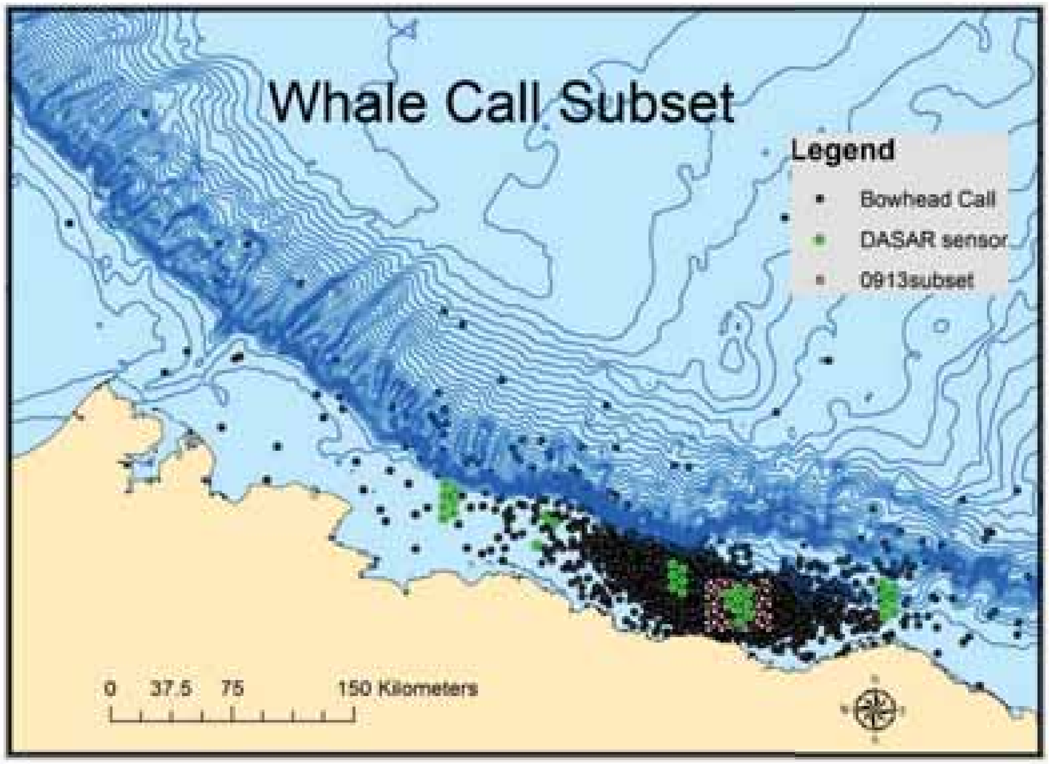

Figure 3

A subset of points near a cluster of DASARs is shown as pink points.

To minimize statistical errors due to edge effects (Kirivoruchko, 2011) and to minimize localization algorithm errors due to distances from the DASARs, a subset of points was selected surrounding DASAR cluster 4. The subset contains 7417 whale calls with hundreds of examples of each call type – re Table 1.

Number of Occurrences	Whale Call type
1963	1
1009	2
1201	3
510	4
412	5
370	6
1952	7

Table 1

Visual Analysis

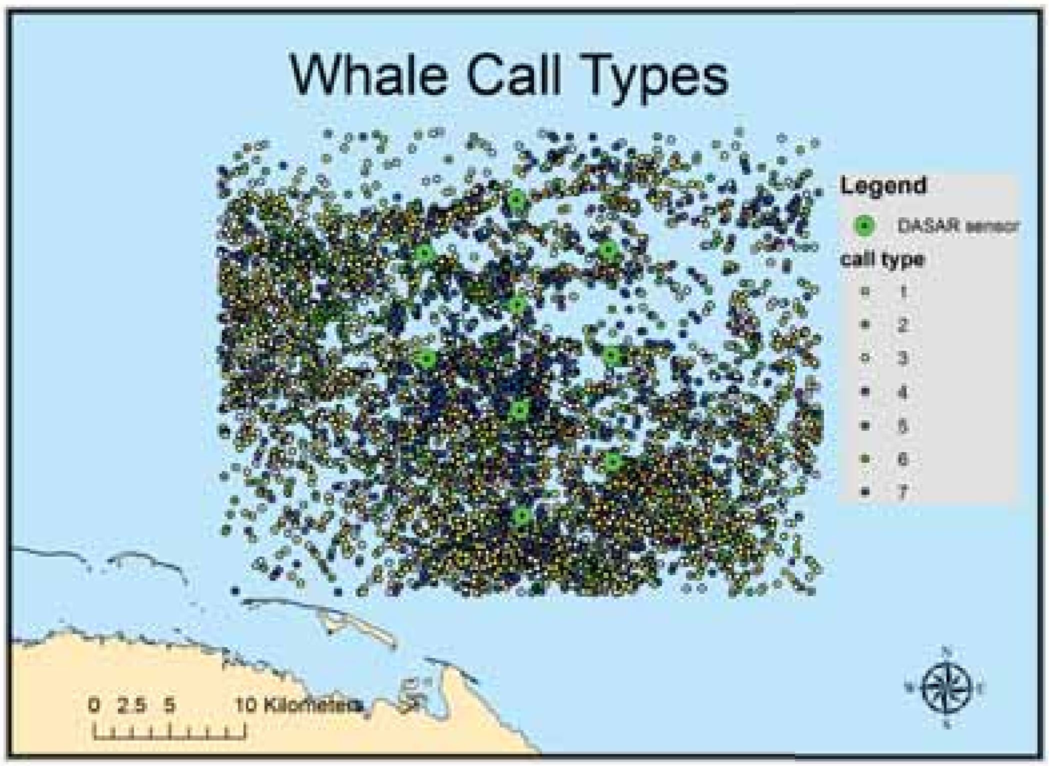

Figure 4

The subset of whale calls around DASAR cluster 4 is displayed by call type.

When displayed by call type as in Fig. 4, the points appear to be spatially diffuse throughout the subset region. The northeast portion of the study area appears to have a lower density of points than the center portion. To explore the distribution of whale call types in space further, each call type is displayed individually.

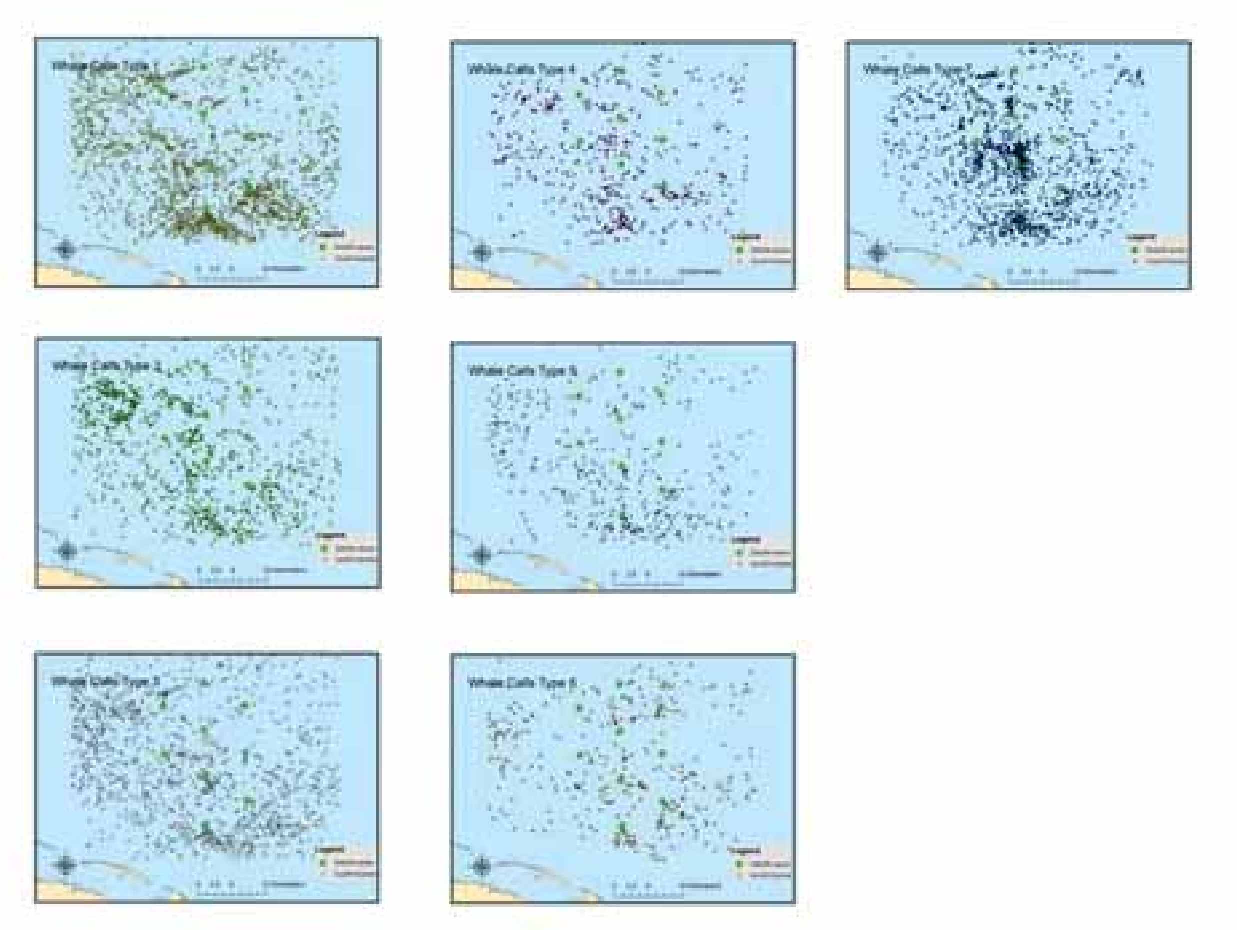

Figure 5

Each call type is displayed individually.

<u>Point density by call type</u>

Point density is calculated in the study area using a cell size of 100 m for the output raster, and using a circle-shaped neighborhood to find the number of input points in the area of the cell. Since the main attribute of interest, the whale call type, is not expected to vary with space, only the spatial location of the points and not their attributes is of interest in the output raster.

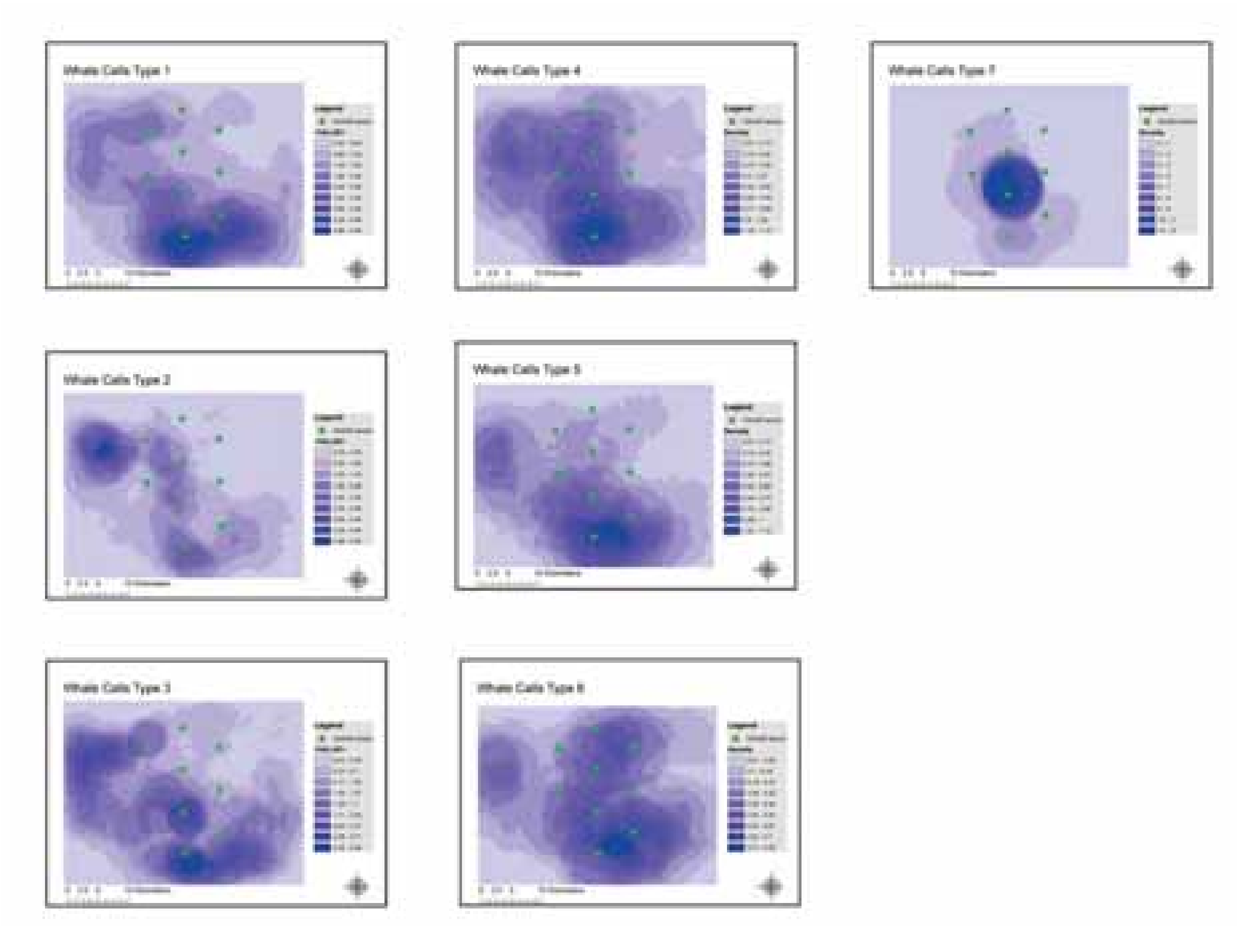

Figure 6

Point density results for each whale call type. These 7 plots each have different density classes in order to show the distribution and variability of the density between the call types.

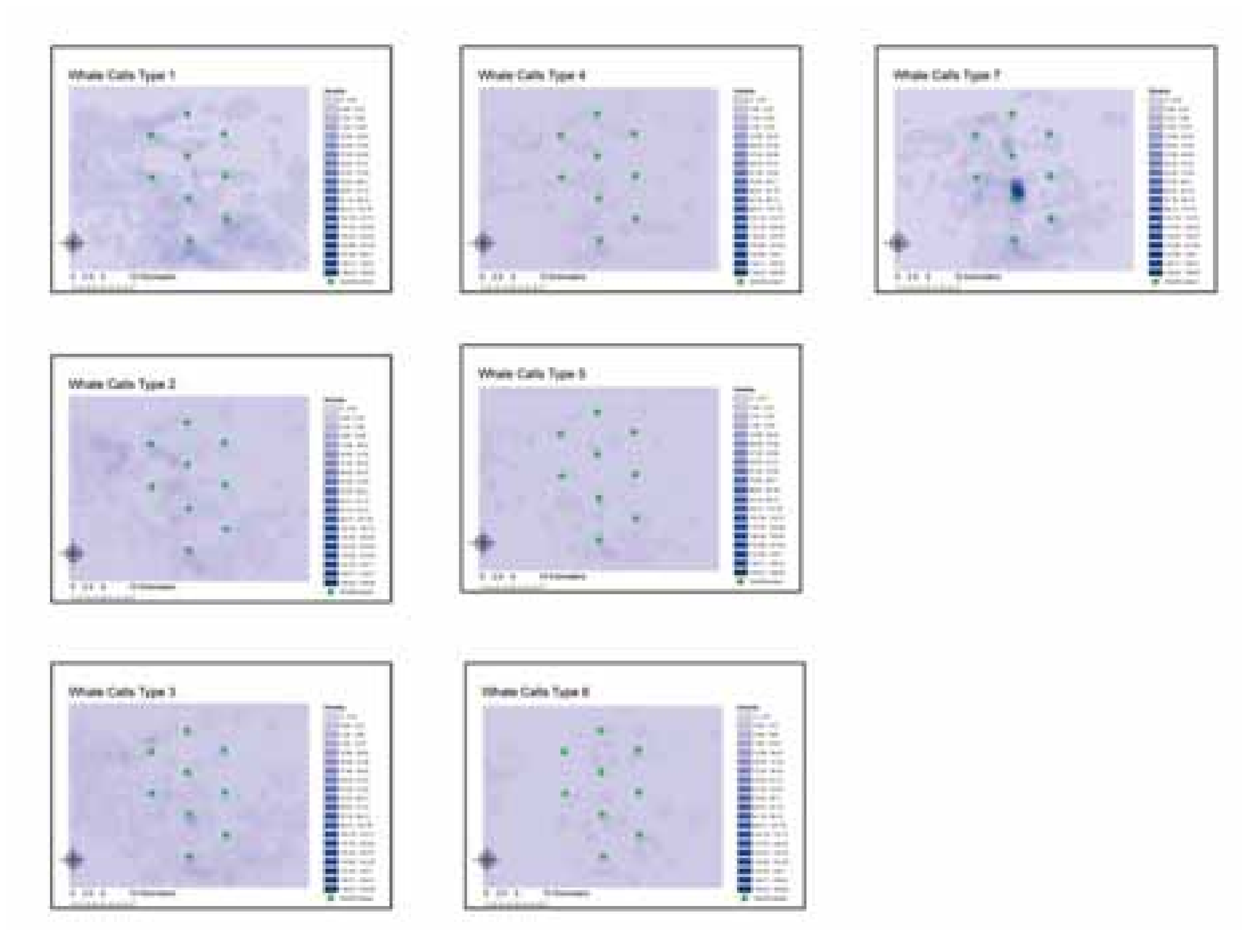

Figure 7

Point density results for each whale call type, where now all 7 plots have the same density classes in order to compare the actual density in the same units between the classes.

Density of the points for the different whale call types can be easily visually discerned. Type 7 shows a very dense area of calls in one main region of the study area, while the other call types have much lower densities and are more dispersed in space.

Spatial distribution by call type

Spatial distributions of point datasets can be categorized into three main types; points can be randomly distributed in space, dispersed equally in space, or clustered together in space. When analyzing point data, the first step is to determine if the distribution in space is homogeneously randomly distributed or not. If the distribution is not homogeneous random, then the point pattern should be described (Krivouruchko 2011, p.142).

To test for a random spatial distribution, the nearest neighbor index is used for each of the whale call types. The nearest neighbor index calculates the distance from each point in the data set to all of the other points in the file; and the shortest distance, c_i is that to the nearest neighbor point. The nearest neighbor distances for all points are summed, and divided by the total number of points, *n*, to obtain the mean of the shortest distances, the mean observed nearest neighbor distance (Mitchell, 2005 Ch. 3).

$$\overline{d}_o = \frac{\sum_i^n c_i}{n}$$

where: $\overline{d}_o$ is the mean shortest distance.

A completely clustered data set (all points are in the same location) would have a mean distance of 0 (Mitchell, 2005 Ch. 3).

A completely dispersed data set would have an expected mean nearest-neighbor distance of:

$$\overline{d}_e = \frac{1}{\sqrt{n/A}}$$

where again *n* is the number of points and A is the area of the study area.

A homogenous random distribution in space has a mean nearest neighbor distance halfway between the mean distance of a fully dispersed distribution and the mean distance of a clustered distribution, i.e.

$$\overline{d}_e = \frac{0.5}{\sqrt{n/A}}$$

The nearest neighbor index *d* is calculated by subtracting the expected mean distance from the observed mean distance.

$$d = \overline{d}_o - \overline{d}_e$$

To test if a spatial distribution of points is homogenous random, the observed and expected means should be equal, with *d* = 0. If *d* is negative, the distribution is clustered, whereas if *d* is positive, the distribution is dispersed.

Alternatively, the ratio of the observed and expected means can be used to test for homogenous random spatial distributions.

$$r = \frac{\overline{d}_o}{\overline{d}_e}$$

To test if a spatial distribution of points is homogenous random, the observed and expected means should be equal, with *r* approximating 1. If *r* is significantly less than 1, the distribution is clustered, whereas if *r* is significantly greater than 1, the distribution is dispersed.

To allow for testing of the null hypothesis (the null hypothesis is that all whale call types are homogenously randomly distributed in the study area), a Z-score is used (Mitchell, 2005 Ch. 3).

$$Z = \frac{\bar{d}_o - \bar{d}_e}{SE}$$

where the standard error is calculated by $SE = \frac{0.26136}{\sqrt{n^2/A}}$

To be significant at the 99% confidence interval, our Z-score needs to be less than -2.58 for a clustered distribution, and greater than 2.58 for a dispersed distribution.

Call Type	Observed Mean Distance	Expected Mean Distance	Nearest Neighbor Ratio	Z-score
1	331.606 m	391.474 m	0.847072	-12.962201
2	465.201 m	546.260 m	0.851611	-9.01742
3	462.92 m	501.800 m	0.922525	-5.136436
4	604.922 m	748.628 m	0.808041	-8.293243
5	720.735 m	842.809 m	0.855158	-5.621367
6	732.724 m	884.485 m	0.828419	-6.31384
7	269.823 m	389.013 m	0.693609	-25.896815

Table 2

Nearest neighbor results for all seven call types.

All of the call types have nearest neighbor ratios significantly less than 1, which indicates that they are in a clumped pattern in space. As the ratio approaches 0, the data distribution exhibits a higher degree of clumping. The ratios for the call types 1-6 range from 0.92 to 0.83, indicating clumping. Whale call type 7 points have a much different ratio of 0.69 which indicates a significantly higher degree of clustering. All of the call type Z-scores are above the threshold for the 99% confidence interval for clumped distributions.

Discussion

Bowhead whale calls can be detected, localized in space, and classified into one of 7 call types. Each of these call types exhibit different characteristics in their spatial distributions, especially the distribution of call type 7. Call type 7 is clumped to a much greater degree than the other types, in a dense cloud of points in one main region of the study area. The degree of clumping, with a Z-score of -25.896815 is quite different that the other types with Z- scores ranging from -5.136436 to -12.962201. The similarities between the Z-scores and density patterns for call types 1-6 indicate that the distributions have similar nearest-neighbor statistics in space.

Acknowledgments

Greeneridge Sciences and Shell Exploration and Production Company provided all of the whale call counts, geographic locations, and call type classification.

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