2014 HYDROACOUSTIC SURVEY FOR PACIFIC INTERNATIONAL TERMINALS, INC.

HTI Project 3667

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1.0 INTRODUCTION

1.1 Project Background

The proposed Gateway Pacific Terminal (Terminal) vessel wharf would be located within the reported spawning area for the Cherry Point herring stock. A 1999 Settlement Agreement required that Pacific International Terminals, Inc., the project proponent, determine if the behavior of Pacific herring (*Clupea harengus pallasi*) gathering in the vicinity during the spawning season demonstrated predictable geographic spatial patterns. The information in this data report provides a snapshot of the density distributions of presumed herring schools in the nearshore region located between Sandy Point and Point Whitehorn, encompassing a portion of the historic spawning area of the Cherry Point herring stock.

A series of mobile hydroacoustic survey transects were conducted during a 19 day period in late April and early May, 2014, during the anticipated period of peak herring spawning activity in the area (Stick and Lundquist 2009). The purpose of these surveys was to evaluate herring school distributions over time.

Eight individual mobile hydroacoustic surveys were conducted between April 28 and May 16, 2014 using a Hydroacoustic Technology, Inc. (HTI) *Model 241 Split-Beam Echo Sounder*. Nine surveys were originally scheduled, however the April 30, 2014 survey was cancelled. The survey dates encompassed the anticipated duration of the Cherry Point herring spawning period. Sampling took place on Mondays, Wednesdays, and Fridays, with one Saturday survey. The sampling incorporated both daytime and nighttime periods and also measured herring density distributions across different tidal states.

Each survey date sampled two parallel near shore transects, each oriented generally north-south along the coastline between Sandy Point to 0.5 nautical miles north of Point Whitehorn. The transect series consisted of an inshore transect following the 10-fathom depth contour (60 feet [ft], or 18.3 meters [m] depth), designated as Transect 1, and a second parallel offshore transect located 500-m farther west (Transect 2).

The Cherry Point 2014 Hydroacoustic Study (2014 Study) incorporated two concurrently-sampled transducers, one oriented forward of the survey vessel to map observed schools in front of the boat, and a second, downward-oriented transducer which provided quantitative (fish per cubic m [fish/m^3] and fish per square m [fish/m^2]) measures of herring school densities as the vessel passed over them.

The downward-oriented transducer was configured to provide quantitative estimates of herring density with depth, as estimated fish/m^3 densities summarized at 30 second intervals along the surveyed transects. These estimates were based on echo integration techniques, which scale the measured fish school biomass to estimates of fish density per unit water volume and/or per unit surface area based on the estimated mean acoustic size of observed herring within each density cell. The sampling and analysis methods employed during the Cherry Point 2014 evaluations followed standard peer-reviewed procedures for quantitative fisheries resource assessment, as described by Kanciruk (1982) and Simmonds and MacLennan (2005).

This study report provides a summary of the herring school densities as observed during the April 28 through May 16, 2014 Cherry Point hydroacoustic herring surveys, based on the results measured from the quantitative downward-oriented transducer.

The data presented in this 2014 Study data report are based on analyses of the quantitative data set and the fish/m^2 estimated herring density estimates presented in the report are comparable within surveys and across survey dates.

2.0 SITE DESCRIPTION

The Cherry Point study site is located in northwest Whatcom County along the eastern shore of the Strait of Georgia, approximately five miles west of Ferndale, Washington (Figure 1). For the purposes of this study, the Cherry Point survey area was defined as the area bordering the approximately nine miles of coastline extending from 0.5 nautical miles north of Point Whitehorn to the south end of Sandy Point. The sampled region extends from the southern boundary of Birch Bay State Park to Sandy Point. The surveyed area encompasses three existing industrial facilities in the vicinity of Cherry Point including the BP Refinery, Intalco Smelter, and Phillips 66 Refinery, and the proposed Terminal.

Each of the existing terminals has a shipping wharf, which served as visual reference points during the 2014 Study. From south to north, these docks were the Phillips 66 wharf, the Intalco wharf, and the BP wharf. The proposed Terminal facility would be located between the Intalco and BP wharves.

The area offshore of Cherry Point is characterized by steep bathymetry, with water depths exceeding 21 m (70 ft) almost immediately offshore. The shoreline adjacent to the north section of the survey area consists of high vertical bluffs that diminish in height to the south. Aquatic vegetation, including eelgrass (*Zostera marina)* and a variety of macroalgae such as *Gracilaria*, *Laminaria*, *Sargassum*, and *Botryoglossum* are present in the intertidal and subtidal areas.

The objective of the 2014 Study was to map the spatial distribution and density abundance of herring schools observed between Point Whitehorn and Sandy Point over time.

Figure 1. Map showing the section of the Cherry Point coastline surveyed in 2014. The locations of the three existing leases and associated wharf facilities within the region are shown.

3.0 METHODS

3.1 Survey Design

Two independent acoustic data sets were concurrently collected in 2014. A quantitative data set describing herring density along the surveyed transects as a series of mean fish/m^2 estimates was collected using a downward-oriented transducer. A forward-sampling qualitative data set was simultaneously collected using a second transducer to map herring school positions in front of the vessel.

The location of all detected herring schools, which included all observed vertically-stacked aggregations of fish, were tabled and plotted on geo-referenced maps. These data allowed comparisons of patterns of school density across the survey area and over time, relative to the proposed Terminal facility location.

The 2014 Study included five daytime and three nighttime surveys (eight total surveys) during the April 28 through May 16 sampling period. Surveys were also conducted across varying tidal stages to assess potential environmental influences on observed herring school density distributions. Three surveys were conducted each week, generally on Monday, Wednesday and Friday, over the consecutive three week period. A single Saturday survey was conducted on May 10, 2014, to make up for the scheduled May 8 sample day missed due to poor weather conditions. The specific dates and times of each of the 2014 Study acoustic surveys are given in Table 1.

The time, tidal stage, location, and relative size of all observed pelagic vertically-stacked fish schools were recorded and plotted on a chart of the area. School locations were established using a wide-area augmentation system (WAAS-capable) global positioning system (GPS). The GPS location precision of each detected school and tracked fish location was established to within 1 to10 m (3 to 33 ft) which was deemed sufficient for the study objectives.

Hydroacoustic data were collected continuously along an inshore and offshore transect during each survey date. Figure 2 presents a map of the two survey transects relative to the shoreline. Transect 1, closest to shore, followed the 10-fathom (18.3 m) depth contour at mean low water (MLW). Transect 2, located 500 m (1,640 ft) farther west (offshore), paralleled the inshore transect.

Each of the two survey transects was approximately 8 nautical miles (14.8 kilometer [km]) in length (16 nautical miles, or 15.6 km total surveyed distance for each 2014 survey). Transect 1 was typically conducted from north to south, and Transect 2 from south to north. Transects were surveyed at a boat speed of approximately 4 knots (2 m per second [m/sec]). In general, the data collection component of each survey transect was completed in approximately 3 to 5 hours, plus travel time to port in either Bellingham or Blaine (1 to 2 hours transit each way). The daytime surveys were conducted between 1100 and1600 hours and the nighttime surveys between 2200 and 0400 hours.

Table 1. Dates and times of the Cherry Point 2014 surveys, including diel period (D/N) and general tidal stage present during the period April 28-May 16, 2014.

Survey Number	Survey Date	Survey Time Start	Survey Time End	Julian Date	Day of Week	D/N Period	Tidal Stage
1	April 28	11:19	15:39	118	Monday	Day	Flood
2	May 1-2	22:44	2:56	121-122	Friday	Night	Ebb
3	May 5	10:54	15:25	125	Monday	Day	Ebb
4	May 6-7	23:05	3:22	126-127	Wednesday	Night	High/Ebb
5	May 10	10:48	15:55	130	Saturday	Day	Flood
6	May 12	10:26	14:32	132	Monday	Day	Flood
7	May 13-14	22:45	2:51	133-134	Wednesday	Night	Flood
8	May 16	10:55	15:14	136	Friday	Day	Low/Flood

Figure 2. Map of the Cherry Point 2014 survey area between Sandy Point and Point Whitehorn showing the location of the two sampled acoustic survey transects. The inshore transect (Transect 1), followed the 10-fathom (18.3 m) depth contour. The offshore transect (Transect 2) was located parallel to, and 500 m (1,640 ft) seaward of Transect 1. The numbered waypoints indicate the referenced coordinate locations used to navigate the 2014 survey transects.

3.2 Hydroacoustic Techniques

Recommended hydroacoustic sampling and analysis protocols and the underlying theory for quantitative hydroacoustic fisheries evaluations are discussed by Kanciruk (1982), Simmonds and MacLennan (2005), and Ransom et al. (1995). Over the last 40 years, hydroacoustics has been developed into a standardized, reliable and defensible method of unobtrusively enumerating fish in marine and freshwater environments (Ransom and Burczynski 1987, Ransom and Steig 1994).

Hydroacoustics provides high spatial and temporal sampling power that is difficult, if not impossible, to obtain with traditional direct-capture fisheries sampling methods. Acoustic methods do not harm fish, alter their behavior or the environment, and offer the capability to survey large areas within a relatively short period. All fish above a defined minimum size threshold are uniformly detected within a defined sampling volume, minimizing sampling bias. For these reasons, hydroacoustic techniques were used to map herring school distributions in the Cherry Point area over the course of the 2014 spawning period.

3.3 Hydroacoustic System Operation

The primary component of any hydroacoustic system is the echo sounder. When triggered, the echo sounder emits a short electrical pulse of known frequency, duration, and transmit power. This is routed to a transducer, which converts the electrical pulse into mechanical energy, i.e., a transmitted “ping”, or sound pulse with the same characteristics as the electrical pulse.

When the transmitted ping (sound waves) encounters fish or other targets in the water column, echoes are reflected back to the transducer. The transducer then converts the returning sound energy into electrical energy, and sends it back to the receiver section of the echo sounder. In scientific-grade quantitative echo sounders, the echo signals are then amplified by a very precise time-varied-gain (TVG) to compensate for geometric spreading and attenuation of the acoustic beam (loss of signal strength) with increased range from the transducer. With an accurate TVG function, on-axis targets of the same acoustic size produce the same amplitude signal regardless of the range (distance) from the transducer to the target. Range for each target is determined by the timing of the echo relative to the transmitted pulse.

The echo signals are then relayed to a display, recording device and/or digital echo processor, depending on study objectives and the capabilities of the acoustic system.

Quantitative fisheries acoustics systems are precisely calibrated against known standard reference transducers, such that their sensitivity is known. These echo sounders provide estimates of individual fish backscatter energy, or acoustic size, to allow scaling of the measured fish biomass to estimates of numeric fish densities. Since absolute herring density estimates were desired for the 2014 surveys, an HTI *Model 241 Scientific Split-Beam Echo Sounder* with these capabilities was employed for sampling.

It should be noted that the Cherry Point herring school distributions represent a time-series of estimated school densities along a pair of adjacent transect lines. As the individual transects were sampled at different times during a given survey, it is possible that individual schools could be detected on both transects, depending on the fidelity of school aggregations over relatively short time scales.

3.4 2014 Field Survey Methods

To provide both quantitative herring school density results and qualitative information on schools in front of the vessel, a dual data collection and analysis approach was employed in 2014.

An HTI *Model 241 Split-Beam Hydroacoustic System* sampling two transducers was used to collect the 2014 Cherry Point data set. This scientific echo sounding system represents state-of-the-art fisheries acoustic research technology and was capable of providing quantitative estimates of herring school density, as either fish/m^3 or fish/m^2 metrics, for each detected school observation.

The HTI system was configured to simultaneously-sample two transducers, a 15˚ circular beam width transducer oriented straight down for the quantitative estimates of herring school density and also a second 2˚x10˚ degree elliptical-beam transducer scanning ahead of the survey vessel to provide relative school size distributions.

The HTI *Model 241 System* was sampled in a “fast-multiplexed” mode, allowing essentially simultaneous sampling of both the quantitative down-looking and forward-looking transducers by alternating transmitted pings between the two sensors. Both data streams were logged directly to computer file and digital audio tape (DAT) record for subsequent analyses. All data was geo-referenced using a Garmin® Model 76 GPS receiver interfaced to the echo sounding system.

The HTI scientific hydroacoustic sampling system was laboratory-calibrated at HTI’s facilities in Seattle before the 2014 surveys, and field calibrations using a 38.1 millimeter (mm) tungsten carbide sphere (standard target) were conducted prior to each survey over the field sampling period. The mean target strength (TS) result from each field calibration was compared against the expected mean TS value (200 kHz, salt-water) of -39.2 decibel (dB). These regular field calibration efforts validated consistent acoustic system fish detection performance over the entire survey period.

The HTI *Model 241 Echo Sounder* employed for quantitative sampling in 2014 was configured to integrate all school energy above a scattering volume, or SV value of -65 dB (20 log R threshold), well below the minimum herring school size-of-interest. The system concurrently collected the 40 log R TVG-amplified data used for target strength estimation (average backscatter, or acoustic size of individual herring), using a -60 dB minimum TS threshold, again encompassing the smallest size herring targets at the site. A -60 dB fish target translates to an estimated length of 16 mm at a sampling frequency of 200 kHz, based on Love (1971), an empirical formula relating fish target strength and length measured in dorsal aspect. The relevant hydroacoustic system calibration and sampling parameters used during the 2014 Study are presented in Table 2. The complete set of laboratory calibration data for the hydroacoustic system is available from HTI on request.

Table 2. Calibration constants for the HTI Model 241 Split-Beam Hydroacoustic System used during the Cherry Point 2014 acoustic surveys, April 28–May 16, 2014.

Transducer	Down Sampling	Forward Sampling
Mux Channel	1	2
Transmit Power (dBw)	20	20
Pulse Width (ms)	0.18	0.18
Band Width	10	10
Ping Rate (per sec)	5	5
Speed of Sound (m/s)	1500	1500
Receiver Gain (dB)	6	-6
TVG Alpha (dB/km)	54.3	54.3
TVG Crossover (m)	11.2	11.2
Transducer S/N	2004420	901501
EchoSounder S/N	923436	923436
XD Frequency (kHz)	200	200
Source Level (dB)	204.60	217.14
Rec G1 40 Log (dB)	-161.65	-170.75
Rec G1 20 Log (dB)	-140.38	-149.56
U-D Plane Beam Width	15	2
L-R Plane Beam Width	15	10
Aequip	2.14569E-05	N/A

3.4.1 2014 Downward-Sampling Transducer

Fish school density estimates were summarized at 30-sec intervals along each surveyed 2014 transect as fish/m^3 within each 1-m depth stratum under the vessel. At a mean survey vessel speed of 4 knots (2 m/sec), this equated to a school density estimate approximately every 60 m (197 ft). Each estimate of fish density had resolution at 1 m (3.3 ft) depth intervals, i.e. echo integration fish/m^3 density estimates were generated for each 1 m (3.3 ft) depth stratum within each 30-second duration density summary. These individual detected fish school density estimates with depth were then summed to estimate mean spawning herring school densities per unit surface area (as fish/m^2) for each interval.

Only vertically-stacked fish aggregations characteristic of spawning herring schools were summarized in the acoustic data record and used for the fish school density estimates reported in 2014. These types of stacked “pillar” aggregations have been reported as indicative of Pacific herring schools in other published studies (Haegele and Schweigert 2011, Sigler and Csepp 2007) and are consistent with herring school observations reported during earlier Cherry Point hydroacoustic evaluations.

Figures 3 and 4 represent examples of typical vertically-stacked inferred herring schools observed during the 2014 Study, generated from the data taken during this survey.

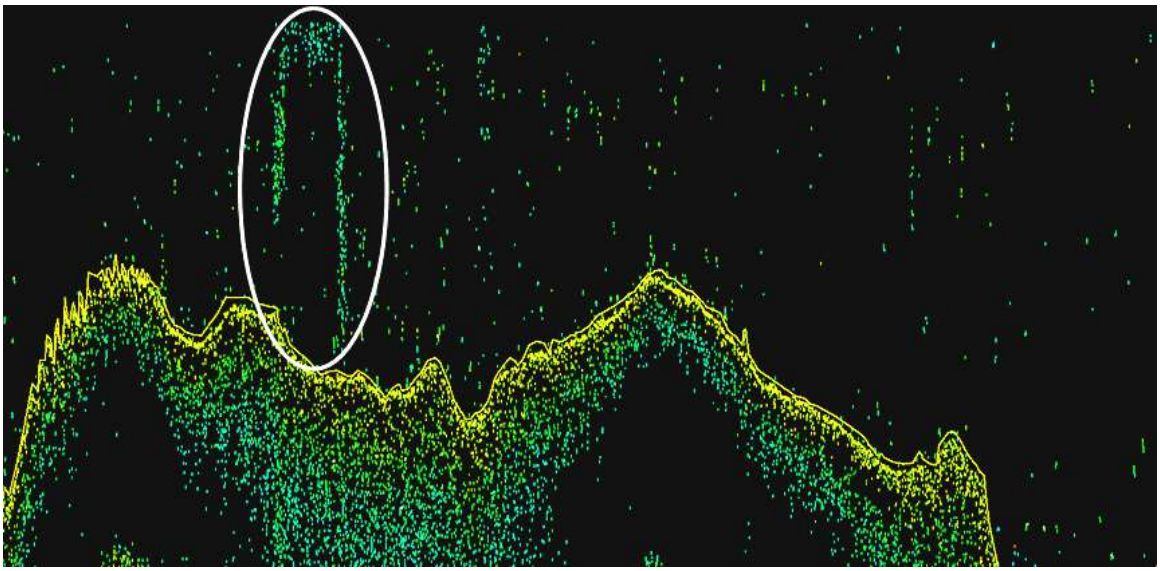

Figure 3. **Graphic of data showing vertically-stacked fish school detected during the Cherry Point hydroacoustic survey conducted on May 16, 2014 (school is encircled in oval for illustration). In this graphic, perspective is from within the water column, the survey vessel transducer is located at the top, and the seafloor is depicted by the continuous yellow line at the bottom. Individual single fish detections are present surrounding the school event.**

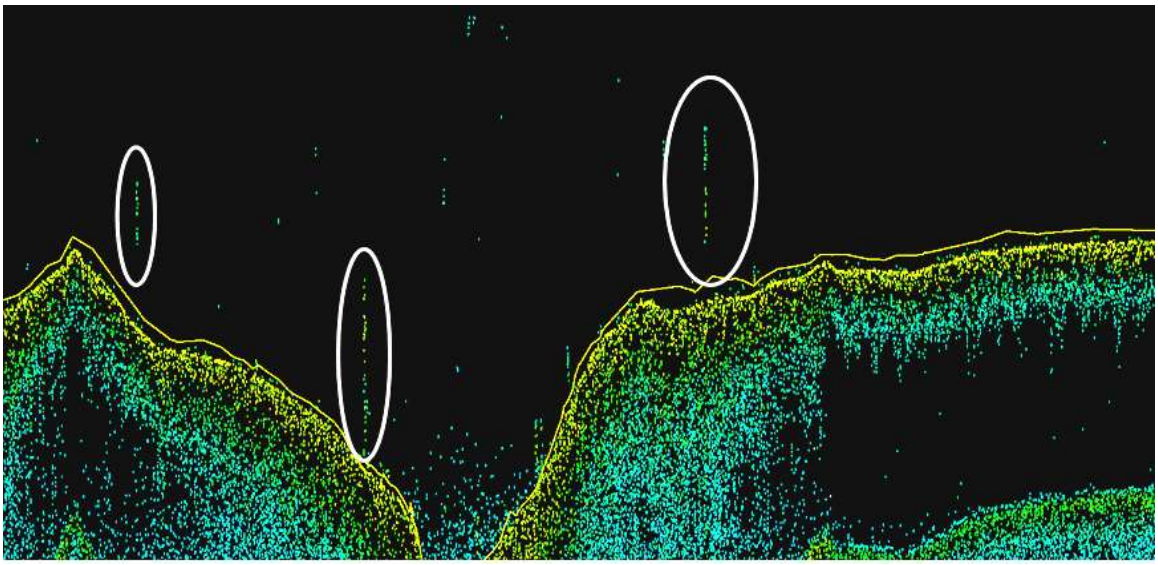

Figure 4 **Graphic of data revealing three vertically-stacked fish schools (ovals added for clarity) classified as herring densities during the Cherry Point hydroacoustuc survey conducted on May 16, 2014**

3.5 2014 Data Analysis

3.5.1 Quantitative Downward-Sampling Transducer Analyses

Echo integration and target tracking techniques were used to estimate fish abundance in the survey area. The use of echo integration was indicating for quantifying the observed school events due to their aggregated nature. Individual herring in the observed schools were generally closely aggregated, such that the fish were spaced closer than one half echo pulse width apart, they could not consistently be individually resolved as single-targets, as required for the alternate acoustic enumeration methods, echo counting or target tracking. At the 0.18 milliseconds (msec) pulse width used for data collection, individual herring would need to be spaced a minimum distance of 14 centimeter (cm) (5.5 inches) apart to resolve them as non-overlapping single targets. However, echo integration techniques do not require a minimum fish separation distance in order to provide quantitative density results, and the herring school results reported here are not dependent on herring spatial distributions.

Echo integration essentially sums (integrates) the acoustic energy returns from fish or other targets within user-selected spatial units (typically range strata and distance/time intervals). This integrated acoustic energy is proportional to the fish biomass, as higher target densities reflect a higher proportion of a given transmitted acoustic signal. Echo integration measures acoustic voltage returns at evenly spaced intervals, squares these voltages, and then calculates a mean voltage from a series of these squared numbers over time. This summed echo intensity or mean accumulated voltage-squared (V^2) values are proportional to the biomass within the depth ranges being sampled (over the area of the sample).

The echo return data used to estimate fish density using echo integration techniques is amplified at a (20 log(*R*)*, where R is the target range)* TVG amplification by the echo sounder. A 20 log(*R*) TVG compensates for one-way signal loss due to attenuation with range), and also for the effect of transducer beam spreading with range, such that fish density estimates are comparable over space and time. The process reports the mean V^2 within the depth/space intervals specified by the user.

These V^2 values are proportional to fish biomass and can be scaled to absolute estimates of fish numbers (or biomass), if the average intensity contribution of individual fish within the area is known. This average fish intensity is termed σ_{bs}, or sigma, and refers to the average backscattering cross-section of a fish (or individual target).

The real-time transect data files served as the primary data record for analysis. DAT taped data was available for playback and analysis in the laboratory, in the event of interruptions in the computer data record. No such interruptions occurred during the 2014 Study. Digital echo integration software integrated the received 20 log(*R*) TVG signals, calculating mean fish densities within each 1 m (3.3 ft) depth stratum at 30-second intervals along each transect. At an estimated mean boat transect speed of 4 knots (2 m/sec), this reporting interval equated to a fish density-reporting interval of approximately every 60 m (197 ft). Strata were surface locked (i.e., were located relative to the face of the transducer).

The echo intensity integration formula was consolidated into a single expression termed the A-constant, which incorporates the calibration and physical parameters from the hydroacoustic system and the average backscattering cross-section of the targets within the area of interest. Ransom et al. (1995) discusses calculation of the A-constant, which is summarized below.

$$A = \frac{1}{\sigma_{bs} * \pi * C * b_{av^2}(\theta,\phi) * \tau * p_0^2 * g_x^2}$$

where:

σ_{bs} , mean average backscattering cross-section for the fish of interest (derived from the 40 *log* R TVG single-target echoes),

π, approximately 3.14159,

C, speed of sound in water, given temperature and salinity for the sample area (approximately 1500 m/sec),

b_{av}^2 (θ,ϕ),beam pattern factor (describes the drop-off in echo intensity return for the sampling transducer as targets move off-axis),

τ, tau, the transmitted echo pulse width (duration) in m,

p_0^2, transducer transmit pressure level ($10^{(0.1 * \text{transducer source level in dB})}$), and,

g_x^2, squared through system gain ($10^{(0.1 * \text{G1 + receiver gain in dB})}$), or total echo sounder amplification gain.

Typically, the A-constant is separated into two parts, denoted as A_{equip} and A_{fish}. A_{equip} was a constant value for the 15º quantitative transducer over the 2014 study period (equal to approximately 6.57526 E -05), as it is derived from the laboratory calibration values and the physical parameters of the environment being sampled.

$$A_{equip} = \frac{1}{\pi * C * b_{av}^2(\theta,\phi) * \tau * p_0^2 * g_x^2}$$

A_{fish} is dependent on the average backscattering cross-section of targets observed within the smallest replicate of interest.

The formula for A_{fish} is the remainder of the total equation, expressed as:

$$A_{fish} = \frac{1}{\sigma_{bs}}$$

Multiplying the mean voltage squared (MV^2) times A_{equip} times A_{fish} returns the estimated target density (D_v) within the area of interest:

$$D_v = MV^2 * A_{equip} * A_{fish}$$

The hydroacoustic echo integration results (expressed natively as squared echo voltage return values) are proportional to the mean fish density present at a given surveyed locations (Simmonds and MacLennan 2005). In order to scale these relative echo integration values to absolute abundance estimates, a scaling factor termed the A-constant was applied. This A-constant scaling factor incorporates both the hydroacoustic system calibration and sampling parameters (A_{equip}) and the mean acoustic size of individual fish detections (A_{fish}) to derive a total estimate of fish/m^3 within each depth stratum for each geographic density cell.

Mean fish target strength, expressed as the mean backscattering cross-section (σ_{bs}) was determined *in situ*, based on split-beam measurements of all single-target echoes within each selected 30 second echo integration sequence.

Knowledge of fish target strength is required to accurately scale acoustic echo integration results to population estimates. Average echo target strengths (expressed in non-logarithmic form as backscattering cross-section) were used to scale the relative echo integrator output values into estimates of absolute fish density. The split-beam technique was used to measure fish acoustic target strength. The split-beam technique has proven to be the most precise acoustic method of estimating fish target strength *in-situ* (Ehrenberg 1983 and 1984, and Ehrenberg and Torkelson 1996). This technique uses differences in phases between the received signals from the beam's two half beams (i.e., up/down and left/right) to estimate angle off axis and calculate on-axis amplitude and target strength.

A mean fish acoustic size, or backscattering cross-section (σ_{bs}) of 1.00E-04, equivalent to a mean target strength value of -40.0 dB, was used to scale the measured fish school densities to fish/m^2 surface area estimates for the results presented in this report.

Once estimates of A_{fish} and A_{equip} were obtained, the final fish density within each sampled 1 m (3.3 ft) stratum was calculated as:

$$\text{fish density} = MV^2 * A_{fish} * A_{equip}$$

Where fish density is expressed in units of fish/m^3 and MV^2 is the measured mean squared voltage return within the sampled cell.

These fish/m^3 estimates by 1 m (3.3 ft) strata were then summed within each 30 second echo integration reporting interval to estimate mean herring school densities under the transect segment encompassed by that interval (fish/m^2).

3.6 Reported Herring School Density Estimates

The estimated herring school quantitative density estimates reported were based on the data collected by the downward-oriented 15º beam width transducer.

The estimated fish densities were calculated as fish/m^3 values for each one m depth stratum within each observed school event, summarized over 30 second intervals as the survey vessel passed over each school. These volumetric fish density estimates were summarized into fish/m^2 (school density per unit surface area) estimates by summing the recorded fish/m^3 density estimates within each time series.

4.0 RESULTS

Weather during the surveys was generally mild. One survey date, (nighttime survey on May 8-9) was canceled due to 4 to 6 foot wind waves with 20-30 mph winds. This scheduled survey was later conducted during the day on May 10. Eight of the nine scheduled 2014 Study dates were conducted.

4.1 Estimated Herring Density Distributions

The observed estimated herring school densities for each individual 2014 Study period are shown in Figures 5, 7, 9, 11, 13, 15, 17 and 19. Tidal stage information for the eight 2014 survey periods is given in Figures 6, 8, 10, 12, 14, 16, 18 and 20.

The distributions represent the instantaneous observed estimated herring per square m point densities along each surveyed transect for the surveyed periods, based on echo integration and target tracking results derived from the downward-oriented 15º transducer.

4.1.1 Survey 1 April 28, 2014 - Day

Herring school density distributions for Survey 1, conducted on April 28 during daylight hours, are presented in Figure 5. Tidal height information over the survey period is shown in Figure 6.

Relatively few herring schools were observed on either the inshore or offshore survey transects during the initial 2014 survey. The highest measured densities occurred in a single school event detected just south of the BP Refinery dock.

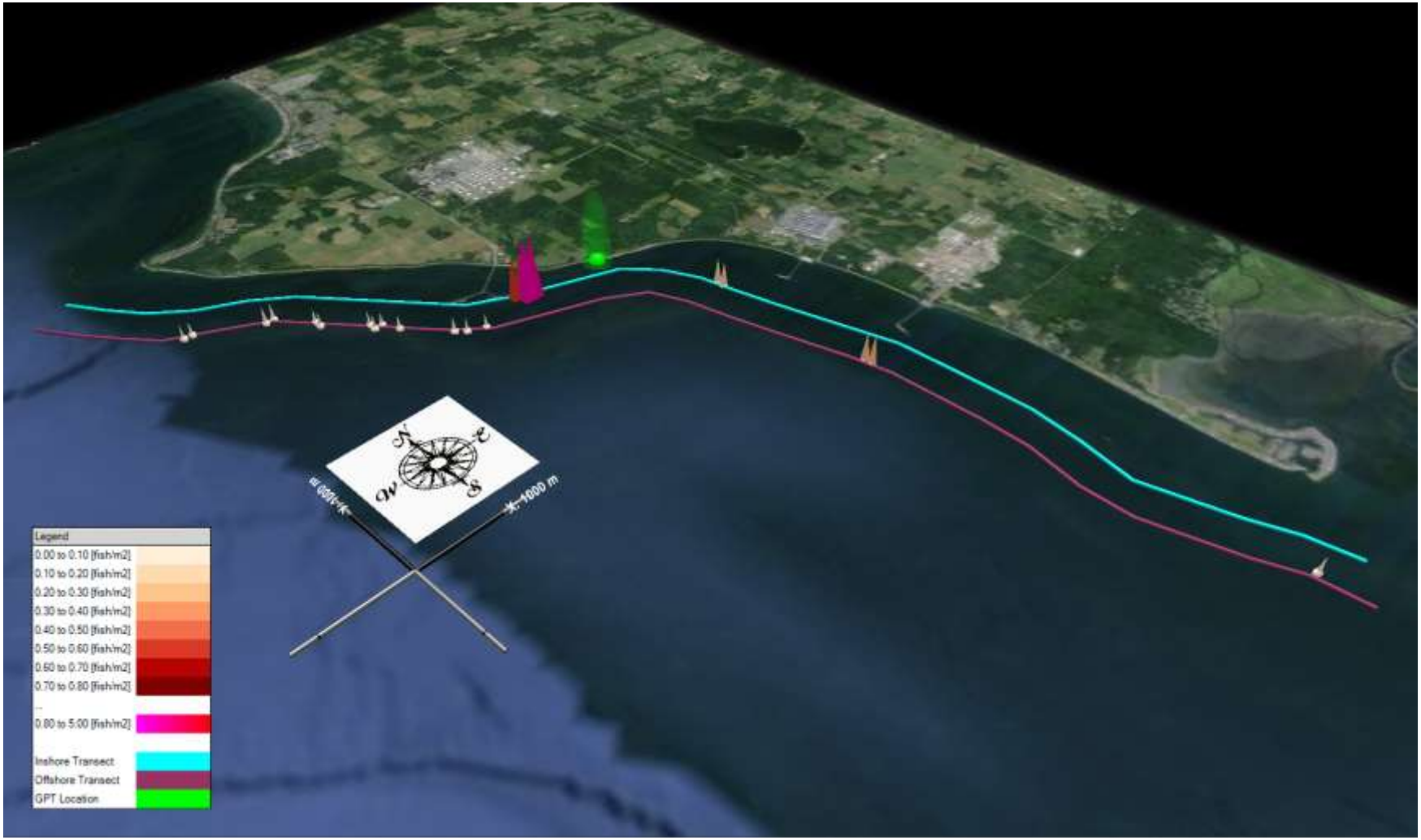

Figure 5. Estimated herring density distributions for Survey 1, conducted on April 28, 2014 during daylight hours. Each value describes observed geo-referenced herring point density estimates measured along each transect survey line.

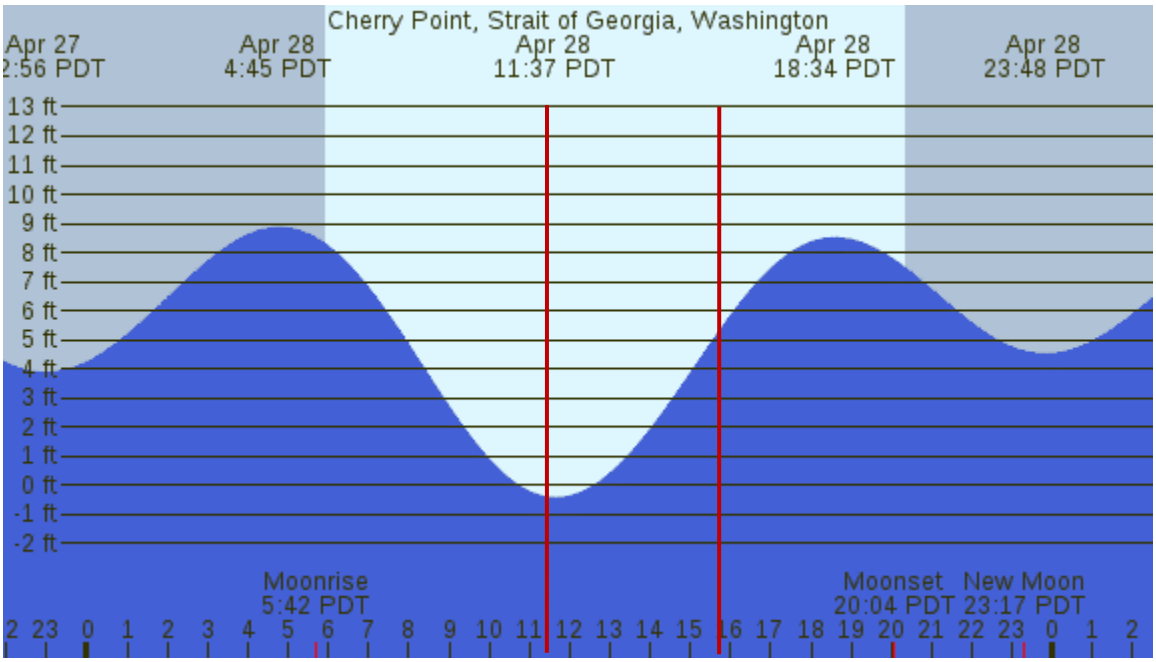

Figure 6. Tidal chart for Cherry Point, Washington during Survey 1, conducted on April 28, 2014 between 1120 and 1539 hours on a flood tide. The horizontal axis lines indicate tidal height and the red vertical lines indicate the surveyed time period. (http://www.dairiki.org/tides).

4.1.2 Survey 2 May 1-2, 2014 - Night

Herring school density distributions for Survey 2, conducted on May 1-2 during nighttime hours, are presented in Figure 7. Tidal height information over the survey period is shown in Figure 8.

The spatial distribution of estimated herring density distributions on the night of May 1-2 was generally similar to the pattern observed during daytime Survey 1, conducted three days earlier on April 28. Relatively few school events were observed and the highest measured fish densities occurred north of Cherry Point, along the inshore transect.

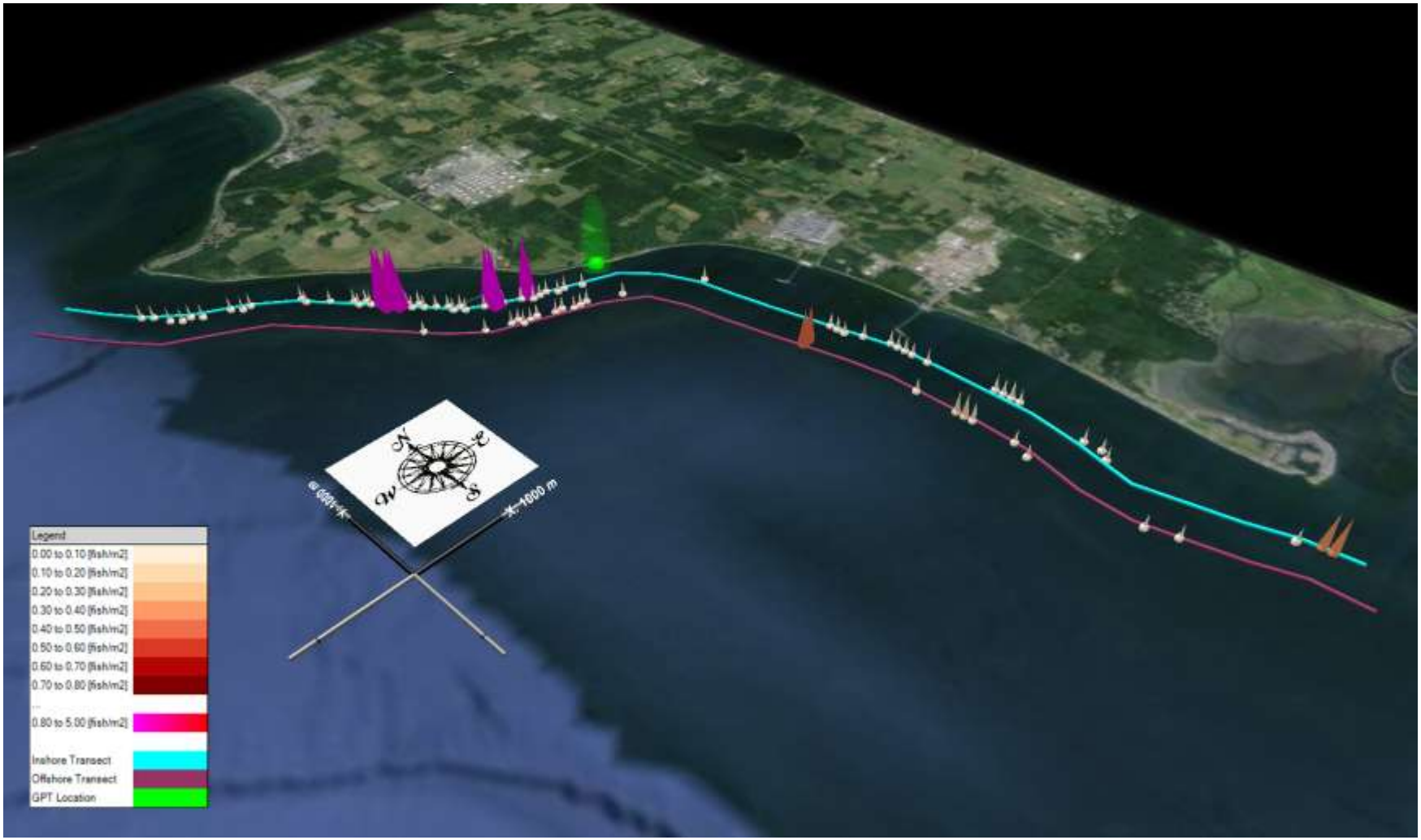

Figure 7. **Estimated herring density distributions for Survey 2, conducted on May 1-2, 2014 during nighttime hours. Each value describes observed geo-referenced herring point density estimates measured along each transect survey line.**

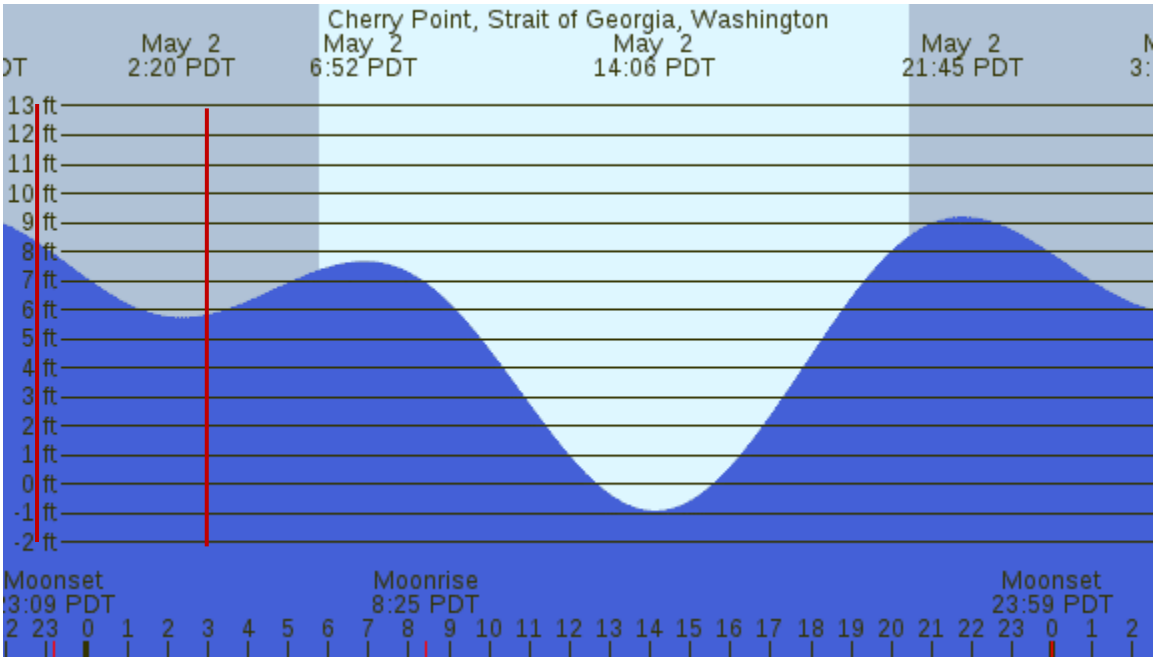

Figure 8. Tidal chart for Cherry Point, Washington during Survey 2, conducted on May 1-2, 2014 between 2244 and 0256 hours on an ebb and slack tide. The horizontal axis lines indicate tidal height and the red vertical lines indicate the surveyed time period. (http://www.dairiki.org/tides).

4.1.3 Survey 3 May 5, 2014 - Day

Herring school density distributions for Survey 3, conducted on May 5 during daylight hours, are presented in Figure 9. Tidal height information over the survey period is shown in Figure 10.

The number of detected school events on Survey 3 was relatively low, and the distribution of these events was patchy in nature. Very few estimated herring aggregations were detected on the inshore transect, and none south of the Cherry Point area. Two schools of relatively higher densities were observed on the offshore transect just south of Cherry Point.

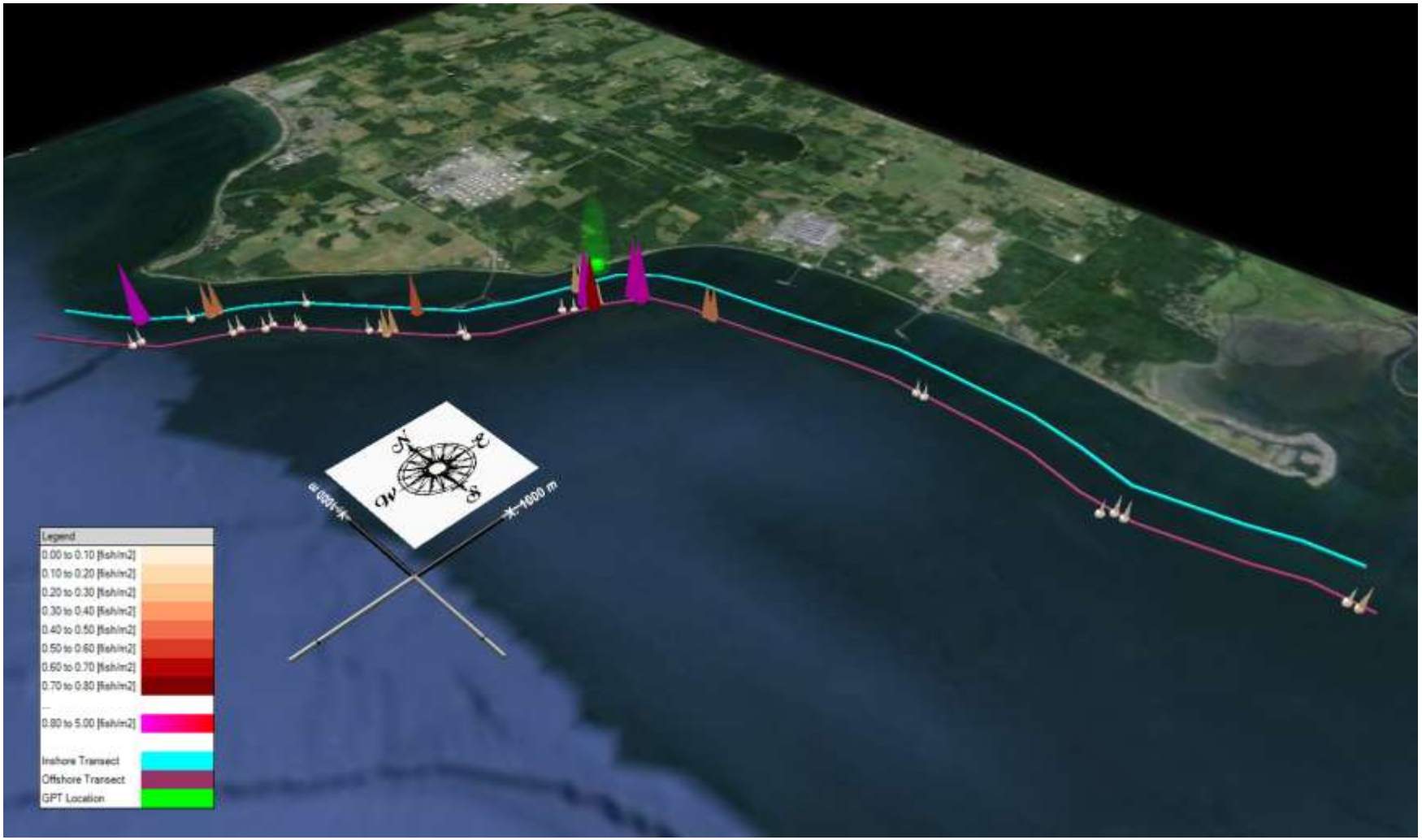

Figure 9. **Estimated herring density distributions for Survey 3, conducted on May 5, 2014 during daylight hours. Each value describes observed geo-referenced herring point density estimates measured along each transect survey line.**

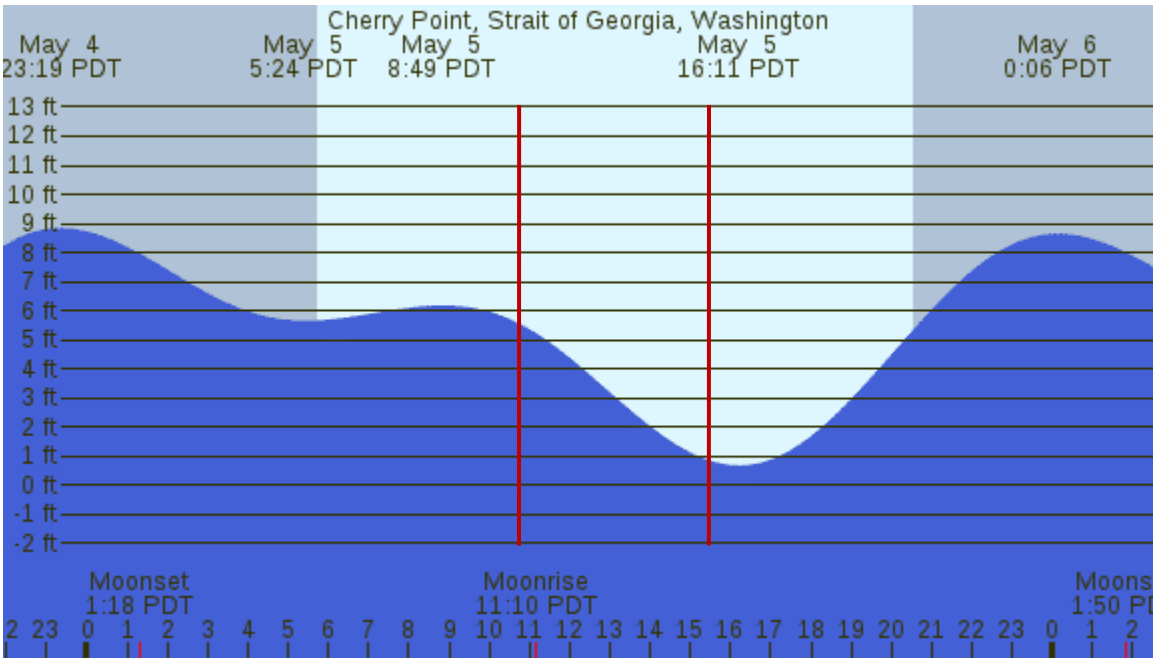

Figure 10. Tidal chart for Cherry Point, Washington during Survey 3, conducted on May 5, 2014 between 1054 and 1525 hours on an ebb tide. The horizontal axis lines indicate tidal height and the red vertical lines indicate the surveyed time period. (http://www.dairiki.org/tides).

4.1.4 Survey 4 May 6-7, 2014 - Night

Herring school density distributions for Survey 4, conducted on May 6-7 during nighttime hours, are presented in Figure 11. Tidal height information over the survey period is shown in Figure 12.

The majority of the estimated herring schools observed during the nighttime survey were small, low-density aggregations located on the inshore transect south of the proposed Terminal site. Relatively few schools were observed north of Cherry Point and none in the area off of Point Whitehorn. The observed spatial distribution of estimated herring distribution over the survey area differed from the pattern of the previous nighttime survey conducted on May 1-2, when the majority of school detections were located north of Cherry Point, along the inshore transect.

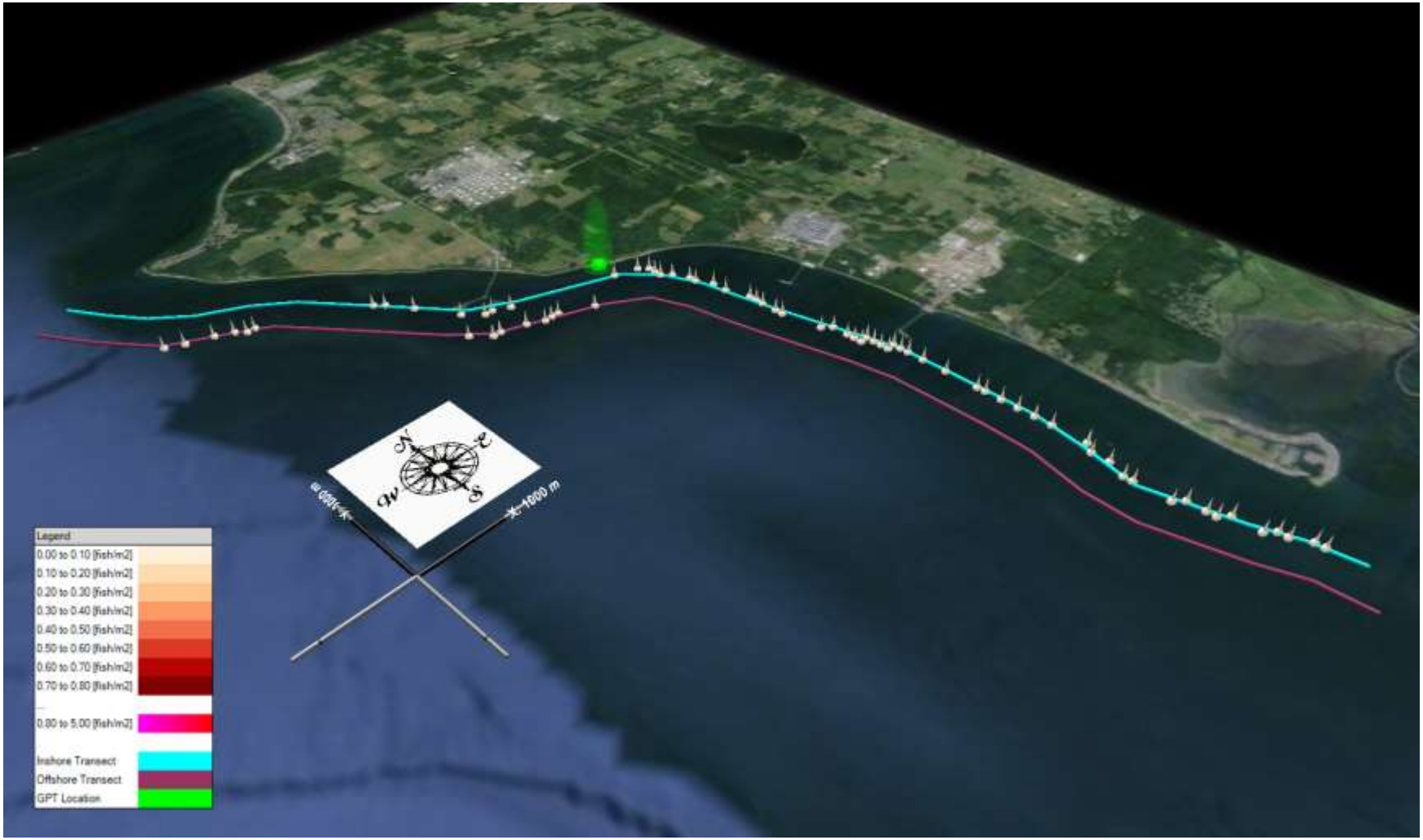

Figure 11. Estimated herring density distributions for Survey 4, conducted on May 6-7, 2014 during nighttime. Each value describes observed geo-referenced herring point density estimates measured along each transect survey line.

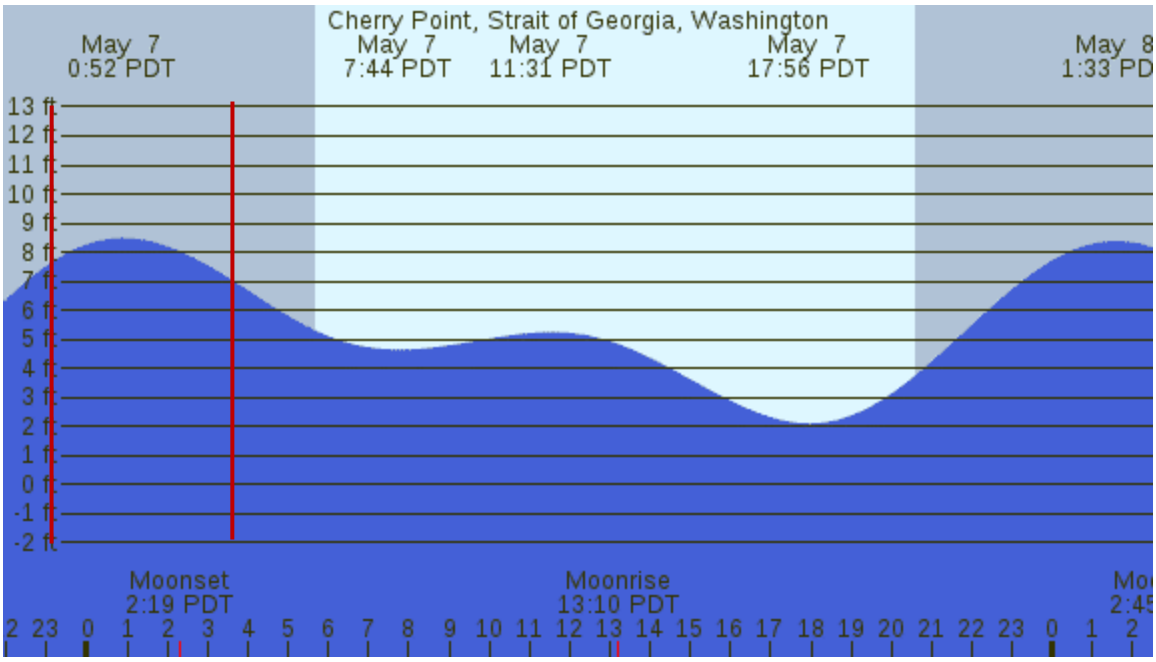

Figure 12. Tidal chart for Cherry Point, Washington during Survey 4, conducted on May 6-7, 2014 between 2305 and 0322 hours during a slack to ebb tide. The horizontal axis lines indicate tidal height and the red vertical lines indicate the surveyed time period. (http://www.dairiki.org/tides).

4.1.5 Survey 5 May 10, 2014 - Day

Herring school density distributions for Survey 5 conducted on May 10 during daylight hours are presented in Figure 13. The associated tidal stage information is shown in Figure 14.

The number of observed estimated herring schools on May 10 was low and the majority of these events were observed on the offshore transect in the general vicinity of Point Whitehorn. The spatial pattern of observed fish densities on May 10 was generally similar to that observed during the previous daytime survey conducted on May 5. Both survey dates observed a reduction in the number of school events relative to Survey 2 (conducted on May 1-2), and a general shift toward greater numbers of aggregations located north of Cherry Point and offshore of Point Whitehorn.

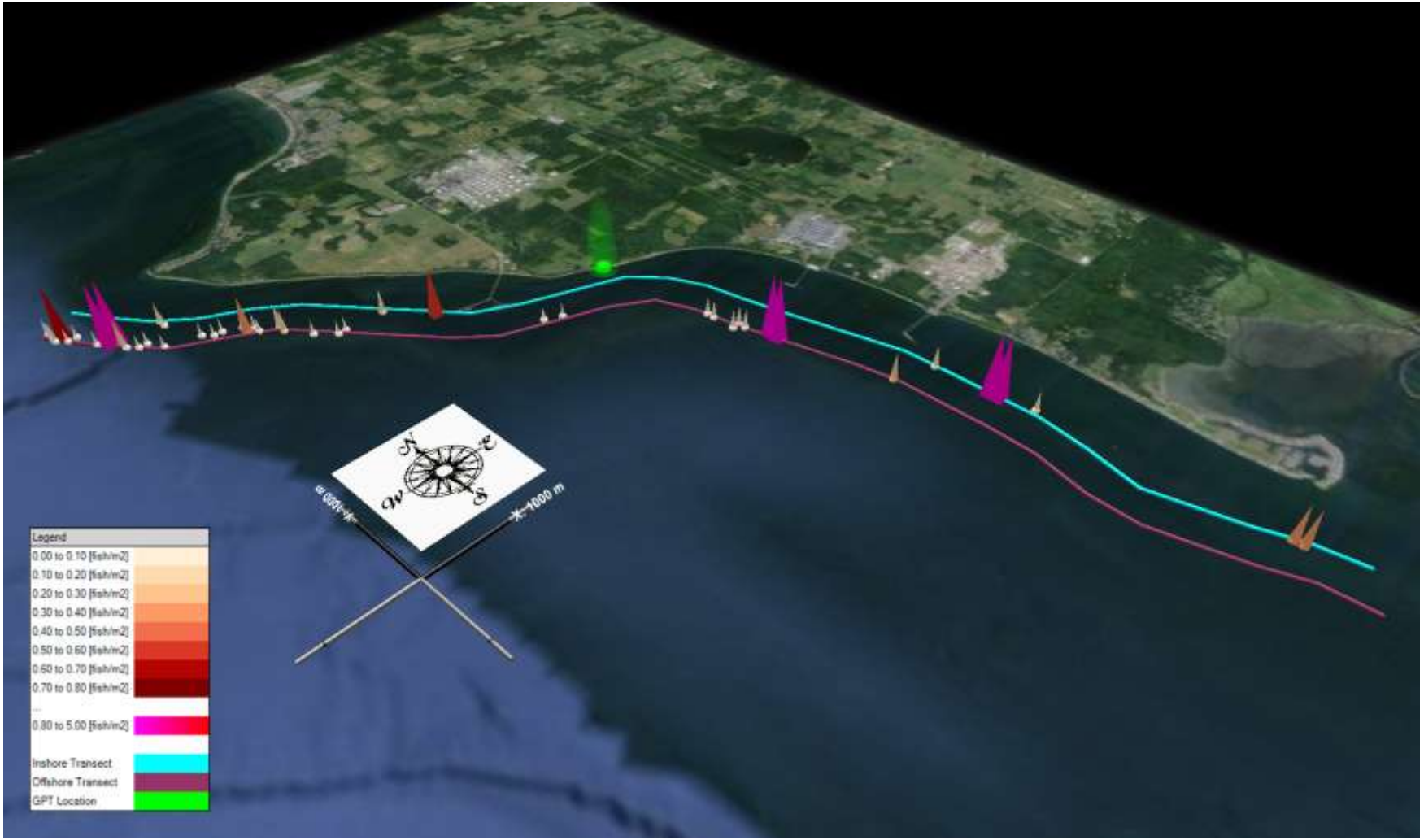

Figure 13. Estimated herring density distributions for Survey 5, conducted on May 10, 2014 during daylight hours. Each value describes observed geo-referenced herring point density estimates measured along each transect survey line.

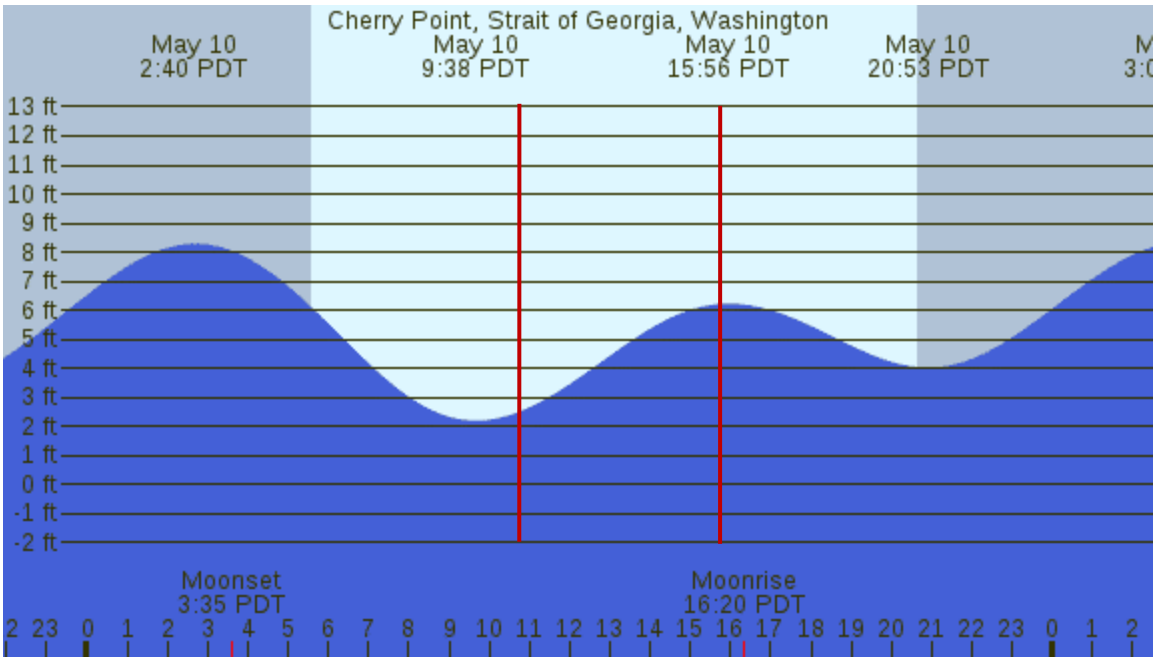

Figure 14. Tidal chart for Cherry Point, Washington during Survey 5, conducted on May 10, 2014 between 1048 and 1552 hours on a flood tide. The horizontal axis lines indicate tidal height and the red vertical lines indicate the surveyed time period. (http://www.dairiki.org/tides).

4.1.6 Survey 6 May 12, 2014 - Day

Herring school density distributions for Survey 6, conducted on May 12 during daylight hours, are presented in Figure 15. Tidal height information for the survey period is given in Figure 16.

The general distribution of estimated herring schools observed on May 12 was skewed north of Cherry Point to just south of Point Whitehorn. The highest relative densities observed during the period occurred near the north end of the inshore transect. Scattered small schools were detected on both transects north of the Phillips 66 pier, but relatively few schools were observed south of that location.

Generally similar patterns of spatial school distribution were observed during the May 12 and May 10 daytime surveys. The majority of detected aggregations were located north of Cherry Point on both dates and the highest density schools occurred in the vicinity of Point Whitehorn.

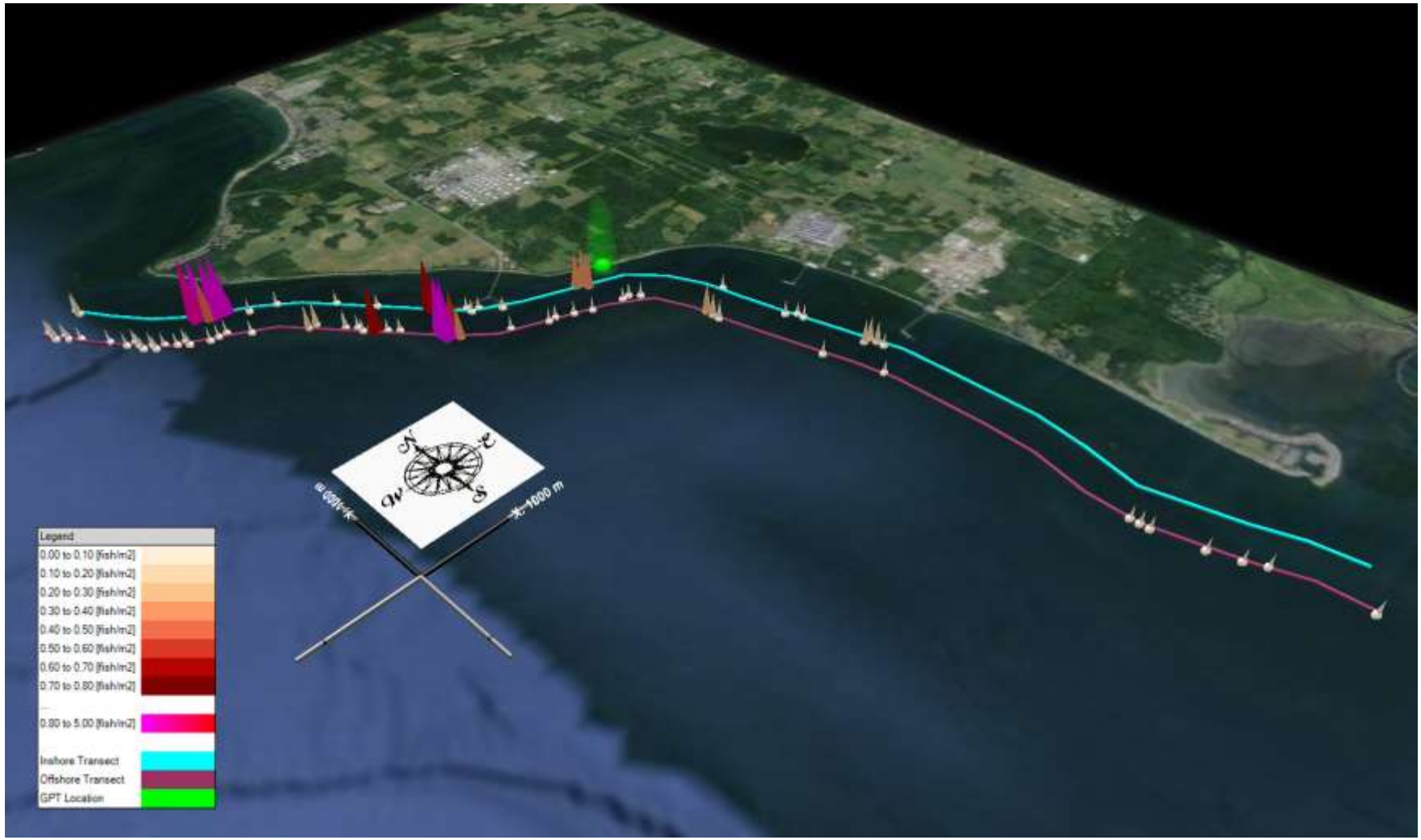

Figure 15. Estimated herring density distributions for Survey 6, conducted on May 12, 2014 during daylight hours. Each value describes observed geo-referenced herring point density estimates measured along each transect survey line.

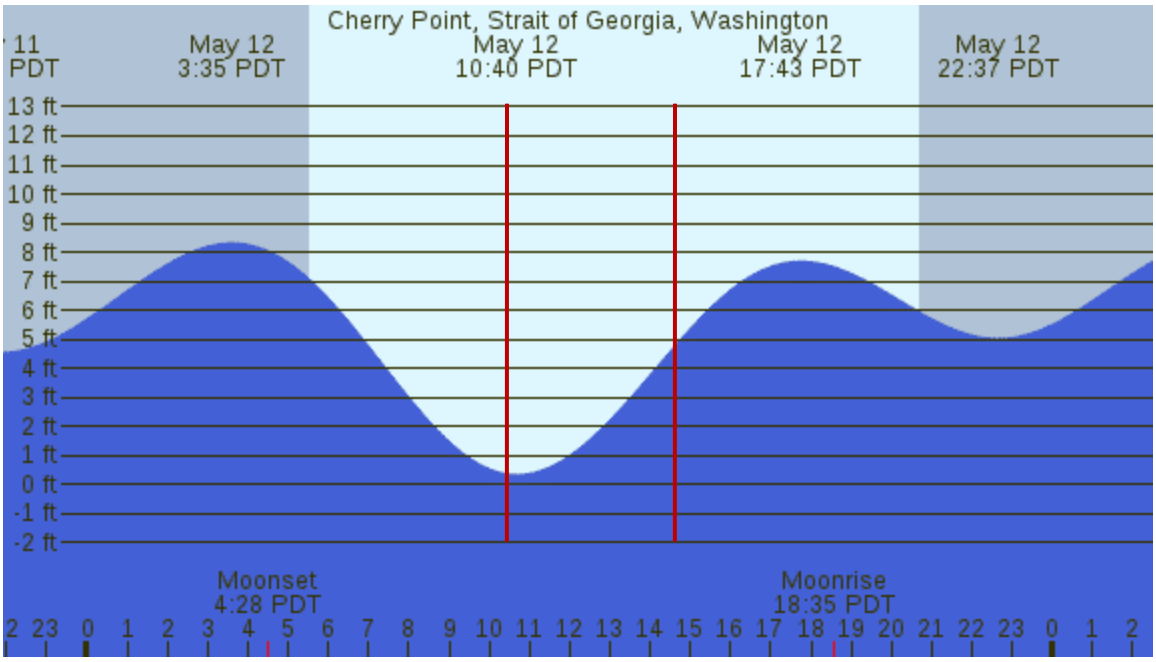

Figure 16. Tidal chart for Cherry Point, Washington during Survey 6, conducted on May 12, 2014 between 1026 and 1432 hours on a slack to flood tide. The horizontal axis lines indicate tidal height and the red vertical lines indicate the surveyed time period. (http://www.dairiki.org/tides).

4.1.7 Survey 7 May 13-14, 2014 - Night

Herring school density distributions for Survey 7, conducted on May 13-14 during nighttime hours, are presented in Figure 17. Tidal height information for the survey period is given in Figure 18.

The estimated herring school detections observed during the nighttime survey conducted on May 13-14 were also skewed north of Cherry Point, demonstrating a similar distribution as that observed during the previous May 12 survey. All fish aggregations observed on May 13-14 were relatively low density events, consistent with the previous nighttime survey conducted on May 6-7. The majority of detected schools were located north of Cherry Point on May 13-14 and south of Cherry Point on May 6-7, possibly indicating a shift in the nighttime spatial distribution of estimated herring densities during the period between these dates.

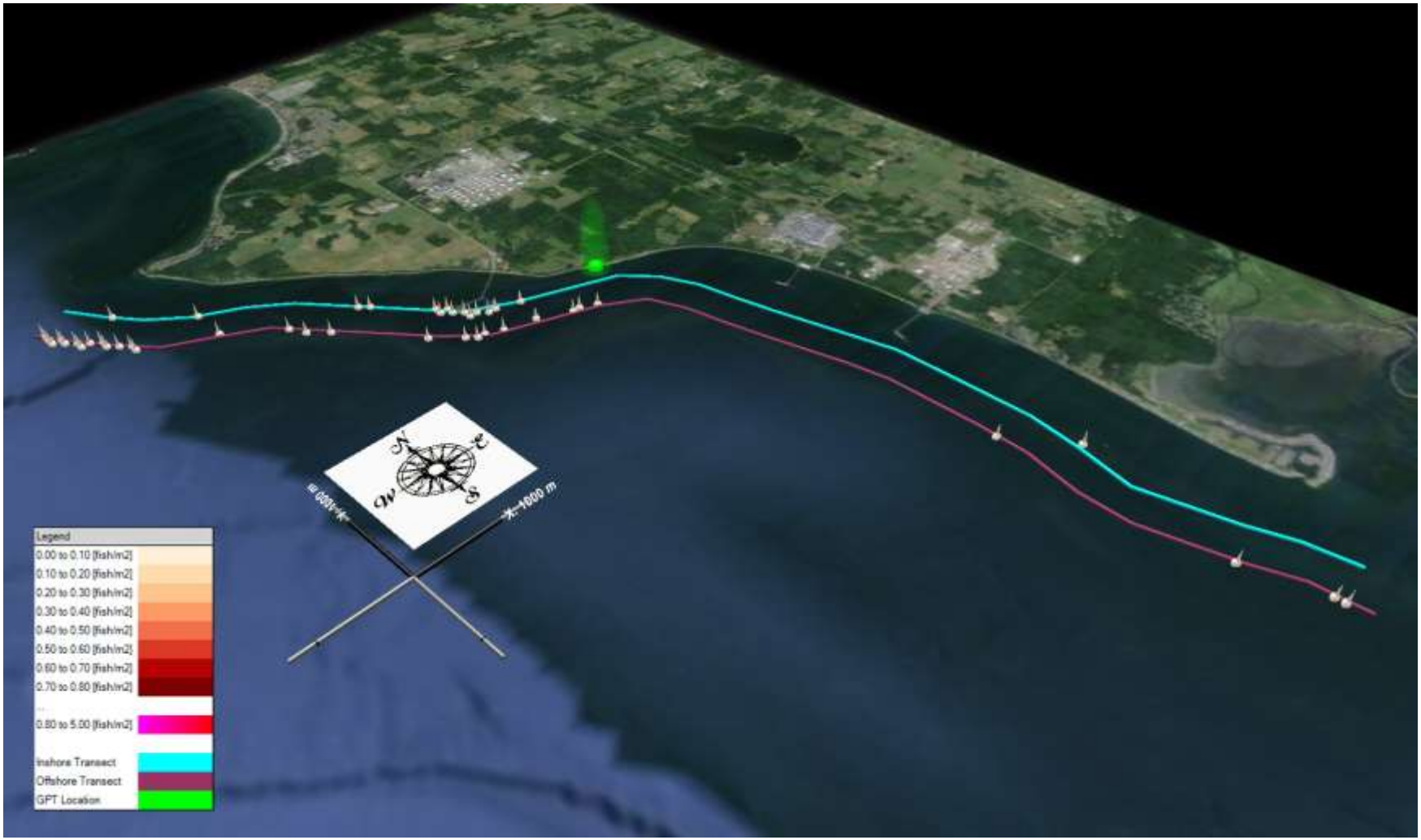

Figure 17. Estimated herring density distributions for Survey 7, conducted on May 13-14, 2014 during nighttime. Each value describes observed geo-referenced herring point density estimates measured along each transect survey line.

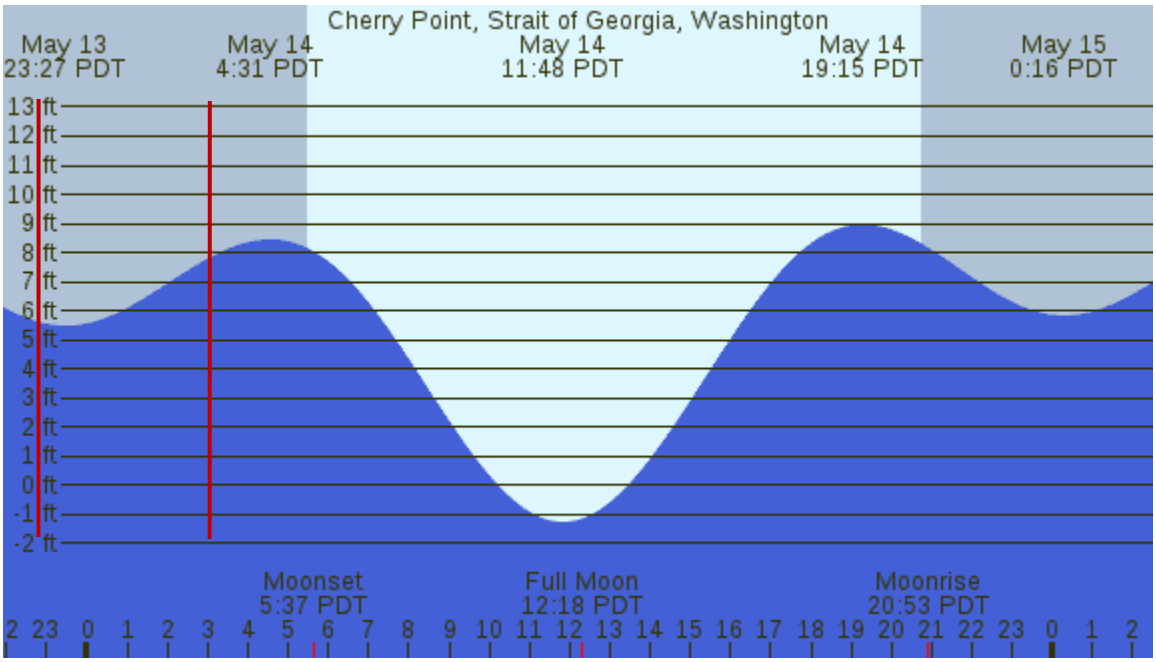

Figure 18. Tidal chart for Cherry Point, Washington during Survey 7, conducted on May 13-14, 2014 between 2245 and 0251 hours on a slack to flood tide. The horizontal axis lines indicate tidal height and the red vertical lines indicate the surveyed time period. (http://www.dairiki.org/tides).

4.1.8 Survey 8 May 16, 2014 - Day

Herring school density distributions for Survey 8, conducted on May 16 during daylight hours, are presented in Figure 19. Tidal height information for the survey period is given in Figure 20.

The highest relative herring school densities detected during the final May 16, 2014 hydroacoustic survey were located on the inshore transect immediately off of Point Whitehorn. Clusters of low density aggregations were present on both transects off of Sandy Point and in the region north of Cherry Point extending to Point Whitehorn. Relatively few school events were detected on either transect along the shoreline reach extending from south of the Phillips 66 pier to Cherry Point.

The general spatial pattern of school distribution was similar to that observed on the preceding daytime survey conducted on May 12, with the highest density aggregations observed in the vicinity of Point Whitehorn on both dates. The May 16 survey observed clustered small school events at the south end of both survey transects, near Sandy Point, which were not present on the inshore transect during the May 12 sampling.

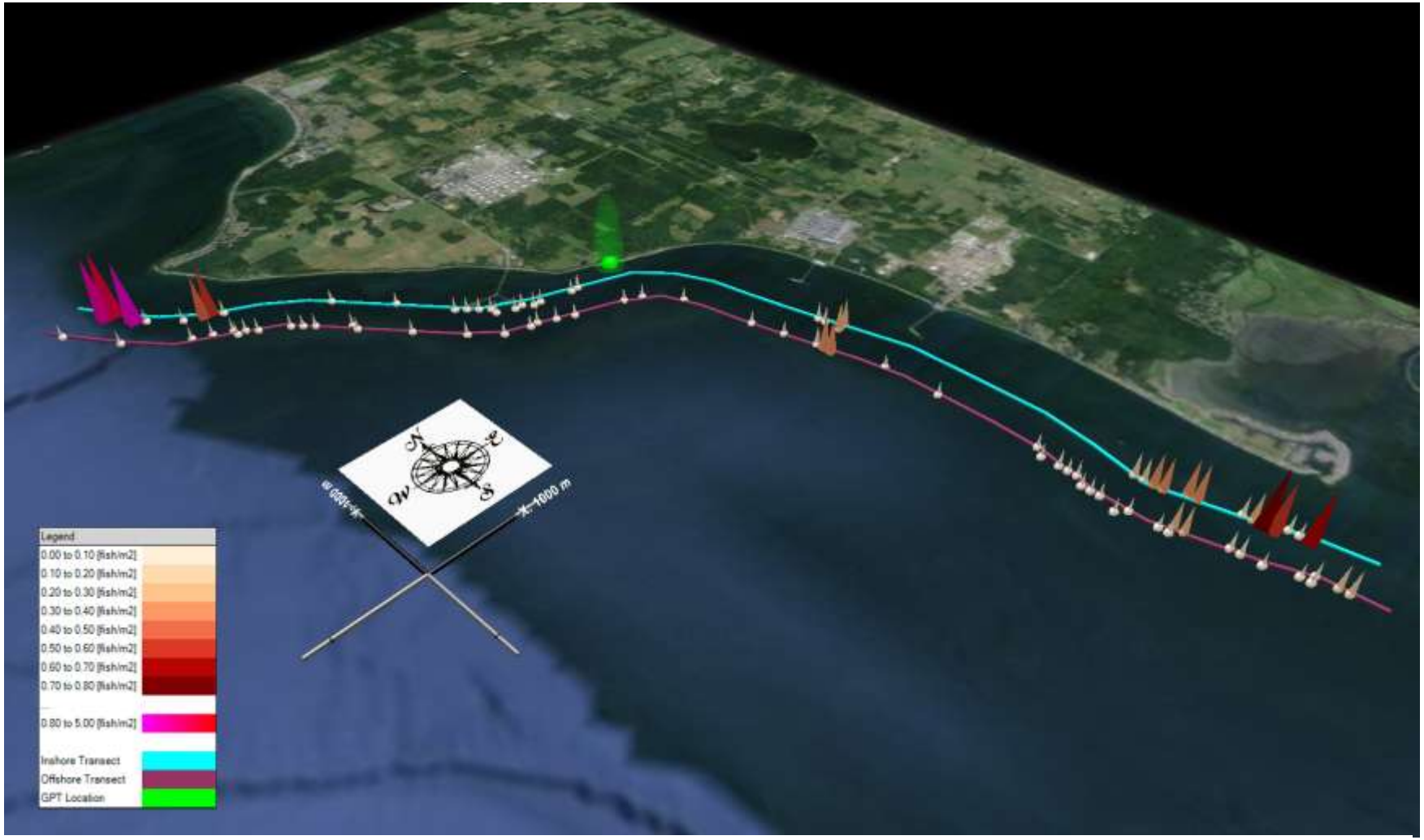

Figure 19. Estimated herring density distributions for Survey 8, conducted on May 16, 2014 during nighttime. Each value describes observed geo-referenced herring point density estimates measured along each transect survey line.

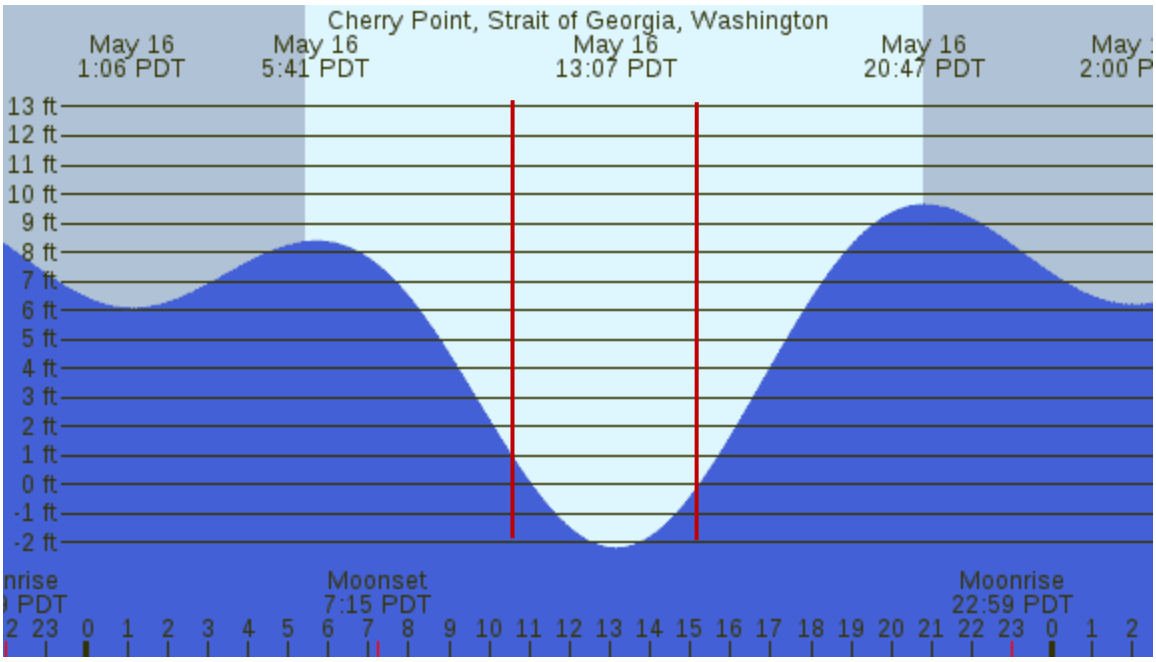

Figure 20. Tidal chart for Cherry Point, Washington during Survey 8, conducted on May 16, 2014 between 1055 and 1514 hours during an ebb to slack tide. The horizontal axis lines indicate tidal height and the red vertical lines indicate the surveyed time period. (http://www.dairiki.org/tides).

5.0 DISCUSSION

The 2014 hydroacoustic herring school study results indicated that the largest number of aggregations and the highest fish/m^2 school densities were detected between Cherry Point and Point Whitehorn, over the combined study period.

Over the April 28 through May 16, 2014 sampling period, greater numbers of estimated herring school events were generally observed north of Cherry Point, in comparison to the transect segments located to the south. School densities were also generally higher within the aggregations north of Cherry Point.

Areas of the highest observed mean herring school density over the entire 2014 monitoring period were generally located in the vicinity of Point Whitehorn, and to a lesser extent, in the region north of Cherry Point. Mean estimated herring densities south of Cherry Point tended to be relatively lower and more widely distributed over the combined 2014 survey period.

Data on schools collected in daytime surveys demonstrated a greater number of higher-density schools than data from nighttime surveys. This probably indicates that herring were more widely-distributed and less aggregated at night than during the day.

The observed daytime schools were generally located north of Cherry Point and this pattern appears to be stronger over time when reviewing the five successive daytime surveys conducted on April 28, May 5, May 10, May 12 and May 16. More frequent low-density herring schools were observed off of Sandy Point, near the south end of the surveyed area, on May 16 and to a lesser extent on May 12.

Spatial patterns of estimated herring school distribution were less evident during the nighttime surveys. Increased numbers of small schools were observed north of Cherry Point from May 1-2 and on May 13-14, with relatively few small school events present south of that location. An opposing pattern of school distribution was observed on the night of May 6-7, when the majority of detected aggregations were located south Cherry Point, along the inshore transect.

Relatively fewer herring schools were observed during the nighttime survey periods during the 2014 Study, and the largest schools observed at night were all located north of Cherry Point. During the daytime surveys in 2014, the largest density schools that were observed were located in the vicinity of Point Whitehorn, although lower density schools were observed on the inshore transect north of Cherry Point and in the vicinity of the Intalco and Phillips 66 wharves.

In general, the observed fish densities were lower and more widely-distributed across the southern half of the surveyed area (south of approximately Cherry Point) during both daytime and nighttime monitoring periods, relative to densities detected in the northern half of the region. The relatively higher school densities present in the vicinity of Point Whitehorn during the combined daytime surveys in 2014 was not observed during the combined nighttime sampling series.

Estimated herring school density distribution trends observed during the April 26-May 16, 2014 hydroacoustic surveys included:

- The observed schools were relatively compact, detected over transect chord lengths varying from approximately 10 to 350 m.

- A general trend of increasing school numbers and in the frequency of relatively higher density schools was observed during the daytime transects conducted from April 28 to May 16.

- With the exception of the nighttime survey conducted on May 6-7, estimated herring schools were detected predominantly north of Cherry Point.

- The highest density schools detected during the surveys conducted from May 10 through16 were located in the vicinity of Point Whitehorn.

- The estimated herring schools were generally lower in density and distributed over a wider spatial extent across the surveyed region at night, relative to the daytime survey observations.

6.0 REFERENCES

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Appendix A. Specifications for the HTI *Model 241 Portable Split-Beam System* and *EchoScape*™ Post-Processing Software.

Table A1. Technical specifications for the HTI *Model 241 Portable Split-Beam Echo Sounder*

Size:	10 inches wide x 4.3 high x 17 long, without PC or transducer (254 mm wide x 109 high x 432 long).
Weight:	20 lb. (9 kg) without PC or transducer.
Power Supply:	Nominal 12 VDC standard (120 VAC and 240 VAC optional).
Operating Temperature:	5-50°C (41-122°F).
Power Consumption:	30 watts (120 - 200 kHz), without laptop PC.
Frequency:	200 kHz standard (120 kHz and 420 kHz optional).
Transmit Power:	100 watts standard for 120-200 kHz.
Dynamic Range:	140 dB
Transmitter:	Output power is adjustable in four steps over a 20 dBw range
Pulse Length:	Selectable from 0.1 msec to 1.0 msec in 0.1 msec steps.
Bandwidth:	Receiver bandwidth is automatically adjusted to optimize performance for the selected pulse length.
Receiver Gain:	Overall receiver gain is adjustable over a 40 dB
TVG Functions:	Simultaneous 20 and 40 log(R)+2αr TVG. Spreading loss and alpha are programmable to nearest 0.1 dB. Total TVG range is 80 dB. TVG start is selectable in 1m increments. The minimum TVG start is 1.0 m to maximum of 200 m.
Receiver Blanking:	Start and stop range blanking is selectable in 1 m steps.
Undetected Output:	12 kHz, for each formed beam
Detected Output:	10 volts peak
System Synchronization:	Internal or external trigger
Ping Rate:	0.5-40.0 pings/sec
Phase Calculation:	Quadrature demodulation
Angular Resolution:	+/- <0.1° (15° beam width, 200 kHz)
Tape recording:	With Split-Beam Data Tape Interface and optional Digital Audio Tape (DAT) recorder, directly records the digitized split-beam data, permitting complete reconstruction of the raw data output.
Calibrator:	Local receiver calibration check using internal calibration source.
Positioning:	WAAS-referenced GPS positioning information (NMEA 0183 format) via serial port of computer
Target Tracking:	Permits selection and de-selection of individual echoes for a specific fish track.
Echo Integration:	Permits selection and de-selection of individual fish aggregations for echo integration (interval- and stratum-based).
Data Displays:	Three-dimensional and two-dimensional displays of fish tracks are available. Echogram display (i.e., range vs. time). Three-dimensional fish tracks (X, Y, and range). Display of data for individual selected echoes: time, position, pulse width, target strength.
Data Files Accepted:	The following data output files from HTI's Model 241 Portable Split-

	Beam System, Model 243 Digital Split-Beam System, and Model 244 Multi-Frequency System are accepted by EchoScape: Raw Echo File (*.RAW): Contains a record every raw echo that meets user-supplied minimum threshold and pulse width selection criteria. Includes echo amplitude, pulse width, and three-dimension location for each raw echo. Tracked Echo File (*.ECH): Contains a record for each raw echo that meets the user-specified fish tracking criteria, including three-dimensional location, pulse width, peak voltage, overall beam pattern factor, and target strength. Tracked Fish File (*.FSH): Summarizes all echoes within each fish tracked through the acoustic beam. Data include mean target strength, fish speed, start X, Y, and Z coordinates, distance traveled in each direction, and transducer number. Echo Integration File (*.INT): Summarizes mean squared voltage values, by range strata.
Operating System:	Windows95/98, 2000, XP using a mouse for selection and de-selection of individual echoes and fish schools.
Database:	MS Access 97, Access 2000, or Access 2003/XP.
Computer Requirements:	Minimum Pentium PC 500 MHz w/MS Windows95 or Windows98 and MS Access, 64 MB RAM, higher specs improve performance. Contact HTI for further specifications.
Note:	All specifications subject to change without notice.
Demo Diskette:	An HTI Demo CD is available for EchoScape and other HTI software packages.