Final Project Report to the California Dungeness Crab Fishing Gear Working Group:

Exploring the use of manned aerial overflight surveys to estimate the spatial distribution and abundance of Dungeness crab fishing effort in Monterey Bay

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Project Participants:
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Flight Date: June 16, 2016

Executive Summary:

The California Dungeness Crab Fishing Gear Working Group identified the need to obtain improved data on the spatial distribution of fishing effort to inform efforts to reduce whale entanglements, and recommended evaluating several approaches including aerial surveys. This project explored and piloted a method for collecting such data at a regional scale by conducting an aerial survey of trap buoys from a single-engine aircraft in Monterey Bay on June 16, 2016. We were successfully able to record trap locations, providing a snapshot of traps near the end of the 2015-16 fishing season, three weeks after the California Department of Fish and Wildlife issued a voluntary advisory to reduce fishing effort within Monterey Bay, specifically at the Monterey Canyon edge. We observed 594 individual traps, and estimated a total of 2,086 traps (SE = 519, 95% Conf. Interval: 1,241-3,507) within a study area of 915 km^2 (average 2.28 traps/km^2) using distance sampling techniques. Trap locations revealed that traps were set at depths ranging from 10-220 meters, with the greatest concentration between the 80-90m depth contours. Point density and grid counts enable the identification of discrete "hotspots" of high relative trap density at a fine spatial scale within Monterey Bay that may be useful in evaluating more fine-scale co-occurrence between fishing effort and whales. This project indicates that under favorable weather conditions, it is possible to obtain quantitative estimates of the total fishing effort at a regional scale, the depth distribution of traps, and identify areas of relative high and low trap density within a region at a fine spatial scale.

Introduction:

In response to a recent increase in whale entanglements with Dungeness crab fishing gear, the State of California convened the Dungeness Crab Fishing Gear Working Group to develop collaborative solutions. Oceana is a member of the working group. The Working Group identified key data gaps and made recommendations for additional data collection, including more accurate data on the spatial distribution of fishing effort in relation to whale aggregation areas. This would inform and improve a co-occurrence model being developed by NOAA Fisheries. Additionally, in response to a high number of entanglements since the fishery opened in spring 2016, the California Department of Fish and Wildlife issued a voluntary advisory to fishermen requesting changes to fishing patterns on May 24, 2016. The Dungeness crab fishing gear working group and local fishing organizations supported the advisory and agreed to voluntarily remove fishing gear from Monterey Bay, specifically the Monterey Canyon edge. Along with other potential methods to record fishing effort, this project seeks to explore the ability of aerial surveys to visually evaluate fishing effort, for the purpose of providing the working group and fishery managers with additional tools to reduce whale entanglements. We explored data gathering tools including GPS equipment and smartphone applications to record trap locations over the course of the flight. The survey also provided a snapshot of fishing effort subsequent to the advisory as an independent data source to document the extent to which fishermen responded voluntarily. The commercial season in Monterey Bay ended June 30. Reducing whale entanglements is important to the sustainability of local fisheries and whale populations that occur off the California coast.

The objectives of this project were to:

1. Evaluate the potential for using aerial surveys (e.g., using LightHawk aircraft) to accurately determine the spatial distribution of fishing traps.
2. Evaluate the extent to which fishermen responded to the voluntary advisory to avoid certain areas, by identifying the number and location of traps currently set in Monterey Bay.
3. Continue to build a partnership between LightHawk (www.LightHawk.org) and the Dungeness Crab Fishing Gear Working Group and its members.

***Figure 1**. Aerial survey participants Geoff Shester (left), Albertha Ladina (center) and pilot Bill Rush (right), with Cessna 182 used in aerial survey.*

Methods

Survey design and planning

We identified a four day window from June 15-18, 2016 in which the pilot and research participants would be available. We monitored the weather in hopes of identifying a four hour period most likely to have low wind conditions (less than 10 knots), and low fog or cloud cover, using www.Windfinder.com and www.Windyty.com websites. We determined June 16 would be the best chance for success based on these criteria, and evaluated conditions the morning of June 16 to confirm. On June 16, 2016, LightHawk pilot Bill Rush brought Oceana Research Intern Albertha Ladina and Oceana California Campaign Director, Dr. Geoff Shester on a flight aboard a single engine Cessna 182 that took off and landed from the Marina Municipal Airport (Figure 1). We flew 15 transects (Figure 2) covering a study area of 915 km^2 (determined by calculating the area of a polygon encompassing the outer boundaries of the transects) during a three hour and 25 minute flight, from 9:55am to 1:20pm, at a constant altitude of 1000 feet and an airspeed of 100 knots (preliminary findings from a previous Lighthawk flight[1] indicated that pot gear could be readily identified from an altitude of 1000 feet at approximately 100-110 knots). The north-south transect lines were spaced one nautical mile apart, extending from the eastern shore of Monterey Bay to about 15 nautical miles west of Moss Landing and from Santa Cruz to Cypress Point (Pebble Beach). These transect lines were developed prior to the flight to 1) provide the finest spatial coverage possible within the study area on a single 3.5-hr flight, and 2) keep the navigation as simple as possible to allow the pilot to use onboard navigation software. Data collection methods followed protocols for *Distance Sampling*, a well-established scientific method for estimating total density and abundance of wildlife or other objects during visual surveys (Buckland et al. 2001). The technical advisors for this project, Scott Benson and Dr. Karin Forney, have extensive experience collecting and analyzing *Distance Sampling* surveys to estimate population sizes of marine mammals, sea turtles, and other species.

Field methods

Using a GPS tracking application on an iPhone (*Motion-X GPS*), we tracked the plane location (latitude, longitude, and altitude) throughout the flight. The data collection team included two positions: an observer, who sat in the rear seats and searched for trap gear through one of the side windows, and a data recorder, who sat in the co-pilot seat and marked the start and end of each survey transect, and recorded information on trap sightings and weather conditions. Initially, the data recorder entered this information on a laptop computer connected to a GPS device using software (*TurtleP*) developed by NOAA scientists to conduct wildlife surveys; however, due to power supply issues partway through the flight, we switched to marking waypoints manually using the *Motion-X GPS* iPhone application and recording the sighting data manually with pen and paper.

During some transects we paused the transect to take aerial photographs, and then resumed the transects from the point at which we diverted from the line. From this, we were later able to clip out

[1] Report: Laughlin, D. and Mattusch, T. "Test" LightHawk Survey, May 1, 2016. CA Dungeness Crab Fishing Gear Working Group Summary Report.

the portions of the continuous flight path (Figure 2, left) to show and measure the actual transect lines on which we actually searched for traps (Figure 2, right). When possible, we also noted the locations of whales, dolphins, or other notable wildlife, however, we did not systematically collect this information as it would have impeded the ability to accurately record trap locations.

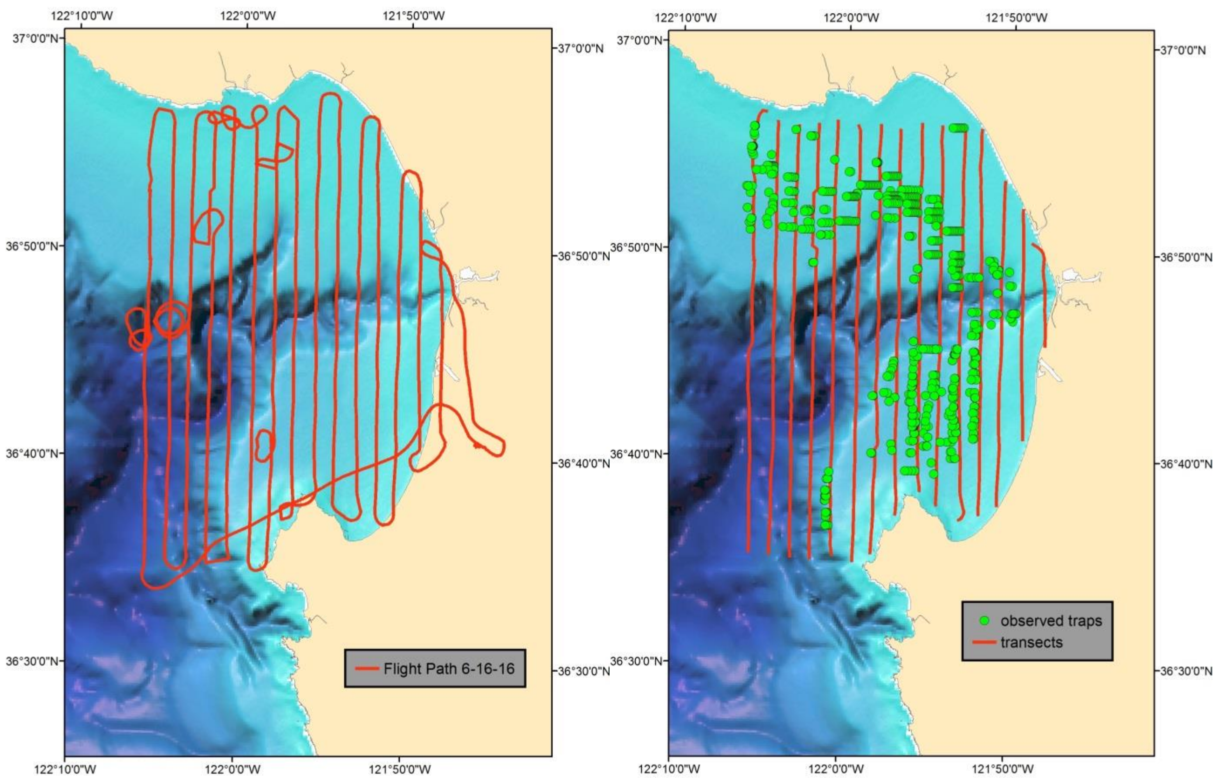

***Figure 2**. Left: Full flight path as tracked using Motion-X GPS iPhone application, beginning and ending at Marina Municipal Airport. Right: Flight path clipped to show only transects where active trap recording occurred, overlaid with locations of all observed traps. Clipped out sections include portions traveling to and from the airport, turning around between transects, and loops where we deviated from the transect line pausing data collection to take aerial photographs.*

On each transect, we recorded a) the sea state using the numerical Beaufort scale, b) the percent cloud cover, and c) the percent of the viewing area obscured by glare, because these factors are known to affect marine wildlife surveys (e.g., Forney et al. 1995). Since we flew in the morning, the observer only searched to the west of the plane to minimize glare effects, switching seats between adjacent transects. When a trap was encountered, we created a waypoint when the trap was perpendicular to the course of the transect, and used a clinometer to note the angle of the trap relative to the plane (90° = directly below aircraft, 0° = horizon). If there were multiple traps at the same waypoint, we either noted the angle of each individual trap, or in the case of a linear string, recorded the angle of the closest and furthest trap visible, as well as the number of traps between them. From this, we could then estimate the angle of each trap assuming the traps were evenly spaced between the furthest and closest traps.

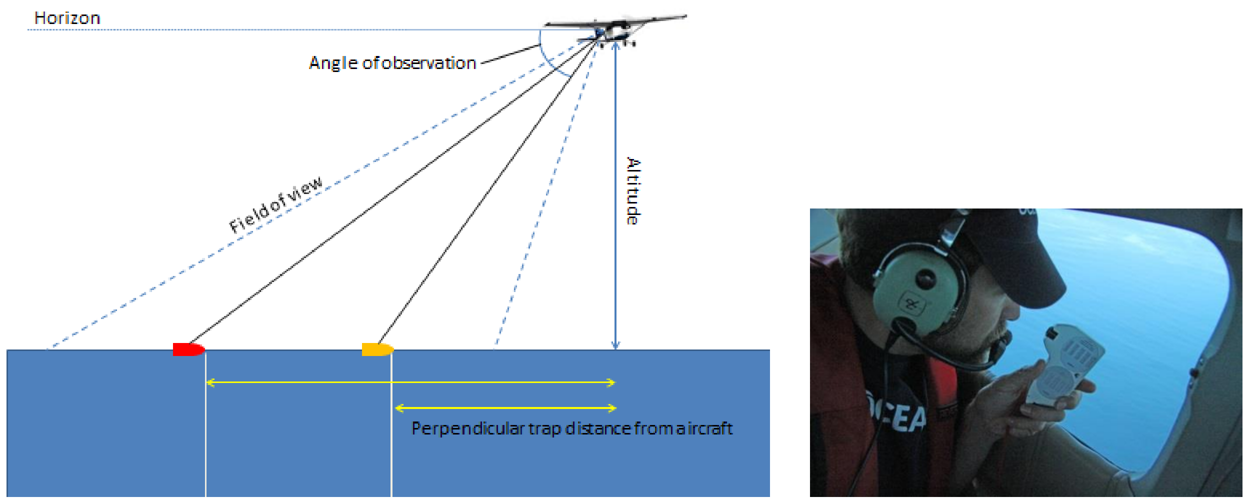

***Figure 3**. Left: Diagram showing how angle of observation can be used to calculate perpendicular distance of buoys from the aircraft transect track line. Right: Observer Dr. Geoff Shester views traps from the window of the aircraft using a clinometer to determine the angle of each observed trap relative to the aircraft.*

Since seabirds or other debris could potentially be confused with traps, we only recorded buoys when we could either confirm it was a buoy based on a single buoy with a bright color (orange, red, or green), a single buoy with kelp clearly attached, or a pair of buoys connected by a line (Figure 4). Therefore, this method may underestimate the total number of buoys, but minimizes the likelihood of false positives (i.e., mistakenly recording a bird or other object as a buoy). We recorded the presence of larger navigation or research buoys that clearly were not fishing traps, however, did not include them in the analysis. We did not attempt to distinguish between different types of buoys from fishing traps, so our analysis may include buoys used in other fisheries than Dungeness crab.

***Figure 4**: Examples of buoys observed. Left: pair of white buoys attached by line; Center: pair of colored buoys along with a trailing buoy with line evident; Right: single buoy with no visible line, but with attached kelp. Photos taken from plane at 1000 ft altitude using 75-300 mm zoom lens on digital SLR camera.*

Data processing

For each trap, we calculated the linear distance of the trap from the transect path from the angle of observation and the altitude (Figure 3) using standard trigonometric equations. From this perpendicular distance, we calculated the position of each trap based the waypoint at which it was observed, offsetting its longitude eastward based on the distance from the plane (using a conversion factor of 89,360 m = 1 degree longitude at 36.7 degrees latitude). Upon plotting the location of each individual observed trap in a Geographic Information System (ArcGIS 10.3.1), we determined the depth range of each trap at a 10 m scale using a 10 m contour interval shapefile (Figure 5). To determine trap density, we conducted a Point Density analysis of observed trap locations using equal weighting for each trap and exploring different radii around each point, and we created a one square (statute) mile grid over the study area and calculated the number of traps within each grid cell.

Trap density and abundance estimation

The survey data were analyzed using standard *Distance Sampling* methods (Buckland et al. 2001) via the package *Distance* (version 0.9.4) in the software program *R* (version 3.1.3). *Distance Sampling* is a well-established scientific method for estimating the density and total abundance of animals or objects from a survey that achieves representative coverage of a study area. For line-transect surveys, representative coverage can be achieved with a systematic set of evenly spaced lines, such as those implemented in this study. A key feature of *Distance Sampling* is the explicit assumption that some objects will be missed during a visual survey, and that the probability of missing objects increases with distance from the transect line.

To estimate density and abundance, the observed perpendicular sighting distances are used to estimate the probability of detection as a function of distance from the transect line. Half-normal, hazard rate, and uniform functions with adjustment terms are commonly explored to estimate the detection function, and Akaike's information criterion (AIC) is used to identify best model. The resulting detection function allows estimation of the effective search width (*ESW*) for the survey (see Buckland et al. 2001 for details). Conceptually, *ESW* is the distance at which the number of traps detected farther away is equal to the number of traps missed closer, yielding an effective 100% detection rate from which trap density and abundance can be calculated.

To improve the robustness and accuracy of distance analyses, truncation of the most distant data is recommended, because these extreme observations contribute little to the analysis while increasing 'noise' and uncertainty. For surveys where it is not possible to view the actual transect line (e.g. directly underneath the aircraft, as in this study), an additional 'left' truncation is required at the distance where the detection probability starts to drop as one gets *closer* to the transect line. A range of potential left- and right- truncation distances were evaluated (e.g., using goodness-of-fit, precision, etc.) to determine the optimal values for this study, based on the observed data. Truncation distances were selected to include as much data as possible while meeting the assumptions of distance sampling (e.g., decreasing detection probability with increasing distance). Following data truncation and model selection, the density (*D*) and total number (*N*) of traps within the study area were calculated as:

$$D = \frac{n}{L \cdot ESW} \qquad \text{and} \qquad N = D \cdot A$$

where
- n = the number of traps between the left- and right-truncation distances
- L = the total length of surveyed transect line (in km)
- ESW = the effective search width (in km), estimated from the detection function
- A= study area size (915 km^2)

Results

Trap observations

We were able to successfully complete the entire set of intended transects and document trap locations over 506.4 km (314.7 statute miles) of linear active transect distance. The LightHawk pilot, Bill Rush, did a phenomenal job of following the planned transect lines and maintaining a constant altitude of 1000 feet, while also pausing transects to allow collection of aerial photographs. We documented a total of 594 traps at depths ranging from 10-220 meters (with a mean of 77 m and a peak at 80-90 m) (Figures 5 and 6). Trap distribution appeared to be most heavily concentrated along the shelf and upper canyon edges, with point density maps indicating highest relative abundance around Soquel Canyon, the shelf north of Pt. Pinos, and the Monterey Canyon head (Figures 7 and 8). Most traps occurred either in clusters or linear strings, as we observed very few solitary traps.

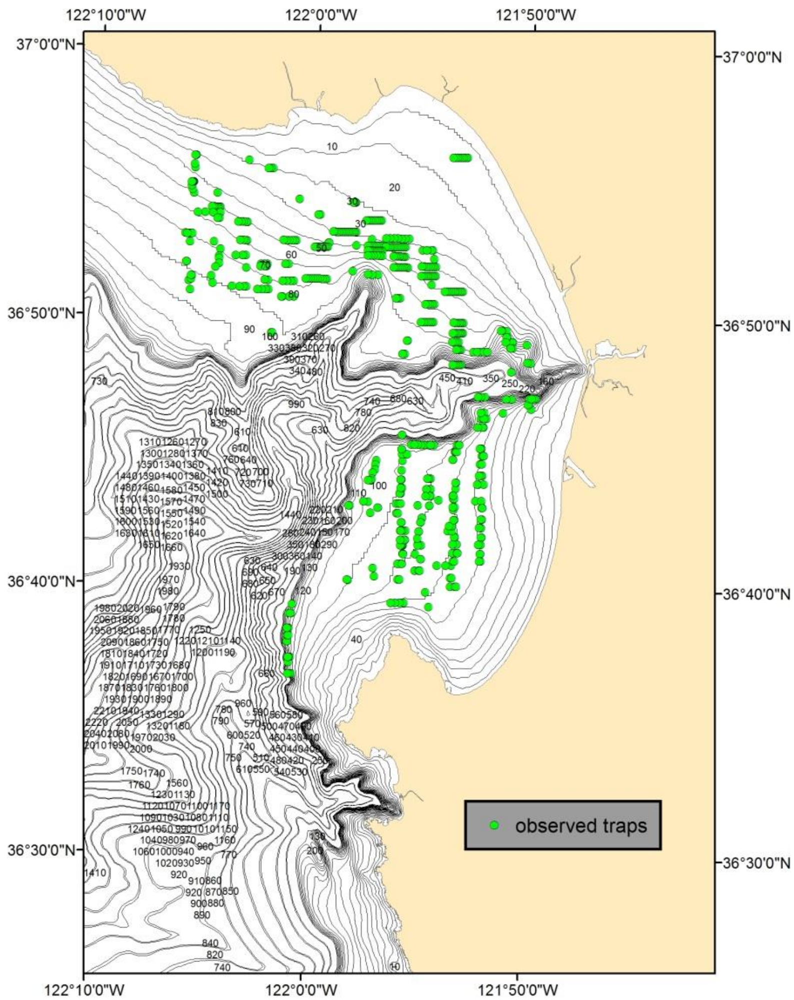

Figure 5*. Locations of observed traps relative to 10-m depth contours. Values refer to the lower end of a 10 meter range (e.g., "40" refers to traps within a depth range of 40-49 m)*

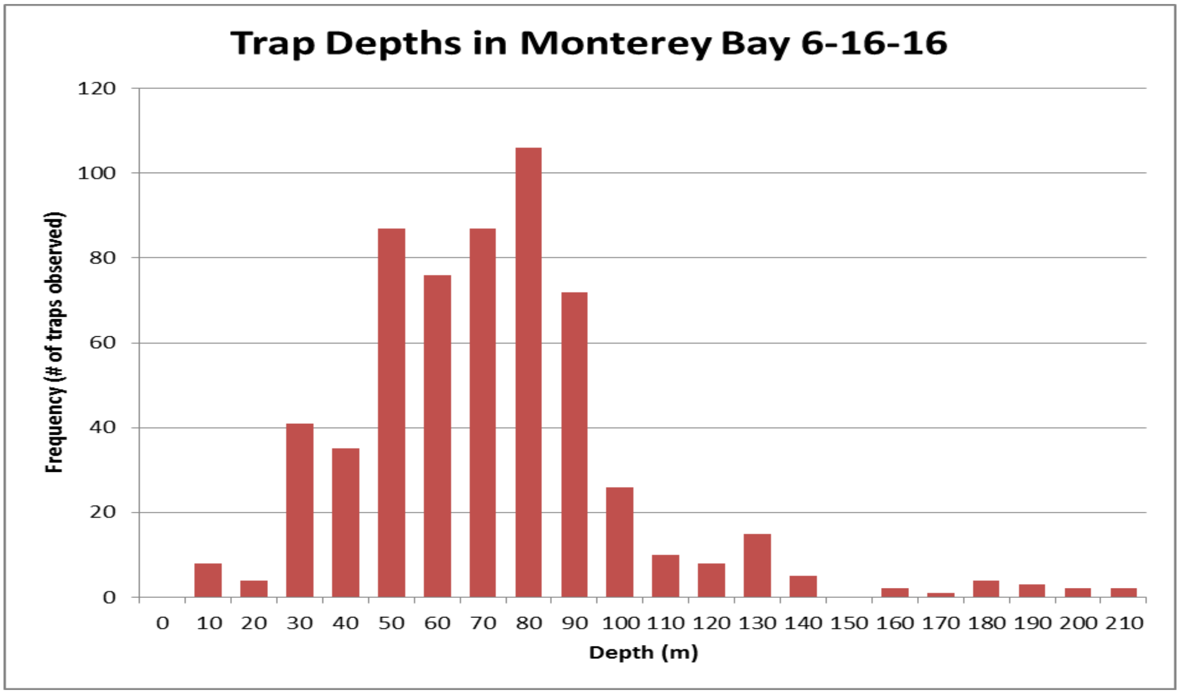

Figure 6. *Frequency histogram of the distribution of observed traps by depth range in Monterey Bay. Values refer to the lower end of a 10 meter range (e.g., "40" refers to traps within a depth range of 40-49 m).*

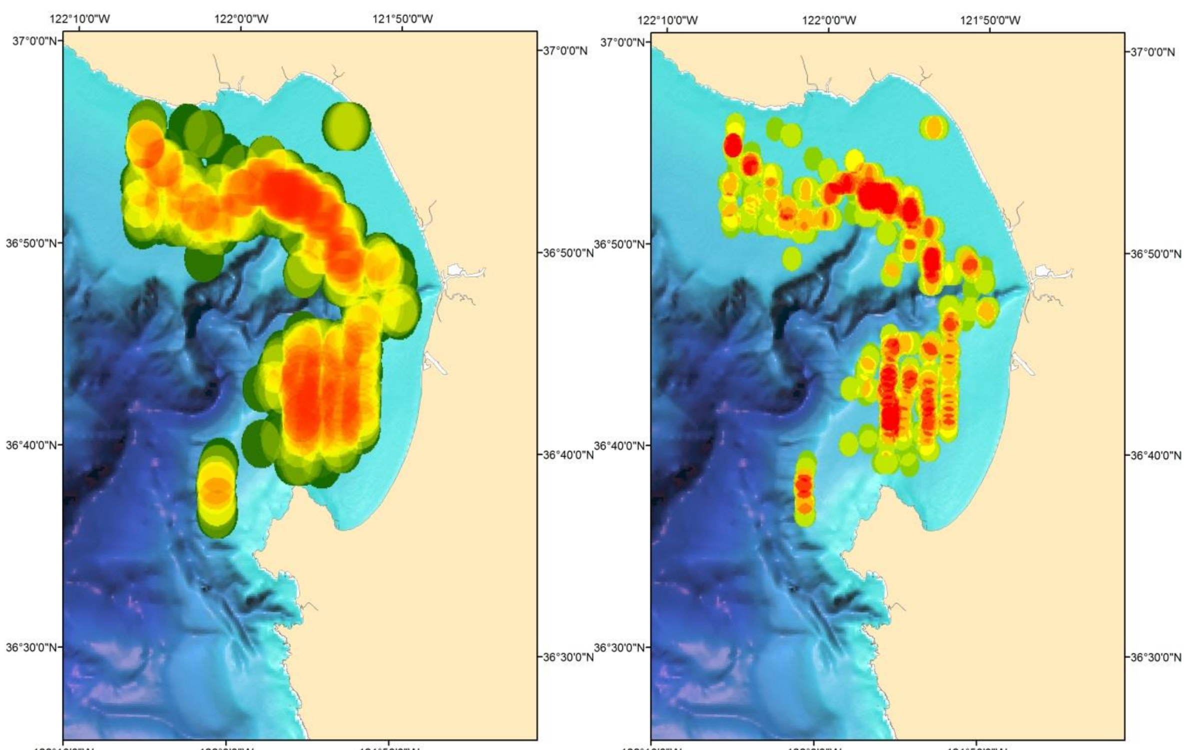

Figure 7. *Point density "heat map" of observed traps using 1 km radius (left) and 2 km radius (right), warmer (red) colors are higher relative density and cooler colors (green) are lower relative density.*

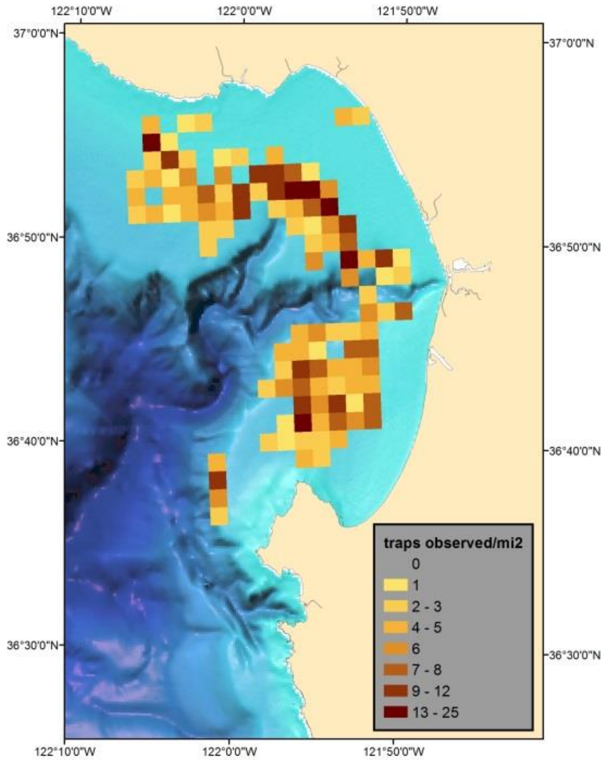

Figure 8*. Number of observed traps within each square statute mile grid cell.*

We observed one humpback whale along an active transect near Santa Cruz and another humpback whale near Santa Cruz while off an active transect. There were also several dozen small pods of dolphins, individual and groups of California sea lions, and likely hundreds of individual ocean sunfish visible from the air, however, we did not attempt to quantify these. The weather remained clear with zero cloud cover for the duration of the flight, and Beaufort sea state conditions remained from 1 to 2 (i.e., no whitecaps) throughout the survey. The westerly observation in the morning prevented glare from the sun, however, glare did begin to impede visibility of traps closer to the aircraft toward the end of the flight.

Estimation of trap density and total abundance

Based on the histogram of perpendicular distances for all detected crab traps, the data were truncated at 0.35 km to account for the reduced visibility under the aircraft, and at 1.5 km (eliminating about 3% of the most distant sightings) to improve model fit and robustness (Figure 9). The best-fitting model (minimizing AIC) was the half-normal function, resulting in an effective search width (*ESW*) of 0.378 km (Figure 10). The density of traps within the Monterey Bay study area was 2.28 traps per km^2, yielding a total estimate of 2,086 traps within the study area on June 16, 2016 (Table 1).

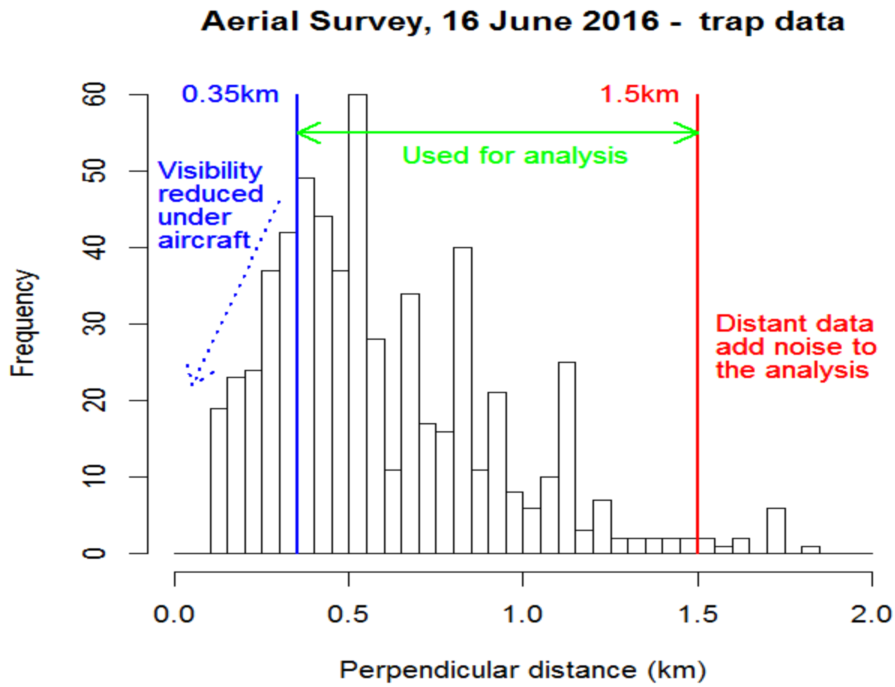

Figure 9*. Distribution of perpendicular distances from the transect line for all detected traps, with left- (blue) and right- (red) truncation distances used for the analysis. Left truncation is required because the aircraft did not allow downward viewing, and Distance Sampling assumes that detection probability decreases with increasing distance. Right truncation to eliminate a small percentage of the most distant sightings improves the robustness of the analysis. The sighting data within the range of the green arrow were included in the density estimation analyses.*

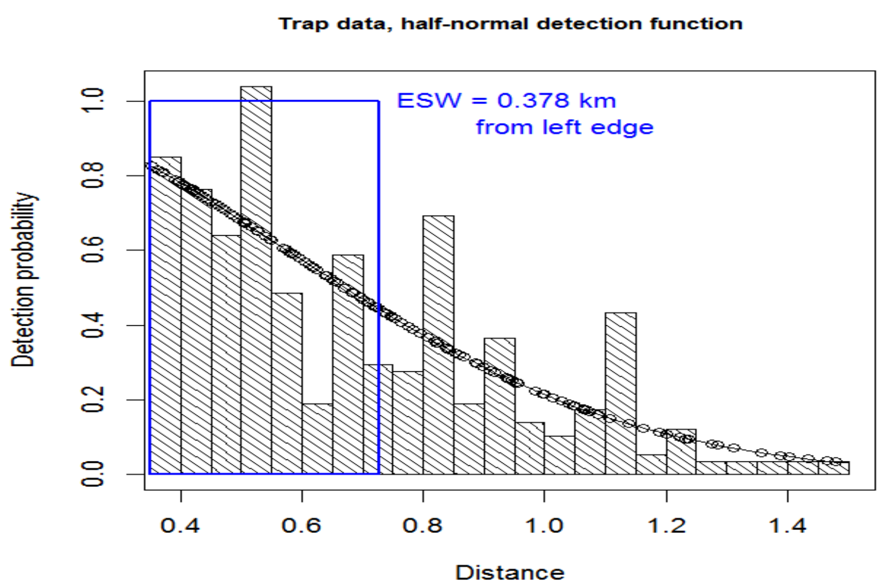

Figure 10. *Perpendicular distance distribution of observed traps (histogram) and detection function (line with circles), with resulting effective search width, ESW, shown in blue. Left-truncation distance is 0.35 km, right-truncation distance is 1.5 km.*

Table 1. *Summary of parameters and results of the distance sampling analysis to estimate density and abundance of traps within the Monterey Bay study area on 16 June 2016.*

		Value	**S.E.**	**C.V.**	**95% Conf. Interval**
Study area size (km^2)	*A*	915			
Transect length (km)	*L*	506.4			
No. traps (after truncation)	*n*	437			
Effective search width (km)	*ESW*	0.378			
Encounter rate (traps/km)	*n/L*	1.726	0.416	0.241	
Density (traps/km^2)	*D*	2.28	0.57	0.249	1.36 - 3.83
Abundance (# traps)	*N*	2,086	519	0.249	1,241 - 3,507

Discussion

This study confirmed that under favorable weather conditions, aerial surveys conducted by human observers in small, low-flying aircraft can obtain quantitative estimates of the total fishing effort at a regional scale, the depth distribution of traps, and identify areas of relative high and low abundance within a region at a fine (~1 km^2) spatial scale. In terms of trap distribution, point density maps at the scale of 1-2 km radius provided alternative ways to view the data, however, generally revealed the same hotspots (Figure). However, the point density approach appeared to be preferable for evaluating relative, rather than absolute densities. The grid approach is more systematic and allowed a quantitative evaluation of trap density, but may be less visually appealing. Further work is needed to explore the appropriate scales and analyses for evaluating relative trap density. Our survey was effective in assessing the depth distribution of traps, however, for steep drop-offs such as the canyon edges or shelf breaks where depth contours are close together, depth estimates are likely less precise.

This study represents a snapshot of trap distribution in Monterey at the end of an unusual fishing season with a delayed start due to an outbreak of domoic acid, and three weeks after an advisory that included requests to decrease overall fishing effort in Monterey Bay, and move traps away from the canyon edge. Since we do not have similar data prior to the issuance of the advisory or during similar months during previous seasons, the data do not allow a quantitative evaluation of the extent to which fishing effort decreased and/or redistributed in response to the advisory. However, our survey data indicate that fishing effort continued to occur in Monterey Bay, including along the canyon edges, three weeks after the advisory was issued.

From an observational and data collection standpoint, both the NOAA software and the manual method of data collection worked, it would help to streamline the recording of each trap by developing new software, such as a simple iPad app. In areas where there was a high abundance of traps, it was challenging to accurately record all the traps in view at an airspeed of 100 knots, therefore it is important to develop rapid means of counting and recording trap locations and angles. It may also prove challenging to attempt to simultaneously survey traps and whales (or other wildlife) without additional observers. However, having a single observer for the duration of the flight and a consistent viewing direction relative to the transect line (in this case due West), provided for more consistent trap detection ability and reduced the potential for an “observer” bias. Although a second observer would provide twice the effective area searched, the high densities of traps in some areas may be difficult to record accurately within a wider strip.

Weather conditions, sea state (Beaufort), wind, bird concentrations, and glare all affect the ability to accurately and consistently detect traps. While we had near ideal conditions, the presence of significant glare, white caps, or fog would make it impossible to conduct this survey. Therefore, the success in expanding this approach will depend on the flexibility in scheduling flights and accurately predicting good weather conditions. The estimated detection function and *ESW* in this study are based on the observed glare and sea state conditions, but if future surveys are conducted in different conditions, the effect of glare, sea state and cloud cover should be explored once sample sizes are sufficient. One caveat with our survey is that we did not distinguish between different types of fishing buoys; therefore the relative proportion of commercial vs. recreational traps is unknown, as well as the proportion of Dungeness crab traps versus those from other trap fisheries. However, it may be possible to distinguish these in the future, if clear visual criteria are established that enable observers to differentiate the gear types used in these fisheries from an altitude of 1000 feet.

The aerial survey method may have advantages and disadvantages over other approaches to estimate fishing effort. Further efforts to continue or expand this work should evaluate the costs of conducting aerial surveys relative to other techniques for determining fishing effort (i.e., fishing logbooks, electronic monitoring of fishing vessels, or vessel tracking systems), as well as safety considerations. Because of the inherent risk of flying over water in offshore areas, NOAA’s policy for aerial surveys requires that twin-engine aircrafts be used and that researchers receive specialized safety and survival training for overwater operations. NOAA has extensively used twin-engine Partenavia P-68 and DeHavilland Twin Otter aircraft for aerial surveys because of their excellent safety record and ability to continue flight using a single engine in the event of engine failure. These slightly larger aircraft also can accommodate additional observers, which would allow a two-sided survey instead of the one-sided survey conducted in this feasibility study. This would be particularly important if trap surveys are expanded to cover a larger geographic area, as the spacing between transects would have to be widened. The use of an aircraft with belly window and bubble windows to allow downward viewing would increase the precision and accuracy of future surveys.

In conclusion, relative to methods that infer fishing effort information from landings data, the aerial survey method provided more accurate and spatially resolved data. A key next step will be to further examine spatio-temporal patterns of whale abundance to improve upon existing co-occurrence models. Replicating this study during different time periods throughout a single fishing season and for multiple fishing seasons would enable a more complete understanding of fishing effort dynamics, particularly how fishing effort patterns may change over time.

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