ESTIMATING ABUNDANCE AND DISTRIBUTION OF JELLIES AS PREY FOR

LEATHERBACK TURTLES OFF THE COAST OF CENTRAL CALIFORNIA

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Erin E. Frolli

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ABSTRACT

ESTIMATING ABUNDANCE AND DISTRIBUTION OF JELLIES AS PREY FOR LEATHERBACK TURTLES OFF THE COST OF CENTRAL CALIFORNIA

The Pacific leatherback turtle (*Dermochelys coriacea*) has been listed as endangered throughout its range since 1970 and critically endangered since 2006. Recently, the pelagic foraging grounds along the U.S. west coast were deemed critical habitat for this species. To be declared critical foraging habitat, a location must have sufficient quantities of prey available. The goal of this study is to use aerial photographs collected in 2009, 2010, and 2011 to calibrate aerial observer data taken during leatherback surveys and to map jelly distributions. Observer data currently are limited to three density categories (low: 1-30 individuals, moderate: 31-300 individuals, and high: 301+ individuals) for all species seen. Relatively simple methods were used to find averages for jelly density categories observed during an aerial transect. This method allows for enumeration of jellies seen at any given time during the aerial transect and allows for an estimate of a minimum number of jellies seen in surface waters for that given monitoring year. Observer estimates were calibrated for two jelly species. For the brown sea nettles, their estimates are approximately low: 1-200 individuals, moderate: 201-500 individuals, and high: 501+ individuals. Similarly, the moon jellies estimates are approximately low: 1-300 individuals, moderate: 301-2,500 individuals, and high: 2,501+ individuals. The extensive data from this study can now be used to create habitat maps that can track the sustainability of the jelly aggregations over time. This will allow for long term monitoring for jelly abundance and sustainability and provide further information for management of the designated critical foraging habitats along the U.S. west coast.

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TABLE OF CONTENTS

LISTS OF TABLES

TABLE PAGE

LISTS OF FIGURES

FIGURE PAGE

LISTS OF FIGURE - CONTINUED

FIGURE PAGE

INTRODUCTION

The central California coast has a diverse gelatinous population due to upwelling events that occur along the coast (Graham et al. 1992, Graham and Largier 1997, Graham et al. 2001). Upwelling is the process in which deep, cold water rises toward the surface and creates water rich in nutrients after wind events. The newly exposed nutrients allow for surface waters to have high biological productivity. This extreme oceanographic variability allows for zooplankton populations to flourish year-round (Graham et al. 1992, Graham and Largier 1997). Zooplanktons such as jellies are no exception. These upwelling events create opportunities for large scyphozoan jellies to form large blooms when conditions are right (Graham et al. 1992, Graham and Largier 1997, Graham et al. 2001). This is especially true after upwelling events during summer months (Benson et al. 2007b, Graham et al. 1992, Graham and Largier 1997, Graham et al. 2001).

There are four common species of large scyphozoan jellies that form extensive aggregations during warm water months (late summer and early fall) off the coast of central California: *Aurelia* spp. (moon jelly), *Chrysaora colorata* (purple stripe jelly), *Chrysaora fuscescens* (brown sea nettle), and *Phacellophora camtchatica* (egg yolk jelly). All four species are large (an average size of 46 cm in diameter) and can be found close to shore (Graham 2009, Graham et al. 2001, Graham et al. 2001). Distribution and abundance of these jellies is poorly understood and data are scarce for these populations off the coast of central California.

Jelly populations are important to understand for many reasons. However, this research will focus on jellies and their importance as prey for the federally listed endangered Pacific leatherback turtle (U.S. Endangered Species Act 35 FR 8495, 2 June 1970, Sarti Martinez 2010). The leatherback turtle (*Dermochelys coriacea*) is the largest sea turtle and one of the larger reptiles in the world (NOAA Fisheries 2010). They are unique in many ways but most importantly leatherbacks are poikilotherms, meaning that they acquire their heat from the surrounding environment and movement (NOAA Fisheries 2010). However, leatherbacks also have a thermoregulatory adaptation that allows them to maintain a higher body temperature than that of the surrounding waters by using counter-current heat exchange within their blood vessels while they swim (NOAA Fisheries 2010). This adaptation coupled with large stores of oil and large body size allows leatherbacks to have a higher tolerance for cooler water temperatures which allows them to have a wide foraging range (Benson et al. 2007a, Benson et al. 2007b, NOAA Fisheries 2010). Leatherbacks are known to have large migrations and the Pacific leatherback population in particular has as many as three main foraging locations including the South China Sea, Kuroshio Extension, and the California Current Ecosystem (Benson et al. 2007a). The focus of this study is the leatherback turtles that migrate across the Pacific to the California Current Ecosystem to forage on scyphozoan jellies in neritic waters off of California, Oregon, and Washington (Benson et al. 2007a, Benson et al. 2007b).

For the last several years, the National Oceanic and Atmospheric Administration (NOAA) have tracked the distribution and abundance of both leatherback turtles and jellies along the U.S. west coast (Benson et al. 2007b). This project has led to the designation of two critical foraging habitats, one of which includes Monterey Bay and surrounding waters (Benson et al. 2007b, NOAA Fisheries 2010, Fig 1). The development of designated critical foraging habitat was based on several factors, but primarily on the abundance of leatherback turtles and a sustainable stock of available prey (jellies) (Benson et al. 2007b).

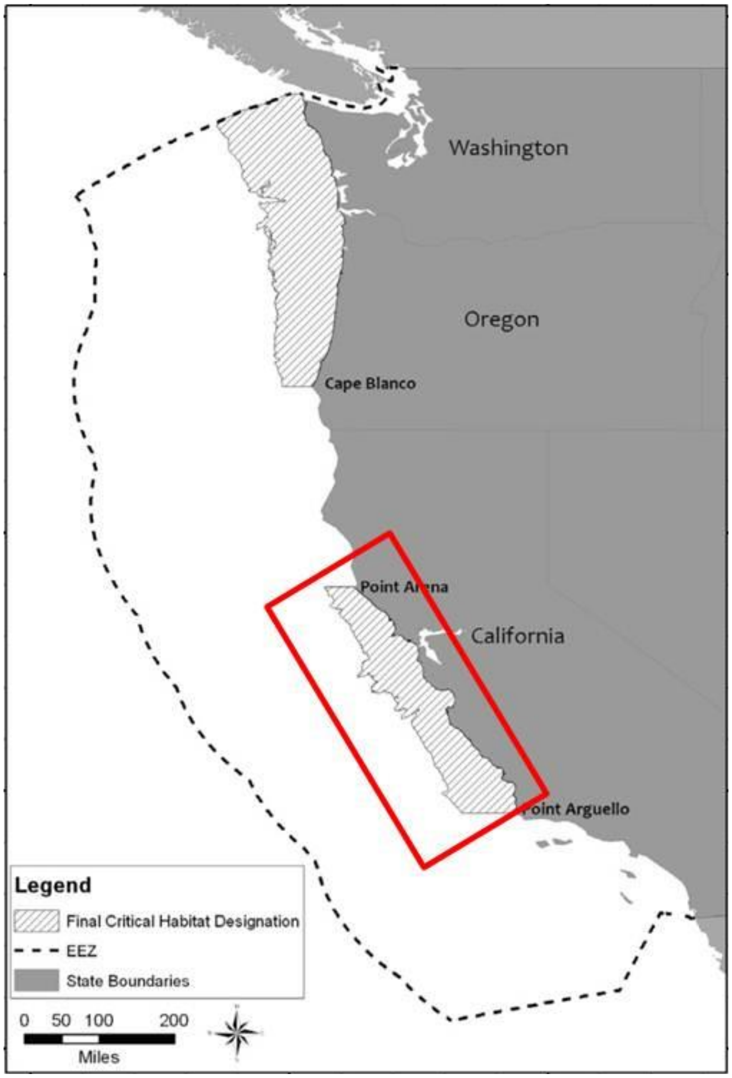

Figure 1: Map of the 2012 U.S. west coast leatherback critical foraging habitat designations (shaded areas) with in the U.S. Exclusive Economic Zone (EEZ). Central California designation highlighted with a red box (figure from NOAA Fisheries 2010).

To manage the critical habitat, long term monitoring methods are required. Currently, aerial survey methods are used to monitor leatherback and jelly distribution and abundance in the waters off of central California (Benson et al. 2007b). Aerial surveys indicate leatherback turtles and jellies are primarily found in retention zones along the coast (Benson et al. 2007b). Though there have been efforts to track jelly abundance during these surveys, they are recorded qualitatively. Tracking the sustainability of the jelly population in the designated foraging grounds is vital to understanding the boundaries of the critical habitat for management purposes. To track the sustainability of the jelly population, there is a need to quantitatively assess the count of jelly aggregations within and outside of the critical habitat designation.

Several methods have been used to obtain jelly abundance in the past, including but not limited to, camera sleds, net trawls, side-scan sonar, and bottom-facing acoustic echosounders (Purcell et al. 2000, Graham et al. 2003, Houghton 2006, Graham 2009). Net trawls are the most widely used method for collecting jelly abundance, but they are the least accurate in assessing the entire aggregation (Graham et al. 2003, Houghton 2006, Graham 2009). This method also has the most potential to harm jellies, because animals tend to get dragged through the net and ripped up by the force of the boat's movement (Graham et al. 2003, Graham 2009). Camera sleds, side-scan sonar, and bottom-facing acoustic echosounders are better at observing jellies *in situ*; however, they require net trawls to confirm the number of jellies seen by the equipment (Graham et al.2003). Most of these methods are conducted by boat transects and are limited to relatively small areas due to the patchiness of the aggregations (Purcell et al. 2000, Graham et al.2003, Houghton 2006, Graham 2009). In addition, these methods do not accurately assess the entire depth of the aggregation. Due to the orientation of the equipment, these methods are not reliable in the upper few meters of the water where jellies can form large surface aggregations (Purcell et al. 2000, Graham et al. 2003) and where leatherback turtles concentrate their dive time (Benson et al. 2007b).

Other methods used to assess broader scales of jelly abundance include using qualitative observer scoring indexes (Benson et al. 2007b, Houghton 2006). For both boat and aerial surveys, observers note the density categories of the jelly aggregation at the time of survey (Benson et al. 2007b, Houghton 2006). Observer visibility on average is up to one meter in depth; however the full extent of the aggregation is covered, thus allowing for the estimation of the aggregation's patchiness (Benson et al. 2007b, Houghton 2006).

Observer data are currently limited to three density categories (low: 1-30 individuals, moderate: 31-300 individuals, and high: 301+ individuals) for all species. To better understand jelly abundance, quantitative versus qualitative estimates are necessary in furthering leatherback foraging viability.

The first goal of this study was to apply the method established in Frolli et al. (2012), a simple method to calibrate observer estimates using a detection algorithm, to aerial photographs taken during aerial surveys in 2009, 2010, and 2011. This qualitative improvement allows for a more an accurate density category estimate based on the number of individual jellies found.

Not only do the original observer guidelines need to be calibrated, variables such as differences in species and observation years need be included in the calibration. If there is a significant difference in how the jellies aggregate, then observer guidelines must be calibrated to meet these differences. Otherwise, an overall average with no species differentiation is used for survey data past and present. Therefore, the data was separated by species and a test was used to determine statistical significance between species. Additionally if there was a significant difference in abundance between years, then observer estimates would have to be calibrated annually. Consequently, the difference in abundance between observation years, whether by species or jellies as a whole, was tested.

The second goal of this study was to incorporate the new observer guidelines with aerial observer data to create more accurate jelly distribution maps.

METHODS

Aerial Observer Methods

Aerial line-transect surveys were conducted for leatherback turtles in the fall of 2009, 2010, and 2011 off the coast of central California (Fig. 2). For the month of September for each year, aerial flights were flown in central California primarily in the San Francisco Bay and Monterey Bay region. All flights were conducted on days when weather conditions were appropriate for observation. All fine-scale transects were flown using a twin engine fixed-wing aircraft (The Partenavia, P 68-OBS “Observer”). The aircraft was flown at an average height of 198 m above the surface of the water with a speed of 90-100 knots following methods described by Forney et al. 1991 and Benson et al. 2007b.

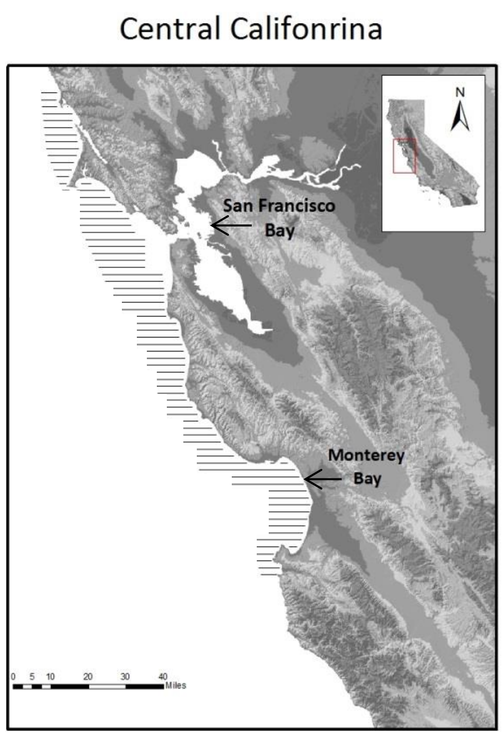

Figure 2: Map of the central California study site with aerial transect lines (<30 km in length) ranging from Half Moon Bay (north) to Carmel Bay (south).

Aerial observers during flights were required to count and track individual turtles, large marine mammals, jelly density conditions, weather conditions and viewing conditions, and most importantly, to help the boat find and collect turtles for tagging and data collection. Three aerial observers continuously assessed the jelly density categories using a qualitative scoring index: low (1-30 individual jellies), moderate (31-300 individual jellies), and high (301+ individuals). For every density change, the data recorder acquired a GPS point and recorded the change. Also during flights, an observer positioned in the "belly" of the plane opportunistically took digital photographs of jelly aggregations through a floor window. All photographs were stored on a hard drive for later analysis.

Analyzing the Aerial Photographs

More than 1,000 photographs were taken over the three year period. To ensure that images could be used to count jellies, photographs were eliminated from the data set based on factors such as glare, absence of jellies, and fog. Out of the remaining photographs, 135 were analyzed. All images were categorized by species to match the observer qualitative jelly density categories of low, moderate, or high using the image time stamp. Of all four jelly species common to the area, only two species dominated the habitat and had enough photographs to analyze: the brown sea nettle and the moon jelly. Data summarized below only account for these two species. Each photograph was analyzed using the detection algorithm outlined Frolli et al. (2012).

This algorithm was designed to incorporate the color properties of each photograph to count total number of individual jellies, by using the red, green, and blue values (RGB values). To create the RGB value requirements for "jelly color", 100 randomly selected jellies from within each photograph were sampled. Then the sampled pixel range was used to set up the maximum and minimum requirements for the algorithms "jelly color" parameters. Once the algorithm was applied to each photograph all pixels that met the "jelly color" parameters were counted. Then the average size of a jelly (in pixels) was divided by the total number of pixels derived by the algorithm to give total number of jellies in each photograph (Appendix A).

Analyzing the Aerial Observer Counts: Statistical Methods

The aerial observer data were separated by species and a Student's t-test was used to assess the difference between the measured abundance of brown sea nettles and moon jellies. This test is important for understanding if the guidelines should be calibrated overall or by species. To decide if the calibration method should be conducted annually, one-way ANOVA's were used to test the difference in jelly abundance for each species between years (2009, 2010, and 2011). If there is large variance between sampling years, observer guidelines must be changed annually; however t if there is little variance then an overall mean can be used to represent the number of jellies found for each jelly density category.

Jelly Distribution and Abundance Maps

Once the mean for each density category was determined, observer original guidelines were adjusted to calibrate the observer data for each fight day. Jelly and turtle distribution data were taken directly from the sightings data for each year (2010 and 2011). The survey data were provided for separate days during the flights. Each data set was appropriately filtered to include desired variables, such as jelly abundance of brown sea nettle, moon jellies, and turtle sightings. Using ArcGIS software (ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.), distribution maps were generated for each species. Since jellies are able to move vertically through the water column, distribution maps were made for each flight day to depict vertical and horizontal migration changes in jelly abundance.

Individual spatial layers were created for each jelly density category. For each layer, a total number of jellies and area were calculated.

For overall jelly distribution in a given year, the jelly abundance averages between all flight data were used to build annual distribution maps. Additionally, turtle sightings were included on annual distribution maps to depict turtle location in relation to jelly abundance.

RESULTS

Analyzing Photographs

More than 135 photographs were used to analyze jelly abundance. The average surface area captured by the camera during flights was 902,785 m^2. Using methods described in Frolli et al. (2012), the mean numbers of jellies observed in the aerial photographs for a given year are summarized for each species by observer density category in Tables 1 and 2.

Table 1: Mean number of brown sea nettles observed each year

Category Type	2009	2010	2011	Total	SD
Low	165	158	170	**164**	**6**
Mid	319	307	393	**340**	**47**
High	541	609	681	**610**	**70**

Table 2: Mean number of moon jellies observed each year

Category Type	2009	2010	2011	Total	SD
Low	53	37	50	**47**	**9**
Mid	1235	1318	2353	**1635**	**623**
High	3474	3352	4574	**3800**	**674**

To better understand the differences between species, the overall average for each density category for each species was plotted (Fig. 3).

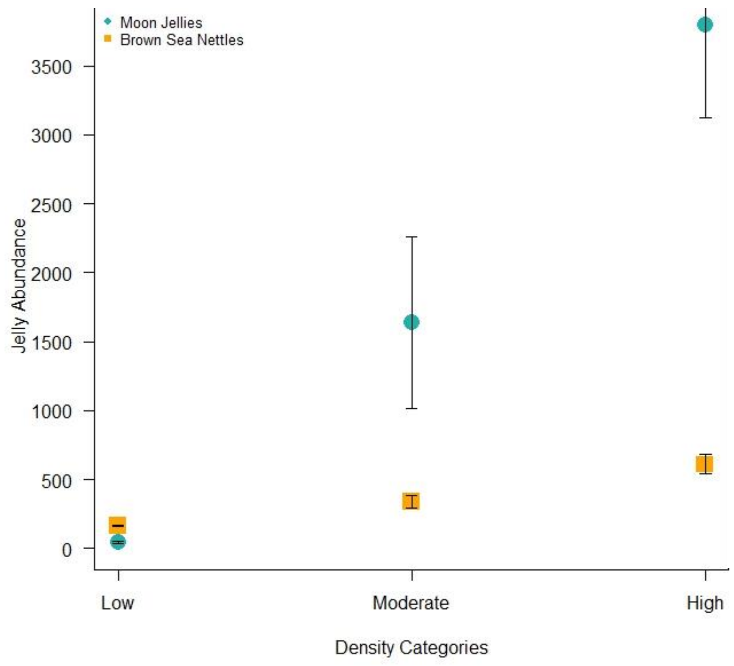

Figure 3. Overall average (for all three years 2009, 2010, 2011) with standard deviation error bars for both the brown sea nettles and moon jellies observed for each observer density category (low, moderate, and high).

There is clearly a visual difference in jelly abundance between species, especially in the moderate to high observer density categories (Fig. 3). When tested for a difference in abundance between species, there was a significant difference between the brown sea nettle and the moon jelly abundance overall ($t = -2.56$, $p = 0.021$). This is important because the density categories for both the brown sea nettle and the moon jelly can be calibrated separately. Thus correcting for the original one size fits all description to have individual category sizes for each species.

Calibrating for Brown Sea Nettles

No significant difference in abundance was found between years for the brown sea nettle ($F = 0.181$, $p = 0.685$). New calibrated estimates for the brown sea nettle can be seen in Figure 4. This new calibration has shown that when observers record low brown sea nettles their estimates are approximately 1-200 jellies rather than the previous 1-30 jellies. For moderate the estimate is approximately 201-500 jellies rather than the previous 30-300 jellies. And finally for the high category the estimate is approximately 501+ rather than the previous 301+ jellies.

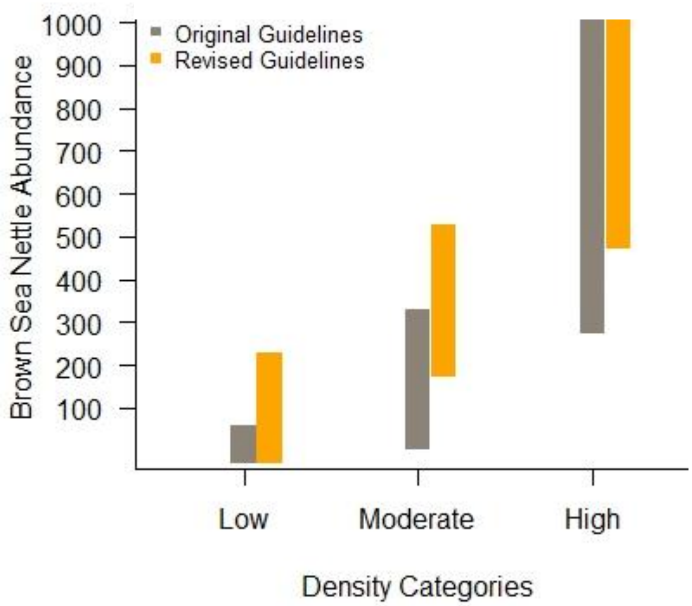

Figure 4. Bar graphs representing the original observer density category guidelines for brown sea nettles (low: 1-30 individual jellies; moderate: 31-300 individuals; high: 301+ individuals) in grey, and the revised guidelines in orange (low: 1-200 individual jellies; moderate: 201-500; high: 501+).

Calibrating for Moon Jellies

No significant difference in abundance was found between years for the moon jellies ($F= 0$, $p = 0.984$). New calibrated estimates for the moon jellies can be seen in Figure 5.

This new calibration has shown that when observers record low moon jellies their estimates are approximately 1-300 jellies rather than the previous 1-30 jellies. For moderate the estimate is approximately 301-2,500 jellies rather than the previous 30-300 jellies. And finally for the high category the estimate is approximately 2,501+ rather than the previous 301+ jellies.

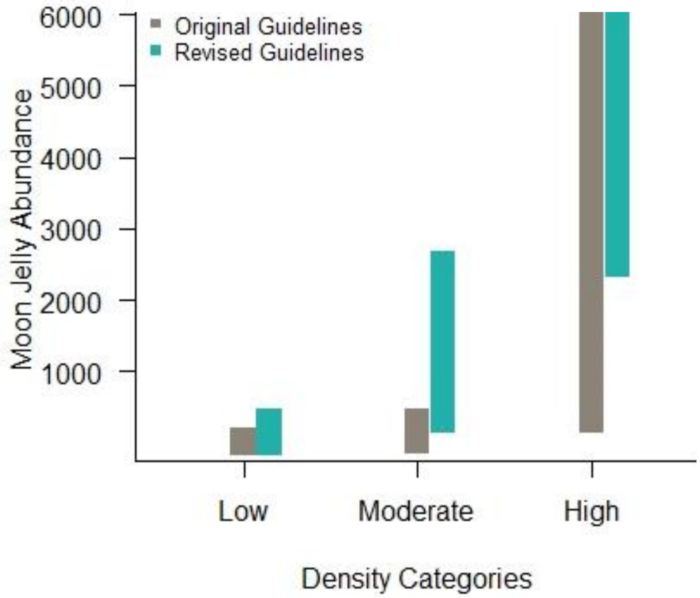

Figure 5. Bar graphs representing the original observer density category guidelines for moon jellies (low:1-30 individual jellies; moderate: 31-300 individuals; high: 301 + individuals) in grey, and the revised guidelines in light blue (low: 1-300 individual jellies; moderate: 301-2,500; high: 2,501 +).

Jelly Distribution and Abundance Maps

Distribution maps were made for every flight day. Figures 6 and 7 for example show the variability of sighting the aggregation at the surface of the water on different flight days.

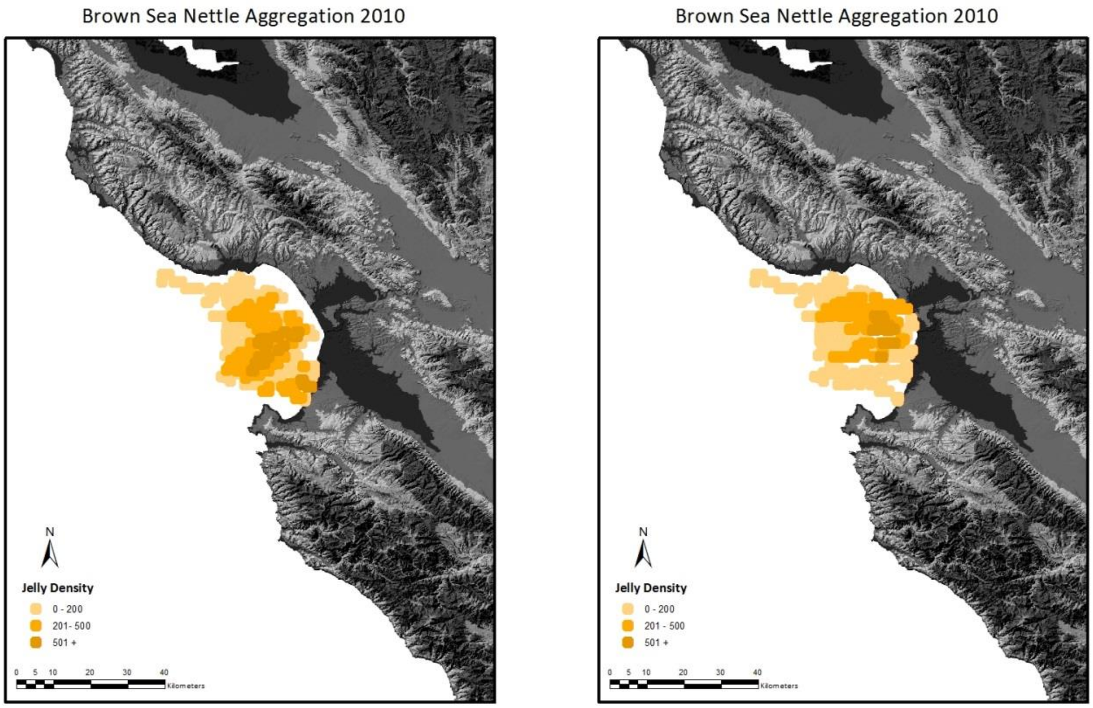

Figure 6. Brown sea nettle distribution maps for 2010. Left: Map of brown sea nettle aggregation in Monterey Bay day 2 of the flight season. Right: Map of brown sea nettle aggregation in Monterey Bay day 3 of the flight season.

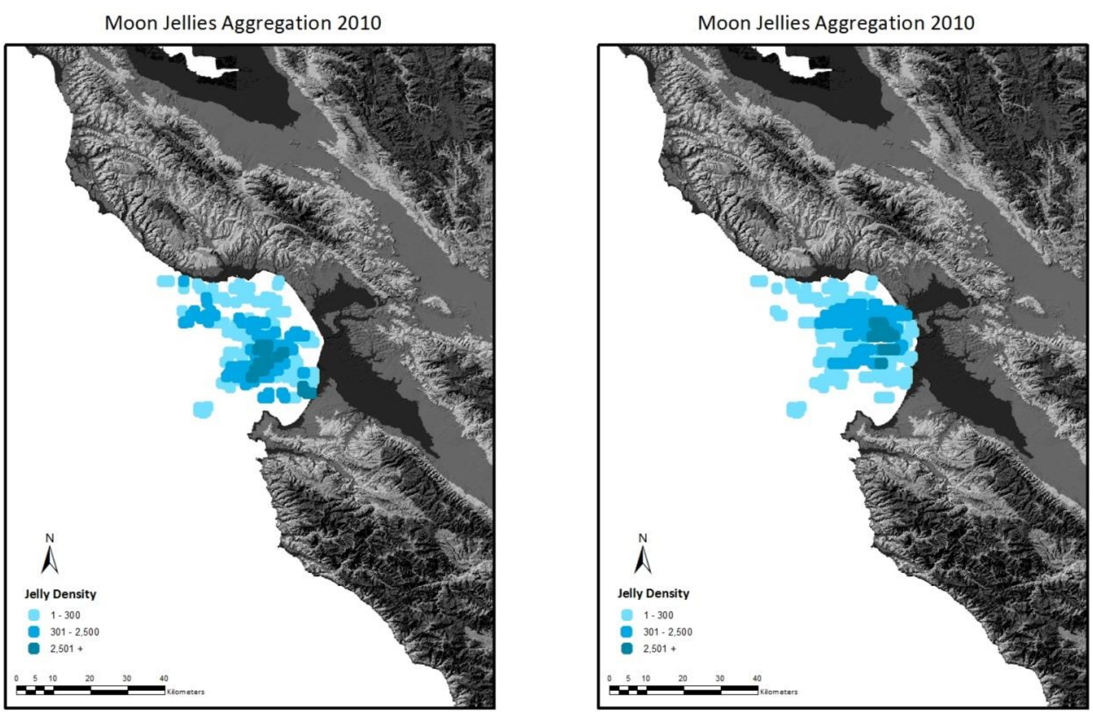

Figure 7. Moon jelly distribution maps for 2010. Left: Map of moon jelly aggregations in Monterey Bay day 2 of the flight season. Right: Map of moon jelly aggregations in Monterey Bay day 3 of the flight season.

To depict the trends of these jelly populations, annual distribution maps were made for 2010 and 2011 (Fig. 8 and 9). The average area surveyed in the Monterey Bay region for both years was about 31,409 km^2. The annual average of total jellies seen for this area was 436,793 $\pm$ 474 individuals. Average density of brown see nettles sighted by observers was 0.0066 jellies/m^2. Similarly the average density for the moon jellies sighted by observers was 0.0073 jellies/m^2. Leatherback turtles were often sighted on the edges of high density patches (Fig. 8 and 9).

Annual Jelly Aggregation 2010

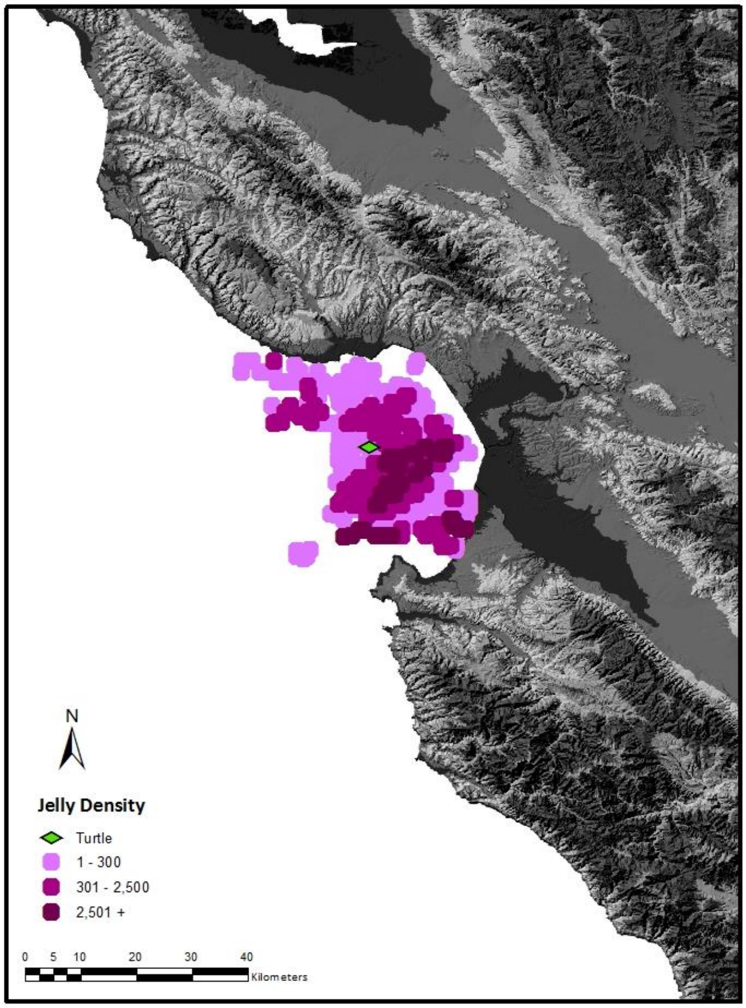

Figure 8. Annual jelly and turtle distribution map for 2010. Jelly distributions are in light to dark purple and leatherback sightings are in green.

Annual Jelly Aggregation 2011

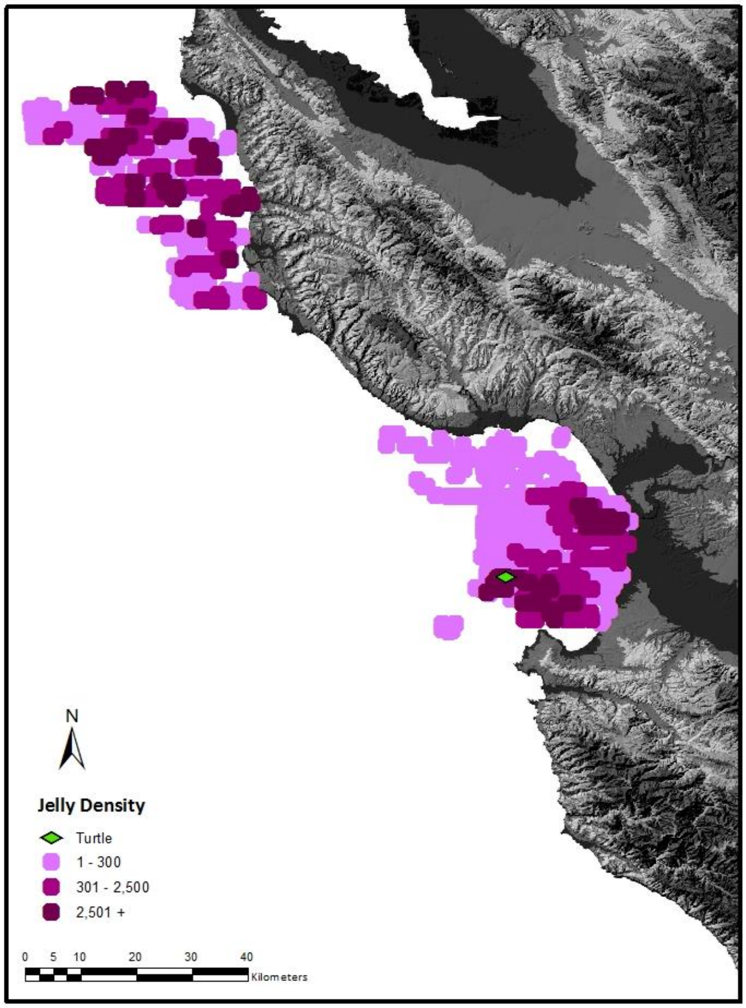

Figure 9. Annual jelly and turtle distribution map for 2011. Jelly distributions are in light to dark purple and leatherback sightings are in green.

DISCUSSION

Understanding predator-prey interactions is essential for the protection and management of the leatherback turtle in the critical habitat designation (Benson et al. 2007b). Aerial surveys conducted by NOAA track both leatherback and jelly distribution and abundance (Benson et al. 2007b). In the past, jelly distributions and abundance were monitored qualitatively (Benson et al. 2007b, Houghton 2006). For management purposes, quantitative estimates of jelly distributions and abundance are needed (Benson et al. 2007b).

Our recently developed method gives us the ability to quantitatively estimate jelly abundance in surface waters. This study provides an example of how these methods can be utilized to understand both past and present aerial observer data. Using photographs taken from a three year period, we quantified inaccuracies based on the original, qualitative observer guidelines. In the past, abundance data were limited to three density categories (low, moderate and high) for all species observed (Benson et al. 2007b). This study demonstrated that the population densities were underestimated, and in fact the jelly density categories are statistically different within each category as well as for each species. The two species observed in this study were found to have significantly different abundances within each category. Moon jellies were found to have on average more individuals in the moderate and high categories than that the brown sea nettle (Fig. 5). There are several factors that can contribute to this difference. For example, each species aggregates differently based on several factors including size, shape, and environmental conditions (Decker et al. 2007, Purcell et al. 2000, Graham et al. 2003, Houghton 2006, Graham 2009, Lynam et al. 2004, Lynam et al. 2005). Aggregation difference can also be contributed to how jellies interact with each other (Matanoski et al. 2001, Suchman et al. 2008). Moon jellies tend to have relatively short oral arms and can easily stack on top of each other while searching for prey (author observation). Brown sea nettles have long oral arms and tend to spread out more to avoid entanglement (author observation). Thus the ability for observers to see the same number of jellies in a singular area is limited by the species and how they aggregate at the surface.

Another factor that contributed to observer category calibrations was annual variability. From the three years of data provided in this study, we found that there were no significant differences in abundance from year to year for each species. This is very important because the mean values for jelly abundance can be used on both past and present survey data, assuming that the environmental conditions for these years are similar. Because jellies are responsive to changes in environmental conditions, there is no need to resample the population annually unless there are large changes in environmental conditions (Decker et al. 2007, Purcell et al. 2000, Graham et al. 2003, Houghton 2006, Graham 2009, Lynam et al. 2004, Lynam et al. 2005, Suchman et al. 2012).

With the new revised observer guidelines for each species (Fig. 4), habitat maps with more accurate jelly abundance estimates for surface aggregations were made. Though there was variability in the ability to detect jellies at the surface (based on species vertical migration habits), this is an important first step towards understanding the distribution and patchiness of the jelly aggregations.

Even though these annual abundance estimates are not representative of the whole jelly aggregation, we can now interpret the area and patchiness of surface aggregation. By knowing the minimum numbers of jellies observed at the surface of the aggregation we can estimate the number of jellies that were observed where leatherbacks were sighted. The annual maps (Fig. 8

and 9) showed that leatherback turtles spend their concentration of dive time on the outer edges of high aggregations of jellies witch is consistent with other observations (Benson et al. 2007b).

The results of the data analysis from this study can be used to create habitat maps that can track distribution and abundance of jelly aggregations over time. We have documented a method that enables us to assess the jelly stocks from all past and future data. Further steps can explore how using the new observer guidelines and other data such as oceanographic conditions, wind abundance, and jelly prey availability can help to explain differences in jelly aggregations both internally and annually (Decker et al. 2007). This will allow for long term monitoring of jelly abundance and sustainability and provide further information for management of the two designated critical foraging habitats along the U.S. west coast.

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APPENDIX A

Schematic: Frolli, E.E., L. Webb, S.R. Benson. 2012. A Novel Method to Estimate Distribution and Abundance of Jellies in Surface Waters off Central California as Prey for the Prey for the Critically Endangered Leatherback Turtle (*Dermochelys coriacea*). Unpublished undergraduate thesis. California State University, Monterey Bay.

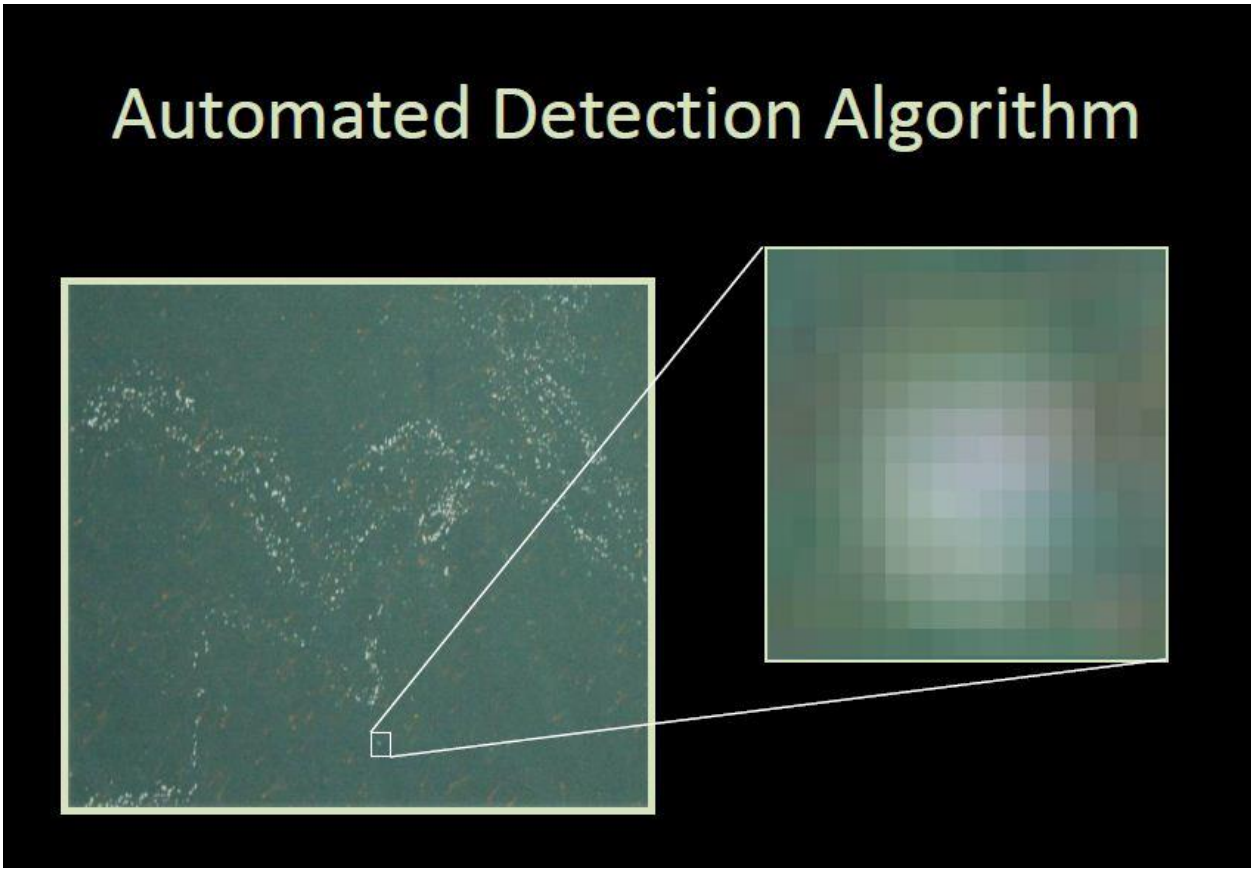

Figure 1. Aerial photograph example zoomed into a moon jelly.

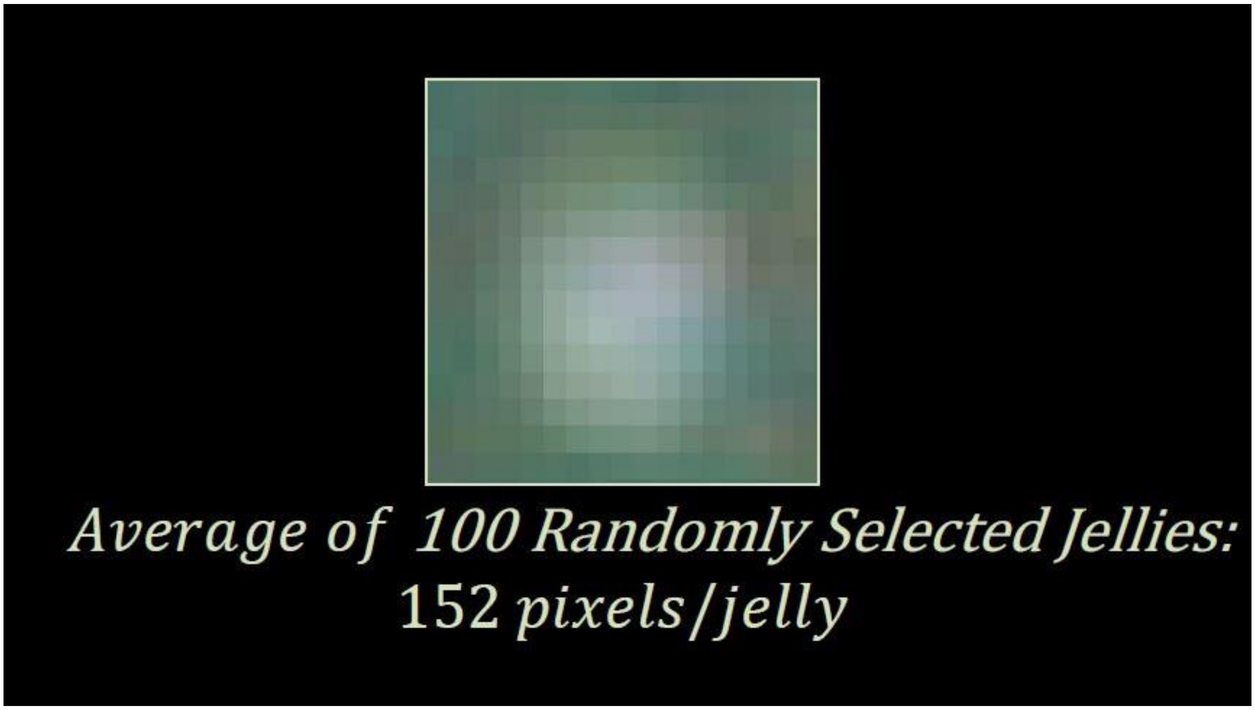

Figure 2. Average size of a moon jelly in pixels.

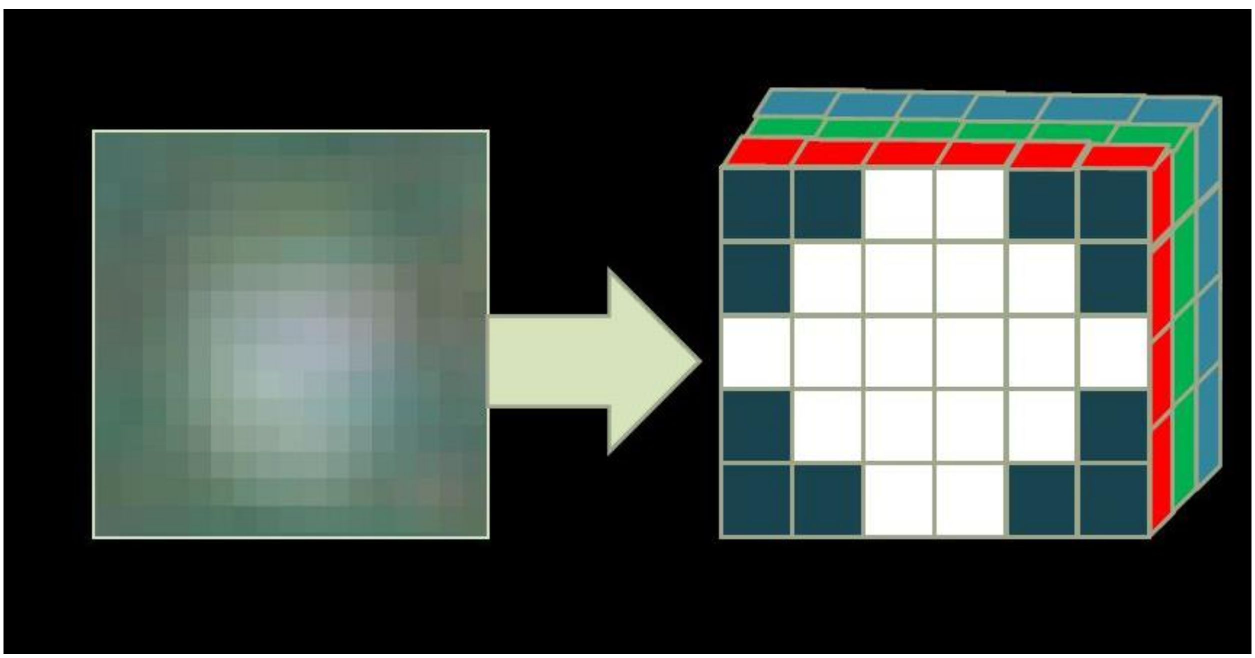

Figure 3. Cartoon representation of the zoomed in moon jelly.

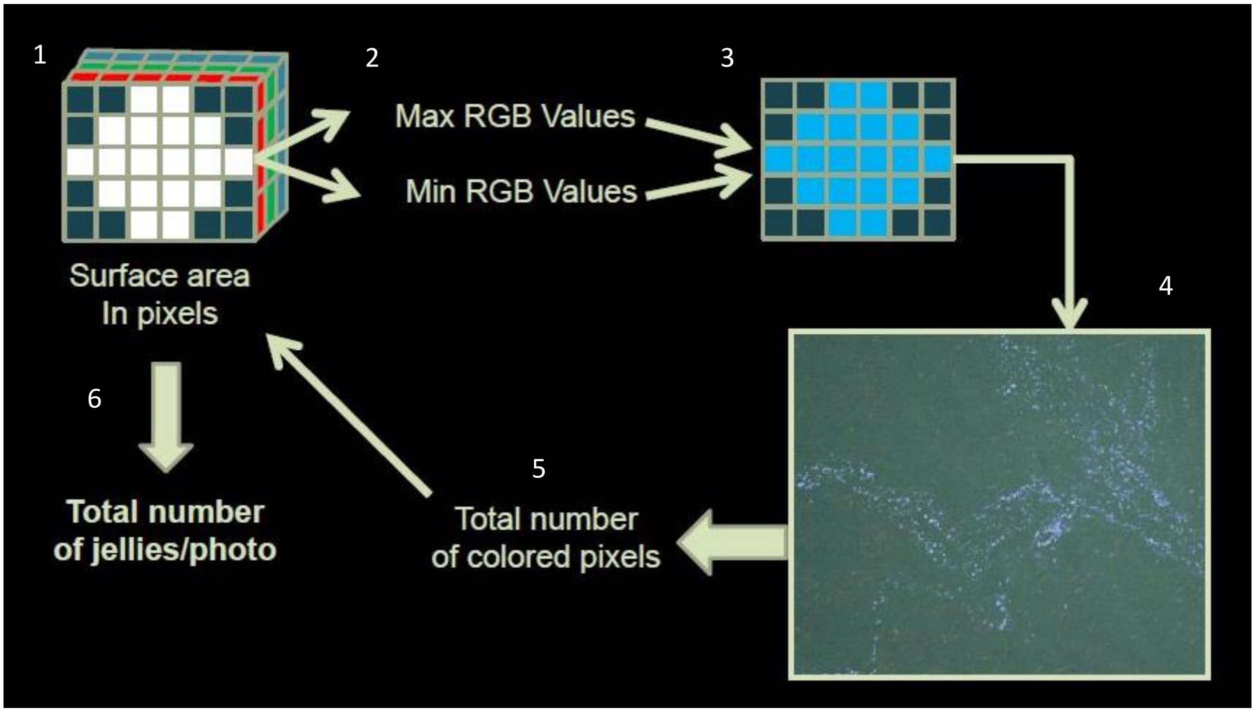

Figure 4. Diagram of the detection algorithm.
1) Randomly selected jellies in each photograph were used to sample RGB values from all four sections of the photograph.
2) Algorithm parameters are based on RGB Values of maximum and minimum requirements.
3) Algorithm searches for all pixels in the photograph that meet "jelly color" parameters.
4). Algorithm searches the entire photograph counting all pixels that meet the requirement.
5) Algorithm produces the total number of pixels that meet the requirements.
6) Divide total number of "jelly color" pixels by surface area of jellies to get total number of jellies per photograph.