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Marine Debris Visual Identification Assessment

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Abstract:

Estimates of marine debris are often based on beach surveys. Few studies have documented the veracity of these observations and the factors that may affect accuracy. Our laboratory-scale experiment identified potential sources of error associated with visual identification of marine debris (1-2 cm long) during shoreline surveys of sand beaches. Characteristics of the survey site (beach characteristics), observer (personal characteristics), and debris (color and size) may be important factors to consider when analyzing data from shoreline surveys. The results of this study show that the ability of individuals to accurately identify plastic fragments depends on the plastic and sand color, and density of shell fragments. Most suggestively, the high accuracy of blue plastic counts (95%) and the under-counting of white (50%) and clear plastic counts (55%) confirmed the hypothesis that a significant amount of clear and white plastic fragments may be missed during shoreline surveys. These results highlight the need for further research and possible modifications of visual shoreline survey methodologies in order to optimize this cost-effective method of marine debris monitoring.

1. Introduction

Marine debris is a burgeoning global issue that threatens marine biota and ecosystems, as well as human health, safety, and the economy (UNEP 2014). Globally, plastics are the most common type of marine debris (Coe and Rogers, 1997; Derraik, 2002). Ubiquitous in the marine environment, plastics have been documented in every part of the ocean, including Arctic sea ice (UNEP, 2014). Jambeck et al. (2015) estimated that 275 million metric tons of plastic debris were produced by 192 coastal countries in 2010. Their report suggested that 4.8 - 12.7 million metric tons of debris were input to the world's oceans that year. In 2014, Eriksen et al., (2014) estimated that 5.25 trillion plastic particles were present in the oceans.

By 2025, the amount of plastic being input to the world's oceans could increase by an order of magnitude, unless significant steps are taken to improve waste management infrastructure in coastal countries (Jambeck et al., 2015). In order to minimize marine debris on a global scale, the problem needs to be recognized, understood, and addressed on the international and local levels. In 2009, the United Nations Environment Program (UNEP) developed the Regional Seas Programme (RSP) to respond to the marine plastic debris issue and to collect and distribute information (Vegter et al., 2014). In total, there are 18 regions recognized within the RSP. For the majority of these regions, minimal data exist on the extent of plastic pollution. Furthermore, there are no data standards (i.e., standardized survey and reporting protocols, size classification, debris type classification), and few countries acknowledge marine plastics as a problem (Vegter et al., 2014). Without a scientifically-based global and local understanding of plastic pollution, it is likely that there will be insufficient governmental and public motivation to make the changes urgently needed.

One of the most common and well established methods for determining marine plastic pollution is shoreline or "beach" surveying (Cheshire et al., 2009). Shoreline surveys provide estimates of plastic loads in coastal waters (Thiel et al., 2013; Ribic et al., 1992), and are far more economically viable than at-sea surveying (Morishige et al., 2007). Shoreline surveys are often conducted by volunteers (citizen scientists) and can be highly effective in increasing social awareness, a key factor in addressing the marine plastics issue holistically (Vegter et al., 2014). With increased social awareness, the marine plastics issue can be addressed in a variety of ways, including changes to consumer behavior.

According to a recently published list of global research priorities to mitigate plastic pollution impacts on wildlife, one of the greatest limitations to the quantification of marine plastic debris loadings is the dependence on the human eye (Vegter et al., 2014). This issue is not specific to citizen scientists. Hardesty et al. (2014) found that citizen scientist-generated marine debris data are comparable to those collected by trained scientists.

In 2015, marine debris surveys were conducted as part of a collaboration between the Commonwealth Scientific and Industrial Research Organization (CSIRO) (Perth, Australia) and the University of New Hampshire (UNH) Coastal Response Research Center (CRRC) (Durham, NH) along the coastline of the Great Australian Bight (GAB). For the GAB survey, >64 kilometers of beach were surveyed and the most common debris item found was small (1-2 cm) (within meso-litter size range under European OSPAR beach litter monitoring protocol) plastic fragments (Unpublished Data, 2015). Exposure to ambient UV radiation, as well as the ocean's physical, chemical, and biological processes, results in plastic fragmentation and size reduction (UNEP, 2014). This leads to the increased presence of meso-(0.5 - 2.5 cm) and micro-sized (0.1 - 0.5 cm) plastic particles, which can be difficult to see.

Certain protocols exclude smaller size ranges from visual surveys and only log debris greater than 2.5 cm, as this is the minimum disposal size allowed under MARPOL for ground shipment of waste (Ribic et al., 1992). As awareness of meso- and micro-plastics has risen, organizations, such as the U.S. National Oceanic and Atmospheric Administration (NOAA), have developed a sieving method aimed at quantifying these plastic loads on beaches (Lippiat et al., 2013). The NOAA method involves sediment core sampling, sieving, and further laboratory analysis to determine meso- and micro-debris densities. Core sampling methods such as this are more costly, time and resource intensive, and limit the ability for citizen scientist involvement when compared to visual shoreline survey methods. Core sampling methods also require a significantly higher degree of extrapolation given the smaller sample areas studied.

Alternatively, a protocol developed by CSIRO uses visual logging for all size ranges starting at 0-1 cm, and continuing 1-2 cm, 2-4 cm, 8-16 cm and >16 cm (Hardesty et al., 2014). This method was designed to allow citizen scientists to rapidly measure debris in the meso- and micro-size range while simultaneously collecting macro debris data. If the error associated with visual identification within the lower size ranges could be better understood, then useful estimates of the uncertainty associated with these CSIRO data could be generated. Through observations made during the GAB survey, an hypothesis was developed that plastic debris characteristics (e.g., color); beach characteristics (e.g., sand color, density of shell fragments); and observer characteristics (e.g., color-blindness, height, age, sex, eyesight, survey speed) may have impacts on the accuracy of small plastic fragment identification. Specifically, we hypothesized that under counting of white and clear plastic fragments would occur on beaches with high shell densities, owing to visual noise and reduced contrast between the plastic debris and its background surface.

Most current survey methodologies include quality assurance procedures (Cheshire, 2009; Lippiatt et al., 2013; Hardesty et al., 2014), but they rely on sample re-surveying by visual means, which does not address the fundamental errors in human visual performance.

To study these issues, a laboratory experiment was conducted to directly quantify the potential error associated with visual identification of plastic fragments (1-2 cm long) during mock shoreline surveys. By quantifying the accuracy of counts associated with different plastic fragment colors, beach and observer characteristics, and interactions between these characteristics, visual estimates in the meso- and micro-size range plastics can be better understood and the uncertainty associated with them further defined. This understanding can be used to develop methods that allow for more reliable and rapid visual measurements of meso- and micro-debris on sandy beaches. It can also be used to estimate the uncertainty bounds associated with visual estimates made by citizen scientists, based on known levels of accuracy associated with debris, beach, and/or surveyor characteristics.

2. Methods

Artificial beach transects were constructed containing known concentrations of plastic fragments in a UNH environmental engineering laboratory. Volunteers were asked to log plastic debris along the transects and the results were analyzed to determine the impacts that debris characteristics, beach characteristics, and observer characteristics have on the accuracy of visual identification.

2.1. Experimental Set-up

Four beach “transects” were constructed in the laboratory, each comprised of six 0.25 m^2 black plastic trays of sand aligned in a row on the floor (Figure 1). Each transect was located in its own section of the laboratory. Within each transect, plastic fragment and beach characteristics varied.

Figure 1: Plan View of Beach Transects

The plastic fragments varied in chromaticity (appearing blue, white, clear (translucent colorless)) and density (#/m^2) in each tray. The colors were chosen based on the preliminary GAB survey which found white and blue plastic fragments are the most commonly occurring colors. Observations made during that survey led to our hypothesis that blue fragments may be highly distinguishable, and logged with greater accuracy, while white and clear may be less distinguishable colors and logged with greater error. The 1-2cm plastic fragments used in this study were provided by Poly Recovery (Portsmouth, NH), a company that collects recycled plastics and processes them for post-consumer use. They fell within the size range of 1-2 cm.

Each color fragment was characterized following the Munsell Color System (Munsell, 1929) by hue symbol, chroma, and value (Angelini, 2017). These characteristics provide a standardized way to compare colors, determine the perceptual distance between them, as well as measure color for repeatability of the experiment.

The total plastic densities varied between 0 fragments/0.25 m^2 to 18 fragments/0.25 m^2. The latter resulted from a maximum of six fragments of each of the three colors in each 0.25 m^2 tray. These densities represented the range encountered during the GAB survey.

The beach characteristics considered were sand color and shell density. White/cream, gray, and brown sands were chosen as they are common hues. Hue symbol, chroma, and value were characterized using the Munsell Color System for each sand type and can be found in Angelini, 2017.

Three different shell densities were used to represent the common range found on sand beaches: no shell, moderate shell (20 mL of shell fragments randomly spread over 0.25 m^2), and high shell

(80 mL randomly spread over 0.25 m^2) densities. The naturally weathered shells were collected from Wallis Sands Beach (Rye, NH). They were an average of 1.1 cm (Range of 0.4 – 3.5 cm) by their longest length. Their average hue symbol, chroma, and value were characterized using the Munsell Color System and can be found in Angelini, 2017.

Several parameters were controlled. All outside light was blocked from entering the laboratory and the experimental area was continually illuminated with 6500K daylight-balanced bulbs, in order to replicate the temperature of sunlight. The luminance reflected off the trays of sand was an average of 206 cd/m^2 (Range = 120 - 320 cd/m^2). This value is below the luminance measured in real daylight conditions (e.g., luminance on a cloudy day is 1000 to 5000 cd/m^2)(Beck, 1999), however, as long as sufficient time has been provided for luminance adaptation, the human visual system calibrates itself to lower luminance levels (Graham, 1965), eliminating the need to replicate the exact luminance of daylight.

Upon visual inspection, the plastic fragments varied by specular reflectance as well as color. In order to remove specular reflectance as a variable, the plastics were artificially weathered for 30 minutes in a tumbler filled with sand. This resulted in fragments with uniform visually reduced specular reflectance for all plastic fragments.

2.2 Experimental Design

The statistical software JMP Pro (Version 12; Cary, NC) was used to create a custom design that allowed estimates of two-way interactions. This generated a design with a default of 24 trays observed (6 trays in each of 4 transects) and no aliasing between any of the main effects and the two-way interactions. No aliasing allows determination of influence from all main effects and two-way interactions. The design automatically randomized the values of each factor in each tray, as well the order of the trays. Each of the 103 human subjects (observers) examined all of the trays in a random order.

2.3. Experimental Runs with Human Subjects

Observers were recruited from within the UNH community and included first through fourth year undergraduate students, graduate students, faculty and staff. Upon entering the laboratory, observers were asked to sign a letter of consent, following protocols mandated by the UNH Institutional Review Board for the Protection of Human Subjects in Research. Observers were given a written experimental protocol and were asked to read it prior to receiving verbal instructions. They were asked to provide their age, academic major, height, gender, and vision (near, far or normal sighted), use of corrective lenses, and previous participation in marine debris surveys or beach clean-ups. Observers conducted an online version of the Ishihara color blindness test (www.color-blindness.com/ishihara-38-plates-cvd-test). The Ishihara test is usually conducted by an eyecare professional and the online version is problematic due to variations in computer monitors (Flück, 2013). While the monitor we used was color calibrated and the test was performed under the appropriate lighting, the color-blindness classification was still not fully accurate. This test was conducted only as a preliminary test for color-blindness. After completing the Ishihara test, observers recorded their score along a sliding scale with categorical values of “None”, “Weak”, and “Moderate/Strong”. [N.B., Observers with color blindness were not excluded from the study because observers used in real-world marine debris projects are not screened for this trait.]

Each participant was verbally informed of the debris logging protocol. Observers were shown NOAA's debris photo manual (Lippiatt et al., 2013) for reference and were told to specifically look for hard plastic fragments, greater than 1 cm in size, and with the colors listed on their debris logging sheets (Angelini, 2017) (Color categories replicated those used by CSIRO). Observers were told to stand upright and walk beside the transects, staying on a designated path, located approximately 8 cm from the transects. Observers were asked to log the color and number of plastics that they saw in each of the six trays, in each of the four transects. Observers were asked to be as accurate as possible, logging only the plastics they saw. They were told to be careful not to log shell fragments or any other natural debris items. After determining that observers understood the protocol, their start time was recorded, and they began logging plastic debris. (On average, observers spent approximately 10 minutes completing the survey preparation procedures, allowing sufficient time for visual calibration to the ~206 cd/m^2 luminance before beginning the survey) (Hecht, Haig, and Chase, 1937). After logging debris along each of the four transects, total observer survey time was recorded and observers were asked to judge their confidence in the accuracy of their results on a scale from 1-10 (10 = fully confident).

2.4. Data Analysis

Data distributions were generated for each of the variables (e.g., fragment color, sand color). Each data point was representative of one tray, viewed by one observer. There were 2472 counts (103 observers recording 24 trays each). From these distributions, initial trends in the data were determined.

Factor and covariant significance on plastic counts were observed through distributions, analysis of variance and simple modelling.

First, several covariates were removed due to a lack of information. "Color blindness" was removed as a factor since only one of the observers, exhibited the condition through the test provided. The covariant "age" was also removed, as only 17% of the observers were between the ages of 30 and 62, whereas, 79% were between 18 and 24. Similarly, "experience" and "amount of experience" were removed since there were so few individuals who had participated in marine debris surveying or beach clean-ups. "Major" (area of study) was also removed because the vast majority of observers were in the fields of civil or environmental engineering.

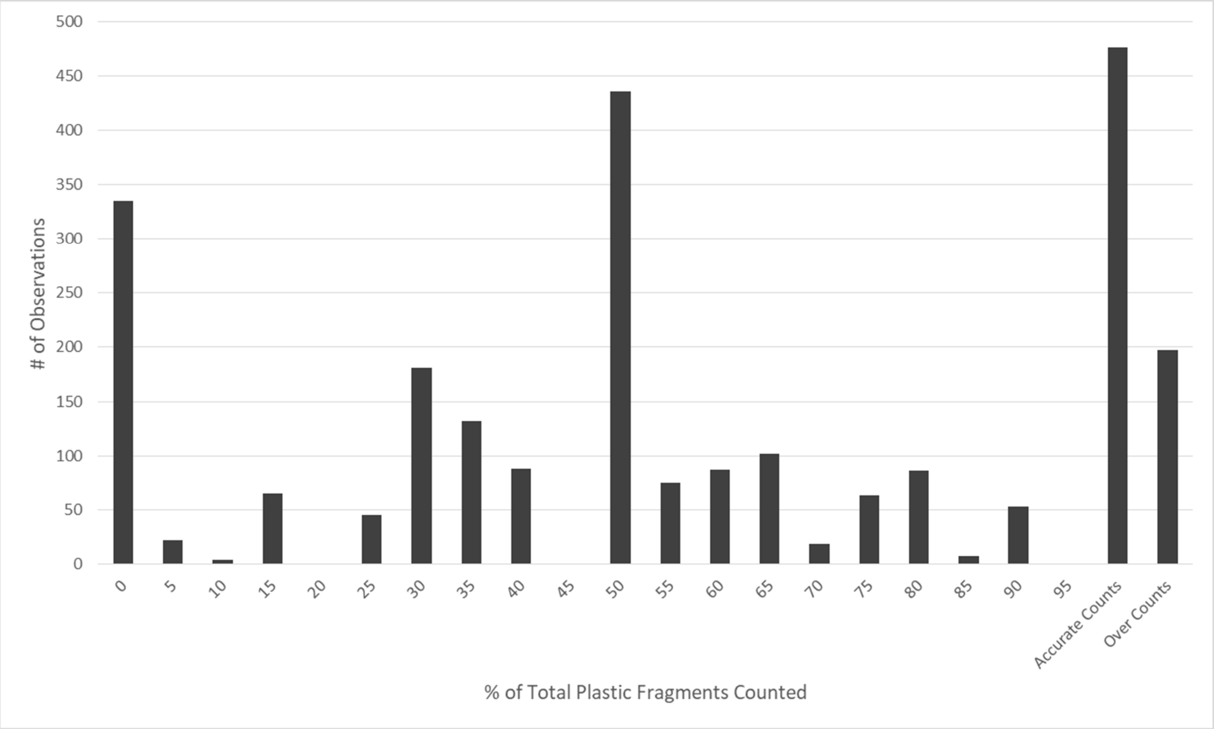
Several factors were removed because they were not observed to have measurable effects. These factors had a sufficient amount of data, however, did not indicate significance ($P > 0.3$), nor did the interactions with them. The factors about the observer removed included "height", "class" (year or status at university), "corrected vision status", and "near, far, or normal sightedness".

The factors for analysis were "plastic debris color", "plastic debris density", "sand color", and "shell density", and their interactions, and "completion time". These factors were determined to have a potentially significant impact on the counts of plastic debris and the observers' accuracy for those counts and were selected for further analysis. All details of graphical and statistical analysis, including the interactions between factors, are located in Angelini, 2017.

3. Results and Discussion

72.8% of the total plastic fragment counts were under-counts, 8.0% were over-counts, and 19.3% were accurate (Figure 2). All over-counts were grouped into a single category due to the occurrence of infinite numbers (i.e., recording any amount of plastic fragments when none were present).

Figure 2: Distribution of Under, Over, and Accurate Total Plastic Fragment Counts



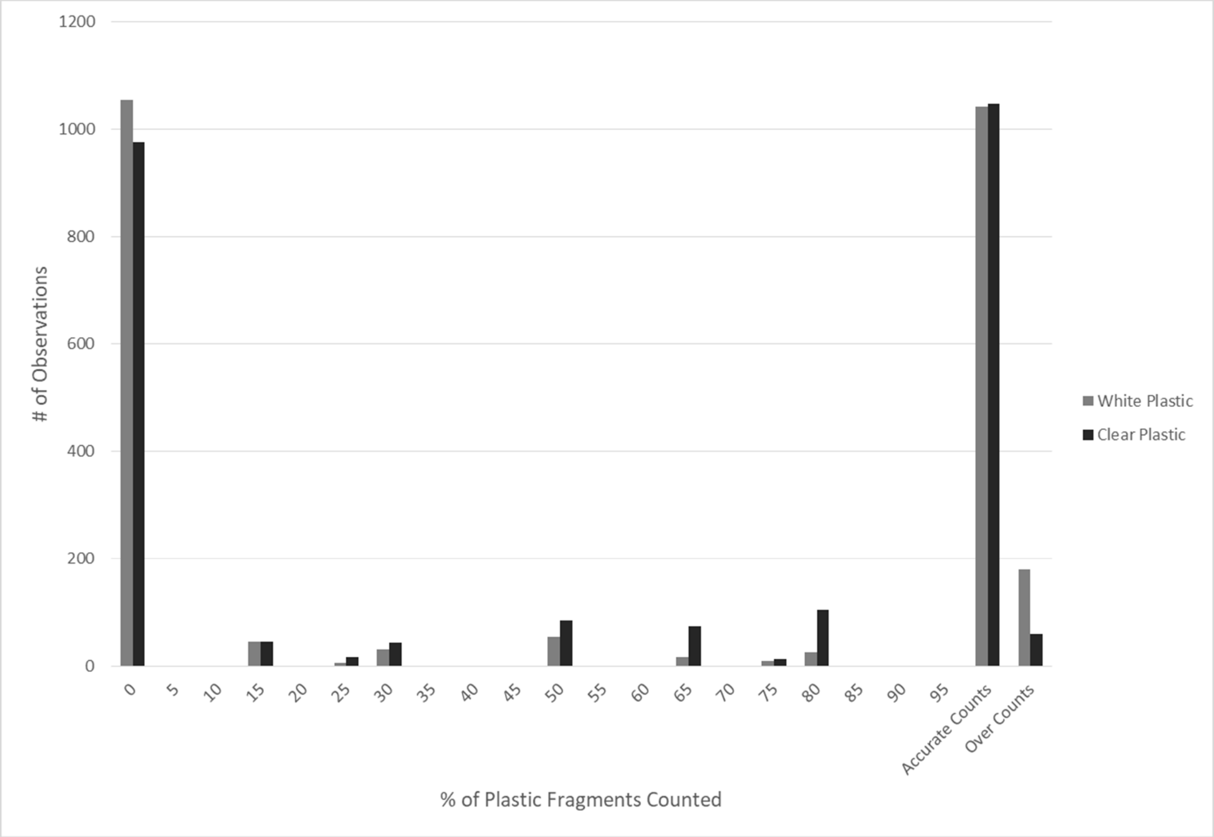
Data peaks at "Accurate", "50%", and "0%" are representative of observers recording exactly the number of plastic fragments present, exactly half of the plastic fragments present, and none of the plastic fragments present, respectively, in each tray. The median of the observers' counts was a 50% under-count.

3.1: Effects of Fragment Characteristics

Consistent with our hypothesis, blue plastic fragments were logged with high accuracy (93.9%), and therefore, were not a major contributor to the inaccuracy of the total plastic fragment counts.

Also consistent with our hypothesis from the GAB survey, the accuracy of clear and white plastic counts (Figure 3) were significantly different than that of blue. Using t-tests, the differences between the accuracy of blue and white plastic counts and blue and clear counts were highly significant (P-values < 0.0001). There was no significant difference between the number of accurate white plastic counts and accurate clear plastic counts (P-value =0.6018). There was also no significant difference between the number of white plastic under-counts and clear plastic under-counts (P-value = 0.1617). However, there was a significant difference between the number of white plastic over-counts and clear plastic over-counts (P-value <0.001).

Figure 3: Distribution of Count Accuracy for Clear Plastic Fragments and White Plastic Fragments



Approximately 55.2% of clear plastic fragment counts were under-counts, 42.4% were accurate counts, and 2.4% were over-counts. A high percentage of under-counting was expected due to the lack of hue contrast and resulting minimal perceptual distance between the clear plastic fragments and sand (as determined by the Munsell Color System). A low percentage of over counting was also expected due to the greater perceptual distance between clear plastic fragments and shell fragments, minimizing the probability of mistaken identity.

Approximately 50.5% of white plastic counts were under-counts, 42.2% were accurate, and 7.3% were over-counts. Compared to clear plastic counts, a greater percentage of white plastic counts were over-counts. It is probable that mistaken identity between white plastic and white shell caused this. Consistent with our hypothesis from the GAB survey, it is probable that a large amount of the under-counts for white plastic occurred due to mistaken identity between plastic fragments and shell as well. While the perceptual distance between white plastic and sand is relatively large (as determined by the Munsell Color System), the perceptual distance between the white plastic fragments and white shell is less.

The accurate counts for clear and white plastic fragments can be further explained by the actual amounts of plastic fragments present.
The majority of accurate white and clear plastic counts (86% and 87%, respectively) occurred when observers counted trays with zero plastic fragments present (true zero counts); only 14% of all accurate clear plastic counts and 13% of all accurate white plastic counts occurred when there were plastic fragments present.

3.2: Effects of Beach Characteristics

Strong trends were only observed between beach characteristics (i.e., shell density, sand color) and the accuracies of white and clear plastic counts.

The majority of inaccurate white plastic counts were under-counts (Table 1). The difference between the accuracy of white plastic counts in zero shell, moderate shell, and high shell density conditions resulted in a p-value = 0.0025 (t-test). This indicated that the accuracy associated with at least one of the shell density conditions was significantly different. Further analysis (t-tests) showed that the accuracy of counts in high shell density conditions was significantly different from zero shell and moderate shell density conditions (P-value =0.0017 and P-value =0.0015, respectively). There did not appear to be a significant difference between the accuracy of counts made in zero shell and moderate shell density conditions (P-value =0.8790). Overall, significantly less accurate counts were made for the high shell density condition than in the moderate and zero shell densities. Observers' counts of white plastic fragments were less accurate when more shell was present, with a tendency towards under-counting. This result may be partially explained by signal detection theory (Swets, Tanner, and Birdsall, 1961). Signal detection theory does not presuppose a sensory threshold and emphasizes judgmental rather than sensory aspects of the psychophysical experiment (Kling and Riggs, 1972). As a result of decreasing the signal (plastic fragments)-to-noise (shell fragments) ratio, through increased shell densities, observer bias may have tended towards the expectation of shell rather than plastic fragments, leading to greater under-counting.

Table 1: White & Clear Over/Under/Accurate Counts vs. Beach Characteristics

Beach Characteristics	Measurement Accuracy of White Plastic	
Shell Density	**Accurate counts**	**Inaccurate counts (Under/over)**
Zero shell	51%	49% (48/1)
Moderate shell	43%	57% (47/10)
High shell	33%	67% (55/12)
Sand Color	**Accurate counts**	**Inaccurate counts (Under/over)**
Gray	39%	61% (58/3)
White/cream	40%	60% (56/4)
Brown	46%	54% (52/2)

There also was a correlation between the accuracy of clear plastic counts and sand color (Table 1). Using t-tests, the difference between the accuracy of clear plastic counts for each of the sand colors resulted in P-value < 0.0001. Further analysis showed that accuracy of counts was significantly different between all three colors (each of the P-values were less than 0.0122).

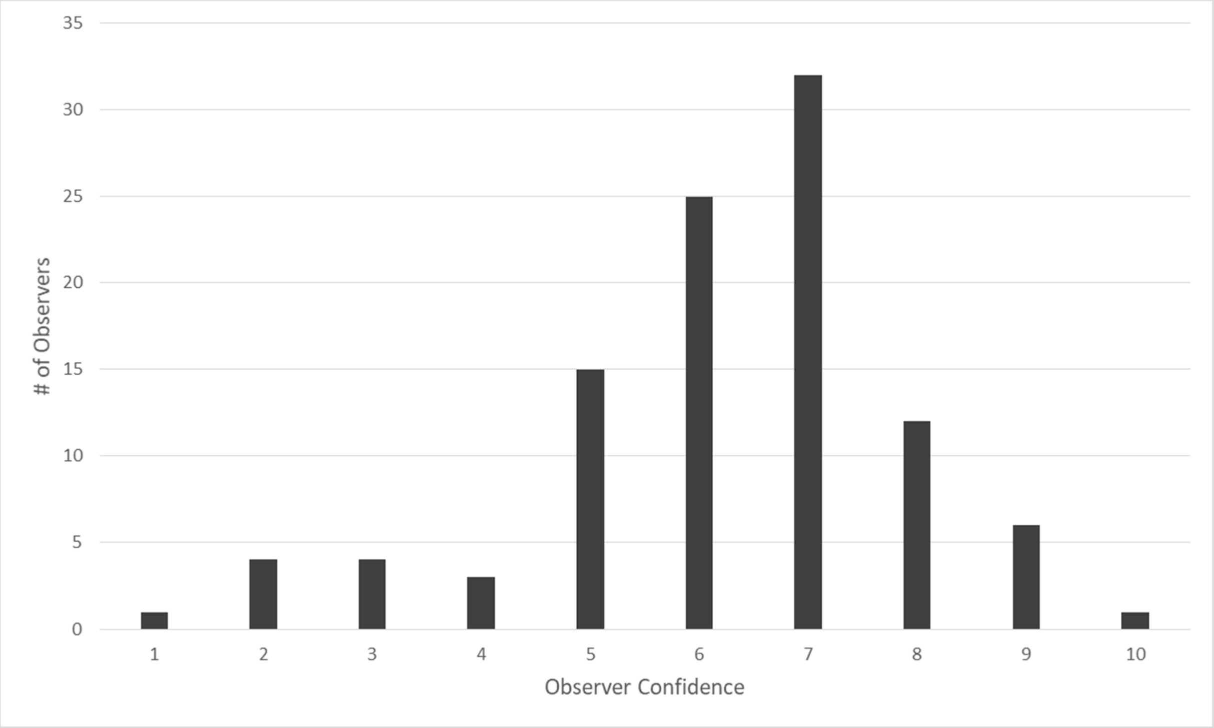
Brown sand resulted in the most accurate counts, while gray sand resulted in the least accurate. One possible explanation for this result is that the clear plastic fragments may have reflected ambient light in a way that, to the observers, their spectral properties appeared closer to grey sand than the other sand colors.

3.3. Effects of Observer Characteristics

As completion time increased, so did median observer accuracy. The longer observers took to log data, generally, the more accurate their counts. However, regardless of how long observers spent observing the transects, their median results never reach 100% accuracy (average observation time = 12.3 minutes).

The median observer confidence (Figure 4) in the accuracy of their results (6 out f 10) was surprisingly high when compared to the low percentage of total accurate counts (19%). This may indicate that many observers would not have bent down to further inspect the sand. This needs further investigation in an experiment where bending down is allowed.

Figure 4: Observer Confidence



4. Conclusions and Recommendations for Future Experiments

4.1. Conclusions

To the best of our knowledge, this is the first study on the effects that these characteristics have on the accuracy of beach surveys. The high accuracy of blue plastic counts and the under-counting of white and clear plastic fragments confirmed the hypothesis that a significant amount of clear and white plastic fragments may be missed during shoreline surveys.

The accuracy of white plastic counts was significantly affected by increasing shell densities due to the low contrast between white plastic fragments and white shell fragments as well as observer bias. The majority of the time, white plastic fragments were mistaken as shell (under-counts), with fewer circumstances of shell being mistaken for white plastic fragments (over-counts). The accuracy of clear plastic counts was significantly affected by the color of the sand; the clear fragments contrasting best with brown sand.

Overall, the results of this study indicate difficulties in visual identification of meso-and micro-plastic debris during beach surveys under the current techniques. However, the alternatives to visual identification during beach surveys (At-sea sampling and sediment core sampling) present significant limitations including increased cost, time, resources, and extrapolation, as well as decreased ability for citizen scientist involvement.

Therefore, the results of this study highlight the need for further research and modifications of current visual beach survey techniques, so that this cost-effective method of data collection can be optimized. Specifically, the results demonstrate that visual identification of lower size ranges during beach surveys should be coupled with advanced beach (sand and shell) and debris (color) characterization. Characteristics including shell cover and sand color should be noted, as well as debris color for each item identified. These characterizations can improve the understanding of estimates and allow better judgement of accuracy. If certain debris colors can be further associated with known degrees of under counting in certain beach conditions, then visual estimates can be adjusted to account for this.

The results also suggest that pre-survey advanced identity training should be further investigated as a means of minimizing under- and over-counting. This training could involve survey leaders setting up visual calibration plots of sand, which include a variety of plastic and natural debris items (i.e. shells). Before beginning the survey, observers could log the plastic debris in the calibration plot. After logging, the results could be discussed and distinguishing factors between plastic debris and natural debris identified.

The results along with the collaboration process with visual perception experts during the course of this study highlighted the added value that experts in visual perception can provide to marine debris survey design and analysis.

The variables tested in this experiment represent only a portion of possible beach, observer, or debris characteristics that may be encountered in shoreline surveys. There may well be other variables (i.e. weather/daylight conditions) that will result in drastic differences in accuracy. By further understanding and identifying these variables, marine debris estimates can be put in perspective and potentially improved. New survey techniques can work to address these issues in order to obtain more accurate meso- and micro-plastic debris estimates from visual surveys.

By further understanding the accuracy of visual observations of marine debris and addressing it, the huge resource potential that citizen scientists represent for collecting data on small plastic fragments can be maximized, resulting in the most accurate data possible.

4.2. Recommendations for Future Experiments

Future experiments could increase variation in shell density, as well as shell size and color. In addition, other natural debris (e.g., seaweed, wood, crustacean remains), could allow for a more realistic representation of beach characteristics.

Additional colors of plastics should be studied. For example, there are ten color categories used by CSIRO (Black, Blue/Purple, Brown, Clear/Translucent, White, Green, Grey/Silver, Orange, Red/Pink, Yellow). It would also be prudent to include other sizes of plastic fragments, since the issues described in this study may apply.

This study did not obtain a sufficient number of observers with the color-blindness trait to analyze their accuracy compared to observers lacking this trait. Therefore, additional studies should be conducted with larger sample sizes in order to determine if this trait significantly impacts survey accuracy, either positively or negatively.

Finally, training procedures to minimize mistaken identity between small plastic fragments and shells should be developed and tested to improve accurate fragment detection.

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