Tobacco Product Waste Monitoring
California Department of Public Health

A Method to Facilitate Comparable Data

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PREPARED BY
San Francisco Estuary Institute
4911 Central Ave.
Richmond, CA 94804

AUTHORS
Shelly Moore, Tony Hale
Lorenzo Flores, Pete Kauhanen

List of Acronyms & Abbreviations

QAPP	Quality Assurance Program Plan
QA/QC	Quality Assurance / Quality Control
SOP	Standard Operating Procedures
TMDL	Total Maximum Daily Loads
TPW	Tobacco Product Waste
U.S. EPA	United States Environmental Protection Agency

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Introduction

Overview

Trash has become a focus of water quality management activities in the last decade; however, much of the focus has been on large items that are aesthetically displeasing on the streets and in recreational areas, such as parks and beaches. While cigarettes and other tobacco product waste (TPW) items are larger than the State of California-mandated 5mm threshold for capture within our stormwater systems, many still escape into the environment leading to potential harm.

The following document offers guidance on effective TPW monitoring techniques for interested agency staffers, volunteers, community-based scientists, researchers, and environmental advocates. "Monitoring," in this context, refers to the measurement of TPW in a given environment. Accurate and precise monitoring of the presence/absence, categorization, or brands of TPW in a known location can in turn help to address questions posed by interested parties and even determine the degree of impact on beneficial uses of a resource, such as a park, beach, road, or commercial district. The following practical considerations are designed to inform choices in selecting and refining monitoring methods to suit the objectives of the associated study or program.

Background

Measuring TPW as accurately and precisely as possible is understandable, given the compelling reasons for assessing the overall amount in a given environment, a measurement that is conventionally called the environmental "load." TPW is an especially common contaminant. It is often found wherever people congregate – sporting venues, bars, parks, and virtually every other gathering place. Conventionally speaking, if you look for TPW, you will often find it. However, for most stakeholders interested in measuring the load associated with TPW in a given space, it is not enough to settle on a presence/absence assessment. To depict a more detailed picture of the issue, one must characterize it in more detail. After all, one might commonly ask, "Is the load of TPW in my neighborhood improving or degrading?" Or one might also wonder, "How does the amount of cigarette butts in my local park compare to those across the city?" To address these questions, we must be able to perform TPW monitoring that is accurate and precise enough to measure change over time (regarding the former question) and facilitates comparisons across distances and likely among different monitoring practitioners (regarding the latter question).

The training detailed in this document sets out to provide principles and guidance to empower TPW monitoring practitioners to conduct assessments that maximize comparability across space and time. If assessments are durable, repeatable, and practical

Figure 1. Left, cigarettes in a storm drain near the Cliff House, San Francisco. (Photograph by Vivian Chen, courtesy of CC 2.0) Right, TPW found in a street. (Photograph by SFEI)

(relatively inexpensive and easy to perform), then they become cost effective and can leverage volunteer labor to good effect. Without such methods, monitoring programs, clean-up efforts, and advocacy efforts rely on data gathered without the requisite accuracy and precision to support scientifically valid findings.

When we assert that 4.5 trillion cigarette butts are thrown away each year, this figure is perhaps the best available, but it is based on models, rather than a wealth of empirical data.[1] With additional, rigorously gathered data, this figure might increase or decrease with time. The methods described below will promote such efforts to measure load and, by extension, the associated impacts of TPW much more comprehensively than we do at present.

Monitoring Context

Regulatory / Mandate Criteria

No specific waste management regulations are in place for TPW. However, in California, the State Water Resources Control Board in 2015 formally adopted a series of enhancements to its guiding plans related to trash control. Commonly known as the "trash amendments,"[1] these mandates were designed to require stricter controls on trash that escapes into the environment: our streams, creeks, rivers, and ocean. Among the mandates included in the acts is a requirement for municipalities to install full trash capture devices or their equivalent, which are designed to intercept trash larger than 5mm. Cigarette butts and other forms of TPW would clearly be included in these mandates to be captured as escaped trash. Accordingly, many parties, ranging from municipalities to other interested stakeholders, are newly motivated to quantify the amount of trash — and TPW, more specifically — that evades capture by conventional means.

Important Considerations

Before embarking on monitoring, it is always important to think ahead about why you are doing it, what information you hope to gain from it, and how you will analyze the data once they are collected to tell a story. Here are some suggestions for things to think about as you prepare to perform your assessments.

Management and Monitoring Questions

The type of monitoring questions answered by each method will determine the method to be used by a given stakeholder. Some may be interested in only assessing the general amounts of TPW present, while others may also want to know how much of the different types (e.g. electronic vs traditional cigarette) are present. Others may be interested in knowing what brands of TPW are present. Understanding the management question is essential to determining the monitoring questions, which is essential to determining the method used to assess the TPW.

Some monitoring questions might include:

- How much TPW is there in my neighborhood/city?
- How does the amount of TPW I have in my neighborhood/city compare to others?
- Is the amount of TPW declining, staying the same, or increasing?
- How much of the TPW is traditional cigarettes versus how much is electronic cigarettes?
- Are there any particular brands of TPW that are more prevalent than others?

1 State Water Resources Control Board. Statewide Water Quality Control Plans for Trash. https://www.waterboards.ca.gov/water_issues/programs/trash_control/

Accuracy / Bias

Accuracy is an important measurement for any method. Here we are referring to how near the truth a given measurement is when in the field. Knowing this can aid us in determining the amount of variation among different assessors and/or different habitat types. As part of the method for assessing TPW we recommend some quality assurance/quality control (QA/QC) measurements below to ensure accuracy in the data.

Precision / Repeatability

Ensuring the method used is both precise and repeatable is key to promoting confidence that the measurements completed by different people/groups are highly comparable. Precision of the available methods can be determined by conducting multiple assessments of the same site, under the same conditions, using the equivalent instruments, with different people/teams. The amount of variability among the results is inversely proportional to the degree of precision. We recommend multiple assessments at the same site with different people/teams for a subset of sites – see Quality Assurance / Quality Control "QA/QC" section below.

Resources

Resources are often a limiting factor in performing assessments. One of the most frequently mentioned issues when talking about performing any type of waste assessment is the amount of time it takes to conduct an assessment. Second to the amount of time is the amount of equipment needed. For these reasons, the TPW methods listed here are meant to allow the assessor to choose a method based on the amount of resources available.

In the end, all the factors above, management questions, accuracy, precision/repeatability and resources, should play a part in determining the method used to assess TPW.

Conceptual Approach

The methods for measuring TPW differ based on the management questions answered and the resources (mostly in time) available. There are a total of 4 Tiers (variations on the method). Tiers 1-3 are detailed in this document and Tier 4 is mentioned and generally described here; however, it is much more complex and is still being developed by researchers at the University of California, San Francisco (see below for more information).

The methods for measuring TPW differ based on the management questions answered and the resources (mostly in time) available. Tier 1 is the simplest and only measures the amount of TPW present in a given area with no information collected on type. Tier 2 involves collecting information on the type of TPW on a high level. For example, it lists whether an item is a cigarette, e-cigarette, cigarette wrapper, cigarillo wrapper, etc. Tier 3 goes a step further and identifies brands of each TPW item where possible. Ideally, the final measurement provided would be a count by area assessed. For example, a Tier

Figure 2. Conceptual model of Tiers for Tobacco Product Waste collection data.

3 measurement would be 3 Marlboro cigarettes/ft^2. For Tier 2 it would be 5 cigarettes/ft^2 and for Tier 1 it would be 10 TPW/ft^2. The importance of this type of measurement cannot be stressed enough, for without an area to normalize the measurements, the amounts of TPW in different spatial and temporal scales would not be comparable.

The thought here is that all information collected using Tier 3 can be compared to other Tier 3 information and can also be simplified and shared with Tier 2 and Tier 1 as well (Figure 2). Tier 2 data can be compared to other Tier 2 data and with Tier 1 data. Tier 1 data can be compared with all other Tiers on a higher level.

For example, a Tier 3 measurement would be 3 Marlboro cigarettes/ft^2. For Tier 2 it would be 5 cigarettes/ft^2 and for Tier 1 it would be 10 TPW/ft^2. The importance of this type of measurement cannot be stressed enough, for without an area to normalize the measurements, the amounts of TPW in different spatial and temporal scales would not be comparable.

Tobacco Product Waste Methods

Two main methods for TPW assessment are listed here. The On-The-Ground Method can be as simplistic or complex as you want and ranges from and can involve one to many people. The second, an aerial method, requires a minimum of two people, and involves the capture of imagery using an UAS (unoccupied aerial system, commonly known as a "drone") and a machine learning algorithm to analyze the imagery for TPW. The former is ready for your implementation, while the latter is still months away from effective operationalization.[2]

On-the-Ground Methods

This method is the boots on the ground method for determining the amount of TPW in each assessment area.

Setting up the Assessment Area

Setting up the assessment area is the first step to performing this method. Consideration of the size of the area is important and will inform the number of assessors and the amount of time needed to do the assessment. This method is intended to allow one or many assessors to perform the method. To achieve greater consistency that does not favor selection bias (eg, choosing a small area with a high amount of TPW), we recommend a minimum assessment size of 100ft^2. In addition, determining the size of the assessment area is critical to normalizing the amounts of TPW both spatially and temporally. This allows the calculation of the amount of TPW for a given area, such as number of items per square foot (x/ft^2). To do this, the assessment area is estimated either by measuring the area with a measuring tape or by using the assessor's average stride distance to walk the boundaries of the area.

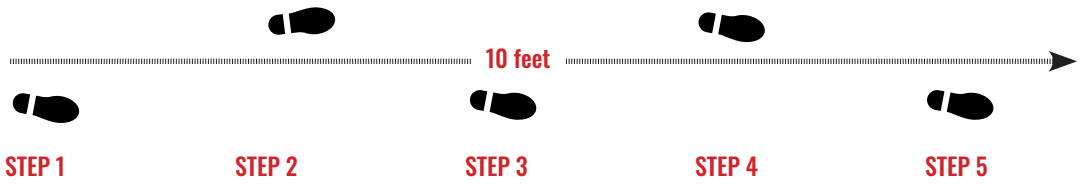


Figure 3. Illustration of pace length measurement.

To measure the assessors stride length, count the number of steps it takes to cover 10 feet. Divide the distance (number of feet) by the number of steps you took to determine the distance of one step. The distance in feet/number of steps = step length. For example, if it took you 5 strides to cover 10 feet, your step length would be 2.0 feet (24 inches).

To measure the area, the assessor would need to measure the different components necessary to derive the total area assessed. The easiest way to do this would be to make

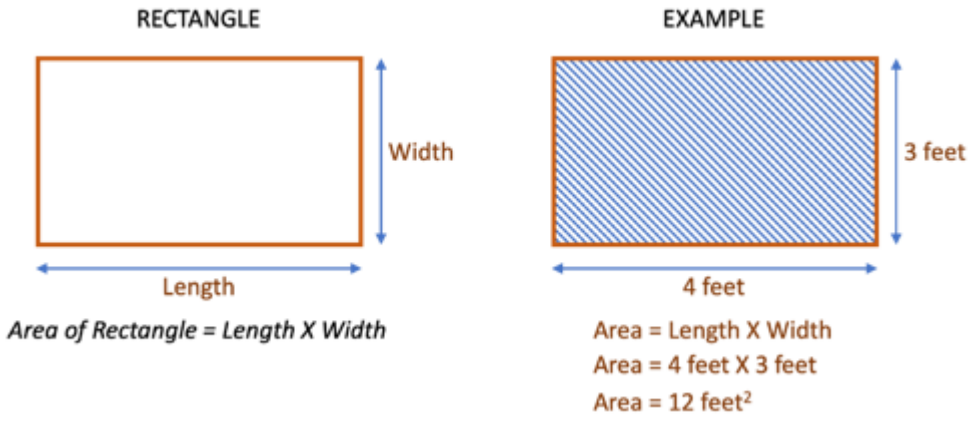


Figure 4. Determining the assessment area with example.

the assessment area a square or rectangle. In this case the length of the assessment area multiplied by the width would give the total area covered. The assessor would then walk the length and width of the rectangular assessment area, count his/her strides, and estimate the length of each side. The area can be calculated by multiplying the width by the length and squaring the units.

If the area is larger and requires more than one pass, a regular pattern of walking, for example the Lawnmower Pattern, is recommended (Figure 7). If there are multiple people performing the assessment a similar, wider pattern, can be used to cover the area. The goal is to make sure all of the area is covered and all of the TPW is seen and accounted for.

Data Sheet for Site Information

Date _____	**Amount of Foot Traffic:** **a. High b. Moderate c. Low**
Time _____	**Weather** _____
Location _____	**Time of the Assessment:**
Nearest Landmark _____	**Relative Assessment of Trash:** **a.High b. Moderate c. Low**
TPW Removed: yes / no	

Figure 5. Depicting an assessment area beside a roadway.

Step Length = 10ft/ 5.5 steps = 1.18 feet/step

Length = 75steps * .18 ft/step = 88.5 ft

Width = 10steps* feet/step /ft = 11.8 ft

Area of Rectangle = Length * Width = 88.5 ft * 11.8 ft = 1,044.3 ft^2


Marlboro
LIGHTS

Assessment Site Information

Basic information about the timing of the assessment and the characteristics of the site should be collected prior to initiating the TPW counts. Date and Time are important to collect, so if the assessment site is visited again a temporal (or seasonal) comparison can be made. Information on the location of the site, amount of foot traffic, and the time it takes to perform the assessment are necessary to understand the probability for the detection of TPW.

Performing the Assessment

Once you have identified and characterized the assessment area it is time to count the TPW. Depending on the type of area you have delineated, you have some different options for ensuring the whole area is covered and all the TPW counted. Walking a regular pattern for the area is recommended. For a small linear area, you can use the Linear Pattern (also called the "snowplow pattern"). Walking in the center with an equal amount of area on either side is recommended (Figure 6). In this case, looking to both

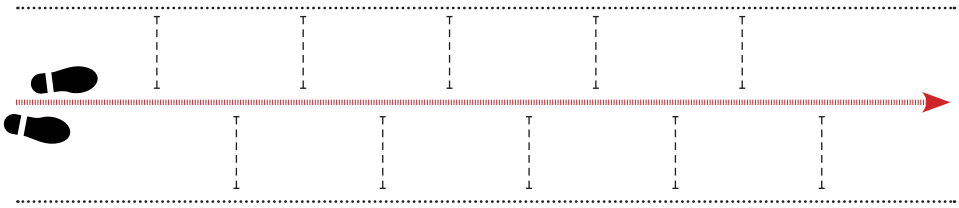


Figure 6. Depiction of the Linear Pattern with measured area to each side of the assessor.

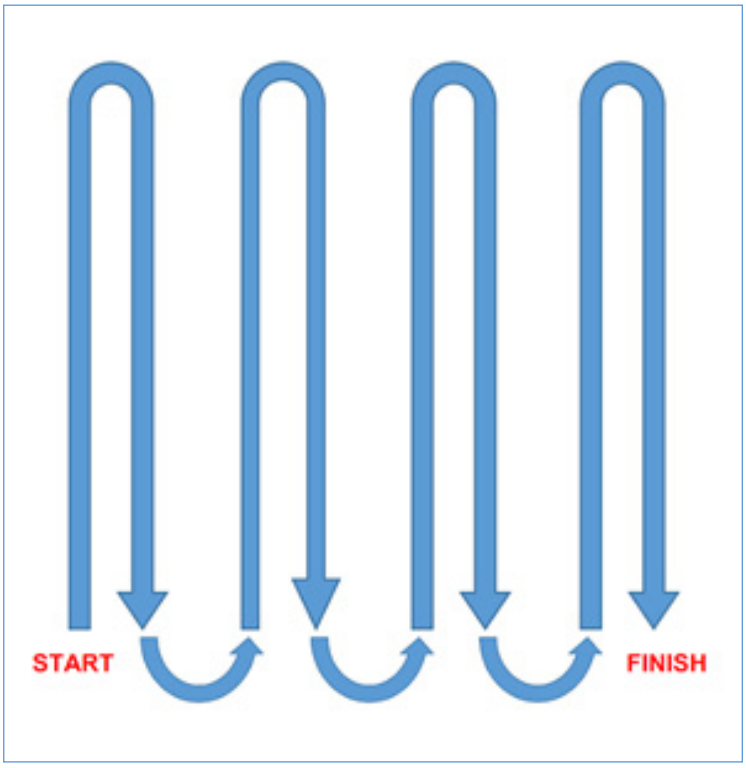


Figure 7. The Lawnmower Pattern, a suggested regular pattern for walking an assessment area.

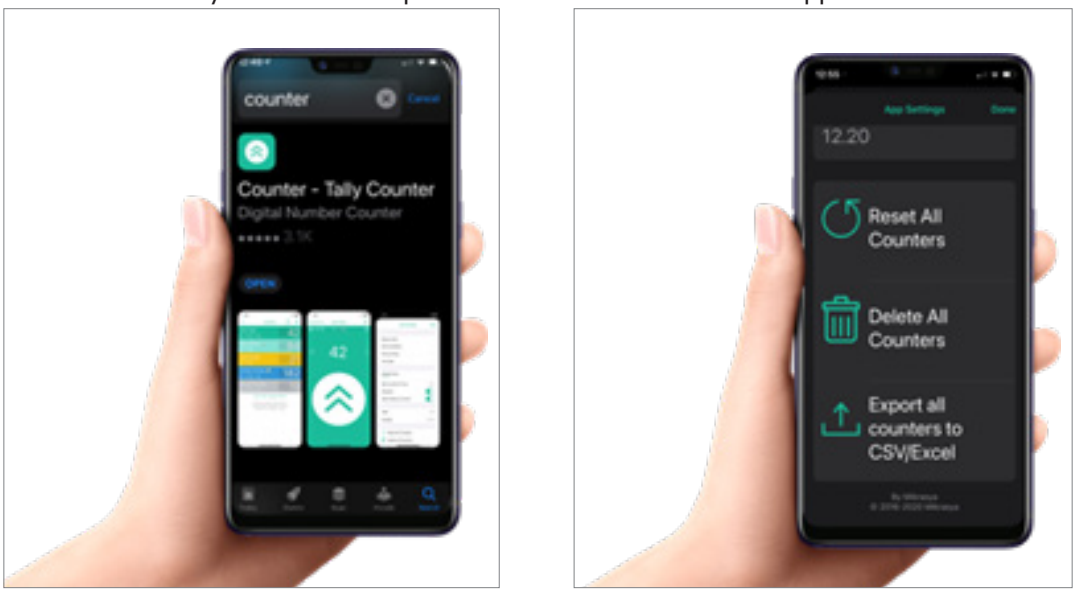
sides as you are walking in a straight line through the center of the assessment area and identifying the TPW as you go will suffice.

If the area is larger and requires more than one pass, then a regular pattern of walking to cover multiple dimensions, the Lawnmower Pattern, is recommended (Figure 7). If there are multiple people performing the assessment a similar, wider pattern, can be used to cover the area. The goal is to make sure all of the area is covered and all of the TPW is seen and accounted for.

Measuring Tobacco Product Waste

COUNTING

Counting the TPW can be performed a couple of ways. We recommend downloading a free smart phone application from an app store, based on your phone type. For example, the Apple store has several free counter/tally apps for the iPhone. Simply type in the word "counter" into the search criteria for the app store and pick an app (Figure 8). We show as an example an app called "Counter – Tally Counter". This app is free and gives the user the ability to create multiple counters and to name them. Apps are available



Figures 8 and 9. Two views of example apps for tallying on mobile devices

through the Google Play app store for free as well. We do not endorse any particular app but do endorse the use of some software application to ease the process of tallying TPW and to ensure accurate counting. Additionally, many apps have the capability to download data as a comma separated (.csv) file or a Microsoft Excel file (Figure 9). See the sections on each method below for instructions on how to set up these apps based on the type (Tier) of TPW information you will be collecting. Alternatively, you can tally the TPW using pencil and paper. Simply mark on the data sheets provided for the method you are using.

Safety Measures When Counting TPW

TPW is hazardous. It typically harbors nicotine, in addition to heavy metals.[2] Therefore, monitoring practitioners should exercise caution when interacting with TPW encountered in the environment. If TPW monitoring practitioners plan to touch the TPW, it is best to assume that the harmful chemicals are present. Consistently don chemically resistant gloves -- made from nitrile, latex, neoprene, vinyl, PVC or rubber -- that conform to the ANSI/ISEA 105-2016 standard.[3]

We should note that extraction for the on-the-ground methods is optional. A visual survey is possible to perform without any requisite touching of the TPW. However, many groups will elect to collect the TPW, either to mitigate perceived impacts, better record change over time, or simply in accordance with custodial cleaning procedures.

Time

Something to keep in mind while sampling for TPW is the amount of time you will need to conduct the assessment. Assessment sites should be kept to a size where it would take no longer than 20 minutes to survey the site. Many factors play into this. If you are assessing a site with a lot of vegetation, it will take longer to assess as you may need to decrease the size of your passes in order to assure you see all of the TPW. Vegetation can make it more difficult to see TPW under its concealing leaves. Sites in parking lots or on sidewalks or other types of hard surfaces are easier to assess and will typically require less time. More area can be covered, and obstructed views of the TPW are less common.

To promote consistency among practitioners and individual assessments, we do not encourage the probing or overturning of leaf litter and other material to search for TPW. It should be visible prior to disturbance.

Normalizing the Data

Since the size of an assessment area is up to the assessor, we recommend normalizing the data to the area assessed. What we mean by "normalizing the data" is devising a standardized value per unit of area sampled. To do this, we recommend not reporting the total amount of TPW found at a site. Instead, we recommend reporting the number of items divided by the area surveyed. This is an important distinction that will increase the comparability of your results. By following this approach, you will arrive at a TPW density value (count of TPW per area unit) that can be compared to other assessments done both at different times and in different regions.

Three Variants on the Method

Here we list three variants from which to choose. The specific variant you select depends on a couple of factors. The first factor is relative to what questions about TPW you are seeking to address. The second factor is how much time or resources you have to perform the assessment. If you want to have information on the particular brands of TPW you are seeing in the environment but you only have a few minutes to perform an assessment, you might want to consider only counting the items of TPW as a broad category. In another instance, if you do not have time as a

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2 Notes from the Field: Environmental Contamination from E-cigarette, Cigarette, Cigar, and Cannabis Products at 12 High Schools - San Francisco Bay Area, 2018-2019. MMWR Morb Mortal Wkly Rep. 2019 Oct 11; 68(40):897-899. Mock J, Hendlin YH. PMID: 31600185.
3 International Safety Equipment Association. ANSI/ISEA 105-2016. https://safetyequipment.org/standard/ansiisea-105-2016/

constraint, and you really do not need to know the brands of TPW, you may also opt to only count TPW items as a broad category.

The flexibility in each of the Tiers presented here is that the counts can be compared at the level the data are collected and/or any lower levels. Because the tiers reflect degrees of specificity and share categories in common, data collected at higher, more specific tiers can be compared to lower tier data. For example, if you collect data for Tier 3, you can use those data to compare to data in Tiers 2 and Tier 1 as well. If you collect data in Tier 2, you can compare them to data in Tier 2 and in Tier 1. However, it is important to note that

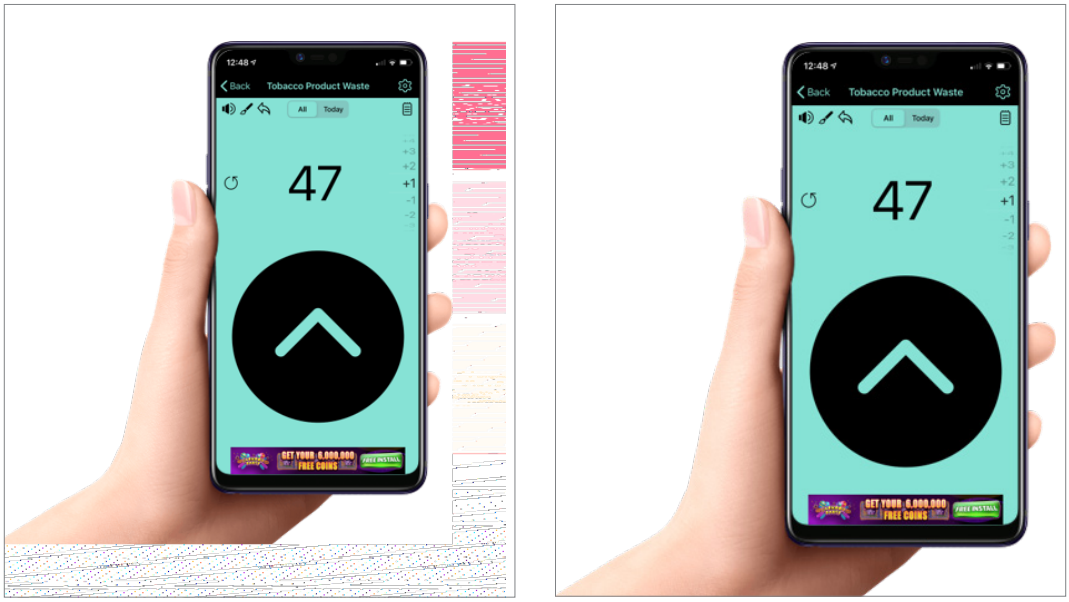


Figure 10. An example of apps for tallying on mobile devices using a single category.

the comparability is not bidirectional. Data collected at the more general Tier 1 cannot reasonably address brand-specific questions to be addressed by the Tier 3 method.

TIER 1: COUNTING TPW

This method is the simplest and quickest type of TPW assessment. The amount of resources needed to perform this assessment is dependent upon the size of the area assessed and the amount of TPW present. However, since no other information is collected on the TPW, other than presence or absence, the amount of time needed is considered minimal for this method. One to two people should be able to complete a relatively small area in a reasonable amount of time.

TPW Count	
	Total 47

What to Count: This method involves simply counting the TPW. Counting is based on whether it is a tobacco product. All types of TPW are considered in the same single category. The idea here is simply to calculate the amount of TPW in a standardized area. The final value computed will be a number/assessment area (e.g. 10/ft^2).

Another Way to Count: The count of TPW can also be accomplished using a smart phone application (see Counting section above for suggestions on searching for a free app). The app can have only one category in this case and a tally can be made by simply tapping on an area of the app to increase the increments by 1.

Additionally you can use the electronic data sheet and a tablet to enter the data (see "Recording the Data" section below). This would require forethought in determining the assessment site and performing the assessment, as the above methods could be performed on the spur of the moment when in an area of interest.

Calculating the Amount per Unit Area

To calculate the amount per unit area you need two values, the measured area (ft^2) and the amount of TPW by Type. Divide the amount of TPW by Type by the amount of area to normalize the measurement to amount of trash per 1 ft^2. Using this method, you can calculate the amount of TPW for Tier 1. Below is an example:

Tier 1 Calculation

Assessment area = 2,480 ft^2

Total amount of trash = 47

Amount of trash per foot squared = 47/2480 ft^2 = 0.019 pieces/ft^2

TIER 2: IDENTIFYING THE TYPE OF TPW

This method offers the benefit of increased classes for identifying TPW. While Tier 1 merely quantifies the overall load of anything related to tobacco products, Tier 2 distinguishes among the various forms of waste. It classifies the TPW according to whether it is a wrapper, box, filter, or whole cigarette. Furthermore, it also identifies the various elements associated with electronic cigarettes and smokeless tobacco. Because it facilitates a higher level of precision with respect to TPW type, it is likely to take slightly longer to perform than Tier 1. However, as with Tier 1, the amount of resources needed to perform this assessment is dependent upon the size of the area assessed and the amount of TPW present. One to two people should be able to complete a relatively small area in a reasonable amount of time.

What to Count: For this Tier you will be counting the types of TPW. The first major split in types here is in between a traditional cigarette and an e-cigarette. Under each of those categories the split is then between the actual cigarette, its parts and any boxes or wrappers.

Data Sheet for Tier 2

Cigarette TPW

Cigarette Wrapper	Cigarette Box	Cigarette Filter	Cigarette (filter and tobacco)
|	|	|	||
Total: 1	Total: 1	Total: 1	Total: 3
			Overall Total: 6

E-Cigarette TPW

E-Cigarette Wrapper	E-Cigarette Box	E-Cigarette Pod	E-Cigarette
|	|	|	||
Total: 1	Total: 1	Total: 1	Total: 2
			Overall Total: 5

Other

Smokeless Tin	Lighter	Cigar Tip	Other - Specify
Total: 0	Total: 0	Total: 0	Total: 0

Another Way to Count: The count of the type of TPW can also be done using a smart phone application (see "Counting" section above for suggestions on how to search for a free app). The app can have multiple categories in this case, and a tally can be made by simply tapping on an area to the right of the category within the app to increase the increments by 1.

Additionally, you can use the electronic data sheet and a tablet to enter the data (see "Recording the Data" section below). This would require forethought in determining the assessment site and performing the assessment, which could serve as a practical constraint, since the above methods could also be performed on the spur of the moment when encountering an area of interest.

Calculating the Amount per Unit Area: To calculate the amount per unit area you need the area and values for the amount of TPW by Type. Divide the amount of TPW of a given Type by the amount of area to normalize the measurement to amount of trash per 1 ft2. Using this method, you can calculate the amount of TPW for Tier 2. Below is an example:

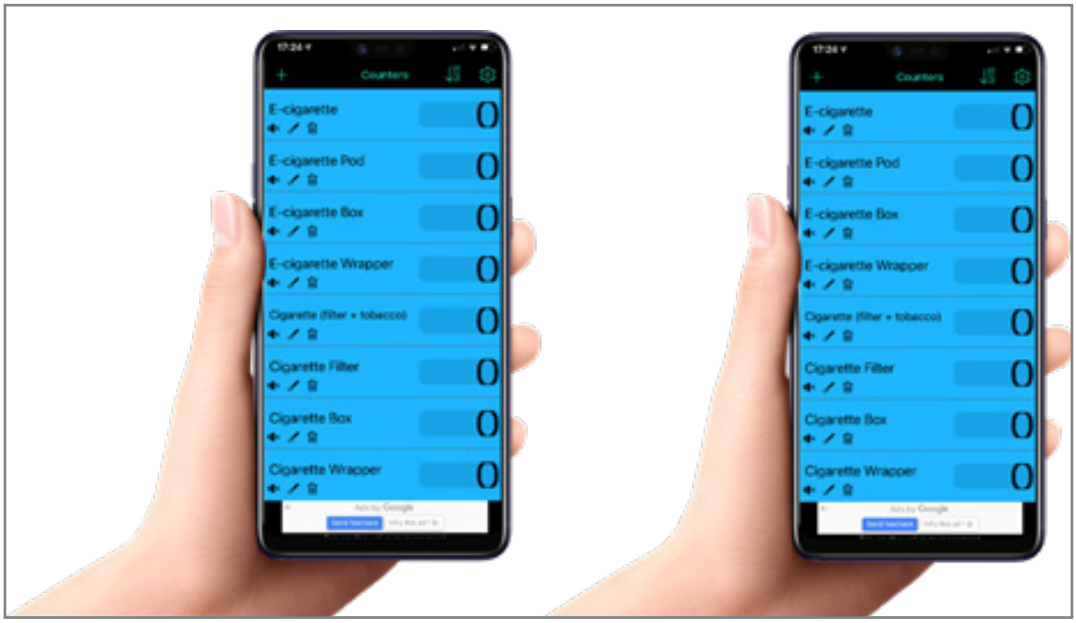


Figure 11. An example of apps for tallying on mobile devices using multiple categories.

Let us say that the assessment area was measured and was 420 ft^2.

Tier 2 Calculations

Assessment area = 420 ft^2

1. Cigarette TPW = 6/420 ft2 = 0.014 pieces/ft^2
    a. Cigarette Wrapper = 1/420 ft2 = 0.002 pieces/ft^2
    b. Cigarette Box = 1/420 ft2 = 0.002 pieces/ft^2
    c. Cigarette Filter = 1/420 ft2 = 0.002 pieces/ft^2
    d. Cigarette = 3/420 ft2 = 0.007 pieces/ft^2
2. E-Cigarette TPW = 5/420 ft2 = 0.012 pieces/ft^2
    a. E-Cigarette Wrapper = 1/420 ft2 = 0.002 pieces/ft^2
    b. E-Cigarette Box = 1/420 ft2 = 0.002 pieces/ft^2
    c. E-Cigarette Pod = 1/420 ft2 = 0.002 pieces/ft^2
    d. E-Cigarette = 2/420 ft2 = 0.005 pieces/ft^2

Tier 1 Calculation

For that same assessment, the calculation can be summarized at the Tier 1 level accordingly:

- Assessment area = 420 ft^2
- Total amount of trash = 11
- Amount of trash per foot squared = 11/420 ft2 = 0.026 pieces/ft^2

TIER 3: BRANDING TPW

This method is the most specific method with respect to TPW classification, and accordingly the most demanding of time and effort. Tier 3 facilitates not only the identification of types, as does Tier 2, but achieves a higher level of specificity by counting brands. As with the other tiers, the amount of resources needed to perform this assessment is dependent upon the size of the area assessed and the amount of TPW present. However, since it demands a higher degree of specificity, precision, and intimacy with the studied material, the amount of time, by comparison to the two preceding tiers is likely to be substantial.

Since weathered items often lose their identifying features, brand identification might not be consistently achievable. Labels wear out, and print fades in sun and rain. Therefore, the hierarchy achieved by reverting to Tier 2, when necessary, can offer value when brand identification is not possible.

What to Count: For this Tier you will be counting the brands of TPW. The first major split in types here is in between a traditional cigarette and an e-cigarette. Under each of those categories the split is then between the actual cigarette, its parts and any boxes or wrappers and its brand.

For this method you will count the number of TPW by Brand Name.

DATA SHEET FOR TIER 3

Cigarette TPW

BRAND	Cigarette Wrapper	Cigarette Box	Cigarette Filter	Cigarette (filter and tobacco)	Total:
Marlboro	1			1	2
Parliament		1			1
Kool	1			1	2
Newport			1		1
Unknown	11				2
Dutch	𝍸				5
	Total: 9	Total: 1	Total: 1	Total: 2	13

E-Cigarette TPW

BRAND	E-Cigarette Wrapper	E-Cigarette Box	E-Cigarette Pod	E-Cigarette	Total:
NJoy	\	\			2
Juul				/	2
Blu				/	
Hojo					/
Unknown			///		
	Total: /	Total: /	Total: 3	Total: 4	9

Other

BRAND	Smokeless Tins		Lighters		Cigar Tips		Other - Specify		Total:
	Total:		Total:		Total:		Total:		

Another Way to Count: The count of the type of TPW can also be done using a smartphone application (see Counting section above for suggestions on how to search for a free app). The app can have multiple categories in this case, and a tally can be made by simply tapping on an area to the right of the category within the app to increase the increments by 1. However, if there are a large number of brands in your survey, we recommend using a paper data sheet.

Additionally you can use the electronic data sheet and a tablet to enter the data (see "Recording the Data" section below). This would require forethought in determining the assessment site and performing the assessment, as the above methods could be performed on the spur of the moment when in an area of interest.

Calculating the Amount per Unit Area: To calculate the amount per unit area you need the area and values for the amount of TPW by Brand. Divide the amount of TPW of a given Type by the amount of area to normalize the measurement to amount of trash per squared foot. Using this method, you can calculate the amount of TPW for Tier 2. Below is an example:

Let us say that the assessment area was measured and was = 530ft^2.

Tier 3 Calculations

Assessment area = 530 ft^2

1. Cigarette TPW = 13/530 ft2 = 0.025 pieces/ft^2
    a. Marlboro = 2/530 ft2 = 0.004 pieces/ft^2
    b. Parliament = 1/530 ft2 = 0.002 pieces/ft^2
    c. Kool = 2/530 ft2 = 0.004 pieces/ft^2
    d. Newport = 1/530 ft2 0.002 pieces/ft^2
    e. Unknown = 2/530 ft2 = 0.004 pieces/ft^2
    f. Dutch = 5/530 ft2 = 0.009 pieces/ft^2
2. E-Cigarette TPW = 9/530 ft2 = 0.017 pieces/ft^2
    a. NJoy = 2/530 ft2 = 0.004 pieces/ft^2
    b. Juul = 2/530 ft2 = 0.004 pieces/ft^2
    c. Blu = 1/530 ft2 = 0.002 pieces/ft^2
    d. Hojo = 1/530 ft2 = 0.002 pieces/ft^2
    e. Unknown = 3/530 ft2 = 0.006 pieces/ft^2

Tier 2 Calculations

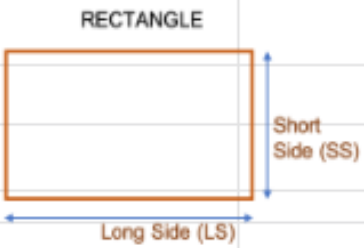
For that same assessment, the calculation can be summarized at the Tier 2 level accordingly:

Assessment area = 530 ft^2

1. Cigarette TPW
    a. Cigarette Wrapper = 9/530 ft2 = 0.017 pieces/ft^2
    b. Cigarette Box = 1/530 ft2 = 0.002 pieces/ft^2
    c. Cigarette Filter = 1/530 ft2 = 0.002 pieces/ft^2
    d. Cigarette = 2/530 ft2 = 0.004 pieces/ft^2
2. E-Cigarette TPW
    a. E-Cigarette Wrapper = 1/530 ft2 = 0.002 pieces/ft^2
    b. E-Cigarette Box = 1/530 ft2 = 0.002 pieces/ft^2
    c. E-Cigarette Pod = 3/530 ft2 = 0.006 pieces/ft^2
    d. E-Cigarette = 4/530 ft2 = 0.008 pieces/ft^2

TOBACCO PRODUCT WASTE DATA SHEET

Site Information			
Date	11/20/2020	Amount of Foot Traffic (Low, Moderate, High)	High
Time	10:35 AM	Weather(e.g. sunny, rainy)	Sunny
Location	Signal Hill, CA	Time to Perform Assessment (minutes)	5
Nearest Landmark	Statue	Perceived Trash Level (Low, Moderate, High):	Moderate
TPW Removed (yes/no):	no		
Latitude (optional)			
Longitude (optional)			



1. Step Length	
a. Count the number of steps you take in 10 feet:	2
b. Divide 10 by the number of steps:	2.0

2. Area Calculation – Measure the long side length and the short side length by counting the steps needed to walk each side and multiplying by the number for feet/step (2b) from above. Then multiply the two values together to get the total area for the assessment site.

a. Number of steps on Short Side	6
Estimated number of feet for Short Side	12.0
b. Number of steps on Long Side	11
Estimated number of feet for Long Side	22.0
c. Estimated Area (Short Side(ft) X Long Side(ft))	264.0

3. Tobacco Product Waste Tally

xxxxxxxxxxxx			
Total	13	Number/ft2	0.0492

Figure 12. Representation of the automatically calculating data sheet

Tier 1 Calculation

Likewise, for a Tier 1 calculation, the assessment can be summarized in the following way:

- Assessment area = 530 ft^2
- Total amount of trash = 22
- Amount of trash per foot squared = 22/530 ft^2 = 0.042 pieces/ft^2

Recording the Data

Once the data are collected, you will need to enter the information into a standardized data sheet that will aid in sharing, storing, and analyzing the data. The data sheet (Figure 12) includes areas for entering site information, measurements for calculating the area of an assessment site, and the TPW data. There are automatic calculations performed as the data are entered to give the total assessment area the amount of a given TPW measurement per unit of area. The boxes in orange are the boxes the user enters data into. The boxes in gray (with orange writing) are boxes that have automatic calculations performed as the data is entered.

When the data are entered into the spreadsheet, a datasheet is automatically filled in, listing the data in a table for easy transfer to a database or another file for storage (Figure 13). This table can also be used for data analysis and visualization.

Date	Time	Location	NearestLandmark	TPWRemoved	FootTraffic	Weather	TimeAssessment	TrashAmount
11/20/2	10:35 A	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	10:35 A	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	10:35 A	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	10:35 A	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	10:35 A	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	10:35 A	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	10:35 A	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	10:35 A	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	10:35 A	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	12/30/9	Signal Hill,	Statue	no	High	Sunny	5	Moderate
11/20/2	12/30/9	Signal Hill,	Statue	no	High	Sunny	5	Moderate

Figure 13. Representation of the data from the data sheet, "flattened" for easy exportability.

TIER 4: A Deeper Dive into TPW

Beyond the time and effort for most standard TPW monitoring practitioners is Tier 4, which will not be covered in this document. This tier includes collecting even more detailed information on the TPW and is designed to be highly rigorous in its sample design, data collection, and reporting. The sample design will include both targeted and random site selections, and systematic repeat collections will be performeddone at chosen sites to determine if there are use patterns and/or seasonality for particular types of tobacco products. Since the TPW is removed at each site, accumulation rates at repeat sites will also be calculated. The intensity of this method is high in that it requires much more time to complete, more planning, and greater preparation. This is due to the larger areas covered, such as a large school or mall parking lots, and the collection and inspection of every item. An example of the information collected on each TPW item includes the amount, type of product, brand, approximate age and much more. Additionally, each item will be documented by photograph to build a library of TPW photos to help others identify TPW. Due to the increased detail, time and for this Tier, it requires a higher level of training and commitment by participants. Data collection and data analysis will also increase the complexity of this method.

Studies conducted under Tier 4 would be able to address questions regarding highly specific geographical features, cultural drivers related to the deposition of TPW in specific locations, the residence time of TPW in the environment, and highly refined time intervals associated with tobacco consumption.

This method is currently being developed by researchers at the University of California, San Francisco. Please contact Jeremiah Mock at Jeremiah.Mock@ucsf.edu for more information.

Figure 14. Unoccupied Aerial Vehicle (UAV) Pilot and GIS Manager Pete Kauhanen pilots a Mavic Pro UAV for a TPW survey

In-The-Air Method

In addition to the methods described above, the authors of this document also pursued a proof-of-concept effort for aerial monitoring of TPW or, to be more specific, cigarette butts. The capture of imagery from the sky, using unoccupied aerial systems (UAS), commonly known as "drones," can facilitate the monitoring of a broader geography and more repeat site visits to produce a relatively rich dataset. This method is non-extractive, meaning that it does not involve any contact with the contaminant. Whereas the on-the-ground method offers the option of extraction, this aerial method does not, in itself, alter the landscape. Rather, it is a remote observation method that merely captures imagery for subsequent measurement of the TPW load.

Building upon the gathered imagery, the authors of this guide also developed a machine learning algorithm to automate the detection of cigarette butts. While a monitoring practitioner could, in practice, leverage imagery for purposes of documentation and manual analysis, we sought to determine the viability for the application of advanced computing techniques to TPW monitoring. The team, focusing on cigarette butts due to its commonly identifiable form factor, trained a neural network to detect such butts in imagery collected from the UAS.

Flights

To begin, the team conducted test flights to determine the optimal flight altitudes. Flying at higher altitudes increases the distance between the detected objects, the cigarette butts, and the UAS-attached sensor (camera). In doing so, the imagery becomes coarser and less resolved. On the other hand, flying at low altitudes bears a trade-off. The lower a UAS flies, the greater the likelihood that it might encounter trees, power lines, and other obstacles. Furthermore, the lower the UAS flies, the less ground it can cover in a given flight.

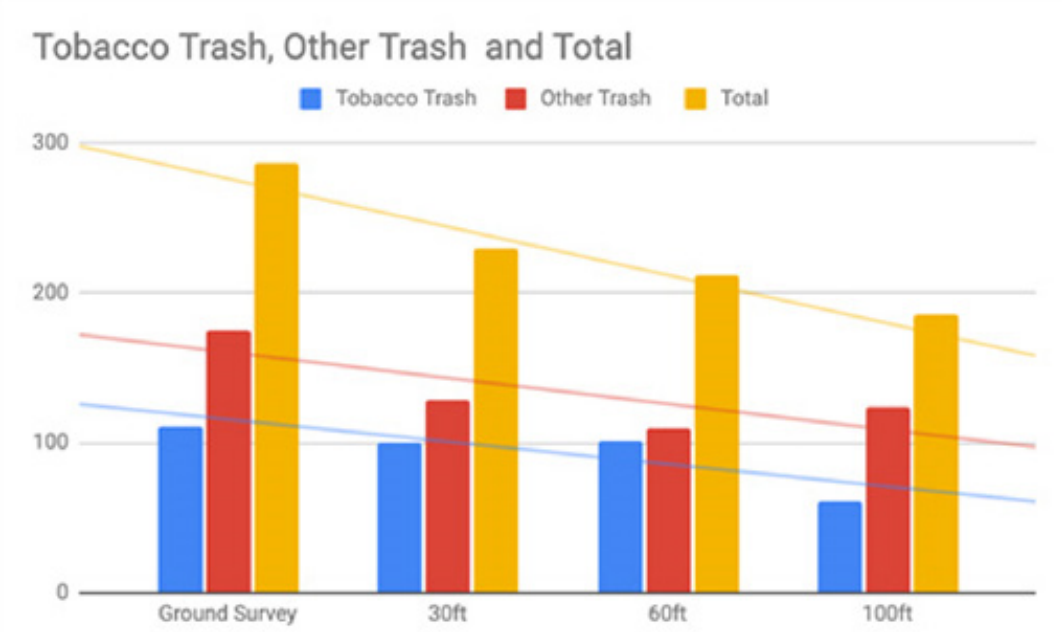


Figure 15: Counts of trash (totals and by type) at 30ft, 60ft, and 100ft elevations compared to Ground Survey Counts.

The initial test flights, using standard optical devices, determines that the optimal altitude for manual detectability was between 30 and 60 feet. Having determined this approach, the team conducted five flights over impervious surfaces, such as parking lots and street gutters. To gather measurable data of known quantity, the team seeded the area with a predetermined amount of cigarette butts. The assembled imagery was then used for purposes of training the machine-learning algorithm and – using a second subset of the imagery – for testing the effectiveness of the developed neural network.

Encountered Challenges

Flying an Unoccupied Aerial Vehicle (UAV) in today's climate of regulation and evolving technology is not as straightforward as it might otherwise appear.

We recommend that prior to piloting a UAV, the monitoring practitioner become a licensed drone pilot. While recreational pilots must not necessarily be licensed, according to present law, commercial users must. We recommend that the license serve as a litmus test for suitability of the pilot since recreational UAV users might otherwise run afoul of legal regulations imparted during pilot training.3

The use of the UAV over-populated areas presented several obstacles. Overcoming these obstacles will test the viability of the vehicle's use in urbanized areas. For instance, flying directly over people who are not protected by a structure or stationary vehicle is prohibited by FAA regulations. Accordingly, best practices dictate that the UAV is piloted to avoid flying over homes and yards where the public and or residents could step directly under the UAV. This risk can be mitigated by pausing the flight or assuming manual control of the UAV. Therefore, generally, the vehicle should be piloted to avoid flying directly over uncontrolled areas, such as private property, without prior coordination with landowners and residents. As safety measures to flight systems and hardware (such as parachutes) advance, restrictions may be relaxed or waived in specific instances.

Flying in coastal California will also be challenging because of the presence of airports, which require special clearance when flying near them. This means extra planning and coordination will be required when flying assessments within 5 miles of major airports.

With the incorporation of Low Altitude Authorization and Notification Capability (LAANC), UAS activities in controlled airspace at or below 400ft are much more logistically feasible. With LAANC one can gain approval to fly within subsets of controlled airspace, compatible with UAS based trash assessments, within seconds of submitting your proposed flight activities from a mobile device. In other cases, approval is necessary from the Air Traffic Control. As technology and regulation continue to advance to accommodate reasonable UAS use within the United States, UAS based monitoring may become more widely feasible.

Tree canopy cover may also occlude the UAS based methods, by obfuscating the ground and trash present. This often depends on the season relative to deciduous trees.

All of these factors limited and constrained the use of this technology, but where appropriate, the team conducted surveys and reported on the usefulness of the exercise. Since site conditions change and flight regulations adjust at a fast pace, some of these rule-based obstacles may change in the near term.

(Top) Figure 16. Example UAS photo featuring cigarette butts on a playground. The colored boxes represent manual annotations of cigarette butts.

(Bottom) Figure 17. Magnified version of a UAS photo featuring cigarette butts on a playground.

Automated Analysis

The team also applied machine learning algorithms to test the viability and practicality of applying these new tools. The team hypothesized that, under certain circumstances, machine learning may be used to accelerate the assessments, thereby potentially expanding the geography and time period surveyed.

The machine learning development is meant to augment UAS methods for TPW monitoring, particularly to increase the temporal and spatial scope of TPW surveys while minimizing time and labor costs. Ideally, such a method could produce a volume estimate and or tallies for the amount of trash at a given site. Considering the novelty of applying this type of technology to aerial imagery, this work should be evaluated with its exploratory nature in mind.

The machine learning algorithm is based on TensorFlow, a commonly used computational engine for these tasks. It is a form of a convolutional neural network (CNN) that leverages large datasets to determine patterns.

Our site surveys formed the basis of analysis for the CNN that was charged with identifying cigarette butts in the images by individual objects.

Results and Next Steps

To determine our model's ability to identify cigarette butts, we decided to compare detections from our algorithm to hand-drawn annotations. In essence, this means that we measure how much computer generated annotation boxes overlap with human drawn annotation boxes. This provides a sense of how well the model performs against the best data we can generate. If a computer generated annotation overlaps a human generated annotation by 50% or more, we can consider it good enough to register as a match.

Using this methodology, our current model was able to identify 1008 cigarette butts out of 1021 human identified cigarette butts. On average, matches identified had a 77% overlap, 100% would mean computer generated boxes had an exact fit to boxes drawn by humans while 50% would mean boxes only matched half. This also means merely 41 computer generated annotations out of 1021 potential matches did not meet our 50% overlap requirement and were either not cigarette butts or just didn't overlap enough. We did not detect 13 of the human drawn annotations at all, but once again there might have been a match below our 50% threshold or it may have completely missed.

Figures 18 and 19 help to illustrate the automated detection of cigarette butts using the model created to detect the familiar shape of such objects when viewed from the sky. For most of the tests, the background was asphalt to provide the most favorable and common conditions for detection. Other times, we conducted tests over grass and other stochastic backgrounds (Figure 20).

(top) Figure 18. Flight conducted in a parking lot.
(bottom) Figure 19. Flight conducted in a parking lot.

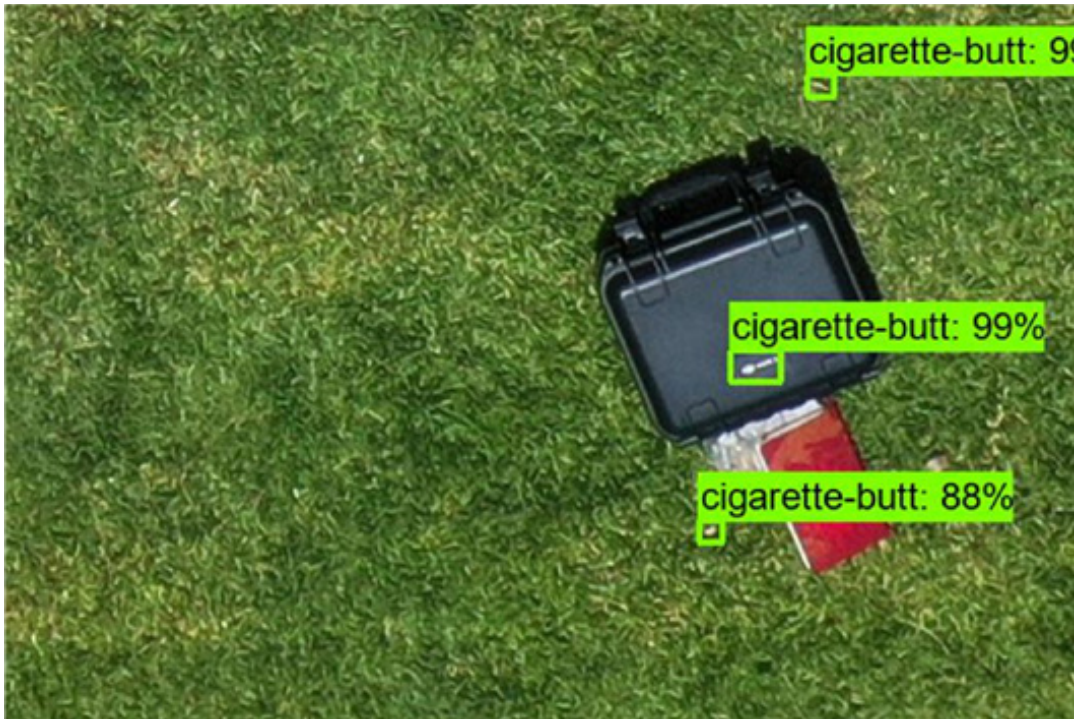


Figure 20. Flight conducted in a park.

Following these field tests, the team will pursue the operationalization of the machine-learning model. The model itself will be made available to everyone, so that those with the technical skill and inclination can further refine it. However, we also foresee the specific opportunity to operationalize the model using high-powered, cloud-computing resources to receive images from UAS-enabled practitioners and return counts of cigarette butts.

Successive generations of the algorithm can be further tuned to detect the broad range of TPW. However, it is our judgment based on related experience that cigarette butts, being at once common and regular in form factor, can reasonably be counted with the greatest confidence in accuracy and precision.

Quality Assurance / Quality Control Procedures: Re-counting the TPW

A modest but assiduously followed recounting measure is bound to produce mismatches, particularly when large numbers of TPW are found. While the differences among the numbers will likely be slight, we recommend double-counting the TPW using a different team at some sites to assess the discrepancies properly and calibrate the method across different practitioners. If a regular team is performing the assessments, we recommend as a best practice that there be double-counting performed for 20% of the sites --meaning that for every 5 sites, at least one is double-counted. This applies to all variants of the method, regardless of the selected tier you are using as a basis for your measurements.

Types of TPW

The types of TPW are numerous and varied depending on the type of product. The sheer number of different types of products is immense. Figure 21 below shows only a small number of cigarillo product wrappers. We have broken up our categories for Tier 1, Tier 2 and Tier 3 above based on the amount of time it would take to perform an assessment. The more detail you want to collect the longer the method will take. At one site during the Trash Monitoring Evaluation project (trashmonitoring.org) we found nearly 300 cigarettes in a small area. Just counting the cigarettes took some time; however, if we were to spend time branding the cigarettes it would have taken much longer. Appendix 1 shows pictures of each type of TPW we have categorized for this study. We kept these categories broad as we wanted to make sure that however much time an assessor has, an effective assessment, salient to the desired monitoring questions, could be performed.

Figure 21. Wide variety of tobacco product packages.

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