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Getting butts off the beach: Policy alone is not effective at reducing cigarette filter litter on beaches in Maui, Hawai'i

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ABSTRACT

Cigarette filters are made of non-biodegradable plastic and are one of the top littered items worldwide. Here, we determine if policy implementation is an effective strategy for reducing cigarette filter litter on beaches in Maui, Hawai'i by comparing cigarette filter counts before and after a policy banning tobacco use was implemented. We use a before–after control–impact (BACI) design to investigate whether changes in cigarette filter accumulation at an impact site, where tobacco use was banned, decreased relative to counts at a control site, where tobacco use was not banned. A total of 764 cigarette filters were removed with no significant difference detected in cigarette filter littering between the control and impact site after the policy went into place. This study shows that policy requiring a shift from social norms, such as tossing cigarette butts, needs to be accompanied by sustained law enforcement and awareness around the policy to be effective.

1. Introduction

Plastic production and resulting environmental impacts are a serious global concern (Sheavly and Register, 2007). Plastic waste can be found in nearshore waters and the open ocean (Geyer et al., 2017) and has been shown to pose considerable threat to marine life (Currie et al., 2017) and their environments (Derraik, 2002), with additional implications for human health, safety, and local and national economies (Sheavly and Register, 2007). Marine debris can further translate into loss of tourism revenue and recreation value (Secretariat of the Convention on Biological Diversity (SCBD), 2012; Sheavly and Register, 2007). With an estimated ~5–12 million tons of plastic waste entering the oceans per year (Jambeck et al., 2015), plastics are considered the most common type of marine debris around the world (Derraik, 2002).

Recent surveys reporting on the number of macro (>2.5 cm) debris items found in the Hawaiian archipelago show that plastics make up 80–90% of the debris counted (Blickley et al., 2016; Currie et al., 2019). Although debris originating from the convergence zone north of the Hawaiian Islands is of concern (Goldstein et al., 2013), debris originating within the Hawaiian Islands from land sources is also a significant environmental issue (Blickley et al., 2016). On Maui, two of the three shoreline sites monitored in Blickley et al. (2016) found that 85–90% of the debris was made up of items that originated on land (as opposed to being deposited on shore by the ocean) with 35–60% of all debris categorized as cigarette filters. The number of cigarettes being introduced into the environment is staggering, with an estimated 15–20 billion cigarettes manufactured each month within the United States of America (Alcohol and Tobacco Tax and Trade Bureau, 2019). Cigarette filters are often discarded on the ground and they frequently rank as the most commonly recovered item at beach cleanups, such as Ocean Conservancy's International Coastal Cleanup (Ocean Conservancy, 2018). Due to their sheer numbers and prevalence in the environment, cigarette filters or "butts" constitute a significant environmental burden (Novotny et al., 2011). Cigarette filters are made of cellulose acetate, a type of non-biodegradable plastic (Puls et al., 2011). In addition to being unsightly and persistent, cigarette filters can leach chemicals such as acetic acid, hexamine, arsenic, and chromium into the surrounding environment, and pose a risk to marine life if ingested (Micevska et al., 2006; Slaughter et al., 2011).

To mitigate the effects of littering and waste, two types of reduction techniques are generally employed by governments and non-governmental organizations (NGOs): (1) policy, such as bans on the use or manufacturing of an item, and/or (2) education, such as outreach campaigns. Policies generally target items before they enter the environment by intervening at some stage between production and deposition, while outreach programs can create mitigation efforts both before

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and after an item has entered the environment (Willis et al., 2018). A major limiting factor to policy is that laws require regular enforcement to be effective, which can be challenging to enact with limited resources. Educating the public through anti-litter campaigns, for example, can encourage individuals to improve their littering behavior and can achieve success when coupled with local programs that encourage community members to be custodians of their environment (Bravo et al., 2009).

In Hawai'i, a combination of anti-litter laws and dedicated environmental organizations work to limit and remove marine debris, including discarded cigarette filters. To help address the issue of cigarette filter accumulation on the islands of Maui, Lāna'i, Moloka'i, and Kaho'olawe, Maui County passed legislation in April 2014 banning the use of tobacco products at all county beaches, parks, and recreation areas (Bill 24; effective April 22, 2014). The state of Hawai'i followed suit shortly after, passing a similar bill which prevents tobacco use at all state parks and beaches (Bill 525; effective July 1, 2015). The goal of this policy at both the county and state level was to reduce cigarette filter litter by banning tobacco use in various areas. However, preliminary research conducted at Maui County beach parks have shown that beach goers are still using tobacco products on the beach and littering their used cigarette filters despite the law prohibiting this (Blickley et al., 2016). In the current climate of enthusiastic environmental campaigns and policies, conducting scientific studies to determine the most effective mitigation method is a step that is often overlooked. However, scientifically monitoring the effectiveness of conservation policies is a crucial step for scaling successful strategies.

Here we determine if policy implementation is an effective strategy for reducing cigarette filter litter on Maui's beaches by comparing cigarette filter counts before and after a policy was implemented banning tobacco products at select beaches. We used a before–after control–impact (BACI) design to investigate whether changes in cigarette filter accumulation at an impact site, where tobacco use was banned, decreased relative to counts at a control site, where tobacco use was not banned.

2. Methods

A BACI design was used to assess the impacts of the policy on reducing cigarette filter accumulation by sampling two beach sites with similar beach and debris accumulation characteristics (Blickley et al., 2016), before and after Bill 24, hereafter referred to as policy, went into effect. The policy (Bill 24 - supplementary material) made it unlawful for any person to engage in smoking or the use of tobacco products within the limit of Maui County park or recreation facility.

Sampling sites were located on the leeward shores of Maui, Hawai'i. Site 1 (20.88421°, −156.68681°, Pu'unoa Beach) served as the control site, as it was not under Maui County jurisdiction, and site 2 (20.66310°, −156.44164°, Po'olenalena Beach) served as the impact site, as it was under Maui County jurisdiction (Fig. 1).

To account for the influence of spatial scale on the analysis, control and impact sites were of the same size, contained the same broad vegetation types with similar beach topographies (Fig. 2), were equipped with restrooms, shower facilities, and trash bins, and are freqented by a mix of residents and tourists. Site 1 is located along a reef-lined coast with a small percentage of volcanic fragments in the very poorly sorted sand and gravel sediment (Moberly, 1963). The beach extends ~310 m along the coast and is bounded to the east and west by lava rocks. Site 2 is also along a reef-lined section of the coast, and consists of sand which is a well sorted mixture medium-sized, predominantly calcareous, fragments (Moberly, 1963). The beach stretches along ~355 m of coastline and is bounded to the northwest by harbor breakwall and

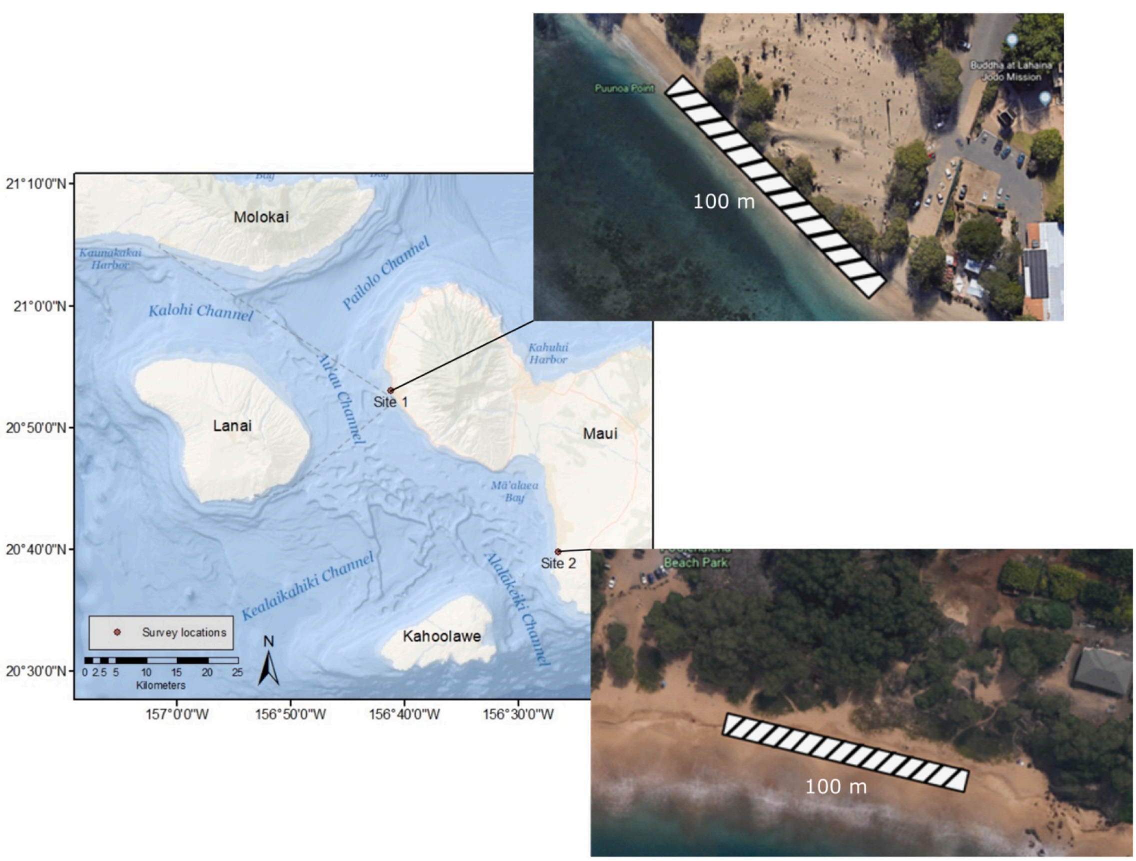

Fig. 1. Map showing the general location of the two survey sites on Maui for case study 1 with inserts showing topographic details and location of 100 m survey area. Site 1 = Pu'unoa Beach; site 2 = Po'olenalena Beach.

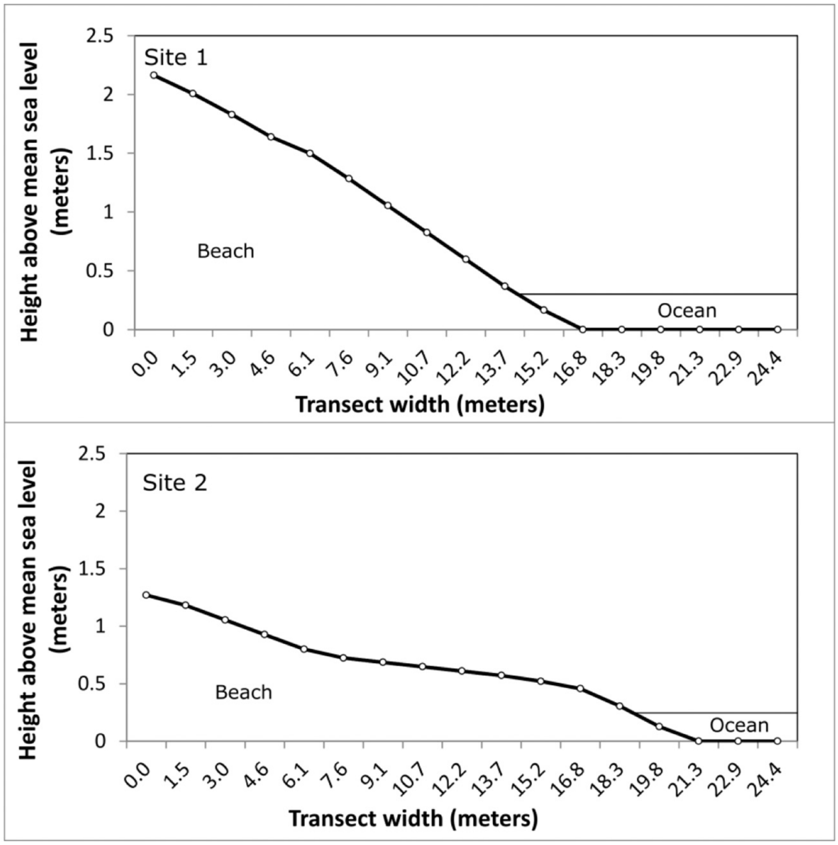

Fig. 2. Beach profiles for site 1 (Pu'unoa) and site 2 (Po'olenalena) determined using methods provided in Emery (1961). Note: Ocean is depicted during high tide and beach transect widths ended when the mean height above sea level was 0.

to the southeast by shrubs and vegetation. Although trash cans were in place at sites 1 and 2, neither beach had dedicated cigarette disposal receptacles.

2.1. Data collection

A 100 meter (m) transect was randomly placed on the beach in ArcMap 10 (ESRI, 2012) for both sites to determine the start and end positions of the survey area. To ensure consistent sampling areas a handheld Global Positioning System (GPS) device was used to find the same start and end survey areas throughout the study period. Each survey area was traversed at low tide by a single researcher who walked back and forth parallel to the water line until the entire survey area was covered from the water's edge to the back of the shoreline indicated by a vegetation barrier in both sites. During each survey, all visible cigarette butt filters and macro-debris items (measuring 1.5 cm or larger) were removed and documented using a paper datasheet. Following accumulation survey protocols presented in Opfer et al. (2012), an initial cleanup was conducted at all sites to remove all debris and develop a baseline for monthly accumulation.

Ten monthly surveys were conducted along the 100 m transect at both control (site 1) and impact (site 2) sites from July 2013 to April 2014 and served as the before period in the BACI design. In April 2014, policy (Bill 24; passed April 22, 2014) was passed that banned the use of tobacco products at site 2 as the legislation only applied to beaches that were managed by Maui County. Ten monthly surveys were then conducted along the same 100 m transects at the control and impact sites from March to December 2018 and served as the after period in the BACI design. To minimize the impacts of observer bias, the same two individuals conducted the data collection throughout survey period.

The four year time period between control and impact surveys allowed for appropriate signage and enforcement measures to be put in place, but assumed that beach cleanups beyond the accumulation surveys remained constant. Data provided from the coastal marine debris monitoring program (Pacific Whale Foundation, 2019), the largest community scientist-led beach cleanup effort on Maui, recorded no cleanups at either site during the survey period. Further, the monthly sampling duration and high re-deposition rate observed for debris on Maui likely minimized the impact of additional cleanups that may have occurred within the study period.

2.1.1. Enforcement

To determine the level of impact that local law enforcement had in implementing the policy, a request of citation records for tobacco use in Maui County beach parks and recreation areas after the ban went into effect (County Code Section 13.04.020) was sent to the Maui Police Department.

2.2. Data analysis

A generalized linear mixed model (GLMM) was used to evaluate the impacts of policy on cigarette filter accumulation following a BACI framework. As such, the period (before/after), the site (impact/control) and an interaction term between period and site were fixed effects in the model. Under the BACI design, a statistically significant interaction term between period and site would indicate that policy had a significant effect on cigarette filter accumulation (Mcdonald et al., 2000). The (null) hypothesis of no effect was rejected at the conventional P-value <0.05 statistical significance level. To account for potential variations in cigarette filter litter over time, the following five metrics were calculated as candidate random effects and described in more detail below: relative exposure index (Walker et al., 2006), relative tidal range (Short, 1996), intertidal area (McLachlan and Dorvlo, 2005), debris count and visitor count. The selection of random effects to include in the final model was done by running a full model and using Akaike's Information Criterion (AIC) to determine which combination of random effects resulted in the lowest AIC (Zuur et al., 2009). To determine how well the final model fit the data, marginal (the variance explained by fixed factors) and conditional (the variance explained by both fixed and random factors) R^2 values (Nakagawa and Schielzeth, 2013) were calculated. Finally, cigarette filter count was modeled using a Poisson error structure and log link function, as assumptions of normality and homogeneity of variance were met. All analyses were completed in R v3.5.3 (R Core Team, 2018) using the glmer function in the lme4 package.

2.2.1. Relative exposure index

To summarize monthly wind speed and direction, a relative exposure index (REI) was used from (Walker et al., 2006) to include eight different wind directions. Wind directions were determined for each site based on orientation and totaled 180°:

$$REI = \sum_{i=1}^{8} \frac{V_i P_i F_i}{100}$$

where V_i is the mean monthly wind speed (km h^{-1}) for wind directions categorized in 45° increments; $P_i$is the percent frequency from which the wind blew within each increment; and F_i is the fetch (U.S. Army Coastal Engineering Research Center (USACERS), 1984) distance (km). Fetch lengths greater than or equal to 100 km were all set to 100 km and assumed to represent unlimited fetch in the *i*th direction (Garcon et al., 2010; Puotinen, 2005).

2.2.2. Relative tidal range and intertidal area

To summarize monthly tide and wave activity, a relative tidal range (RTR) (Short, 1996) and an intertidal area (IA) (McLachlan and Dorvlo, 2005) were calculated for each site:

$$RTR = \frac{H_t}{H_w}$$

$$IA = \frac{H_t}{S}$$

where H_t is mean monthly tide height in meters (m), H_w is the mean monthly wave height (m) and S is the beach slope.

2.2.3. Visitor count

To account for potential differences in the number of beach users at each site over time, the total monthly visitor counts to Maui were determined. Logistical sampling constraints precluded the counting of beach users for each sampling period of the study. As such, the visitor counts presented here serve as a proxy for the potential volume of beach users and do not represent the actual counts at each beach. Although this is not an exact count, it is thought to limit the potential bias for changing beach users, as beach use is known to fluctuate with tourism numbers (Maui County, 2016, pp. 2017–2026).

2.2.4. Debris count

Monthly debris counts were determined by summing all the non-cigarette filter debris collected within the survey area for each site.

2.2.5. Data sources

Tide height data for each site were extracted from the Center for Operational Oceanographic Products and Services (Center for Operational Oceanographic Products and Services, 2020). Tide data for site 1 was taken from station TPT2799 (20.88333°, −156.68333°) located approximately ~490 m from site 1. Station 1615202 (20.65667°, −156.44500°) was used to determine tide heights for site 2 and was located ~790 m from the site. Wave height data for both sites were extracted from the National Data Buoy Center's (NOAA, 2020) buoy 51003 (19.17500°, −160.62500) located ~400 km northwest of Maui. Wind speed and directions were extracted for each site using the *weatherData* package (Narasimhan, 2017) in R (R Core Team, 2018). Station KHILAHAI5 (21.00200°, −156.65800°) was used to gather wind data for site 1 and was located ~14.5 km from the site. Wind data was taken from station KHIKIHEI4 (20.68167°, −156.45333°) for site 2, which was located ~850 m from the site. Monthly visitor counts were obtained from the Hawai'i Tourism Authority (Hawai'i Tourism Authority, 2020), which tracked daily arrivals of visitors to Maui.

3. Results

3.1. Environmental data

Tide heights did not change between the time periods and varied an average of 41 cm (range: 3–95 cm) at site 1 and 35 cm (range: 1–77 cm) at site 2. The mean monthly wind speed at site 1 was 4.2 kph (range: 0.3–8.3 kph), which was lower than the mean monthly wind speed of 5.26 kph (range: 4.1–6.29 kph) recorded at site 2.

3.2. Visitor counts

The monthly visitor counts increased by an average of 32% between 2013 and 2018, with peaks occurring in March and July each year (Fig. 3).

3.3. Enforcement

Citation records for Maui County Code 13.04.020 provided by the Maui Police Department showed zero citations were issued under the policy banning tobacco use on public beaches and recreation areas as of August 2018.

Throughout the survey period, 764 cigarette filters were collected across both sites 1 and 2. The amount of cigarette filters accumulating at both the control and impacts sites decreased in 2018, but both sites continued to accumulate cigarette filters in the sampling period following policy implementation (Fig. 4).

3.4. Modeling results

The final GLMM selected to assess the impact of policy of cigarette filter count included random effects for relative tidal range, visitor count, and debris count, with 49% of the variance explained by the fixed effects and 97% by both the fixed and random effects (Table 1). Period, regardless of site, was found to significantly impact cigarette filter counts (P-value = 0.011; Table 1) with a 64% reduction observed at site 1 (control), and a 56% reduction at site 2 (impact). This reduction cannot be attributed to policy implementation as policy only applied to site 2, and no significant effect was detected for the interaction between period and site (Table 1).

4. Discussion

Policy was not effective at reducing cigarette litter in Maui, with no significant difference detected in cigarette filter littering between the control and impact site after the policy went into place. Both sites continued to accumulate cigarette filters four years after the ban went into place and despite a reduction in cigarette filter litter at both locations, the results of this study show that the policy could not be attributed to reducing tobacco-related litter on Maui County beaches. The inclusion of tidal action (RTR) as a random effect in the model presented here aligns with findings of previous marine debris surveys conducted on Maui's beaches (Blickley et al., 2016), which also found a relationship between RTR and monthly accumulation rates. The relationships of RTR to cigarette filter accumulation was not investigated in the BACI

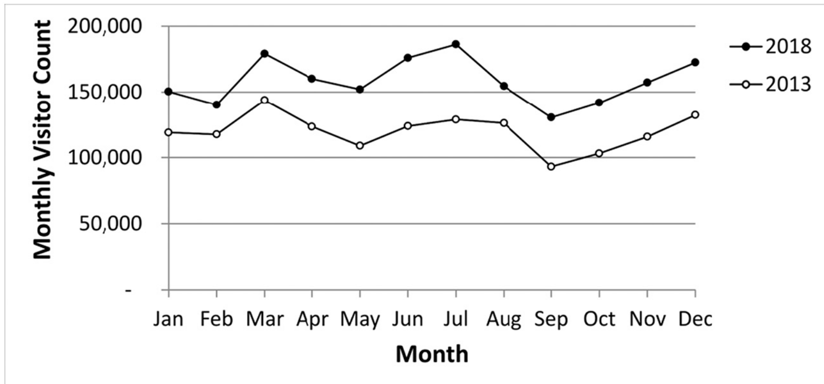

Fig. 3. Monthly visitor counts for Maui during the two sampling periods of the study. Monthly visitor count data were obtained from the Hawai'i Tourism Authority (Hawai'i Tourism Authority, 2020).

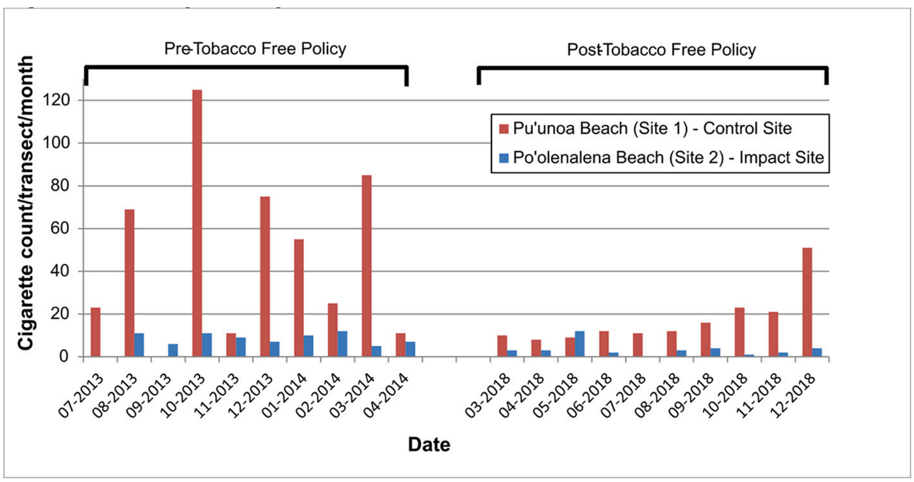

Fig. 4. Monthly cigarette filter counts collected pre- and post-implementation of the tobacco ban within a 100 m section of Pu'unoa Beach (site 1; control) where the tobacco use ban did not apply and Po'olenalena Beach (site 2; impact) where the tobacco ban did apply.

Table 1
Fixed effects results of the top Generalized Linear Mixed Model (Poisson family, log link function) for the before-after (B-A), control-impact (C-I) analysis on monthly cigarette litter count at Pu'unoa Beach (site 1; control) and Po'olenalena Beach (site 2; impact), Maui.

Variables	Estimate	Standard error	z-Value	P-value
Intercept	2.448	0.313	7.823	<0.001***
Period (B-A)	1.066	0.417	2.556	0.011*
Site (C-I)	−1.113	0.576	−1.933	0.053
Period * Site	−0.613	0.747	−0.820	0.412

Note: model includes random effects for RTR, visitor count, and debris count and had marginal and conditional R^2 values of 0.489 and 0.970 respectively.

design, however, Blickley et al. (2016) noted that debris is swept on and off the beach with changing tide height. These findings highlight the need to dispose of cigarette filters in proper receptacles to prevent wave and tidal action from washing the litter into the ocean. The significant reduction in cigarette filters observed in 2018, after the policy went into effect, may be attributed to variety or reasons including inter-annual changes in accumulation rates, increased beach cleanup efforts, and reduced tobacco use. High inter-annual variation in beach debris accumulation has been observed for both land (Blickley et al., 2016) and ocean (Currie et al., 2019) based debris in Maui, with some changes as high as 400% (Currie et al., 2019). Cleanup efforts, such as the coastal marine debris monitoring program on Maui, have grown in recent years. Finally, there has been a general decrease in smoking behavior over the past 50 years that has been attributed to greater awareness around the negative health implications of smoking (Burns, 2014), and may explain the decrease in cigarette filters observed in 2018.

The use of monthly, as opposed to daily, sampling intervals in this study likely impacted the observed accumulation rates as noted in Blickley et al. (2016). The impact of events that occurred between sampling dates, such as additional cleanup efforts or extreme weather events, could not be accounted for in this analysis. Indeed, several dates presented outliers with July 2018 finding no cigarette filters, while October 2013 showed a spike in cigarette filters. These anomalies may have been explained by daily sampling. Debris turnover, which includes cigarette filters, can occur rapidly and is influenced by variations in local conditions (Bowman et al., 1998; Ryan et al., 2009; Smith and Markic, 2013), which will vary between years. However, the potential impact of rapid debris turnover applies throughout the BACI design and the repeat measurements are thought to minimize the potential impact in final analysis. Further, the effects are thought to be minimal in determining the effectiveness of eliminating tobacco use at county beaches, with the presence of cigarette filters indicating continued use throughout the study period.

4.1. Outreach

Policies that target the public should be accompanied by an awareness campaign that educates the target audience and is specifically designed to create a behavior change. The initial outreach about the implementation of the ban on tobacco use on Maui County beaches and parks was limited to the installation of a small rectangular sign (Appendix A, Fig. A.1) at all affected areas and a post on Maui County's official website (County of Maui, 2019). The NOAA Marine Debris Program funded a 'Tobacco-Free Beaches' public awareness campaign on Maui from 2016 to 2018 following the policy implementation (https://marinedebris.noaa.gov/prevention/tobacco-free-beaches-public-awareness-campaign) as increased education and outreach has been previously shown as an effective method of reducing littering rates (Campbell et al., 2014). This campaign, in conjunction with a growing awareness on the impact of plastic and debris (Bettencourt et al., 2021; Veiga et al., 2016), may also have been contributing factors to the decrease in cigarette filter litter observed at both control and impact sites in 2018.

4.2. Designing effective policy

In contrast to the findings presented here, an earlier study (Blickley et al., 2016) found that Maui's 2011 ban on single-use plastic bags (Bill 69; effective January 2011), which made it unlawful for businesses to provide plastic bags to their customers at the point of sale for the purpose of transporting groceries or other goods, to be very successful at reducing the number of plastic bags found on beaches. Indeed, waste management policies on land have been shown to influence marine debris pattern in other regions as well (Liu et al., 2013). Blickley et al. (2016), found zero plastic bags on Maui's beaches a trend which was maintained in the 2018 surveys in this study. The difference between the ban on tobacco use and the ban on plastic bags was the intended target audience of the policy and therefore the type of policy that was created. The tobacco ban targeted smokers and required them to change their behavior, while the plastic bag ban targeted retailers and prohibited them from distributing the banned item rather than relying on consumers to change their behavior. Despite new policies, laws have been in place since the 1990's that make it illegal to litter on a public or private place (Ord. 1876, Maui County), which includes discarding cigarette filters. Developing policy that requires a shift from social norms must be accompanied by either law enforcement or sustained awareness around the policy in order to be effective (Willis et al., 2018). Long-term education campaigns for the general public are necessary in order to guide people and communities about disposal methods and policies (Liu et al., 2013). This requirement becomes even more important when the policy is implemented in an area with a high number of seasonal visitors and tourists (Campbell et al., 2014) such as Maui County, which received ~2.9 million visitors in 2018 (Department of Business, Economic Development, and Tourism, 2019).

4.3. Enforcement

Despite regular and frequent violations of the law, as reported here, the Maui Police Department has issued zero citations in the five years since the law went into effect (Merry Greer Prince, Police Intelligence Research Analyst, pers. comm., Maui Police Department, 2019). Without a substantial financial investment, compliance is difficult to achieve and this highlights the shortfalls of the tobacco ban in Maui County. Future research should investigate if an increase in enforcement leads to the desired behavior change and a reduction in cigarette filter litter in Maui.

Well-developed policies, in combination with outreach programs, have been shown to reduce the amount of litter and marine debris (Willis et al., 2018). However, additional scientific research is needed to determine the connection between policy intervention and enforcement in reducing the amount of cigarette filters on Maui's beaches. Policy intervention may still be a viable option on Maui, if accompanied with sufficient enforcement that results in individual behavior changes. To this end, future research efforts should supplement cigarette counts with a metric describing the level of compliance with the policy being evaluated, such as recording the proportion of observed beach goers using tobacco products.

5. Conclusions

The results presented here are important for government representatives to consider as they work to develop and support environmental legislature and for environmental organizations who are lobbying in support of proposed mitigation measures. In order to produce meaningful and impactful policy, resources should be allocated to determine what the most effective policies are and the level of community support they require. Identifying the items that are littered in high quantities represents the first step of a successful policy framework; however, equally important is identifying successful mitigation strategies and the resources that they will require.

We recommended that new policies are implemented in conjunction with a robust education and outreach campaign to raise awareness on the issue and with a comprehensive research plan that includes monitoring pre- and post-implementation to evaluate efficacy. We recommend that Maui County focuses on strengthening the 2014 ban on tobacco use by conducting a state-funded outreach campaign raising awareness of the policy in conjunction with increased enforcement effort.

CRediT authorship contribution statement

Jens Currie (JC) and Stephanie Stack (SS) conceived and conceptualized the study. JC supervised the data collection and conducted the analysis. JC and SS interpreted the results and drafted the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Maui Country beach park signage

Fig. A.1. Example of the Maui County signs used to notify the public on the ban of tobacco products throughout Maui County's beaches, parks, and recreational areas.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2021.112937.

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