REPORT

RENOREK

Optimising the frequency of coastal clean-up actions to maximize debris removal: a case study from depositional coves in the Lofoten archipelago, Norway.

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RENOREK - Optimising the frequency of coastal clean-up actions to maximize debris removal: a case study from depositional coves in the Lofoten archipelago, Norway.

Forfatter(e) / Author(s)

Therese Meyer

Marthe Larsen Haarr

Kjersti Eline Tønnessen Busch

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Sammendrag / Summary

Coastal clean-up actions were carried out at randomised intervals ranging from 1-63 days at ten beaches and coves in the Lofoten archipelago. For locations with moderate to high litter accumulation there was a strong inverse relationship between the estimated daily accumulations rates of litter and sampling interval. This suggests that such locations should ideally be cleaned 1-2 per month to maximise the amount of litter removed from the surrounding marine environment. While the standing stock of litter on the beach generally increases over time if left uncleaned, it does not increase at the rate expected based on observed daily accumulations rates, suggesting that considerable amounts of litter are lost back into the marine environment of not removed quickly. When clean-up actions are undertaken regularly, the amount of litter collected each time is not necessarily very high, making such schemes more suitable for individual persons set to "adopt-a-beach".

Prosjektleder / Project manager

Fredrik Johannessen

Kvalitetskontroll / Quality control

Kjersti Eline Tønnessen Busch

PREFACE

This project is a continuation of SALT's work with RENOREK in 2016, were 27 days of field work were conducted at two beaches (Rekvika and Følvika) in Lofoten.

RENOREK was further funded by the Norwegian Environment Agency in 2017 together with the project Proof Clean. Invaluable experiences regarding coastal clean-up actions best practices were gained through the latter project. Having gained the experiences, RENOREK was initiated in the fall of 2017 and data collection being terminated in late May 2018.

The project has been expanded beyond its initial scope by incorporating it into a Masters thesis. MSc candidate Therese Meyer is enrolled in the Marine Coastal Development programme at Department of Biology, Faculty of Natural Sciences at the Norwegian University of Sciences and Technology (NTNU). Ms. Meyer is co-supervised by Dr. Martin Wagner (NTNU) and Dr. Marthe Larsen Haarr (SALT).

This report summarises the work done to date. One final round of field data collection is still taking place, and the dataset will be further analysed to assess impacts of wind patterns on litter accumulation rates and how weather forecasts can be used to optimise coastal clean-up strategies. The data will also be further analysed with respects to patterns specific to certain types and sizes of litter. The thesis will be completed during the fall of 2018.

SALT and Ms. Meyer thank the Norwegian Environment Agency for their support and opportunity to engage in this important work.

Svolvær, 30.05.2018

Marthe Larsen Haarr

Prosjektleder, SALT

Main chapters

x

SALT
post@salt.nu
+47 482 20 550
Postboks 91 8301
Svolvær
www.salt.nu

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1. INTRODUCTION

Marine litter is one of our times' biggest environmental challenges, harming a vast amount of marine species and posing negative economic consequences (see Bergmann *et al.* 2015 for review). A decrease in the annual influx of litter into the oceans will be critical to combating the problem, yet efforts to reduce the staggering amounts of litter already present in the oceans are also paramount. To achieve the latter, the first step is understanding where and how marine litter accumulates and how to optimize clean-up efforts.

In general, action taken close to the source will be more cost effective and have a greater impact than actions taken in the open ocean. The density of marine litter afloat in the water column is generally quite low; the clear majority of debris sinks to the ocean floor (Eunomia 2016). The highest concentration of floating litter documented in the Great Pacific Garbage Patch is 18 kg km^{-2}, with an average of only 0.75 kg km^{-2} estimated globally, accounting for a meagre 1% of marine debris (Eunomia 2016). As a result, clean-up attempts in the water column are likely to be inefficient and with exceedingly high costs in terms of fuel consumption, greenhouse gas emissions and bycatch of fish and other marine organisms. In contrast, 94% of marine debris is believed to lie on the ocean floor, with an average density of 70 kg km^{-2} (Eunomia 2016). However, debris here is often difficult to access and with considerable potential of habitat destruction and bycatch.

The remaining approximately 5% of marine debris gets washed ashore along beaches (Eunomia 2016). While this may be a relatively small proportion of the overall problem, the density of litter along coastlines is on average two orders of magnitude greater than on the ocean floor with an average global estimate of 2,000 kg km^{-2} (Eunomia 2016). Such high concentrations of litter along the coastline, combined with ease of access, make coastal cleanup actions one of the most cost effective methods of combating marine litter. Potential negative environmental impacts are also minimal.

The value of coastal cleanup actions is further highlighted by the continuous cycle of fresh input and resuspension of already beached materials. Tagging studies have shown that beach litter frequently gets resuspended, moved about the beach and washed back out to sea (Johnson 1989; Garrity and Levings 1993; Johnson and Eiler 1999). Such resuspension and movement of litter on a beach can greatly exceed the cumulative input of litter during a month (Bowman et al. 1998), and there is a marked negative relationship between sampling frequency and estimated litter accumulation rates (Eriksson *et al.* 2013; Smith & Markic 2013; Ryan *et al.* 2014). This suggests that considerable amounts of beached litter are returned to the environment with time. Consequently, more frequent, smaller cleanup actions will likely result in a greater cumulative removal of litter than will a single or few spread actions. Thus, regular removal of beach litter not only reduces pollution on the beach itself, but removes litter that would otherwise very likely be returned to the marine environment.

Many beaches also show strong seasonal variation in the amount and composition of litter (e.g., Garrity & Levings 1993; Walker *et al.* 1997; Lee and Sanders 2015; Simoneova *et al.* 2017). This suggests that the processes driving influx varies over the same time scale, and that frequent clean-up actions may have increased value during certain times of the year. Weather patterns are likely highly influential in determining seasonal variation in beach litter dynamics. Several studies indicate that wind strength influence the movement of marine litter (Kako *et al.* 2010; Eriksson *et al.* 2013; Blickley *et al.* 2016). Winter storms, for example, may therefore be a considerable force for deposition and resuspension of beached marine litter.

An organised and informed coastal clean-up strategy could prove an important tool in mitigating the impacts of marine litter. Because of the dynamic nature of beached litter, optimising coastal clean-up actions also means optimising the interval at which they are done. An appropriate question to ask is whether resources should be allocated towards more frequent clean-ups of highly depositional beaches, to minimize the rate of loss and resuspension of debris to the surrounding environment, and if so how frequent these should be. This study therefore aimed to investigate what impact of clean-up frequency at ten locations in the Lofoten archipelago.

2. METHODS

2.1 Site selection

A total of ten locations were chosen for monitoring on the islands of Austvågøy and Vestvågøy in the Lofoten archipelago (Table 1; Fig. 1). Sites were chosen based on several criteria. Firstly, we sought to obtain relatively broad spatial coverage. Secondly, we chose sites observed to have considerable amounts of litter at some point in time. Thirdly, we primarily chose somewhat obscure locations unlikely to be visited and cleaned by members of the public. Lastly, we made use of locations previously cleaned by SALT to generate longer time intervals than possible within the duration of the study. The locations ranged in size from 75 to 30,000 m^2 (Table 1). Nine of the ten sites had an area of 500 m^2 or less. Sites were limited to these relatively small locations because (1) locations with high litter accumulation are often narrow coves, and (2) to ensure sampling was possible even in the event of snow. The last site was an order of magnitude larger than the average size of the other nine. This site was chosen because repeated sampling had been conducted on this relatively long sand beach in 2016, potentially allowing some additional data for comparison. Substrate at the sites was variable, but most were covered primarily by cobbles or boulders, often mixed with sand or vegetation (Table 1).

Table 1: Site overview (see Fig. 1 for map).

Site #	Site name	Area (m^2)	Substrate	Municipality
1	Laukvika 1	277	Pebbles and grass	Vågan
2	Laukvika 2	75	Sand	Vågan
3	Laukvika 3	500	Pebbles and sand	Vågan
4	Følvika	32,663	Sand	Hadsel
5	Finnvika	118	Boulders	Vågan
6	Rekvika	262	Pebbles	Vågan
7	Børvågen	155	Grass and pebbles	Vågan
8	Valberg 1	222	Pebbles	Vestvågøy
9	Valberg 2	164	Pebbles and grass	Vestvågøy
10	Valberg 3	179	Pebbles and sand	Vestvågøy

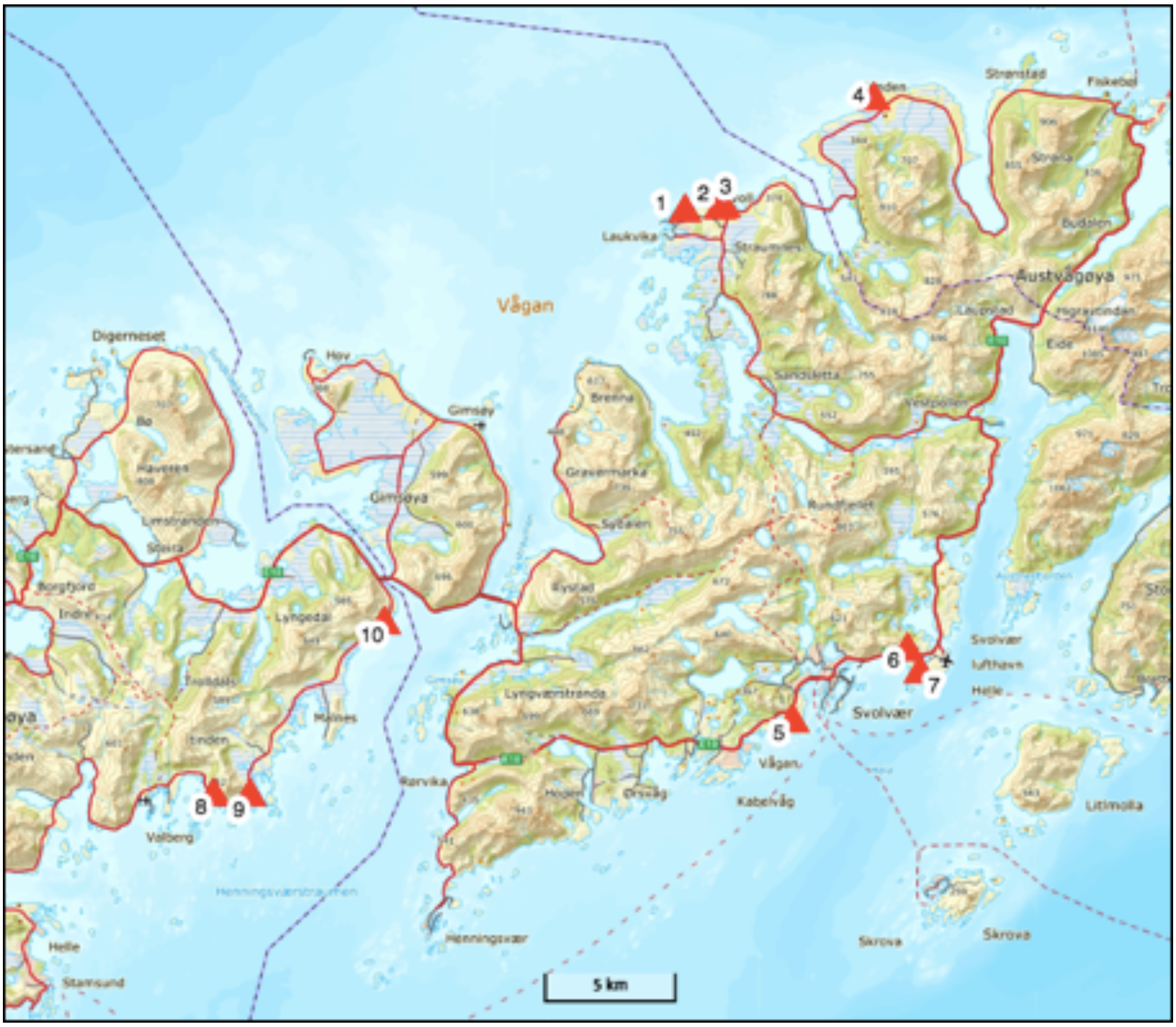

Figure 1: Map of sampling locations. Refer to Table 1 for site names.

2.2 Field sampling

Field work was conducted from December 2017 to April 2018. During this time, sampling was fully randomised to generate a range of sampling intervals spread in time. Multiple (2-5) sites were sampled each day in the field. This resulted in sampling intervals from 1 to 63 days (Figure 2) and a total number of sampling days at each site from 5-13. Randomising the sampling intervals avoided bias related to the same intervals (e.g., 1 day, 5 days) sampled consecutively and being confounded by seasonal or other temporal impacts on litter deposition.

All visible macrolitter (>5 mm) was removed from each site during sampling and brought back to a storage facility for processing. Given sampling was conducted during the winter, there were times when the sites were covered in snow. In instances when there had been a fresh snowfall since the previous sampling, shovels and rakes were used to turn over all the snow and locate any litter present underneath.

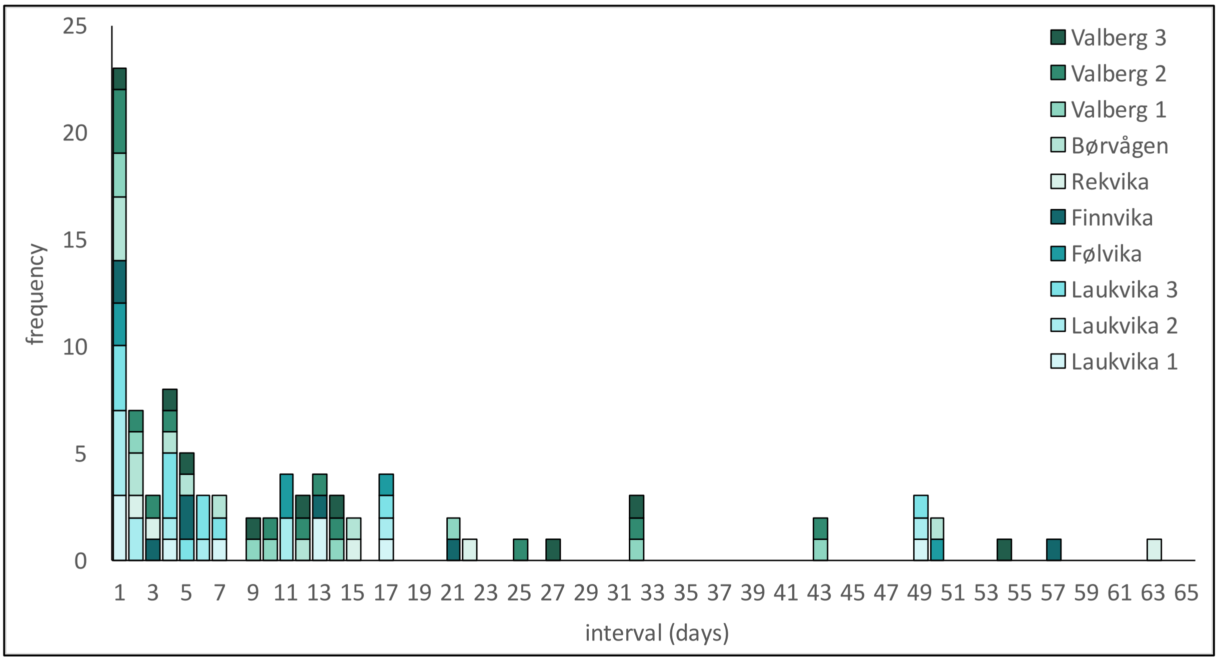

Figure 2: Frequency histogram showing the randomised sampling intervals from December 2017 through April 2018.

Clean-up actions had been carried out at Finnvika, Valberg 1 and Valberg 2 by SALT in June and July 2017, providing additional sampling intervals of 155 to 215 days. Rekvika and Følvika were sampled repeatedly by SALT during the summer of 2016. Attempts are being made to incorporate these data into analyses, but this has not yet been done (methodological differences given improvements made following Proof Clean poses some challenges). A final round of sampling is also underway during the last week of May to obtain a 30-day interval for each site.

2.3 Data processing and analyses

All litter was counted and weighed individually. Each item was also categorised by material: ropes and nets, rigid plastics, soft plastics, expanded polystyrene, metals, glass, textiles, cardboard and paper, and rubber. Items not readily classified given relatively equal proportions of different materials were categorised as “mixed”. Such detailed recording provides excellent opportunities for further data mining. However, the key data relevant to the present research question are total weight and number of items collected at each site during each sampling event.

Estimated daily accumulation rates (EDAR) were calculated by dividing the total weight and frequency of litter found by the survey interval. We regressed EDAR against sampling interval for each site and used AICc model selection to fit the best-fit function to the data (linear, quadratic, exponential or logistic). This was done to determine whether the ten sites show similar negative patterns in EDAR as reported in the literature elsewhere (e.g., Eriksson *et al.* 2013; Smith & Markic 2013; Ryan *et al.* 2014) and whether patterns differed across sites. We also conducted similar analyses for raw litter counts and weights to compare the actual amounts of litter collected each sampling interval.

3. RESULTS

3.1 Overview of litter sampled

A total of 2,700 items weighing 430 kg were collected during the initial clean-ups of each site. Over 1,900 items (290 kg) were collected in Finnvika, with an average of approximately 100 items (15 kg) for the remaining sites. A total of 5,000 items weighing over 90 kg were collected during subsequent repeat clean-up actions. The sites with the greatest accumulation of litter were Finnvika, Rekvika, and Valberg 2. The sites with the least accumulation of litter were Følvika and the three sites in Laukvika.

3.2 Effects of sampling interval: estimated daily accumulation rates

3.2.1 Total weight

All sites did show the expected negative relationship between estimated daily accumulation rates (EDAR) and sampling interval (Fig. 3), suggesting that beached litter is also transported off the beach over time if not regularly recovered through clean-up actions.

However, the patterns of EDAR with respect to total weight of litter versus sampling interval were highly variable among sites (Fig. 3). Only six of the ten sites showed the expected exponential trends, and some of these very weakly. The remaining four sites showed weak linear relationships. The sites which do show the expected strong negative exponential relation are those with the highest litter accumulation rates. Where litter accumulation rates were relatively low there was little or no pattern.

3.2.2 Number of items

The negative relationships between EDAR and sampling interval were even stronger with respects to number of litter items than they were for weight (Fig. 4). With the exception of Følvika, where the area was very large and litter accumulation very low, all sites showed clear negative exponential relations (Fig. 4).

The rapidity by which EDAR decreased with sampling interval was, however, highly variable among sites. EDAR typically stabilised at 10 to 20-day intervals (Fig. 4). At the three sites in Laukvika, however, where litter accumulation was relatively low, EDAR stabilised close to zero after approximately 5-day, or shorter, intervals. In contrast, EDAR levelled off at close to 50-day intervals in Finnvika where accumulation was very high.

Left: Følvika. Right: Valberg 2 (SALT/Marthe Larsen Haarr)

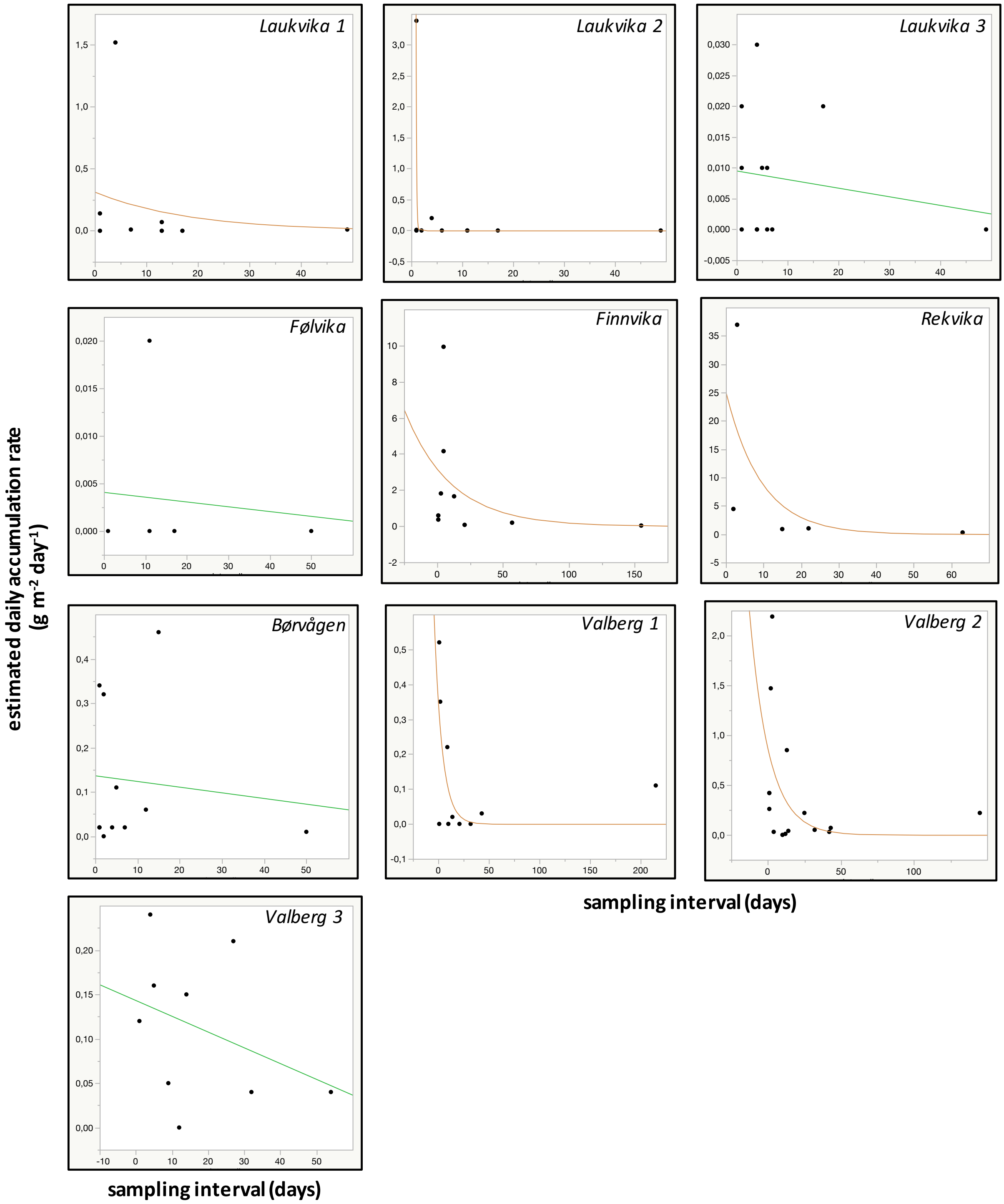

Figure 4: Estimated daily accumulation rates, in weight standardised for site size, versus sampling interval. Fitted curves show the best-fit models based on minimising AICc scores (linear, quadratic, exponential and logistic models considered). Note the varying scale on the y-axes.

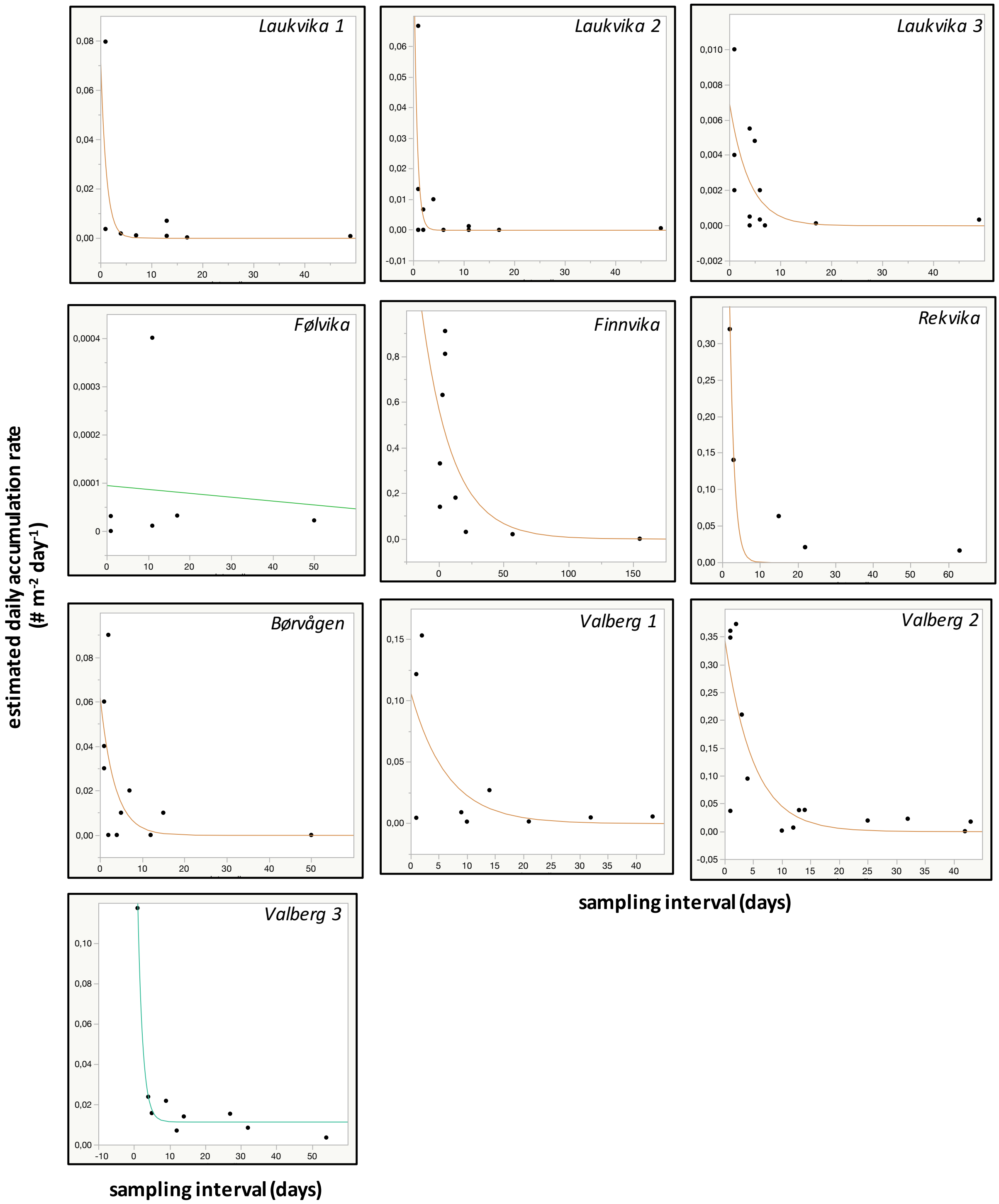

Figure 3: Estimated daily accumulation rates, in number of items standardised for site size, versus sampling interval. Fitted curves show the best-fit models based on minimising AICc scores (linear, quadratic, exponential and logistic models considered). Note the varying scale on the y-axes.

3.3 Effects of sampling interval: total amounts of litter collected

3.3.1 Total weight

The relationship between the total amount of litter, in terms of weight, collected and sampling interval was highly variable among sites and no clear pattern emerged (Fig. 5).

Sites, such as the three in Valberg, where litter accumulation was moderate to high, showed a positive relationship where longer intervals, particularly those spanning several months, clearly yielded greater amounts of litter during a clean-up action (Fig. 5). Rekvika, which also had relatively high accumulation, showed a negative relationship where shorter intervals generally yielded more litter during a clean-up action. However, this relationship is primarily driven by the discovery of a large propane tank during one of the short interval clean-up actions.

Sites with relatively low accumulation, such as Børvågen and those in Laukvika, either showed essentially no relationship between sampling interval and amount of litter collected, or a dome-shaped relation where the greatest amount of litter were collected with intermediate intervals (20-30 days) (Fig. 5).

Finnvika, the site with the greatest litter accumulation, showed a weak negative relationship where more litter was collected, on average, when clean-up actions were held more regularly (Fig. 6).

3.3.2 Number of items

As for total weight, the relationships between the total number of litter items collected and sampling interval were highly variable among sites (Fig. 6).

Laukvika 3 (SALT/Marthe Larsen Haarr)

Sites with moderate accumulation rates generally showed positive relationships where the number of items collected during a clean-up action were maximised by prolonging the time between actions (Fig. 6). Despite this general trend, however, these fits were typically rather poor and sampling interval was not a particularly reliable predictor of litter collected.

The sites with the lowest accumulation (i.e., Følvika and the three sites in Laukvika) also showed positive relationships between the number of litter items collected and sampling interval, but these were very weak (Fig. 6). Sampling interval was therefore not a useful predictor of the amount of litter collected during clean-up actions at these sites.

Finnvika, which has the highest litter accumulation, showed a negative relationship where more litter items were collected when clean-up actions were held close together in time (Fig. 6).

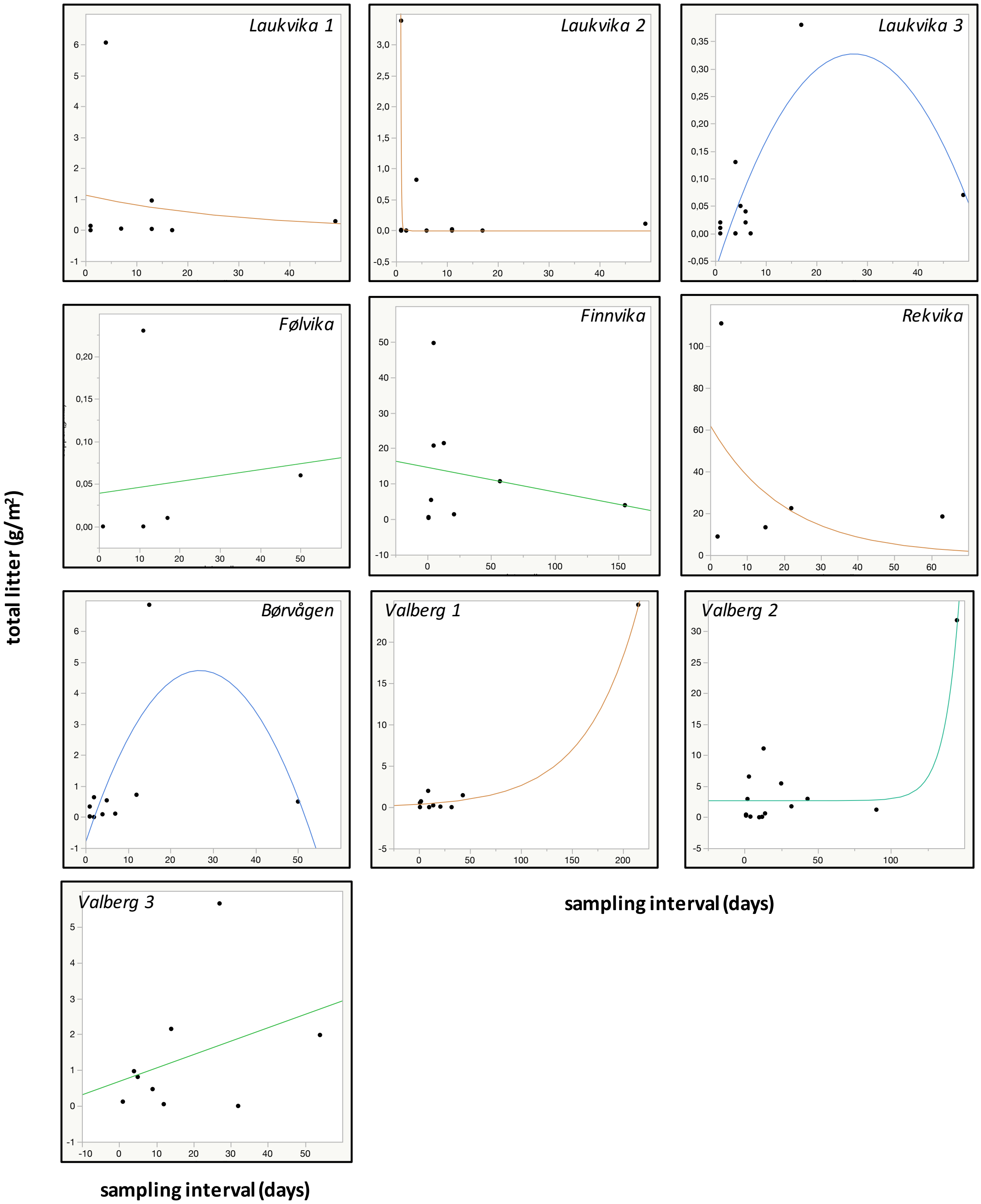

Figure 5: Total amount of litter collected, by weight standardised for site size, versus sampling interval. Fitted curves show the best-fit models based on minimising AICc scores (linear, quadratic, exponential and logistic models considered). Note the varying scale on the y-axes.

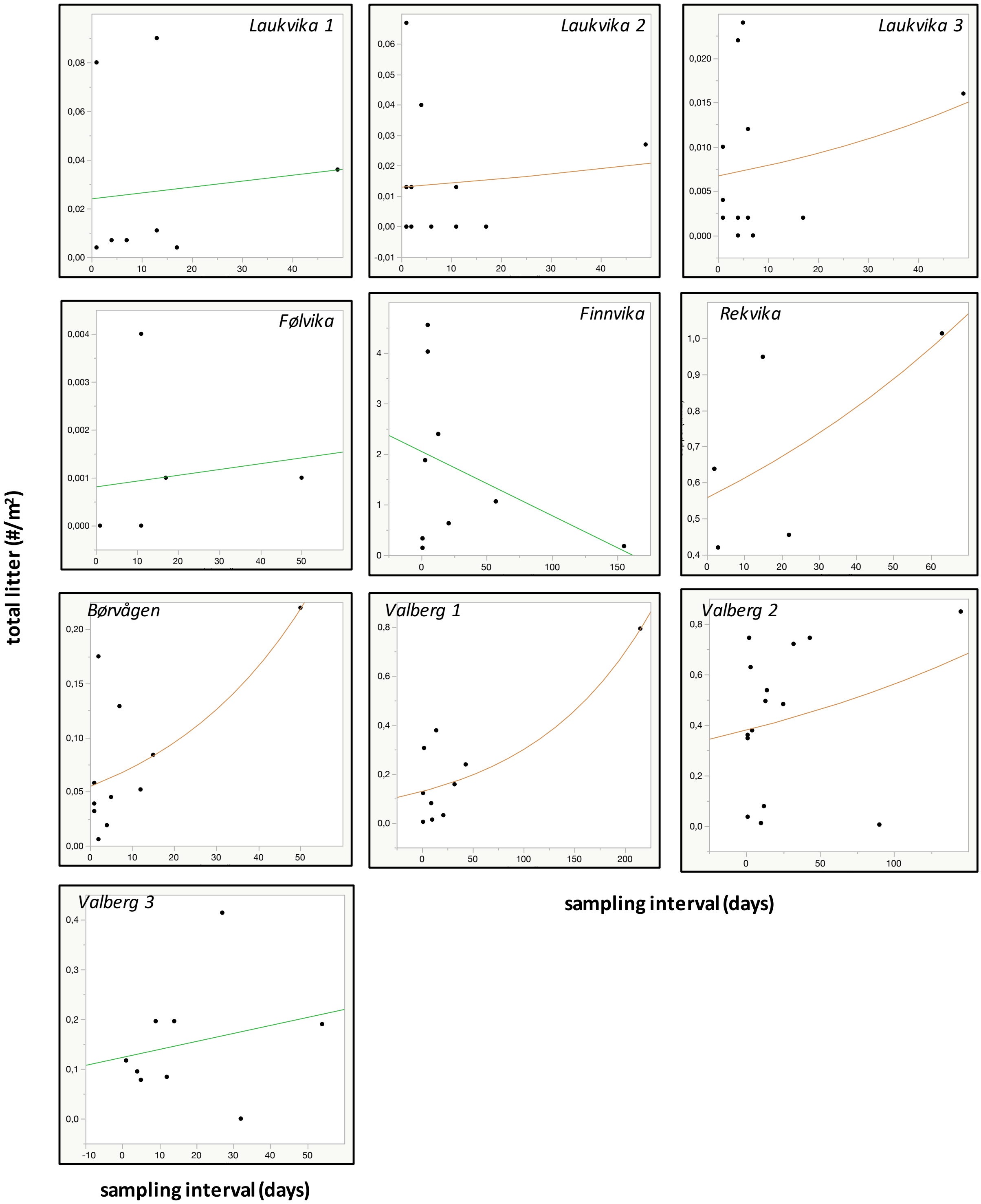

Figure 6: Total amount of litter collected, in number of items standardised for site size, versus sampling interval. Fitted curves show the best-fit models based on minimising AICc scores (linear, quadratic, exponential and logistic models considered). Note the varying scale on the y-axes.

4. DISCUSSION

4.1 Determining the optimal clean-up frequency

The estimated daily accumulation rates and the total standing stock of litter on beaches and in coves, and their relationships with clean-up interval, is highly variable among locations. Consequently, it is not possible to recommend a general strategy for scheduling coastal clean-up actions to optimise litter removal in affected locations. Strategies will thus need to be tailored for individual locations, which makes optimisation more challenging. It is possible, however, to draw some general conclusions for locations with low, medium and high litter accumulation.

Were litter accumulation is low, frequent clean-up actions are unlikely to be cost-effective or an effective mitigation measure. While a rapid decrease in the number of items estimated to accumulate daily with increasing sampling interval, and a lack of relationship between sampling interval and standing stock (total amount of litter) does suggest the few items that arrive are rapidly lost again, the low amounts of litter collected during a clean-up action does not merit focusing efforts here. Such sites can be cleaned opportunistically.

In contrast, it is likely beneficial to clean locations with moderate to high accumulation every 2-3 weeks. At such locations, the estimated daily accumulation rates level off at clean-up intervals of 10-20 days, suggesting that over intervals longer than this, processes removing beach litter operate occur at equal rates with those depositing litter. Minimising the amount of litter either returned to the marine environment or otherwise lost to the surrounding terrestrial environment, will therefore likely require clean-ups at 2-3 week intervals. Nevertheless, the total amount of litter recovered each time remains fairly low and does not merit large-scale clean-up actions; these can really only be justified from an effort perspective at intervals of 3-6 months.

Good solutions for moderate to high accumulation locations may therefore involve either (1) staging larger clean-up actions twice a year, with the knowledge that this will not capture all the litter that deposited at the location, or (2) engage individual persons in "adopt-a-beach" schemes where the location is checked and cleaned once to twice a month.

At locations with very high litter accumulation, monthly clean-up actions appear readily defensible. Estimated daily accumulation rates level off after longer sampling intervals than for moderate to high accumulation sites. This likely reflects higher deposition rates where influx outweighs loss to a greater extent. Consequently, the optimal clean-up frequency can be extended somewhat to match this. The optimal interval will not extend much beyond monthly, however, as the total amount of litter recovered during clean-up actions decreased with increasing interval length.

The first clean-up action conducted at new location will invariably produce much higher amounts of litter than regular clean-ups if the site has never before been cleaned and litter accumulated for decades. This does not mean, however, that subsequent more regular clean-ups are not valuable. Once "old sins" have been removed, regular cleanups in accordance with the recommendations above will contribute to optimising the removal of new litter.

4.2 Next steps

It is worth noting the high variability in litter deposition over small time scales. A portion of this variability is most likely related to weather, and particularly wind. As this relationship is explored further, recommendations can be made more specific. For instance, regular clean-ups may be more beneficial during fall and winter than during the summer, particularly following storm events. In Valberg 1 and 2, for example, clean-up intervals of several months revealed the by far greatest standing stock (total amount) of litter. This may be because these months were in the fall, and accumulation may have been greater then. While frequent sampling was conducted during the winter months, the winter in question had few storms and bad weather days.

The relationship between litter accumulation rates and wind will be investigated for all ten sampling sites. We will also attempt to consolidate data from the summer of 2016 from two sites (Rekvika and Følvika) to assess seasonal variation in litter accumulation rates. This is important to investigate as clean-up actions are typically concentrated during the spring and summer months when doing so is generally easier. Based on weather patterns, however, is it potentially not the optimal time in wich to focus efforts.

The dataset will also be explored more in depth with respects to individual items and potential differences in the predictability of patters of small, medium and large litter objects, and between different material types.

These further analyses of the dataset forms the basis for an MSc thesis (candidate: Therese Meyer, NTNU/SALT), which will be completed by the fall of 2018.

5. LITERATURE CITED

Bergmann, M., Gutow, L., and Klages, M. (eds.) 2015. Marine anthropogenic litter. Springer International Publishing. Available from: https://link.springer.com/book/10.1007/978-3-319-16510-3.

Blickley, L.C., Currie, J.J. and Kaufman, G.D. 2016. Trends and drivers of debris accumulation on Maui shorelines: Implications for local mitigation strategies. Marine Pollution Bulletin 105:292-98.

Bowman, D., Manor-Samsonov, N., and Golik, A. 1998. Dynamics of litter pollution on Israeli Mediterranean beaches: a budgetary, litter flux approach. Journal of Coastal Research 14: 418-432.

Eriksson, C., Burton, H., Fitch, S., Schulz, M. and van den Hoff, J. 2013. Daily accumulation rates of marine debris on sub-Antarctic island beaches. Marine Pollution Bulletin 66:199-208.

Eunomia 2016. Plastics in the Marine Environment. Eunomia Research & Consulting Ltd, Bristol, United Kingdom. Available from: http://www.eunomia.co.uk/reports-tools/plastics-in-the-marine-environment/.

Garrity, S.D., and Levings, S.C. 1993. Marine debris along the Caribbean coast of Panama. Marine Pollution Bulletin 26: 317-324.

Johnson, S.W. 1989. Deposition, fate, and characteristics of derelict trawl web on an Alaskan beach. Marine Pollution Bulletin 20: 164-168.

Johnson, S.W., and Eiler, J.H. 1999. Fate of radio-tagged trawl-web on an Alaskan beach. Marine Pollution Bulletin 38: 136-141.

Kako, S.I., Isobe, A. and Magome, S. 2010. Sequential monitoring of beach litter using webcams. Marine Pollution Bulletin 60:775-79.

Lee, R.F., and Sanders, D.P. 2015. The amount and accumulation rate of plastic debris on marshes and beaches on the Georgia coast. Marine Pollution Bulletin 91: 113-119.

Ryan, P.G., Lamprecht, A., Swanepoel, D., and Moloney, C.L. 2014. The effect of fine-scale sampling frequency on estimates of beach litter accumulation. Marine Pollution Bulletin 88: 249-254.

Simeonova, A., Chuturkova, R., and Yaneva, V. 2017. Seasonal dynamics of marine litter along the Bulgarian Black Sea coast. Marine Pollution Bulletin 119: 110-118.

Smith, S.D.A. and Markic, A. 2013. Estimates of Marine Debris Accumulation on Beaches Are Strongly Affected by the Temporal Scale of Sampling. PLOS ONE 8:e83694.

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SALT

Postboks 91, 8301 Svolvær

www.salt.nu