# Efficiency of Varying Sediment Traps under Experimental Conditions Simulating Tidal Inundations

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LRH: Nolte, Butzeck, Baldwin, Felton, Jensen

RRH: Sediment trap efficiency

## ABSTRACT

Accelerated sea-level rise (SLR) is threatening tidal marshes worldwide. An important control of tidal marsh survival under accelerated SLR is the sediment deposition. Therefore, factors affecting sediment deposition rates (SDR) have been studied extensively using various types of sediment traps. The efficiency of various sediment traps has been compared in several studies, but most of these were conducted in shallow lakes or rivers. In contrast, the efficiency of different sediment traps in tidal marshes is unknown. Therefore, the aim of this study was to compare the trapping efficiency of four frequently used sediment traps, namely flat traps constructed of either tiles or floor mat, and circular traps with and without a lid, under controlled experimental conditions simulating tidal inundations in a flume. The strong differences between circular sediment traps (high efficiency) and both flat surface sediment trap methods (low efficiency) found in this study were remarkable. Additionally, further evidence was found for decreases of SDR with increasing distance to the inflow of the flume (sediment source) and with decreasing suspended sediment concentration (SSC). These findings indicate that trap design has a large influence on sedimentation rate and that studies using different types of sediment traps are not directly comparable.

## ADDITIONAL INDEX WORDS:

*Tidal marsh, wetland, sediment deposition, sedimentation*.

## IINTRODUCTION

Accelerated sea-level rise (SLR) has been recently discussed as a major threat to tidal marshes (Craft *et al.*, 2009; Crosby *et al.*, 2016; Kirwan and Megonigal, 2013; Kirwan *et al.*, 2016). An important control of tidal marsh survival under accelerated SLR is the sediment deposition, which can be defined as the gravity-based deposition of organic and inorganic particles during inundations (Allen, 2000; Nolte *et al.*, 2013; Temmerman *et al.*, 2005). However, sediment deposition rates (SDR) in tidal marshes are highly variable in space and time (Butzeck *et al.*, 2015; Reed, 1989). The spatial and temporal variability is affected by various factors, including for example the distance to the sediment source (Esselink *et al.*, 1998; Temmerman *et al.*, 2003) and the variability of suspended-sediment concentration (Butzeck *et al.*, 2015; Fettweis, Sas and Monbaliu, 1998).

These factors affecting sediment deposition and surface elevation change have been studied extensively (*e.g.,* Craft *et al.*, 2009; Kirwan and Megonigal, 2013; Suchrow *et al.*, 2012) to understand and predict possible effects of accelerated SLR on tidal marshes. However, these studies used a wide variety of methods such as varying types of sediment traps to quantify SDR. The efficiency of different sediment traps to measure SDR has previously been compared by several studies (see review by Nolte *et al.*, 2013). Yet, most of these studies were conducted in shallow lakes or rivers (Bloesch and Burns, 1980; Kozerski and Leuschner, 1999). Tidal marshes surely differ from such shallow lakes and river systems in their hydrodynamics, which, however, greatly affect sediment trap efficiency (de Swart and Zimmerman, 2009). Therefore, the trapping efficiency of different commonly used trap designs needs to be evaluated for intertidal systems. The most commonly used traps in tidal marshes are either flat traps or cylindrical traps with a rim (Nolte *et al.*, 2013). Such a rim could affect trapping efficiency as it prevents lateral relocation processes (Temmerman *et al.*, 2003), while a sediment trap with a flat surface might be vulnerable to washout of sediment by heavy rain events (Steiger, Gurnell and Goodson, 2003). Among flat sediment traps there are also different types such as, for example, flat ceramic tiles (Pasternack and Brush, 1998) or AstroTurf® floor mats (Lambert and Walling, 1987).

The latter are used to mimic vegetation and a more natural surface roughness, which might greatly affect trapping efficiency compared to, for example, ceramic tiles. Additionally, it is unknown how a frequently used circular trap with a floatable lid (Butzeck *et al.*, 2015; Temmerman *et al.*, 2003) compares to traps without such a lid.

To better understand the influence of trap design on sedimentation rate measurements in tidal systems, the trapping efficiency of four frequently used sediment traps were compared under controlled experimental conditions in a flume. Results were additionally analyzed with respect to the distance to the sediment source, and different suspended-sediment concentrations of the flooding water.

## METHODS

Measurements were conducted at the Department of Environmental Science and Technology, University of Maryland using a self-contained glass sided tilting re-circulating flume. The flume consisted of a 7.3 m long, 0.3 m wide, and 0.45 m high rectangular channel. The flat inner bottom of the flume was completely covered with a soft and flexible artificial grass floor mat (stem length: 43 mm) to simulate the friction of tidal marsh vegetation. Patches were cut out of the mat at the sampling points for the sediment traps. Four different sediment traps were tested, including two different flat traps, namely, ceramic tiles (*e.g.,* Pasternack and Brush, 1998) and circular AstroTurf® floor mats (*e.g.,* Lambert and Walling, 1987), and circular traps with and without a floatable lid (Butzeck *et al.*, 2015; Temmerman *et al.*, 2003; Figure 1, Table 1).

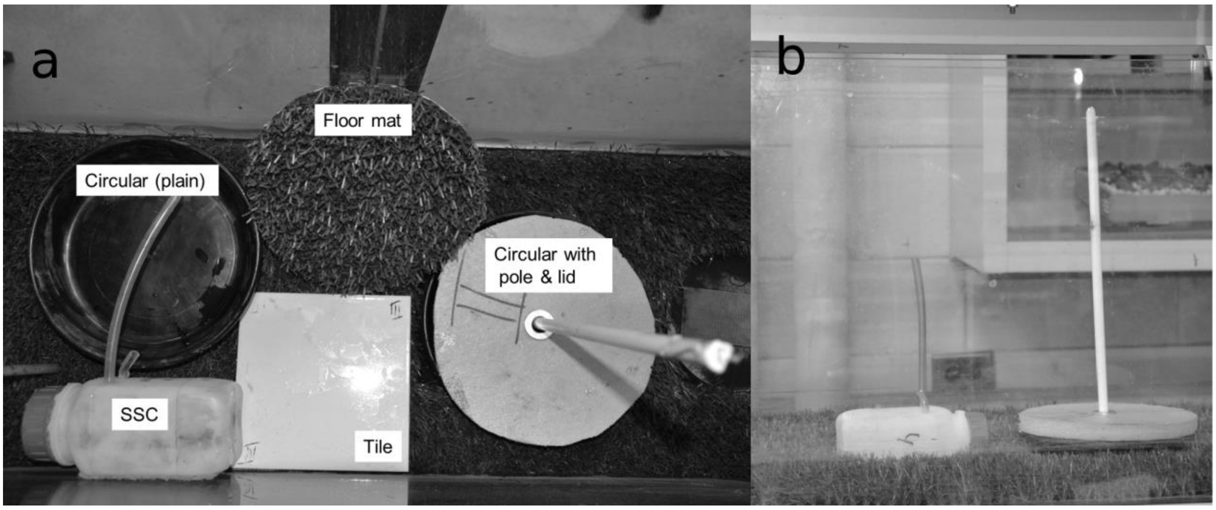


**Figure 1 (a)** Different types of sediment traps used to measure sediment-deposition rate and plastic bottles used to measure suspended sediment concentration (SSC). (b) Example of the setup in the flume for the test runs, which in this case include the SSC-bottle (left) and circular sediment trap with lid (right). The flume bottom was covered with an artificial floor mat which was removed at sampling locations

*Table 1 Area [cm²], size and specific features of the different sediment trap types.*

| Trap type | Surface Area [cm²] | size | specific feature |
|---|---|---|---|
| Circular trap (with lid) | 280.55 | 18.9 cm (inside diameter) | 3 cm high rim |
| Circular trap (plain) | 280.55 | 18.9 cm (inside diameter) | 3 cm high rim |
| Floor mat | 314.16 | 20.0 cm (diameter) | at bottom level, stem length: 20 mm |
| Ceramic tile | 232.26 | 15.24 x 15.24 cm | at bottom level |

## Set-up and Test Procedure

The sediment traps were installed at 0.5, 2.0 and 6.0 m distance from the inlet opening of the flume (Figure 2). The circular traps and floor mats were attached with Velcro® tape to the flume bottom. In addition the setup included bottles (adapted from Butzeck *et al.*, 2015; Temmerman *et al.*, 2003) to measure suspended-sediment concentration (SSC) positioned directly behind the sediment trap.

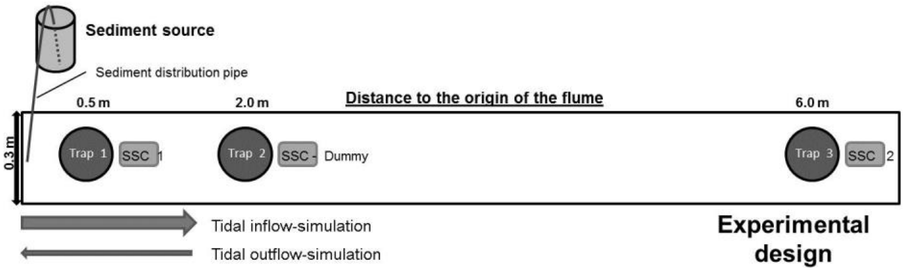


**Figure 2** Schematic drawing of flume to illustrate the experimental setup. The flume is indicated by the rectangular shape with the sediment source on the left side. The sediment source container is positioned adjacent to the flume but in an elevated position and is connected to the flume with a pipe. The tidal flow direction is indicated by arrows below the flume. The position of sediment traps with increasing distance to the origin of the flume is indicated using circles

The sediment used consisted of over 99 % of clay and fine silt and was collected from an oligohaline marsh at the Nanticoke estuary (Maryland, USA). Sediment was sieved with 1.18 mm and 425 µm sieves to remove large organic particles. A high (*SSC-high*: ~100 mg $l^{-1}$) and a low sediment supply scenario (*SSC-low*: ~65 mg $l^{-1}$) were applied by mixing the sediment with a defined quantity of water in a container positioned adjacent to the flume but in an elevated position. To prevent the sediment from settling inside the container, an air pump was installed in the container to provide a constant movement of the sediment-water mixture. The sediment-water mixture was then transported from the container to the inlet opening of the flume via a pipe using low pressure at the flume end of the pipe and gravity. The outlet of the flume was closed during the entire experiment to simulate inundation heights of 15 cm above surface. Inundation heights were measured at Trap 1. The duration of the tidal water inflow was between 8 and 11 minutes. Water samples ($SSC_{Initial}$) were taken automatically as soon as the inundating water submerged the inlet opening of the SSC bottle. After reaching the maximum inundation height of 15 cm the inflow of the water and the discharge of the sediment water-mixture were stopped. At maximum inundation SSC-bottles were replaced to obtain SSC-samples ($SSC_{Slack}$) from the outflowing water. The outflow of the water (ebb) occurred over the inlet opening of the flume. Total inundation time of one run of the tidal simulation lasted between 37±2 min (short inundation runs) and 61±2 min (long inundation runs). Long inundation runs with *SSC-low*, and short inundation with *SSC-high* were performed, using one trap type per run. Ten runs with each of the four trap types of the *SSC-low* and the *SSC-high* simulations were conducted in random order.

After each run, the sediment was rinsed from the sediment trap with distilled water into aluminum boxes and dried at 105 °C to a constant weight. Values were then converted into sediment deposition rates [g $m^{-2}$] per tidal inundation. SSC-samples were well mixed before taking a subsample of 200 ml, which was vacuum-filtrated through pre-weighed 0.45 μm glass fiber filters (Whatman™). Afterward, SSC-samples were dried at 60 °C for 4 h to constant weight to determine SSC [mg $l^{-1}$].

### Statistical Analysis

Data met the assumptions of normality and homogeneity of variance. Thus a three-factorial ANOVA was used to analyze differences in SDR between sediment trap types. Sediment trap type, distance to the inlet of the flume, and sediment supply (*SSC-low/ SSC-high*) were included as factors. If a significant effect was detected, pairwise comparisons using Bonferroni post-hoc tests were applied. All statistical analyses were done with STATISTICA 10 (StatSoft Inc. 2010).

## RESULTS

Mean sediment deposition rate significantly differed between sediment trap types (Figure 3, Table 2). The highest SDR was found in plain circular traps. According to the post-hoc tests SDR in circular traps with a floatable lid were slightly, but not significantly lower (7 %) than SDR in plain circular traps without a floatable lid. Sediment traps made of floor mats differed significantly from both tiles and plain circular traps, but the post-hoc test indicates no significant difference between floor mats and circular traps with a lid (Figure 3). The lowest SDR were found on tiles, which significantly differed from all other sediment trap types. In total, the SDR of tiles was 31 % lower than the SDR of floor mats, and 43 to 47 % lower than the SDR of circular traps with lid and plain circular traps, respectively.

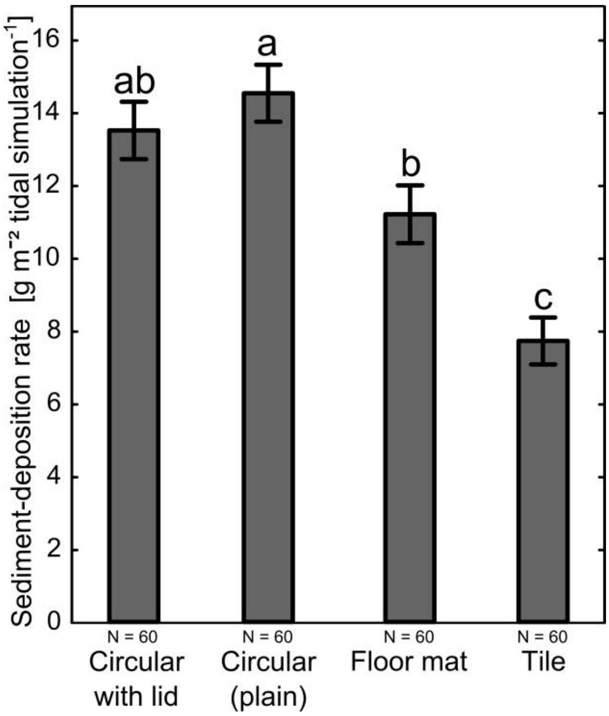


**Figure 3** Plotted values are means (±SE) of sediment-deposition rates [g m$^{-2}$] of four different sediment traps. Letters denote statistical differences between sediment-trap types ($p < 0.05$) based on post-hoc tests

Results revealed strong effects of distance to the inlet of the flume (Figure 4, Table 2), and sediment supply (Figure 4, Table 2) on SDR. All sediment trap types showed a highly significant decrease in SDR with increasing distance from the inlet of the flume (Figure 4, Table 2), although the reduction was greater under high than under low sediment supply rates (significant distance × sediment supply rate, Table 2). A higher SSC (Figure 4) resulted in a higher SDR, but the effect of SSC varied with distance (Table 2, significant distance x sediment supply rate). With higher sediment supply, the percent decreases of SDR with distance were slightly higher. The interaction effects trap type x ssc and trap type x distance were not significant (Table

2) indicating the differences in trapping efficiency of different sediment traps to be constant regardless of the spatial and temporal variation represented by distance to the inlet and SSC, respectively.

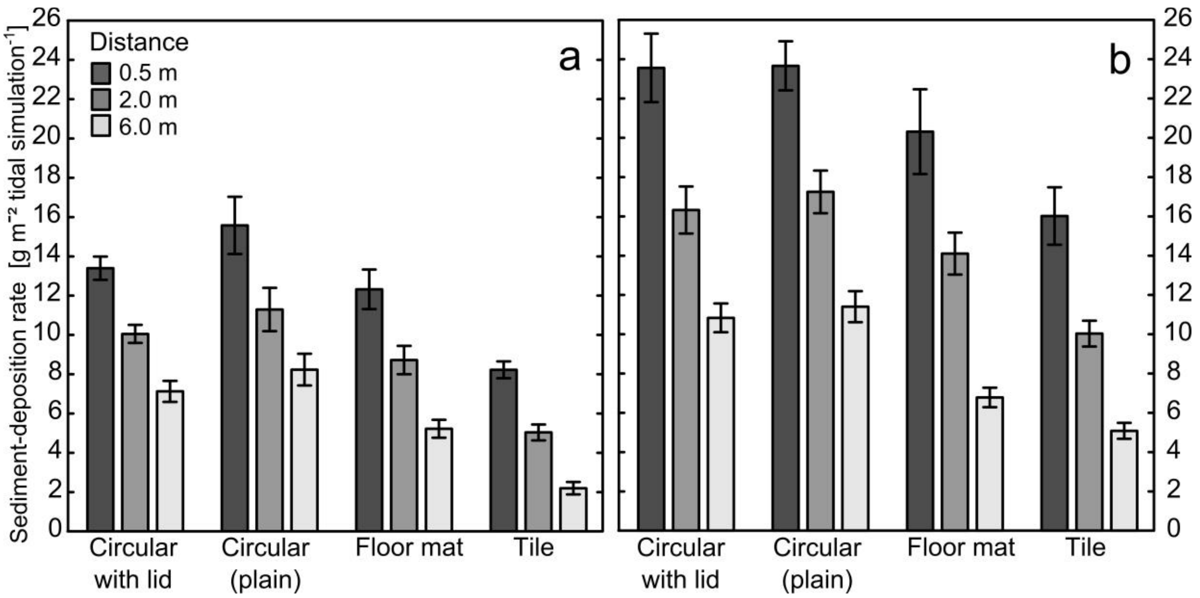


**Figure 4** Plotted values are means (±SE) of sediment-deposition rates [g $m^{-2}$] of different sediment traps, depending on distance to the origin of the flume, during (a) low and (b) high suspended sediment concentration (SSC)

*Table 2 Results of the three-factorial ANOVA for effects of trap types, distance to the origin of the flume and SSC on sediment-deposition rate.*

| | Sediment-deposition rate | |
|---|---|---|
| Factor | *F* | *p* |
| Trap type | 61.5 | *** |
| Distance | 212.7 | *** |
| Sediment supply | 273.3 | *** |
| Trap type × Distance | 0.4 | *n.s.* |
| Distance × Sediment supply | 13.0 | *** |
| Trap type × Sediment supply | 1.3 | *n.s.* |
| Trap type × Distance × Sediment supply | 0.2 | *n.s.* |

*n.s.* not significant, ****p* < 0.001

## DISCUSSION

In line with the expectations, trapping efficiency was found to differ significantly between commonly used sediment trap designs. These differences in trapping efficiency were constant regardless of the conditions (distance to inlet and SSC). The strong differences between circular sediment traps (high efficiency) and both flat surface sediment traps methods (low efficiency) found in this study were remarkable. Therefore, studies using different types of sediment trap may not be directly comparable due to differences of the trapping efficiency of the various available trap designs (Nolte *et al.*, 2013).

During this study, SDR in both circular sediment trap types was higher than in flat sediment trap types. This difference between the circular sediment trap (with a rim) and the flat surface sediment trap might indicate re-suspension and/or lateral sediment-transport processes. This might occur on different scales depending on sediment trap type. Some studies have found that collected sediment trapped by flat surface traps is sensitive to washing off by rain and partly by tides (Gardner, 1980; Kozerski and Leuschner, 1999). Although it can be expected that the rim of the circular sediment trap prevents trapped sediment from lateral dispersal to the surrounding surface (Neubauer *et al.*, 2002), it might also prevent a relocation of sediment from the surrounding surface into this sediment trap type. No or only a marginal amount of re-suspension of fresh deposited sediment from circular sediment traps was found by both Reed *et al.* (1999) and Temmerman *et al.* (2003). The higher SDR in circular traps compared to flat tiles found here might also be due to reduced bottom shear stress (Kozerski and Leuschner, 1999), while simultaneously the rim of the circular trap induced local flow acceleration and the formation of eddies which can increase deposition rates (Butman, Grant and Stolzenbach, 1986).

When comparing two types of flat sediment traps higher SDR was found on floor mats compared to ceramic tiles, probably because of the higher surface roughness of the floor mat. This is in line with Steiger, Gurnell and Goodson (2003), who suggested the usage of floor mat sediment traps for riparian sedimentation studies as the surface simulates surrounding vegetation. However, it could be argued that the commonly available floor mats do not represent the vegetation sufficiently, as vegetation in many marshes is taller than the stem length of the floor mat (Leonard and Luther, 1995; Neumeier and Amos, 2006; Rupprecht *et al.*, 2015). One exception might be marshes where canopy height is reduced due to livestock grazing *e.g.* in the Wadden Sea region (Nolte *et al.*, 2014) or in the Yangtze estuary (Yang, Nolte and Wu, 2017). Nevertheless, Steiger, Gurnell and Goodson (2003) argue, that the increased surface roughness of the floor mat provides an easy handling during collecting and processing. Also Kleiss (1996) used flat surface sediment traps with a rough upper surface to minimize re-suspension of deposited sediments. Contrastingly, Mansikkaniemi (1985) found no significant differences between flat sediment traps with and without attached floor mats during a shallow water study, possibly because of different hydrodynamic forcing. Also Steiger, Gurnell and Goodson (2003) did not find significant differences between flat surface sediment traps with varying roughness.

No significant difference between circular sediment traps with and without a lid was found in this experimental flume study. In field studies the floatable lid is supposed to protect trapped sediment from splashing out by heavy rain events during low tides (Temmerman *et al.*, 2003), which of course did not occur in the flume. In their study Bloesch and Burns (1980) stated that the geometry of circular sediment traps (ratio of height to diameter) also affects the amount of re-suspension. However, in this case the circular sediment traps were identical except for the lid. The slightly higher SDR found in circular sediment traps without a lid might be partly explained by sediment adhered below the lid or on the pole.

Significant decreases of SDR with increasing distance to the inflow of the flume (sediment source) and decreasing SSC were found for all sediment trap types. SDR has previously been found to relate to distance to the sediment source, like marsh edge and nearest creek (*e.g.,* Esselink *et al.*, 1998; Butzeck *et al.*, 2015; Temmerman *et al.*, 2003), as well as to seasonal and spatial variability of SSC (*e.g.,* Butzeck *et al.*, 2015; Fettweis, Sas and Monbaliu, 1998; Temmerman *et al.*, 2003).

## CONCLUSIONS

Based on the clear difference between the flat and circular trap types found in this study, the use of flat traps would be recommended to prevent overestimation of SDR. However, in systems with very high SDR, the flat tiles might be less p as sediment might be lost during the collection process. Therefore, the choice of sediment trap design should be made taking various aspects of the study site and study design into account (see review by Nolte *et al.*, 2013). It is furthermore concluded, that differences in trapping efficiency impede the comparability of sediment trap types commonly used in tidal wetland studies. This especially needs to be considered in meta-analysis of studies assessing marsh-resilience to sea-level rise (*e.g.,* Crosby *et al.*, 2016; Kirwan *et al.*, 2016). Standardization of sediment traps for intertidal habitats would be necessary for a direct comparison. As a next step, field studies to compare different sediment trap types under different inundation regimes, flow velocities, as well as different marsh types (mineral and organic) would be recommended. Short-term measurements of SDR with sediment traps like those compared in this study are especially useful for analyzing spatio-temporal variation in SDR and in their predictors.

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