MEASURING CLAST MOVEMENT ON GRAVEL BEACHES

MARK E. DICKSON[1], PAUL S. KENCH[1,2], BRITTANY KNIGHT[1], COURTNEY MURRAY[1]

1. *School of Environment, The University of Auckland, Private Bag 92019, Auckland 1142, New Zealand. m.dickson@auckland.ac.nz.*
2. *Department of Earth Sciences, Simon Fraser University, British Columbia, Canada. paul_kench@sfu.ca.*

Abstract: Native tracer cobbles were tracked on a mixed sand and gravel beach at three temporal scales. Passive Integrated Transponder tags were inserted in 400 cobbles and tracked at monthly intervals over 130 days; tags were inserted in a further 200 cobbles and tracked on days 1, 2, 4, 6 and 16. Despite similar incident wave conditions, opposing directions of dominant sediment transport occurred in the two tag tracer experiments. A new technique was developed using painted cobbles and drone video capture to provide a third set of measurements on 175 tracer cobbles at the scale of individual swash events. Large differences were quantified between net and gross sediment transport rates. Collectively these data provide rare direct comparable measurements of the dynamic and variable nature of sediment transport on gravel beaches across different temporal scales.

Introduction

Research interest in gravel beaches is growing, particularly in the context of coastal defense, because gravel beaches typically maintain a high level of stability during storms and reduce the potential for wave overtopping (e.g. Kirk, 1980, Bradbury & Powell, 1992, Forbes et al., 1995, Moses and Williams, 2008, Scott et al., 2016). However, the defensive capability of gravel beaches can be compromised under extreme conditions leading to erosion and inundation (e.g. Williams et al., 2012). Use of gravel beaches as a coastal management tool requires an improved understanding of development of beach morphology, which necessitates greater understanding of sediment transport patterns, rates and mechanisms (Stark and Hay, 2016). Fundamental questions concerning sediment fluxes remain unresolved. For instance, seaward-directed sediment transport might be expected during storms (Buscombe and Masselink, 2006), but storm field observations reveal landward sedimentation and beach-crest growth (e.g. Orford, 1977, Kirk, 1980). Fair-weather sediment transport patterns are also uncertain. Clast transport is a direct function of swash hydrodynamics, but clast size and shape are also important factors governing particle mobility. Smaller cobbles are more susceptible to burial and become protected within the matrix of larger cobbles; conversely, larger cobbles can be more exposed to fluid forces and move more rapidly on beaches where clasts are densely packed (Osborne, 2005, Allan et al., 2006). Some studies have shown that transport distances increase with particle size to a certain limit, beyond which transport distances decrease (Osborne, 2005); other studies have not detected a relationship between size and transport distance (e.g. Dickson et al., 2011) but have explored the influence of grain shape on transport (e.g. Miller et al., 2011, Stark and Hay, 2016).

Efforts to improve understanding of gravel sediment transport have utilized Radio Frequency Identification (RFID) technology and Passive Integrated Transponder (PIT) tags inserted within clasts to provide direct measurement of the movement of individual clasts over sampling time periods ranging from days to months (e.g. Osborne, 2005, Allan et al., 2006, Dickson et al., 2011, Miller et al., 2011, Dolphin et al., 2016). These measurements provide definitive data on the direction and distance of sediment transport and the amount of abrasion that clasts undergo during transport. However, the technique is laborious, recovery rates rapidly decline through time associated with tracer diffusion and burial, and measurement data depict net rather than gross transport distance. These facts limit potential to detect causal relations between wave forcing and sediment transport and abrasion, which restricts the extent to which measurements can be used to inform numerical models.

This paper describes a further advance in gravel sediment transport measurement techniques. We describe contrasting observations of gravel movement using RFID cobble tracking at two time scales (130 and 16 days), and introduce a new technique to detect cobble movement at the scale of individual swash events using painted cobbles and a hovering drone.

Field setting and methods

Field measurements were taken at a mixed sand and gravel (MSG) beach in southern Hawke Bay, New Zealand (Figure 1). Chronic erosion is occurring in the vicinity of Clifton and Haumoana due to a local deficit in the sediment budget, whereas the shoreline at the study site (Awatoto) is relatively stable (Komar, 2010, Dickson et al., 2011).

Native tracer cobbles were sourced from the Ngaruroro River 26 km upstream of the field site. Cobbles less than 64 mm long-axis were sub-sampled, consistent with the size of cobbles on the beach-face (Dickson et al., 2011), and 4 x 13 mm incisions were drilled to house 12 mm PIT tags that had a read range of ~30-50cm (Ford, 2014). Tracers had a unique number that was read with an RFID pole antenna, backpack reader and wireless handheld monitor. Two sets of observations were made using PIT tags: (1) tags were inserted in 400 cobbles, placed within the swash zone and then tracked at approximately monthly intervals over 130 days; (2) tags were inserted in 200 cobbles, placed within the swash zone and tracked on days 1, 2, 4, 6 and 16.

A third set of transport measurements were made at the scale of individual swash measurements using spray-painted cobbles that were inserted into the swash zone and tracked using vertical drone video surveys. Seven 15-minute surveys were conducted with 25 cobbles in each frame, providing 175 tracer cobbles.

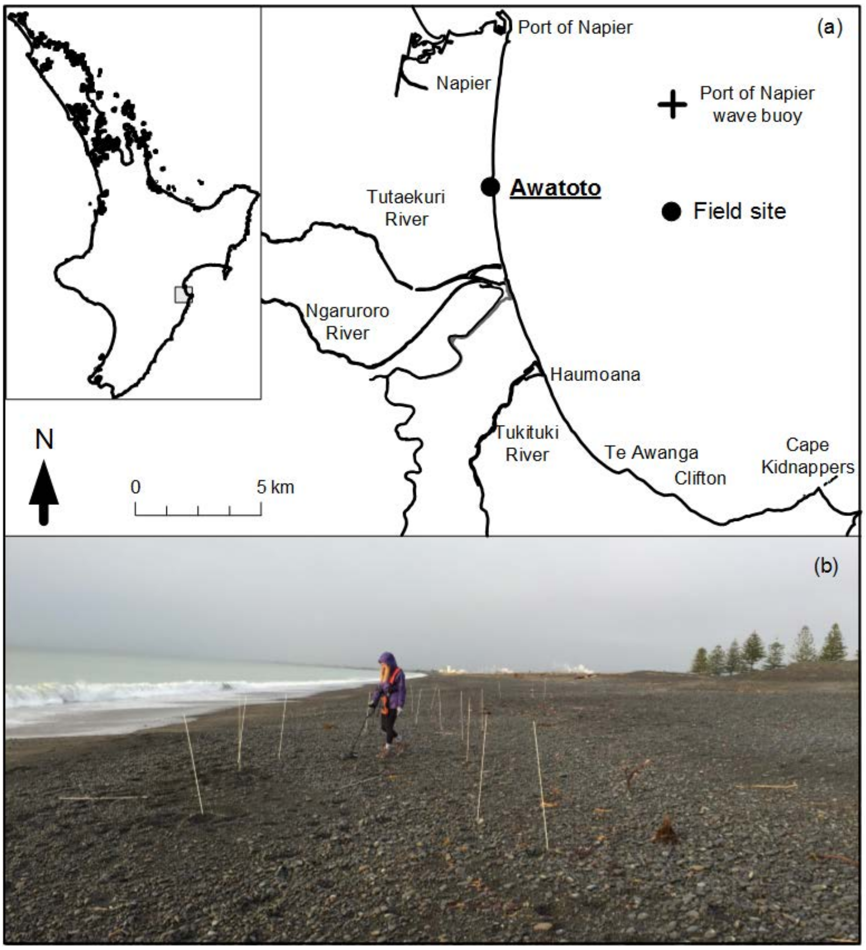

Fig. 1. (a) Map showing the field location. (b) Photograph showing mixed sand and gravel beach and RFID tag tracer cobble detection.

Results

The RFID cobble-tracer observations revealed contrasting dominant directions of sediment transport on the MSG beach (Figure 2). During the long-term (130-day) observation period, clast transport was almost entirely unidirectional and northward. In contrast, the medium-term (16-day) observation period at the same site showed predominant southward transport. Analysis of offshore wave angle at the Napier wave buoy (Figure 1) shows that during the 130-day observation period mean Hs was 1m and the mean effective wave angle was 27° (northward-directed). These conditions are consistent with the observed northward sediment transport. During the 16-day observation period mean Hs was 0.8m and mean effective wave angle was 16° (northward-directed). A frequency plot of effective wave angle (Figure 2, b) shows that during the 16-day observation period conditions were somewhat more conducive to southward sediment transport, but the distributions are more similar than might be expected given the very different cobble transport observations. Offshore significant wave height (Hs) during the 16-day observation period was <1m on all but two days, during which Hs was <1.5m and the effective wave angle was <10°; hence, anomalous high southward sediment transport on these more energetic conditions is unlikely. Interpretation of measured cobble abrasion data from the long-term observation period is also confounding, because mass loss through abrasion does not correlate with net cobble transport distance. These incongruities highlight the need for a technique that resolves the details of cobble sediment transport at finer scale than that provided by occasional sediment tracer recovery observations using PIT tags.

A new technique was trialed at the same field sites in an attempt to monitor cobble movements at the scale of individual swash measurements. A drone, hovering at 25 m elevation had sufficient battery life to monitor cobble movements over 15 minutes. In each frame 25 cobbles were inserted in five groupings, and within each grouping five different paint colours were used to distinguish cobbles individually. The dimensions of each cobble were recorded. In total, 7 surveys with 25 cobbles provided 175 tracer cobbles. A series of matlab codes were written to scale images, correct for drone wobble (using fixed points), and digitize cobble locations. Digitising was conducted manually (heads-up on-screen), but could potentially be automated on the basis of the colour difference between painted and native grey-coloured cobbles. A wave pressure sensor recorded water level associated with each cobble movement event, although the swash front could also be digitally tracked in the images. A null value was recorded for any cobble that could no longer be observed, which occurred only when cobbles were moved seaward and obscured beneath the swash (i.e. no cobbles were lost laterally out-of-frame).

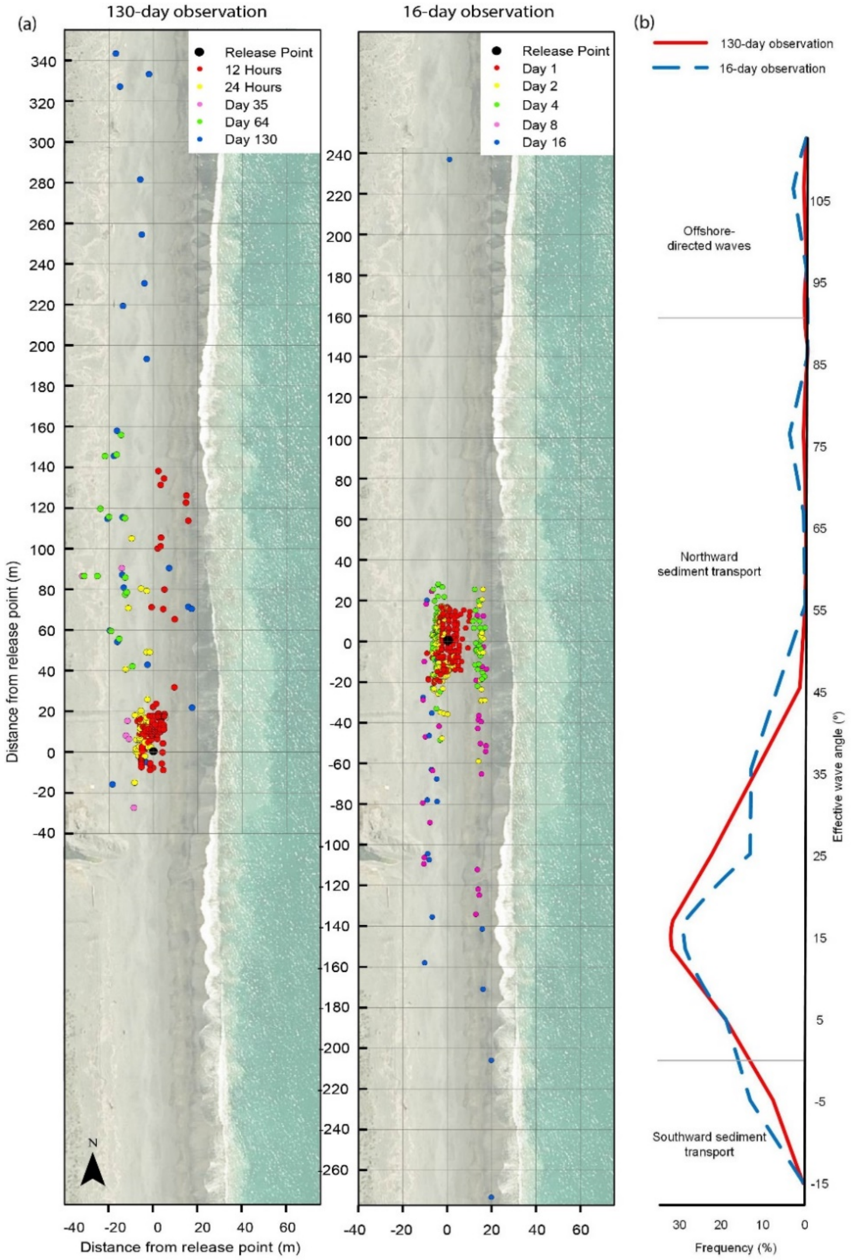

Fig. 2. (a) Cobble tracer recovery (PIT tags) during two observation periods. Contrasting dominant directions of sediment transport are only partly explained by differences in wave angle (b). Note also clear across-shore separation in transport corridors apparent in the 16-day observations.

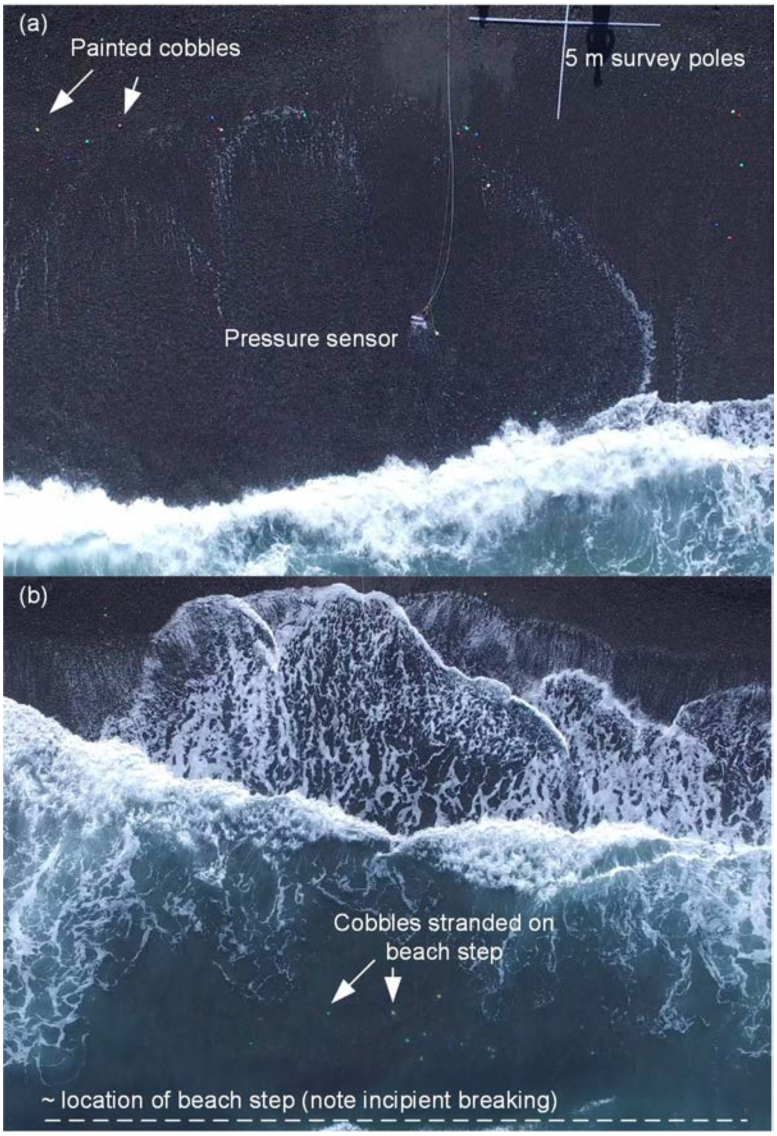

Fig. 3. Two example frames captured from drone survey. (a) Cobbles stranded the swash uprush limit and location of pressure sensor. (b) Cobbles stranded landward of the top of the beach step.

Visual inspection of cobble movement confirmed, as expected, that cobbles were removed from the swash zone in both across-shore directions. A small proportion of cobbles were stranded on the swash berm, above the reach of subsequent swash events, but more than 80% of cobbles removed from the swash zone were lost seaward. No other studies have documented what happens to cobbles when swept seaward of the swash zone. Our expectation was that cobbles would be swept seaward of the steep beach step that characterizes coarse-grained beaches. However, visual inspection of video records (Figure 3, b) showed that many cobbles remained strained on the top (landward) edge of the beach step. Once in this position, cobbles underwent very little further transport during the video observation period.

Significant swash wave height (Hs) during the video observation period varied between 0.25 and 0.38 m and significant wave period (Ts) varied between 7.9 and 13.8 s (Table 1). A positive correlation (R^2=0.6) exists between the number of observed movement events in each survey and wave period (longer period waves have higher runup and are more likely to entrain cobbles in the swash), but no clear relationship exists between Hs or Hmax and the number of movement events. No relationship was found between grain size or shape and transport rates. The total (gross) transport distance averaged between ~7 and 27 m in each survey lasting 15 minutes, but maximum transport distance was around 70 m (Table 1). Net transport distances were much smaller, less than 5 m per 15 mins.

Obs. day	**Survey**	**Move-ment events**	**Hs**	**Ts**	**Hmax**	**Average total travel distance (m/15min)**	**Max total travel distance (m/15min)**	**Net travel distance (m/15min)**
14-1-18	**1**	32	0.38	9.1	0.6	20.1	71.8	4.9
	2	41	0.29	11.7	0.4	6.7	14.7	2.6
	3	41	0.25	13.8	0.4	8.7	20.1	2.4
15-1-18	**4**	24	0.30	7.9	0.3	17.5	61.2	2.7
	5	41	0.33	13.7	0.5	26.8	66.7	3.5
	6	34	0.26	10.4	0.4	10.1	36.9	3.5
	7	25	0.26	11.2	0.4	12.1	42.8	2.9

Table 1. Summary of cobble transport data obtained from video drone survey.

Discussion

Local complexity in sediment transport patterns on gravel beaches have been revealed in tracer experiments over the past 60 years (e.g. Kidson and Carr, 1959). Similarly, our observations from the same field site under relatively similar wave conditions reveal opposing patterns of longshore sediment transport when comparing one injection of tracer sediments observed over 130 days with another set of tracers observed over 16 days. Not only were there dominant directions of transport opposite, but parallel transport corridors at the upper and lower beachface only became obvious in observations conducted at shorter time periods (Figure 2). It is clear that while tracer experiments provide valuable direct evidence of net sediment transport over a period of time, there is less insight into the actual pathway that sediments took to reach their location position (i.e. the gross transport distance), nor the periods of time where sediments may have been inactive (e.g. buried or transported beyond the swash zone). Owing to these limitations we developed a tracer-observation technique using vertical drone survey and painted cobbles. Initial analyses show that gross sediment transport rates within the 15-minute observation windows were 2-8 times higher than net transport rates, and differences become much larger when these observations are compared with tracer measurements using PIT tags at the same location. For instance, across 130 days and 16 days respectively, net transport rates were about 0.1 and 0.8 m/day in our PIT tracer observations. At Clifton and Haumoana (Figure 1), where waves make a sharper angle to the coast inducing higher transport rates, PIT observations by Dickson et al. (2011) recorded long-term (7 months) average transport distances of 2 to 2.5 m/day. In contrast, if cobbles remained constantly entrained within the active swash zone, our drone observations indicate that gross transport distances are likely to be in the order of 600 to 2500 m/day, but could be higher than 17km/day, and net transport distances might be in the order of 250 to 500 m/day with maximum values higher than 1 km/day. The large differences between the gross sediment transport rates recorded in our drone-video surveys and net sediment transport rates determined from PIT tracer observations are attributable to the long periods of quiescence that cobbles typically undergo during their history of transport on gravel beaches. Results imply that tracer studies using tagged cobbles require very large numbers of tracers and repeated measurements over long time periods to be able to successfully resolve dominant directions of sediment transport, determine relationships between observed net transport distance and measured gravel abrasion data.

Conclusion

A new drone-based video technique allows measurement of clast sediment transport on gravel beaches at the scale of individual swash events. Results confirm and quantify the high gross movement of individual clasts compared with comparatively small rates of net movement. Differences are particular high when made in comparison to clast tracer observations made with Passive Integrated Transponder tags at the same field site. These data highlight the challenges involved in understanding transport behavior and clast abrasion from long-term tracer experiments, and underscore the need to resolve the high frequency dynamics of clast motion on the beachface to gain a complete understanding of sediment transport on gravel beaches.

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