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Behavioral response of Dungeness crab (*Cancer magister*) to dredged sediment deposition events assessed with acoustic positional telemetry

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ABSTRACT

Maintenance of river mouths and harbors, coupled with environmental impacts of rising sea levels on ocean beaches, has led to management strategies that direct sediment supply to impacted areas. Judicious "beneficial" placement of sediment requires limiting negative impacts to critical species. The effects of one such strategy, "thin-layer deposition", was investigated on its impact on Dungeness crab (*Cancer* [*Metacarcinus*] *magister*), a prized fishery species, at the mouth of the Columbia River, USA. These deposition events include an energetic "lateral surge" of sediment that was hypothesized to stress or injure animals, and would be manifested as reduced activity (quiescence). The study details a novel approach: using acoustic positional telemetry, derived behavioral metrics, and a before-after control-impact (BACI) statistical design to measure activity of tagged Dungeness crab immediately following deposition events. Crab movement metrics (average velocity, linearity, and duration in arrays) were first compared to reference and loose tags to evaluate possible tag loss or mortality. Few crabs had activity patterns similar to these more quiescent tags. Crab positions (tracks) in control and impact treatment areas (receiver arrays) were then compared using velocity and linearity as response variables. No statistically significant differences in crab activity metrics were detected between control and impact treatments. Crabs were active with few quiescent periods both before and after sediment deposition, and residence times within arrays was generally short (<2 d). For a subset of crabs, movements recorded days to weeks post-release were similar to those observed at the initial release. Compared to previous acoustic studies in estuaries and the Salish Sea, there was high motility in coastal crabs. Thin-layer deposition was deemed effective at distributing sediment while minimizing adverse effects on biota. Acoustic positional telemetry provided a means to measure crab behaviors at meter-scale accuracy and offers a methodology relevant to a number of other epifaunal species and sediment deposition scenarios.

1. Introduction

Management of sediment from rivers and estuaries has long been critical to the maintenance of ports and waterways; however, goals of dredging and dredged sediment placement also seek to minimize negative effects on biota (Essink, 1999; Wenger et al., 2017). In the Columbia River, USA, operation of dams and control structures has altered natural sediment dynamics by sequestering sediment in upriver reservoirs and dampening the magnitude of seasonal floods that historically dispersed sediment downstream (Helaire et al., 2019). The resultant sediment deficit at ocean beaches, coupled with climate-induced wave intensification, has caused erosion that threatens coastal communities and infrastructure, including the jetties stabilizing the river mouth (Kaminsky et al., 2010; Stevens et al., 2024). Present management practices include transfer of sediment from the Columbia River navigation channel to nearshore deposition sites in an attempt to mitigate this deficit (LCSG, 2023; USACE, 2023).

One deposition strategy used to minimize negative effects on both biota and navigation is known as "thin-layer deposition" (Johnson and Fong, 1995; Wilber et al., 2007; LCSG, 2023). Under this strategy, sediment is released from dredges over a pre-determined distance within the permitted deposition site, and deposition tracks are arranged to evenly distribute sediment over time. Together, these actions aim to reduce the sediment depth of individual disposal runs, while dispersing cumulative loads over an extended area. Thin-layer deposition avoids previous practices that resulted in mounding, which has deleterious effects on both the biota and vessel navigation. However, during deposition events the descending plume of sediment strikes the seafloor as an energetic slurry that spreads as a "lateral surge" before settling (Johnson and Fong, 1995; Roegner et al., 2021). There are few studies of the

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in-situ effects of this lateral surge on biota and any harm it may cause to organisms.

In the Pacific Northwest, concern for deposition effects has centered on the Dungeness crab, *Cancer* [*Metacarcinus*] *magister*, because of its important ecological and economic roles (Pauley et al., 1986; Rasmuson, 2013; for fishery landing data, see www.fisheries.noaa.gov/foss). Past investigations of sediment deposition on Dungeness crab have included laboratory experiments (Chang and Levings, 1978; Pearson et al., 2006; Vavrinec et al., 2007) and in situ video techniques (Fields et al., 2019; Roegner et al., 2021). Both sets of experiments concluded that thin-layer deposition has negligible burial effects, in agreement with previous summaries describing sand deposition on epifauna in a dispersive wave regime (Wilber and Clarke, 2001; Bolam et al., 2011). However, the lateral surge has been shown to directly displace crabs and other fauna as it transits the seabed (Roegner et al., 2021), and the fate of crabs impacted by the lateral surge, including possible injury due to mechanical stress, has not been studied.

Until recently, there were few in situ methods available to measure behavioral aspects of crabs to a stressor, such as a response to a sediment deposition event, but developments in acoustic telemetry have provided a means to measure high-resolution movements and behaviors in aquatic animals (Florko et al., 2021; Matley et al., 2022; Lennox et al., 2023). Acoustic telemetry systems are composed of a coded transmitter (tag) attached to an animal and receivers tuned to the code frequency. Receivers can be mobile (active telemetry) or moored (passive telemetry), and passive systems include solitary or grouped receivers that are autonomous once deployed. A single receiver logs timed transmitter detections from within the receiver's detection radius, generally on order of 0.10 km^2, and thus has low effort but also relatively low position accuracy. In contrast, where three or more receivers are moored with overlapping reception radii, the difference in detection timing from a transmitter signal can be used to triangulate the tag position via hyperbolic positioning (Smith, 2013). This technique is known as acoustic positional telemetry (APT), and meter-scale position accuracy can be achieved. Using APT, a time-series of positions define an animal's track (movement) and can be used to quantify activity, habitat use, and behavior (Lennox et al., 2023).

Recent studies of crabs and lobster behaviors using passive acoustic telemetry techniques cover a range of objectives including elucidating migration patterns (Bowlby et al., 2017; Florko et al., 2021), evaluating habitat preferences (Holsman et al., 2006; Skerritt et al., 2015; Aune et al., 2022), determining responses to fishing pressure (Wiig et al., 2013; Burns et al., 2020), estimating effects of marine protected zones (Henkel and Roegner, 2020), or measuring habitat use around aquaculture sites (Lees et al., 2023; Roegner et al., 2023), as well as others. Here for the first time, we used an APT system in an experimental framework to test crab activity metrics following sediment deposition events. We hypothesized the lateral surge may cause stress or injury to crabs that could be identified as reduced activity levels as crabs buried themselves for shelter or became moribund from the impact event. Our main experimental design used APT to compare activity of crabs subjected to sediment deposition events to controls that were unimpacted. Support for the hypothesis would therefore include an increase in duration and decrease in average velocity and sinuosity for impacted crabs compared with controls. We also evaluated post-deposition movements over subsequent days from a subset of tagged crabs as a measure of chronic effects. Together, these measurements include both immediate and longer term effects of deposition on crabs, and the study provides a model for the wider application of telemetry research to management practices. Our specific objectives were 1) Develop an experimental framework to compare movement metrics using acoustic positional telemetry, and 2) Evaluate Dungeness crab response to thin-layer deposition events.

2. Methods

2.1. Sediment deposition overview

Deposition events from hopper dredges commonly used in ocean disposal occur in three phases (Johnson and Fong, 1995). The first, *convective descent*, is the release, mixing, and descent of a sediment-water plume through the water column. Second, *dynamic collapse* occurs as the sediment plume encounters the seabed, where it transitions into a *lateral surge* that propagates along the seabed perpendicular to the direction of the disposal track. Third and finally, as the slurry loses momentum, the sediment is deposited and re-sorted by the hydrodynamic regime in a process known as *passive transport and diffusion*. Velocities of the sediment-laden lateral surge can reach 2–3 m/s; however, the impact period is short (~7 min at a stationary monitoring location), and the deposition footprint appears limited to roughly 100 m from the centerline of the hopper dredge track (Moritz et al., 2014; Roegner et al., 2021). Sediment levels immediately following deposition events were <4 cm (Roegner et al., 2021). Thus, while intense, the impact has limited temporal and spatial extent. This study focuses on crab behavior in the hours surrounding these energetic deposition events. We also consider post-deposition behaviors where applicable.

2.2. Site description and deposition schedule

Experiments were conducted at the South Jetty deposition site, located immediately south of the mouth of the Columbia River, USA (Fig. 1). The site occupies an area of 6.2 km^2 at depths of 10–20 m. These nearshore areas are dispersive sediment environments where high wave energy redistributes disposed sediment into the larger littoral cell (Kaminsky et al., 2010; Stevens et al., 2023). Sediment deposition in this area was intended to nourish the adjacent Clatsop Beach. At present, the South Jetty site is one of four nearshore ocean deposition sites utilized by the U.S. Army Corps of Engineers for the disposition of Columbia River dredged sediments (USACE 2024).

Dredging and disposal periods by the USACE were limited to August through September to reduce effects on migrating Pacific salmon (*Oncorhynchus* spp) and take advantage of the seasonally benign weather conditions. The commercial crab fishery is also restricted during this period to allow male crabs to build biomass after molting. Sediments were dredged from the nearby Columbia River navigation channel and were composed of uncontaminated medium-to fine-grained sand (0.22-mm diameter with <3 % silt and mud). Each deposition layer was comprised of roughly 4200 m^3 of sediment, and cumulative loads over the deposition period ranged from 2.2 to 3.6 × 10^5 m^3 per year. Deposition events were conducted by the USACE *Essayons*, a multiple-door hopper dredge.

2.3. Acoustic telemetry system

The acoustic telemetry system consisted of 69 kHz acoustic receivers deployed on moorings and individually coded transmitters (9 × 5 mm V9A tags) attached to crabs (Innovasea Systems, Inc., Nova Scotia, Canada). The study initially used VR2W and VR2Tx receiver models deployed on surface floats. These models were gradually switched to VR2AR units on subsurface moorings (with an acoustic release mechanism), which were less vulnerable to storm events and vandalism. Receivers were moored 3–5 m above the sea bottom at depths of 10–15 m.

To enable APT measurements, receiver moorings were arranged into array networks of various geometries, as described below. The reception range of receivers varies due to tag transmission power, distance, oceanographic conditions such as noise from elevated wave amplitudes, and other factors (Kessel et al., 2014). We determined the distance between receivers in arrays by range testing that revealed consistent reception at 400 m, with reception extending to 700 m under ideal

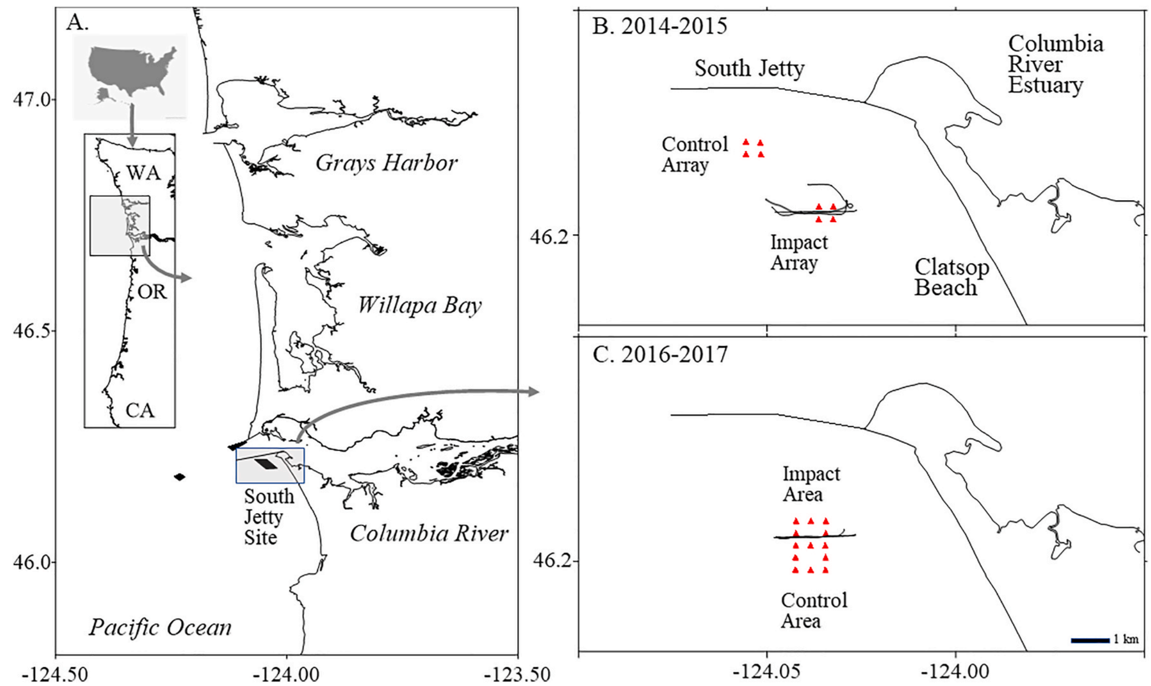

Fig. 1. Study area and positions of acoustic receiver arrays, 2014–2017. A. Location of the South Jetty Site (SJS) sediment placement zone and regional setting. B. & C. Locations of control and impact receiver arrays (triangles) during 2014–2015 (small arrays) and 2016–2017 (large arrays). Black lines through impact areas denote deposition runs of the USACE dredge *Essayons*. See LCSG (2023) for additional deposition sites.

conditions. Receivers were thus deployed 300–350 m apart in orthogonal arrays with overlapping reception ranges. A schematic is provided in the Supplementary Information (SI01). Crab positions were most accurate within the array perimeter, but positions were also recorded outside the perimeter when conditions allowed. All positions were processed by the Vemco positioning system (VPS; Innovasea Systems, Inc.).

The array geometries changed over time. In 2014 and 2015, we deployed two arrays of four acoustic receiver moorings (small array, Fig. 1). One array was deployed to the north in the control area and the other to the south in the impact area; the centers of the two arrays were separated by 2.2 km. Detection areas were each approximately 0.67 km^2, assuming a 300-m detection radius. In 2016 and 2017, the mooring geometry was changed to a single 2.28-km^2 detection area. This "large array" straddled the South Jetty deposition, area with the northern section designated the impact area and the southern area the control treatment (Fig. 1).

We also deployed reference tags within arrays to compute position accuracy. These tags were tethered 10–25 cm above the seabed on small weights at known positions within arrays. Horizonal position error (HPEm) estimates were computed as the average of deviations from the mean position. HPEm ranged from 1.00 ± 0.87 (sd) to 5.18 ± 3.55 m (full data in results). Additionally, unmoored "loose" tags were deployed on three occasions to simulate tag loss. These tags could be transported by waves and currents but were expected to exhibit different metrics than a tag attached to a dead or damaged crab (tags were not deployed on euthanized crabs). Both reference and loose tags were used to define movement metrics and thresholds, as described below.

Acoustic tags had an estimated battery life of ~300 d and were programmed with a variable ping rate to avoid signal "collisions," which reduce detection efficiency. Tags were programed for high output at a transmission rate of 18–26 pings/h, which resulted in a time-series of detections from the time of release. Dungeness crabs were caught in recreational crab pots (1 m diameter × 0.3 m high) baited with northern anchovy (*Engraulis mordax*). Crabs captured for tagging were graded by size and sex into treatment groups, with adult, undamaged and lightly fouled individuals prioritized. Demographic characteristics of tagged crabs are shown in the Supplementary Information (SI02). The acoustic tags were affixed to the dorsal carapace with fast-curing epoxy glue. Handling of crabs was minimized during the tagging procedure, and their respiratory currents were monitored in shallow-water trays as the adhesive cured (roughly 5 min). During an experiment, approximately 10 tagged crabs (range 9–11), with an even sex ratio where possible, were released per treatment group. However, sexes were pooled after regression analysis revealed no effect of size or sex on average velocities (SI03).

During these investigations (2014–2017), we conducted 9 experiments using 179 Dungeness crab released into acoustic receiver arrays. The experimental design called for releasing tagged crabs near-simultaneously at a sediment deposition area (impact treatment) and at a non-deposition area (control treatment). Operationally, as the hopper dredge *Essayons* approached the test site, the tagged crabs were released into control and impact treatment areas, after which the dredge traversed the impact area while releasing its sediment load. We remained on site during the experimental deposition runs, and coordinated with the dredge personnel to synchronize the release of crabs with the arrival of the dredge. Crab releases at respective treatment locations occurred within a period of 5 min over an area of approximately 50 m^2, and the time between releases at treatment and control sites was generally less than 15 min. A deposition run was about 20 min in duration.

2.4. Movement metrics

We analyzed individual crab positions provided from the Innovasea VPS product and developed activity metrics as response variables for statistical tests. Each position (P) is a time-stamped X-Y coordinate beginning with the time of release. For each crab, the sequence of positions comprises a movement "track", from which activity metrics were calculated (SI01). These time-series data sets were filtered for positions with horizontal position error (HPE) > 20 (Smith, 2013), which generally occurred outside the array perimeter. Tracks were also filtered for time gaps exceeding 24 h. Where such gaps existed, the time-series segments were partitioned and numbered, with segment 1 for the initial segment, 2 for the second segment, and so on. This allowed for analysis of initial metrics followed by subsequent movement patterns.

Each time-series was normalized to release time (t_0) and location of first detection (P_0). For each sequential time stamp and position, we determined the time interval as t_2-t_1 (s), distance moved as ($D_t = [(X_2 - X_1)^2 + (Y_2 - Y_1)^2]^{0.5}$, m), instantaneous velocity as ($U_t = D_t/t$, m/s), and direction of movement as ($\theta = \tan^{-1}$ (y/x), degrees). Instantaneous change in direction, or turning angle, was calculated as $\partial\Theta = \partial\Theta/\partial t$.

From all points of a track, we calculated cumulative distance traveled (ΣD) and the average velocity ($U_{AVE} = \Sigma U_t/n$), where n = number of positions. Additionally, from first and last positions (endpoints) of the track, we determined absolute travel distance as $D_{ABS} = P_F - P_0$. D_{ABS} was used to formulate the linearity index (LI), or inverse sinuosity, as $LI = D_{ABS}/\sum D$. This is the straight-line distance traveled divided by the cumulative distance traveled. LI approaches 1.0 during straight line movement while deviating from unity during nonlinear (curved) movement, meandering, or periods of quiescence. For descriptive purposes, the instantaneous metrics D_t, U_t, LI_t, and $\partial\Theta$ were plotted as time-series. These and additional metrics are shown in the supplementary information (SI01). To screen for injured crabs or tagged loss and for statistical tests we used duration, U_{AVE}, and LI as response metrics. These three metrics combined to distinguished active versus inactive crabs to address the main hypothesis that sediment impacts would reduce crab activity.

3. Analysis

We hypothesized crabs impacted by the sediment surge would become inactive due to stress or injury. We used several lines of evidence to test this overall hypothesis. First, we used the response metrics to set thresholds characterizing movement as quiescent, meander, or transit. Quiescence, or inactivity, in crabs was determined by comparison to metrics from reference and loose tags. We expected more quiescent crabs in the impact treatment. Second, we compared residence times (duration) in control and impact arrays, with the expectation residence would be higher in the impact treatment. Third, we considered a BACI experimental design using the activity metrics average velocity and linearity. We expected these metrics to be lower in the impact treatment (more quiescence/meandering). Finally, we considered post-impact movements from a subset of observations to evaluate possible behavioral differences between initial and later movements and possible experimental effects of tagging. This includes crabs that re-entered arrays (secondary tracks) as well as those that moved between arrays. Together, these behavioral tests and observations provide a framework for evaluating deposition effects on crab activity.

3.1. *Characteristics of crab movements and estimation of injury/mortality or tag loss*

Movement categories were based on video observations (Fields et al., 2019; Roegner et al., 2021), and are quiescence (periods of limited movement that may entail shallow burial), meander (non-directional and low-velocity movement typifying foraging), and transit (rapid movements of high linearity). To categorize individual crab tracks, critical thresholds of the response metrics were developed and applied together in a graphical framework. Conceptually, a quiescent animal was defined as exhibiting a low velocity, low linearity, and high duration track. A meandering animal expressed moderate velocity, moderate linearity, and moderate duration. Transiting animals had moderate to high velocity, high linearity, and low duration. Threshold values were determined empirically.

It was hypothesized that the behavior of impact crabs would differ from that of controls, specifically, impact crabs may exhibit higher quiescence, indicative of stress, injury, or mortality. We screened for quiescent crabs by plotting $U_{AVE} \times$ Dur and $U_{AVE} \times$ LI, and comparing tagged crabs to reference and loose tags. Threshold values of these metrics (see results) created reference windows in plot space. Crab track metrics that fell within or near these windows (high duration, low U_{AVE}, and low LI) were further inspected visually for effects from the experimental procedure (by comparing to controls). Additionally, tag loss is always a consideration and its characteristics may resemble quiescence. We differentiated quiescence from tag loss by the duration a tag is stationary (alive but quiescent crabs eventually move).

3.2. *Residence time*

Damage or stress induced by lateral surge of disposed sediment may result in decreased motility of crabs once the surge dissipates (~7 min). We used the duration of time in an array (residency) as an overall measure of activity. ANOVA tests were used to compare duration within impact and control treatments, with the expectation that residency at impact treatments would be higher than at control treatments. Due to their different detection areas, single-factor ANOVA tests were made separately for the small and large arrays. Statistica v14 (TIBCO Software Inc.) was used for all statistical tests.

3.3. *Experimental effects of deposition*

A before-after control-impact (BACI) statistical design was used to detect differences in velocity and linearity. The statistical design required time synchronization to standardize the treatment comparisons. Tagged crabs were released into control and impact treatment arrays (usually within a 15-min period), after which the dredge traversed the impact array while releasing its sediment load. Thus, the impact treatment was composed of the period before and after sediment release. The control treatment had no sediment impact event; thus for comparison, we standardized the before time period at the control site to equal that of the impact treatment.

From the impact treatment, we defined the T_0 as the release time and T_I as the impact time. The before time period was $T_B = T_I - T_0$, and the after period was $T_A = T_I + 60$. The 60 min period was selected because it was found that crabs could transit through small arrays in less than 60 min. These time periods defined the four treatment groups comprising a BACI design: before-impact, after-impact, before-control, and after-control. One caveat was that due to vagaries of scheduling with the hopper dredge, T_B was not constant among release experiments. Thus, while metrics for both control and impact treatments were determined for the same length of time within each release experiment, this period varied by up to 20 min among experiments.

Average velocity and linearity were independent of receiver array detection area (large vs. small arrays) as well as time to impact T_I, and allowed use of the largest number of replicates for the analysis. We hypothesized that crabs from the after-impact group would differ from those from the other groups due to the impact of the lateral surge. We tested these expectations using a two-factor ANOVA, where significant interaction terms would support the hypotheses (Underwood, 1991).

3.4. *Initial and secondary movements*

The majority of crabs exhibited a single track after release and did not return to an array reception area, but a subset of crabs re-entered arrays one or more times during the subsequent days. To fully characterize movement metrics of all crab tracks, frequency analysis was used to determine the percent of time crab activity fell within the critical thresholds of the response metrics U_{AVE} and LI. We compared the ranges of response metrics between initial and subsequent tracks to evaluate possible tagging effects, specifically, whether the proportion of quiescent, meander, and transits activities were similar.

Additionally, for the small arrays only, a further subset of crabs moved between arrays, which were separated by a distance of 1716 m (closest receivers). Tag detections from two receivers positioned outside their respective reception radii (i.e. not in an array) can also be used to estimate transit time (T_T = destination – release) and transit velocity ($U_T = D/T_T$) for a tagged crab moving between them, where D is the distance between receivers (SI01). A major caveat is the unknown and variable reception radius of the receiver. Percent error for U_T is inversely proportional to the distance between receivers (higher when receivers are closer). Here we used D – (300 m × 2), a conservative measure of detection radius. Note the actual (cumulative) path is unknown, so linearity cannot be computed, but faster transits are assumed to be more linear. Transit time and transit velocity were determined for the subset of crabs moving between arrays during the small array experiments, and compared with movements derived from APT data.

4. Results

4.1. Release schedules

Small acoustic arrays were deployed from 19 August to October 10, 2014 (R01-R03) and from 25 August to October 17, 2015 (R04-R06), and three tagging experiments were performed each year using a total of 119 tagged crabs (Table 1). Large acoustic arrays were deployed from 28 August to October 12, 2016 and from 29 August to October 30, 2017. Two releases were conducted in 2016 (R07-R08) and one release in 2017 (R09), with 20 tagged crabs released during each experiment.

Deposition events tended to be clustered within the permit window and generally trailed off by the final weeks of the period (Fig. 2). Note that during deposition operations, multiple sediment releases per day often occurred; however, the newly released crabs were never exposed to repeat deposition events during a single day.

4.2. General patterns of crab movement

Individual tracks were plotted and inspected, and positions with high position-error were removed. The dataset resulted in 203 tracks from 17730 positions. A comparison of movement metrics for track 1 (initial release) to moored reference tags and loose tags is illustrated in Fig. 3. These initial tracks show that crabs generally moved steadily away from the deployments site, which can be observed in the plot of x-y positions and time-series of distance (D_{ABS}). Note that both instantaneous velocity (U_t) and change in direction ($\partial\Theta$) were computed from sequential positions; thus the mostly horizontal lines for U_t and the preponderance of $\partial\Theta = 0$ indicated relatively constant velocities and lack of turning, respectively, over the track. In contrast, reference and loose tags had minimal movements with high incidents of turning, due primarily to meter-scale variation in position accuracy.

Most crabs presented a single track before leaving the detection area, but 33 others were detected secondarily in arrays over the course of the experiments. A total of 19 crabs moved between receiver arrays such that transit time T_T and instantaneous velocity U_T could be calculated.

Table 1
Summary of tags released per experiment 2014–2019.

Year	Release date	Release code	Study period (d)	Array	N Control	N Impact
2014	4 Sep	R01	52	Small	11	10
	18 Sep	R02		Small	10	10
	29 Sep	R03		Small	10	9
2015	16 Sep	R04	53	Small	10	10
	26 Sep	R05		Small	10	10
	30 Sep	R06		Small	9	10
2016	28 Aug	R07	45	Large	10	10
	8 Sep	R08		Large	10	10
2017	30 Aug	R09	60	Large	10	10
Total		9	210		90	89

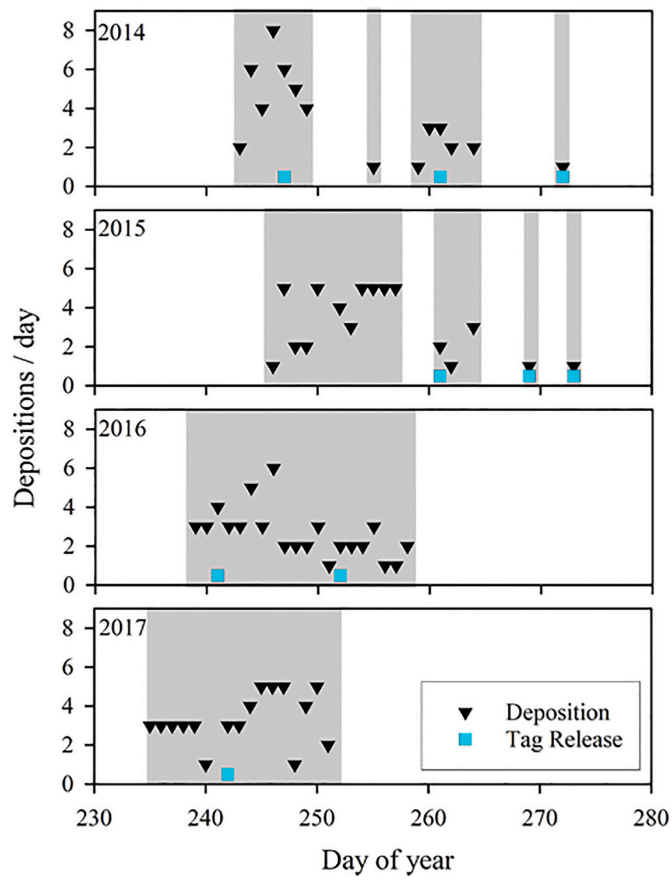

Fig. 2. Time-series of experimental tagged crab releases (blue) and number of daily sediment deposition events (black). Grey shading indicates windows of active sediment deposition operations. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

During a single track, crab motions could include ranges of activity, from rapid transits through quiescence, and transit pathways ranged from linear to non-linear. Periods between multiple tracks ranged from days to weeks. An example of crab activity patterns and derived movement metrics are shown in Supplementary Information SI01.

4.3. Crab activity levels and stress/tag loss

Crab activity levels and critical thresholds were developed based on data from reference and loose tags and observations of crab tracks. Moored reference tags had continuous reception periods (duration) from 33 to 51 d and thousands of positions were measured for each tag (Table 2). Absolute movement was <10 m, average velocity was <0.010 m/s (except for RI2015 which moved slightly), and linearity was generally <0.001. The horizonal positions errors (HPEm) for refence tags were low (~1–2 m), except for RI2015 (Table 2). Loose tags also had long durations and thousands of recorded positions but moved between 5 and 181 m during the measurement periods. The HPEm values for loose tags were therefore higher (6–56 m). Average velocity of the three loose tags was ≤0.02 m/s, with low linearity (<0.001 to 0.020).

Crab activity categories (quiescence, meander, and transit) were defined by these critical values of the reference and loose tags and by the distribution of crab movement metrics. Long duration (high residency) was unusual for tagged crabs and was considered indicative of crab injury/mortality or tag loss. The critical threshold for duration (Dur_{CRIT}) was therefor set at 2 days, factoring in the different reception ranges of the arrays. The critical thresholds for quiescence were set at U_{CRIT} < 0.02 m/s, LI_{CRIT} < 0.25, and Dur_{CRIT} > 2 d. Meander and transit

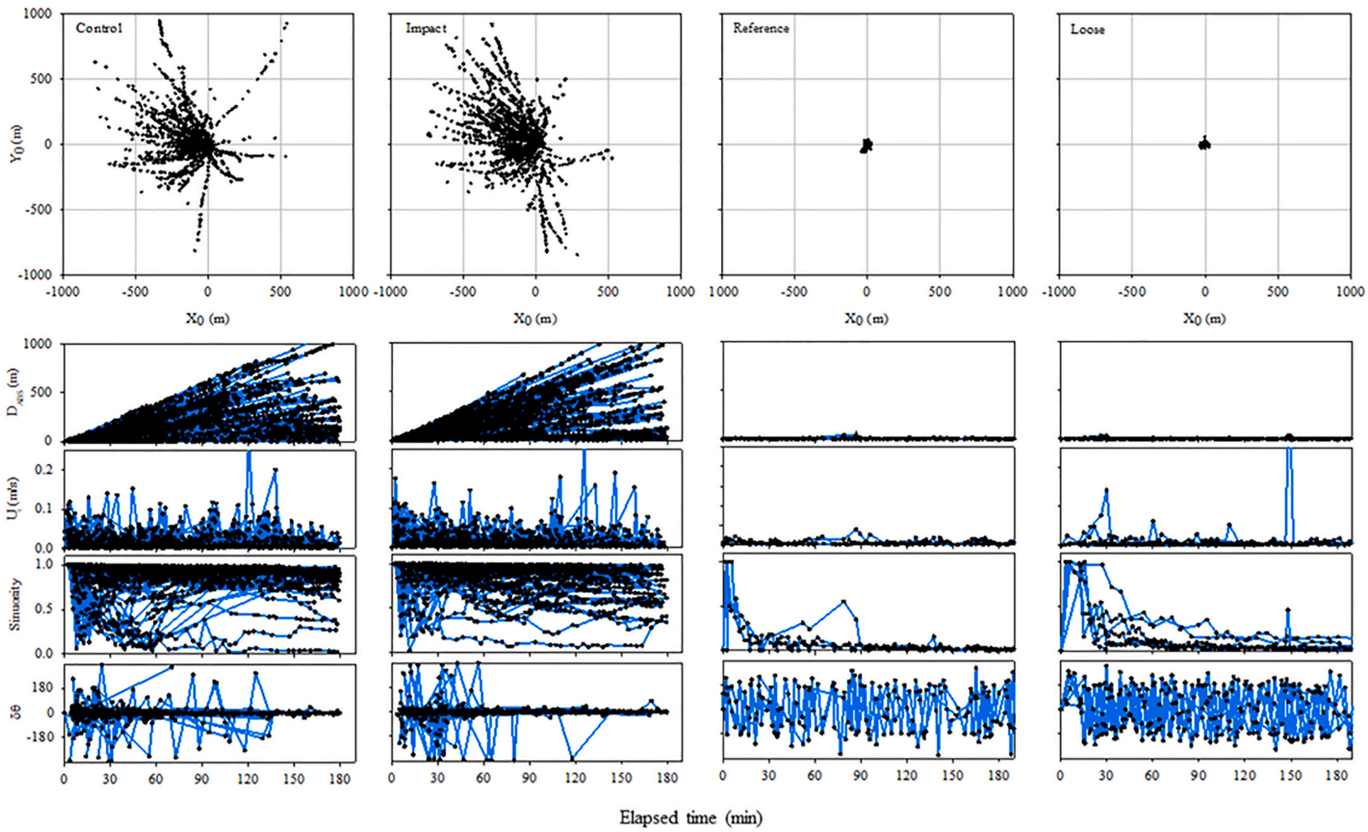

Fig. 3. Movement response of Dungeness crab to thin-layer deposition events at control and impact treatment sites compared to movement of moored reference and loose tags. Upper plots: Composite of normalized positions (X_0, Y_0) for all initial tracks. Lower plots: Time-series of movement metrics. From top to bottom: distance traveled (D_{ABS}), instantaneous velocity (U_I), linearity index (LI), and turning ($\partial\Theta$). Time-series were truncated at 180 min post-release. Reference and loose tags were quiescent compared to active crab movements.

Table 2
Movement metrics for loose tags (LT), reference impact (RI), and reference control (RC) treatment tags. N_{POS}, positions per track. Dur, duration (d). U_{AVE}, average velocity during track ± sd (m/s). U_{CRIT}, percent of observations <0.02 m/s. D_{ABS}, absolute distance traveled (m). ΣD, cumulative distance traveled (m). LI_{AVE}, average linearity. LI_{CRIT}, percent of observations <0.25. HPEm, Horizontal Position Error (m).

Tag	N_{POS}	Dur	U_{AVE}	U_{CRIT}	D_{ABS}	ΣD	LI_{ABS}	LI_{CRIT}	HPEm
LT0248	2940	28.9	0.017 ± 0.02	73.0	181.5	9689.8	0.02	99.7	56.77 ± 15.98
LT2243	8328	59.9	0.020 ± 0.02	66.6	5.5	19517.3	<0.001	99.9	6.81 ± 3.41
LT9633	5346	36.3	0.011 ± 0.01	86.3	52.2	11736.3	0.004	99.9	25.43 ± 5.57
RC2014	12742	36.3	0.004 ± 0.01	99.5	2.3	10892.7	<0.001	99.7	1.88 ± 1.67
RI2014	7673	19.8	0.003 ± 0.01	99.9	7.8	4720.4	<0.002	99.7	1.00 ± 0.85
RC2015	15021	43.0	0.006 ± 0.01	96.0	7.6	19727.2	<0.001	100.0	2.36 ± 1.57
RI2015	2995	33.0	0.015 ± 0.03	75.0	5.1	14720.1	<0.001	99.9	5.18 ± 3.55
RC2016	10451	41.7	0.007 ± 0.01	95.0	9.0	12743.5	0.001	99.9	1.64 ± 1.57
RI2016	8040	36.2	0.008 ± 0.01	92.5	3.7	12710.1	<0.000	99.9	1.67 ± 1.30
RC2018	10248	51.4	0.003 ± 0.01	96.6	2.4	13729.5	<0.001	99.8	1.38 ± 1.16
RI2018	9865	51.4	0.005 ± 0.01	93.1	1.1	18011.9	<0.001	99.7	1.80 ± 1.35

behaviors were on a continuum of velocity and linearity values with durations <2 d. Transits were defined as velocity above the critical value (U_{AVE} > 0.02) and high linearity (LI ≥ 0.75), while meandering thresholds were intermediate (U_{CRIT} = 0.02 m/s, LI_{CRIT} > 0.25 to 0.75).

We plotted all tracks (initial and subsequent) and compared them to metrics from loose and reference tags (Fig. 4). Loose and reference tags partitioned together in parameter space defined by the critical thresholds (Fig. 5). Few tagged crabs plotted within the critical windows, and none overlapped the loose or reference tags. Thus the incidence of tag loss appeared minimal. For the impact treatment, seven crabs were within or bordering the U_{AVE} × Dur window, and a subset of four tags were within the U_{AVE} × LI window (seven crabs total). For control crabs, six crabs were within or bordering the U_{AVE} × Dur window, and two tags were within the U_{AVE} × LI window (one in common for seven crabs total). Inspection of the tracks indicated most of these crabs had extended quiescent periods interspaced with meandering or transit segments, indicating they may have suffered a treatment effect but appeared alive. Conservatively, 3.9 % of crabs from each treatment were possibly stressed or injured (7.8 % combined). It was concluded no extensive mortality, injury, or tag loss were associated with the experimental procedure or by the thin-layer deposition events.

4.4. *Residence time*

Residency ranged from fewer than 24 h to over 2 weeks in duration. In the small array, mean residency for both treatments was about 2 d,

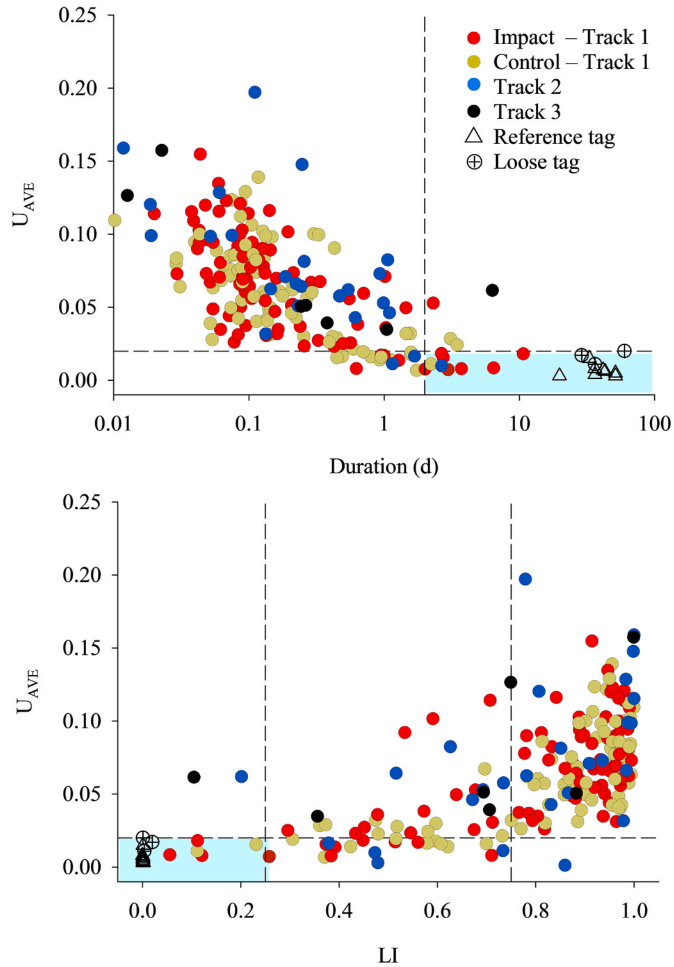

Fig. 4. Critical threshold plots based on velocity (U_{AVE}), duration, and linearity (LI) for individual crab tags, moored reference tags, and loose tags. Crab tracks were color coded for initial (control and impact) as well as post-impact tracks, as indicated. Dashed lines delineate critical thresholds: $U_{CRIT} = 0.02$ m/s, $LI_{CRIT} = 0.25$, and $DUR_{CRIT} = 2$ d. Blue windows enclose the critical ranges. Tags enclosed by critical windows were examined for tag loss or were considered crabs affected by the experimental procedure (stress, injury, or mortality). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

but a few crabs were continuously detected (lingered) at each array for over a week (Table 3). Analysis indicated no significant difference in residence time of crabs released to control vs. impact arrays (ANOVA $F = 0.004$; $P = 0.949$). The large array comprised a continuous area, and no distinction was made between control and impact locations within it. Residence time within the detection radius of the entire array was compared by treatment. Results indicated crabs left the large array detection radius rapidly, with the majority exiting in less than 0.5 d. No difference was detected in residence time between control and impact releases ($F = 0.127$; $P = 0.722$).

4.5. Deposition effects

Using a BACI design to compare average velocity and linearity of tagged crabs, we found thin-layer deposition by the hopper dredge had no significant effect on crab movement metrics. Data from individual experiments are shown in Fig. 5, and results of the BACI tests in Fig. 6 and Table 4. During the pre-impact period, U_{AVE} in control and impact treatments were nearly identical (0.041 and 0.043 m/s) and not significantly different from each other (Table 4). In the post-impact treatments, mean velocities increased to 0.054 m/s for the control

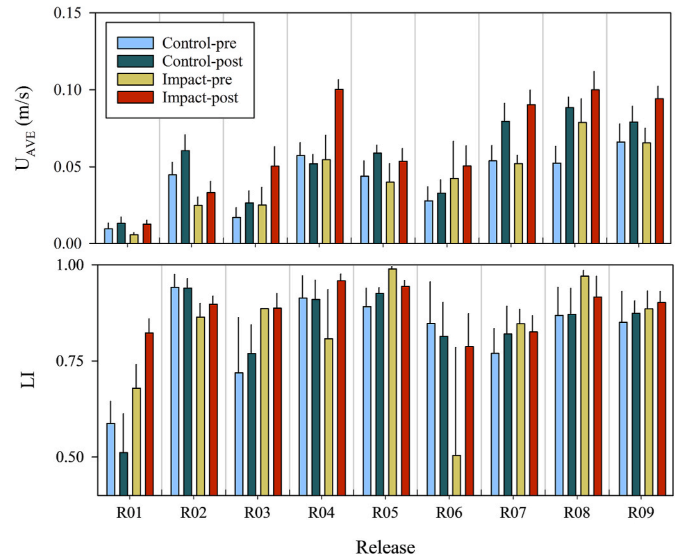

Fig. 5. Frequency distributions of average crab velocities (U_{AVE}; upper) and average linearity (LI_{AVE}; lower) during initial (left) and subsequent (right) tracks. Movement activities were characterized as quiescent, meandering, or transiting based on critical values.

group and 0.065 m/s for the impact group. Post-impact values were significantly higher in the impact group than in the two control groups but were not significantly different from the post-impact control-group (Fig. 6). The interaction term in the BACI model was not significant (Table 4). Mean linearity values were relatively high for all treatment groups (<0.8) and increased marginally in the impact-post group. BACI results for linearity indicated no significant effects (Table 6).

Note the analysis was repeated after excluding experiment R01, when crab movement was much lower than that of the other experiments (Fig. 5). However, the results did not change (data not shown). In both cases, there was a significant time effect (post-impact > pre-impact), but no treatment or interaction terms were significant. No effects for the linearity tests were significant.

4.6. Initial and secondary movements

Movement metrics from initial and subsequent tracks (track = 1 and track >1) were evaluated for control and impact sites as a check on post-impact behaviors. There were 85 initial tracks for each treatment, 13 subsequent tracks from control crabs and 20 subsequent tracks from impact crabs. For the initial tracks, both control and impact treatments exhibited similar mean metrics (Table 5), while mean metrics of subsequent tracks varied inconsistently relative to the initial tracks. The overall mean velocity for all tracks was 0.066 ± 0.03 m/s, and mean linearity was 0.79 ± 0.25; crabs generally moved at a near-constant velocity transits in relatively straight trajectories until leaving the array detection area.

Frequency analysis of position data allowed for a general characterization of crab movements during the initial and secondary tracks (Fig. 7). The distribution of data relative to critical thresholds of average velocity and mean linearity confirmed the mostly active nature of the tagged crabs. For initial tracks, average velocities were broadly distributed up to 0.12 m/s with a maximum of 0.15 m/s, and with only about 10 % of tracks classified as quiescent (Table 6). Most initial tracks were highly linear (78.8 % > 0.75). Secondary tracks had a similar velocity range, but a slightly higher proportion of quiescent animals (16.2 %). Linearity was similarly high (66.7 % > 0.75). There were no distinctive differences in metrics between initial and subsequent movements. Table 6

We also examined transit times for the subset of crabs that moved

Table 3
Statistics for residency in days (Dur) of crabs released into control and impact areas of both the small (R01-R06) and large array (R07-R09). N, number released. sd, standard deviation, Min, minimum. Max, Maximum.

Treatment	N	Small array			N	Large array		
		Dur (sd)	Min	Max		Dur (sd)	Min	Max
Control	59	1.92 ± 3.37	0.10	16.98	28	0.44 ± 0.62	0.05	3.00
Impact	57	1.96 ± 3.15	0.07	17.19	28	0.56 ± 1.54	0.08	8.35
All	116	1.94 ± 3.25	0.07	17.19	56	0.50 ± 1.16	0.05	8.35

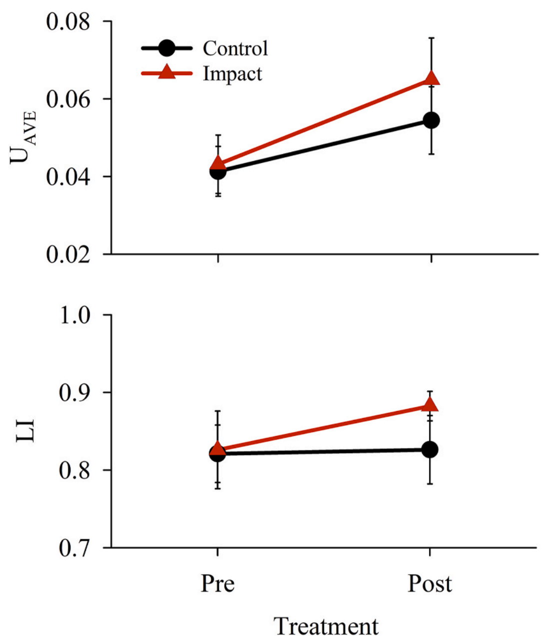

Fig. 6. Mean movement metrics by treatment level for releases R1 through R9. Upper: Velocity (U_{AVE}). Lower: Linearity (LI). Treatment levels are Before-After Control-Impact (BACI) periods. Error bars are standard error.

Table 4
BACI results for average velocity (U_{AVE}) and linearity (LI) for experimental releases R01-R09. TRT, treatment (control, impact). Pre-post (pre-impact, post-impact).

Metric	Effect	SS	DF	MS	F	p
U_{AVE}	Intercept	0.094	1	0.094	144.439	<0.001
	Treatment	0.000	1	0.000	0.530	0.472
	Pre-post	0.003	1	0.003	4.228	0.048
	Treatment * Pre-post	0.000	1	0.000	0.261	0.613
	Error	0.021	32	0.001		
LI	Intercept	25.329	1	25.329	1820.969	<0.001
	Treatment	0.008	1	0.008	0.608	0.441
	Pre-post	0.009	1	0.009	0.616	0.438
	Treatment * Pre-post	0.006	1	0.006	0.425	0.519
	Error	0.445	32	0.014		

between the two small arrays. Crabs moved both north and south. Of 119 viable tags, 10 crabs left the control array and were detected at the impact array, while 17 impact crabs were detected in the control array. Additionally, 1 control and 4 impact crabs made a second transit back to the array of origin, and crab 10 made a third transit back to the control array (SI01). Transit time (T_T) and transit velocity (U_T) were calculated for pooled data after ANOVA tests failed to find significant differences between treatments for either metric (T_T: $F = 3.2$, $P = 0.08$; U_T: $F = 0.04$, $P = 0.84$; results from initial movements only).

Table 5
Summary of crab track characteristics for thin-layer deposition control and impact treatments. Mean and standard deviation (sd) values are presented. Track, 1 = initial, 2 = secondary, and so on. N_T, number of tracks. N_{POS}, mean positions per track. Dur, duration. U_{AVE}, average velocity during track. D_{ABS}, mean absolute distance traveled. ΣD, mean cumulative distance traveled. LI, linearity.

Track	N_T	N_{POS}	Dur (d)	U_{AVE} (m/s)	D_{ABS} (m)	ΣD (m)	LI
Control treatment							
1	85	55.7 ± 78.9	0.37 ± 0.61	0.060 ± 0.03	517.2 ± 233.8	736.5 ± 473.1	0.80 ± 0.25
2	12	56.2 ± 74.1	0.45 ± 0.53	0.090 ± 0.05	774.9 ± 654.4	1098.6 ± 790.4	0.75 ± 0.22
3	1	4.0	0.01	0.126	185.9	186.1	1.00
Impact treatment							
1	85	61.1 ± 131.6	0.36 ± 0.62	0.068 ± 0.03	527.0 ± 319.2	733.8 ± 500.8	0.81 ± 0.22
2	14	28.2 ± 26.1	0.56 ± 0.72	0.069 ± 0.03	565.1 ± 631.0	842.6 ± 791.6	0.71 ± 0.30
3	4	81.5 ± 56.6	1.80 ± 3.01	0.051 ± 0.01	607.3 ± 149.7	1861.1 ± 2020.9	0.53 ± 0.25
4	2	9.5 ± 7.8	0.53 ± 0.72	0.096 ± 0.08	190.7 ± 144.2	380.5 ± 123.9	0.59 ± 0.57
	203	55.9 ± 101.4	0.41 ± 0.74	0.066 ± 0.03	536.8 ± 346.4	780.0 ± 605.7	0.79 ± 0.25

Altogether, mean transit time between arrays was 2.90 ± 4.20 d, but a wide range of transit times was observed. The majority of crabs (>60 %) made the transit in less than a day, while others remained in the South Jetty area for up to 18 d before being detected in the opposite array (Fig. 8). Mean velocity was 0.08 ± 0.11 m/s (range of >0.01–0.40 m/s), which within the variation range of the average velocities from positional data (0.066 ± 0.03 m/s). Because of the long transits and assumption of linear travel, over 60 % of transit movements were classified as quiescent, but in fact all ranges of crab activity could have occurred during the period crabs were undetected.

5. Discussion

Dredged sediment operations can have profound impacts on marine organisms (Newell et al., 1998; Bolam et al., 2011). This research was conducted as part of a larger program to evaluate use of “thin-layer” deposition techniques on benthic epifauna at the mouth of the Columbia River. Previous work included the use of benthic video sleds to survey epifauna at disposal and control sites over large spatial scales, and before, during, and after sediment deposition seasons (Fields, 2016; Fields et al., 2019). Seasonal changes were found to explain more variability than treatment (disposal) effects. Benthic video landers were also employed to observe in situ dynamics of the lateral surge in order to quantify direct effects on Dungeness crabs and gastropods (*Nassarius* sps) (Roegner et al., 2021). The energetic lateral surge displaced all crabs from the impact area, but this effect was localized and transitory, and crabs soon returned to the baited landers. Gastropods were less impacted than crabs.

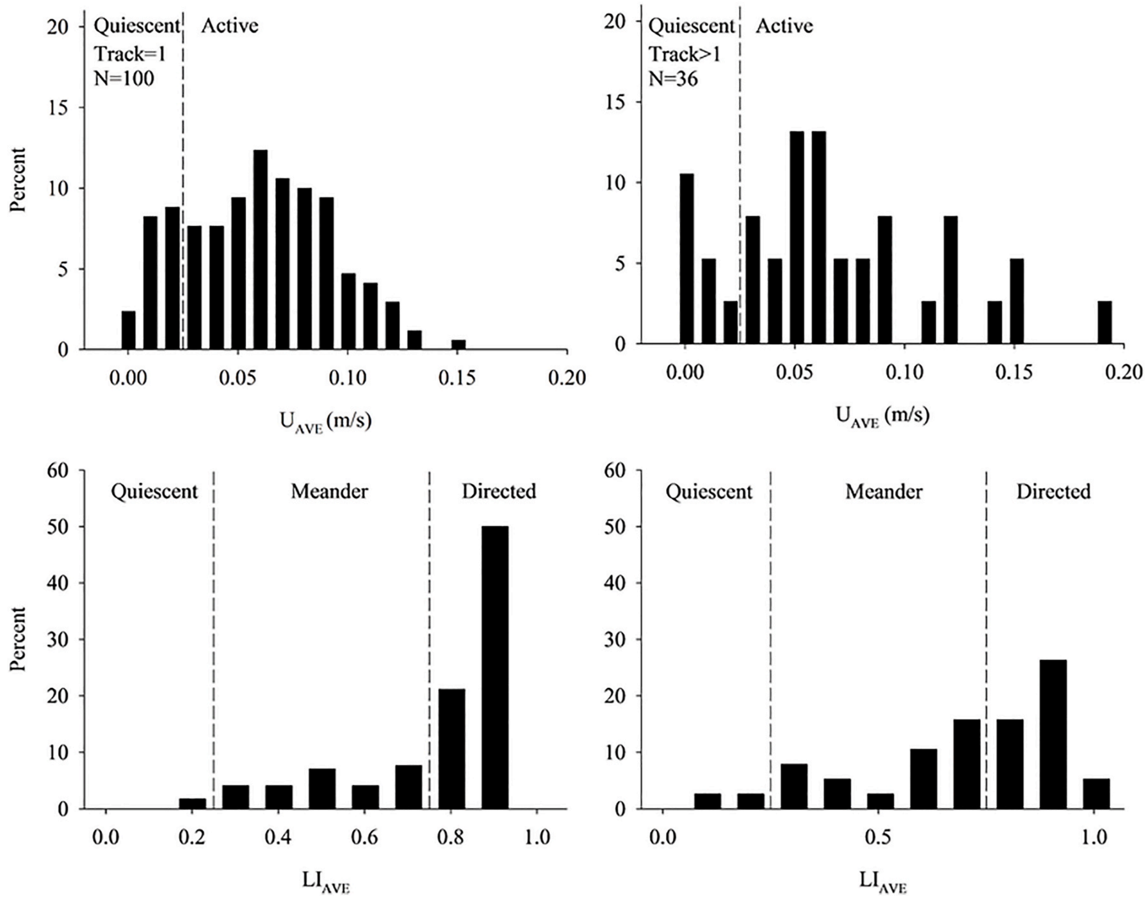

Fig. 7. Results of Before-After Control-Impact (BACI) statistical determinations for velocity (U_{AVE}; upper) and linearity (LI; lower). Error bars are standard error. The results do not support a sediment impact effect.

Table 6
Percentages of movement metrics by critical values for average velocity (U_{AVE}) and linearity (LI) for initial and subsequent tracks. Mid, mid-range.

Track	N	U_{AVE} (%)			LI (%)		
		<0.02	Mid	>0.10	<0.25	Mid	>0.75
1	170	10.6	75.8	13.6	1.7	19.5	78.8
>1	33	16.2	62.2	21.6	5.5	27.8	66.7

Our acoustic positional telemetry project was designed to investigate the fate of Dungeness crabs immediately following the lateral surge impact events. Individual crab tracks were evaluated for deposition effects. First, potential mortality or injury and tag loss were assessed by comparing the movements of tagged crabs to reference and loose tags. These data showed that few crabs from any release were quiescent during the observation period, and based on critical thresholds of select metrics, only 7 % were flagged as impacted by the experiment. However, crabs flagged as potentially injured occurred about equally at both control and impact treatments. Thus, there was minimal apparent behavioral stress due to either the experimental procedure or as a

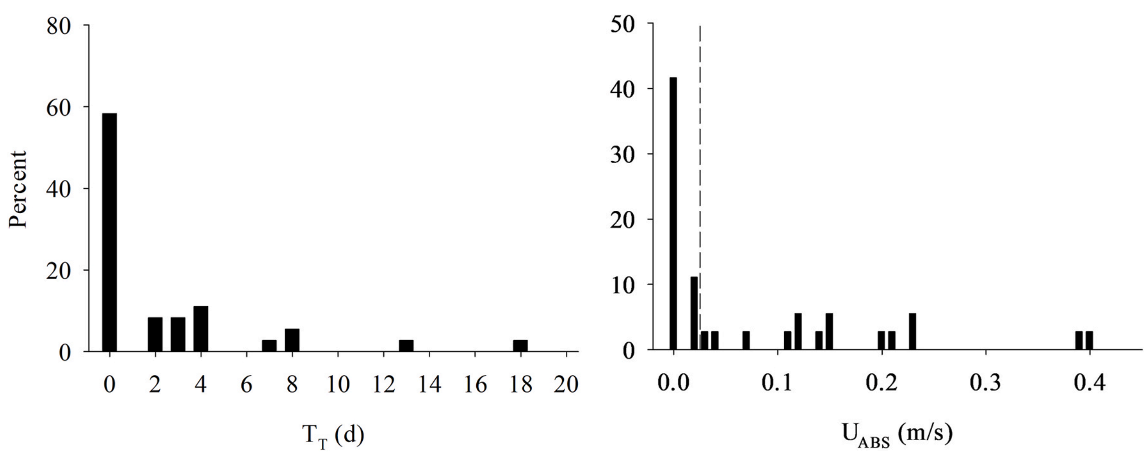

Fig. 8. Frequency of transit time (T_T) and transit velocity (U_{ABS}) for movement between small arrays in 2014 and 2015. N = 33.

treatment effect of sediment deposition.

When planning the experiments, we initially expected that newly released crabs would exhibit quiescent or meandering behaviors and remain for longer periods within the detection radius of receivers, thus providing a longer response time for sediment deposition trials. Contrary to this expectation, crabs were active in both control and impact treatments and moved rapidly from both test areas. This prompted us to increase the receiver reception area in 2016 and 2017, which was intended to increase the observation area and period. Nevertheless, the majority of crabs left even the larger arrays (2.28 km^2) rapidly (most within a few hours). Thus, no difference in residency could be ascribed to any one treatment effect. An even larger array size would allow longer behavioral observations and is recommended for future studies.

Crabs moved steadily from the point of release and maintained linear tracks both in control treatments and before and after impact. Neither BACI test for velocity or linearity resulted in a significant interaction term. While crabs impacted by sediment deposition tended to move faster and in a more linear path than controls (contrary to expectations), the differences in mean velocity (~0.02 m/s) and linearity (<0.006) were slight. Considering the wide ranges of velocity and linearity observed, the biological significance of these slight differences appear negligible. However, smaller crabs, newly molted individuals, and gravid females likely have increased vulnerabilities to deposition events, and additional studies on these life stages are warranted. To partially address this, the permitted period for deposition was designed to avoid these vulnerable periods of crab growth and reproductive cycles. We thus conclude there was minimal effect of thin-layer sediment deposition on adult crabs.

Characterization of movements for Dungeness crabs ranged from quiescence, to non-directional, low-velocity meanderings, to rapid and directed transits. Crabs exhibited all three behaviors but were usually active or meandering (>89 % of movements). The fastest movements observed were probably related to sculling (beating of legs and movement into the water column), possibly within tidal currents. Sculling was observed as an escape response to sediment deposition events (Roegner et al., 2021), and the enhanced velocities in impact treatments can plausibly be explained by crabs moving with the lateral surge. Note again the lateral surge was a relatively brief, albeit intense, event. That only 10–16 % of initial and subsequent tracks were considered quiescent ($U_{AVE} < 0.02$ m/s; LI < 0.25) is evidence of a minimal impact effect on crabs. Quiescence can include burial, sheltering, or small-scale foraging. Shallow burial is a normal crab behavior frequently observed in video surveys at deeper sites, but for reasons unknown, was less often seen at the nearshore South Jetty site (Fields et al., 2019). This behavior was related to digestion in laboratory studies (Curtis and McGaw, 2008), with an interesting field anecdote provided by Bernatis et al. (2007), who found fed tagged crabs were quiescent for up to 24 h post-release, while unfed crabs were motile and moved up to 1.3 km within 6 h of release (U = 0.60 m/s). Quiescence in embayments is also associated with brooding female crab aggregations (Stone and O'Clair 2001; 2002). Female crabs in the present study period (autumn) were likely fertilized but had not extruded eggs at the time of tagging.

While tag transmission can potentially be disrupted by burial, the attached tags protruded above the crab carapace and would be at or above the sediment surface of a buried crab, thus reducing likelihood of transmission interference. Additionally, detection statistics from loose tags indicated weeks-long detection time-series interspaced by few gaps, suggesting that any buried crabs would likely have been detected. The high transmission rate of tags also increased the likelihood of detection. No tagged crab movement patterns directly overlapped with our diagnostic plots, suggesting few instances of tag loss during the observation period. Additionally, one cannot discount high activity as an artifact of the tagging procedure. However, the ranges of velocity and linearity measurements from secondary and later tracks, while more variable, were of similar magnitude and deviated inconsistently with the patterns of initial tracks (some values were higher and some lower). Low sample size of secondary tracks reduced confidence in these comparisons, but both impact and control crabs were handled with identical methods, and no systematic bias in procedures between treatments due to the BACI design is obvious. These results support the conclusion of a minimal impact effect on crabs.

Based on detection data (not positions), the 27 crabs that moved between small arrays had a wider range of movement metrics and higher mean velocities than those moving within arrays. These movement estimates are rendered less precise by the unknown detection radii, and there is no way of determining the degree of activity when out of reception range. However, over 60 percent of crabs made rapid transits and, it can be inferred, had high linearity. The remainder were out of detection range for up to 18 d and had corresponding lower transit velocities.

Our study is the first to use receiver arrays and positional telemetry to measure fine-scale movements of Dungeness crab in an open ocean setting. Meter-scale positioning accuracy was generally achieved within arrays, and extrapolated travel distances at the average velocity of 0.06 m/s and linearity of >0.80 yield travel rates of 0.21 km/h or 5.18 km/d. These rates are generally supported by previous movement studies of Dungeness crab from continental shelf habitats that relied on passive fishery-dependent mark-recapture techniques using Floy or similar tags (Waldron, 1958; Gotshal, 1978; Diamond and Hankin, 1985; Hildenbrand et al., 2011). Note these studies included multi-year recoveries, yet most found generally localized movements (10s of km) over seasonal time frames.

Other recent studies have employed passive or active directional acoustic telemetry to detect Dungeness crab in relatively small coastal estuaries and embayments of the Pacific Northwest or within the Salish Sea. Compared to most of these studies, crabs at coastal sites appeared more mobile than those within estuaries or fjords. Smith and Jamieson (1991) tracked 10 adult crabs for up to 86 d in Tofino Bay, British Columbia, with approximate dispersion rates of 0.29 km/d for males and 0.42 km/d for females. These values are below the rates we observed. Stone and O'Clair (2001; 2002) studied seasonal habitat use by adult crabs (10 male and 16 female) in southeast Alaska, and found home ranges of only 0.65–1.34 km^2 for females and 1.14–10.5 km^2 for males. These smaller home ranges are within the detection radius of the large array in the present study, which crabs readily exited. Stone and O'Clair (200) found some male crabs moved up to 7.2 km from the mouth of the bay during winter, a distance crabs in the present study could achieve within a few days. Note that while we found no meaningful differences in velocity between male and female crabs (SI03), others have reported on behavioral differences between sexes over the longer measurement periods, which may reflect reproductive activities (Waldron, 1958; Gotshal, 1978; Diamond and Hankin, 1985; Stone and O'Clair, 2001; 2002).

In deeper waters of Hood Canal, Washington, Froehlich et al. (2013) used a combination of active and passive telemetry and pressure-recording transmitters to study Dungeness crab movements in relation to low dissolved oxygen concentration. Over a 69-d period, crabs generally remained within 5 km of their release site, but mean cumulative movement was 11.0 ± 25.6 km (n = 40) indicating activity with a localized area. Burns et al. (2020) studied movement and retention in open and fishery exclusion zones in the Frasier River delta (Salish Sea) using mobile telemetry and fishery-dependent Floy tags. Of 60 crabs tagged, 14 were tracked over a 61-d period from August to October (n = 194 observations; 3.3 detections per crab). Crabs readily moved between zones, with mean rates of 0.10 km/d inside vs. 0.26 km/d outside the closure area. These net movement rates were lower than those measured from positional data in the present study.

It is of interest to speculate on the energy requirements of crab movements as well as the motivation for high crab activity. Since fed crabs may be more quiescent than hungry ones (Bernatis et al., 2007), the high activity observed in our study supports a general hypothesis that crabs on these open, sandy substrates may be food-limited, and their observed movements are related to foraging. Henkel and Roegner (2020) found residence times were higher for tagged crabs released at rocky vs. sandy nearshore habitats, and hypothesized that food or shelter benefits at the more complex structural habitats may explain the higher residence times there. Our unpublished data with more dispersed receiver deployments also demonstrates tagged crabs routinely move more than 5 km/d over these open sand (low structure) areas (Roegner, unpublished). However, movement is not without energetic cost. In laboratory studies, De Wachter and McMahon (1996) examined ventilation of Dungeness crabs at rest and at an average walking speed (U = 0.058 m/s) and found a doubling of ventilation rate during movement and a 60-min period for recovery to quiescent levels. In Willapa Bay, Holsman et al. (2006) found Dungeness crabs made intertidal sojourns to fulfill energetic demands, with round-trip movements up to 1.2 km/night. These feeding excursions were facilitated by moving rapidly with tidal currents. Similarly, crabs at ocean sites may also move with tidal currents, which are tidal-rotary and average 0.10–015 m/s (Golder Associates, 2016), double the average crab velocity of ~0.06 m/s we observed. It thus seems reasonable to postulate Dungeness crab facilitate transits with tidal currents in open ocean environments to reduce energetic expenditures. More studies of the energetic cost of movements in ocean settings is warranted, especially with future scenarios of warmer, low food, and low dissolved oxygen conditions.

In conclusion, using several experimental techniques from this study and others (Fields et al., 2019; Roegner et al., 2021), the only demonstrable effect of thin-layer deposition by hopper dredge on Dungeness crabs has been short-term displacement by the lateral surge, an energetic event lasting several minutes. Our acoustic data showed little evidence of direct harm from the surge, and post-deposition tracks and transits confirmed high activity in both control and impact groups. Velocity measurements demonstrated that crabs are capable of moving hundreds of meters per hour and can effectively escape a localized disturbance such as a sediment deposition event in a disposal area. Crabs likewise can evade adverse water quality conditions, such as low dissolved oxygen events, by migrating to more oxygenated shoreward regions (Bertanis et al., 2007; Roegner et al., 2011). More broadly, the ability for rapid transits would aid foraging capacity, especially in areas like the dispersive South Jetty site, where prey resources appear patchy and sparse.

As sea levels rise, beneficial uses for sediment become increasingly important to the mitigation of coastal erosion (EPA, 2007; Stevens et al., 2024), but minimizing adverse effects on biota will remain a critical concern, especially for species such as the Dungeness crab with important ecological and economic roles. Our research examined the thin-layer deposition method at a sandy nearshore deposition site. Based on this study and previous work, we conclude that the overall effects from this deposition method appear negligible for most species in general (Fields et al., 2019) and for the Dungeness crab in particular (Roegner et al., 2021).

Many epifaunal organisms in the sandy substrate of the coastal ocean may be resistant to the shallow sedimentation and lateral surge effects of thin-layer deposition, but future studies are needed to confirm potential impacts at other sedimentary systems. Among these critical considerations are sediment grain size and toxicity and organism life-history attributes such as infaunal vs. epifaunal habitat, size, reproductive status, and migration timing (Bolam et al., 2011; Donázar-Aramendía et al., 2020). The thin-layer deposition technique tested here appears to be appropriate for the species and environment we investigated.

Acoustic positional telemetry can be used to infer behaviors of organisms and presents a tool well suited to experiment on the in situ effects of stressors such as sediment deposition. Acoustic measurements are especially useful where turbidity or substrate composition limit visual sampling techniques. We developed a simple set of metrics that are applicable to a range of sites and disturbance regimes, although additional metrics may be needed for other organisms and sites. One consideration should be the detection area of the receiver array relative to the mobility of the organisms studied (Ellis et al., 2019). Larger arrays are encouraged. Another is the time frame of deployments; the present study was logistically limited to a relatively short seasonal window of deposition events compared to crab migration patterns derived from fishery-dependent studies (e.g. Waldron, 1958). Establishment of large, maintained arrays could bridge the gap between acoustic and fishery-dependent studies. This may help elucidate the effects of natural and anthropogenic stressors on multi-species assemblages over time frames relevant to the life-history stages of various motile marine fauna.

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. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marenvres.2025.107427.

Data availability

Data will be made available on request.

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