2020

Dungarvan Waterbird Monitoring 2019/20

REPORT TO THE MARINE INSTITUTE ITT19-046

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Executive summary

1. Previous work at Dungarvan Harbour SPA indicated that inter-tidal oyster cultivation is potentially having significant negative displacement impacts on four of the Special Conservation Interest species occurring at the site. The primary evidence for this appears to be the exclusion of considerable numbers of birds from the tideline area when it occurs within the trestle structures but which occur on the upper shore at higher tidal states. The suggested primary impact has been the loss of feeding time due to the presence of trestles.

2. In order to mitigate the potential negative impacts of trestles, a 400m wide buffer 'bird corridor' was created amongst the trestle structures between summer 2016 and the end of 2017. The primary objective of this study is to investigate the efficacy of the bird corridor to facilitate bird movement and site use throughout the full tidal cycle.

3. We investigated the usage of areas of Dungarvan Harbour oyster culture structures by wintering waterbirds in winter 2019/20 using a combination of through-the-tide counts, specific monitoring of the bird corridor, low- and high-water counts and GPS telemetry of one of the target species - Grey Plover. In addition to analysing our own data from 2019/20 we present (a) preliminary analysis of long-term trends (2009-2019) of selected waterbirds at the site, (b) use a time series of data from 2014/15 collected via this and similar preceding contracts to investigate selection/avoidance of the trestle structures and the corridor created within them.

4. Preliminary analysis of I-WeBS trends at the site showed that the local population of Grey Plover has seen a significant marginal increase over 10 years at the site whilst Dunlin, Knot and Bar-tailed Godwit have remained stable. Separate analysis of these patterns in local, regional and national contexts is underway to try to disentangle the role of site-based (intrinsic) and broader-scale (extrinsic factors) in trends of selected species, including the priority (target) species described here.

5. Analysis of site-specific data collected through this and previous contracts showed that waterbirds numbers were lowest in Whitehouse Bank and Inner Harbour (Upper), lowest at low tide and total waterbird numbers significantly higher in 2016/17 and 2019/20. Analysis of species-specific patterns of use showed that Grey Plover numbers were significantly higher in the three years (2016/17 – 2018/19) and numbers significantly lower during low tide phases. Dunlin numbers were (all statistically significant) lower in the bird corridor, higher in Inner Harbour (Main), lowest at LT and they were most abundant in 2016/17 and 2017/18 & 2018/19.

6. Using Whitehouse Bank data only over the period 2014/15 – 2019/20, similar densities of Grey Plover, Knot and Dunlin occurred in and outwith the Bird Corridor. Only Bar-tailed Godwit densities were significantly higher in the corridor than outside it. However, this result is heavily influenced by just several high counts (short-term infrequent use by hundreds over multiple counts). In 2019/20 Bar-tailed Godwit was the only one of the four target species recorded in the Bird Corridor and that comprised one flock present within a 3-hour time block. Neither Grey Plover or Dunlin were recorded in the Bird Corridor.

7. To increase sampling effort around all tidal and day/night stages, we tracked the movements of eight Grey Plovers using high resolution GPS in January-February of 2020, acquiring GPS positions continuously at 40-minute intervals. These tracked birds spent ~ 41% of their time outside the main site (above the Dungarvan HWM or outwith the SPA entirely). They primarily utilised the Inner Harbour area but 25% of 'in site' positions were on the upper sections of Whitehouse Bank on ebb of flood tide phases. Resource selection analyses indicated that across all states of the tide, Grey Plovers actively avoided trestle areas and the corridor in-between by day and night; just 0.3% of positions (from ~ 4,900 observations) being recorded on trestles or in the corridor.

8. There was no significant effect of disturbance from vehicles/personnel associated with aquaculture and bird numbers in the corridor and generally over Whitehouse Bank. While testing for relationships between invertebrate food resource abundance and bird abundance was beyond the scope of this study we did establish a significant relationship between mean particle size and the proportion of 'fines' which probably, in part, explains the distribution of birds within the site – sand-dominated sediment on Whitehouse Bank holding fewer birds than the Inner Harbour (muddier) sediments.

9. We conclude that there is little evidence that the Bird Corridor is effective as a mitigation measure since levels of utilisation are so low. Dunlin and Grey Plover were almost wholly absent from the zone during our observations and those of previous years. In the absence of a proper experimental approach, it is not possible to determine whether the presence and/or spatial extent and arrangement of trestle structures is having a negative impact on the waterbird populations at the site. Preliminary analyses indicate that at least since 2009 there has been no change in numbers of Dunlin at the site and a marginally, though significant, increase in numbers of Grey Plover. We suggest a detailed Individuals-Based Model approach to assess this and/or a wider assessment of trends at Dungarvan compared to larger spatial scales will help determine impacts.

1. Introduction

1.1 KRC Ecological Ltd. were commissioned in autumn 2019 to undertake a programme of tidal cycle monitoring of waterbirds at Dungarvan Harbour, Co. Waterford. The focus of the work programme was an examination of the numbers and distribution of selected species in response to the creation of a 400m buffer zone intersecting oyster culture trestles on Whitehouse Bank. Counts were undertaken at the exposed (low tide) period twice per month from October to March inclusive, focussing on usage within the 400m buffer zone and adjacent areas of the Whitehouse Bank and Inner Dungarvan Harbour.

1.2 The work commissioned in 2019/20 follows from a series of investigations at this site including a study on the impacts of oyster trestles (Gittings & O'Donoghue 2012), the Dungarvan Harbour SPA Appropriate Assessment (AA: Gittings & O'Donoghue 2014) and consecutive years of tidal cycle monitoring 2014/15 – 2018/19 (Gittings & O'Donoghue 2015, 2018a 2018b).

1.3 The AA (Gittings & O'Donoghue 2014) concluded that inter-tidal oyster cultivation was having a potentially significant displacement impact on four species of Special Conservation Interest (SCI) at Dungarvan Hbr SPA, namely Grey Plover *Pluvialis squatarola*, Red Knot *Calidris canutus*, Dunlin *Calidris alpina* and Bar-tailed Godwit *Limosa lapponica*. These species were considered the focal species for this study. The negative impact appeared to be the displacement of most if not all Grey Plover, Dunlin and Red Knot from the oyster trestle areas during the low tide period when the tideline was within the footprint of the trestles. The evidence for this was the fact that large flocks of some of these focal species occurred on the upper shore of Whitehouse Bank both before and after the tideline reached the trestles.

1.4 Monitoring in the period 2014/15 found evidence of a marked decrease in the usage of Whitehouse Bank by Grey Plover and the authors suggested that this may have been linked to changes in configuration of trestles on Whitehouse Bank resulting in the elimination of trestle-free corridors – effectively fragmentation of the exposed mudflat in a manner which may have resulted in reduced usage of the zone.
In response there was a reorganisation of the footprint of existing, new and renewed aquaculture licences in 2016 and, between then and October 2017, a trestle-free 400m wide corridor was created in a section of Whitehouse Bank where Grey Plover were recorded in the 2011 study (Gittings & O'Donoghue 2012).

1.5 In this study we replicated the methods of Gittings *et al*. where they focussed on monitoring waterbird numbers through the tidal cycle in (a) Whitehouse Bank and the Inner (Main) Harbour, and (b) in and adjacent to the 400m 'corridor'. The priority species as specified were Dunlin and Grey Plover but Bar-tailed Godwit and Knot were also recorded as were all additional waterbirds. The absence of a proper experimental design to the study (e.g. before and after control/intervention study) severely limits our ability to be conclusive about the potential impacts of both the presence of the oyster trestles, the efficacy of the corridor and the impacts of both the structures themselves and disturbance associated with their operation.

1.6 In addition to replicating previous studies we undertook additional work – (a) some limited sediment sampling (to test for possible relationships to bird distribution within the site, (b) a GPS tracking study to examine movement and distributional patterns within the site of one of the high priority 'target' species, particularly in relation to selection/avoidance of the corridor and trestle footprint and (c) a rigorous analysis of the long-term data set using data gathered since 2014/15. A further study which examines long-term trends in selected waterbird species at Dungarvan compared to regional and national scales in currently underway and will be reported separately.

2. Methods

2.1 Monitoring the numbers and distribution of waterbirds

The definition of the study area and its subdivisions intentionally followed that adopted in the previous monitoring studies (e.g. Gittings & O'Donoghue 2015) and I-WeBS monitoring count units. The primary sub-divisions of the site are (a) Inner Dungarvan Harbour, (b) Outer Sandflats and (c) Outer Dungarvan Bay which are in turn further subdivided into smaller count sectors (Figure 1).

Low-tide and high-water counts were undertaken across the entire site excluding Outer Dungarvan Bay whilst the focus of the through the tide counts were on the outer sandflats where the oyster trestles occur at Whitehouse Bank and the main Inner Harbour. The Bird Corridor monitoring work focussed on the 400m corridor within and adjacent to the trestle blocks on the SE part of Whitehouse Bank and the extent (in spring 2020) is shown in Figure 2.

Figure 1. Location of main count sectors, showing Whitehouse Bank (green), Inner Harbour Main (brown), Inner Harbour Upper (purple) and Ballyrandle Sandflats (pink). Low and high tide counts were undertaken across all areas; through the tide counts restricted to Inner (East) Harbour Main and Whitehouse Bank. Oyster culture trestles occur in sectors OY1-OY4 inclusive and the Bird Corridor lies in sector OY2.

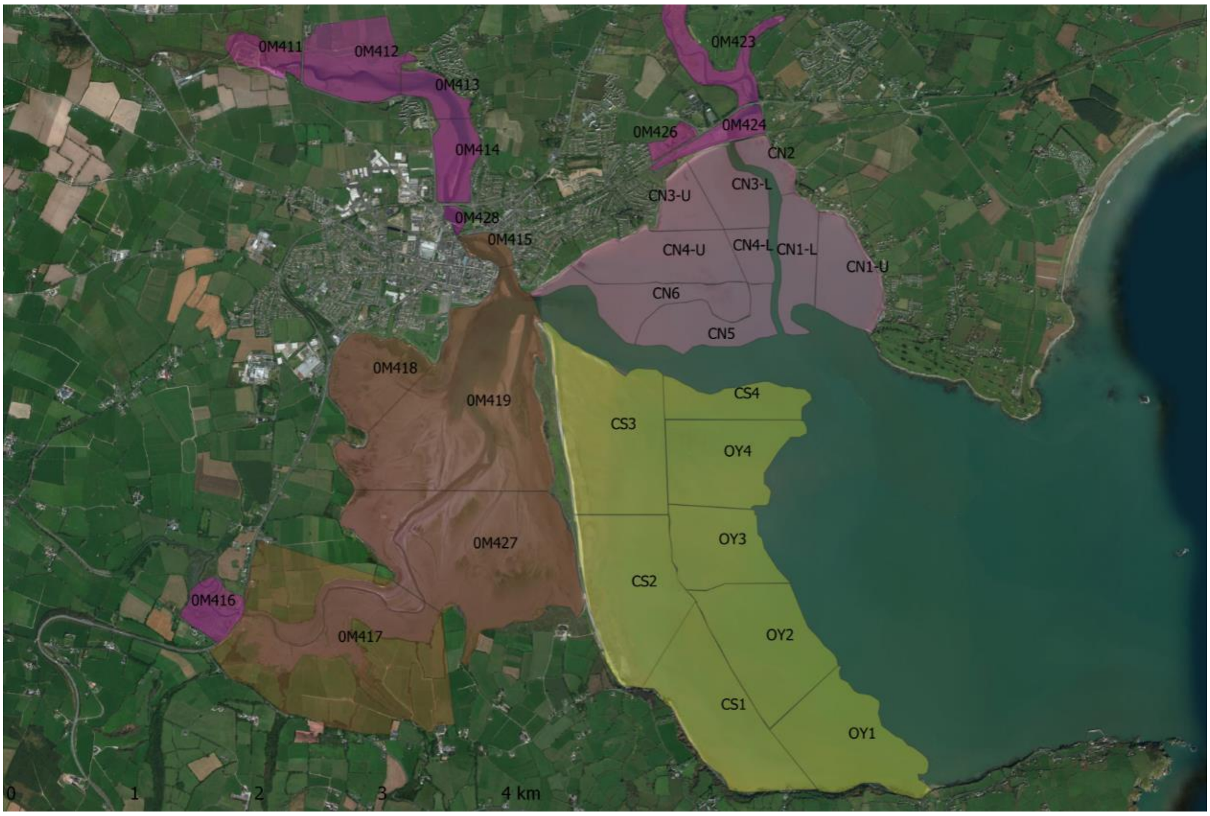
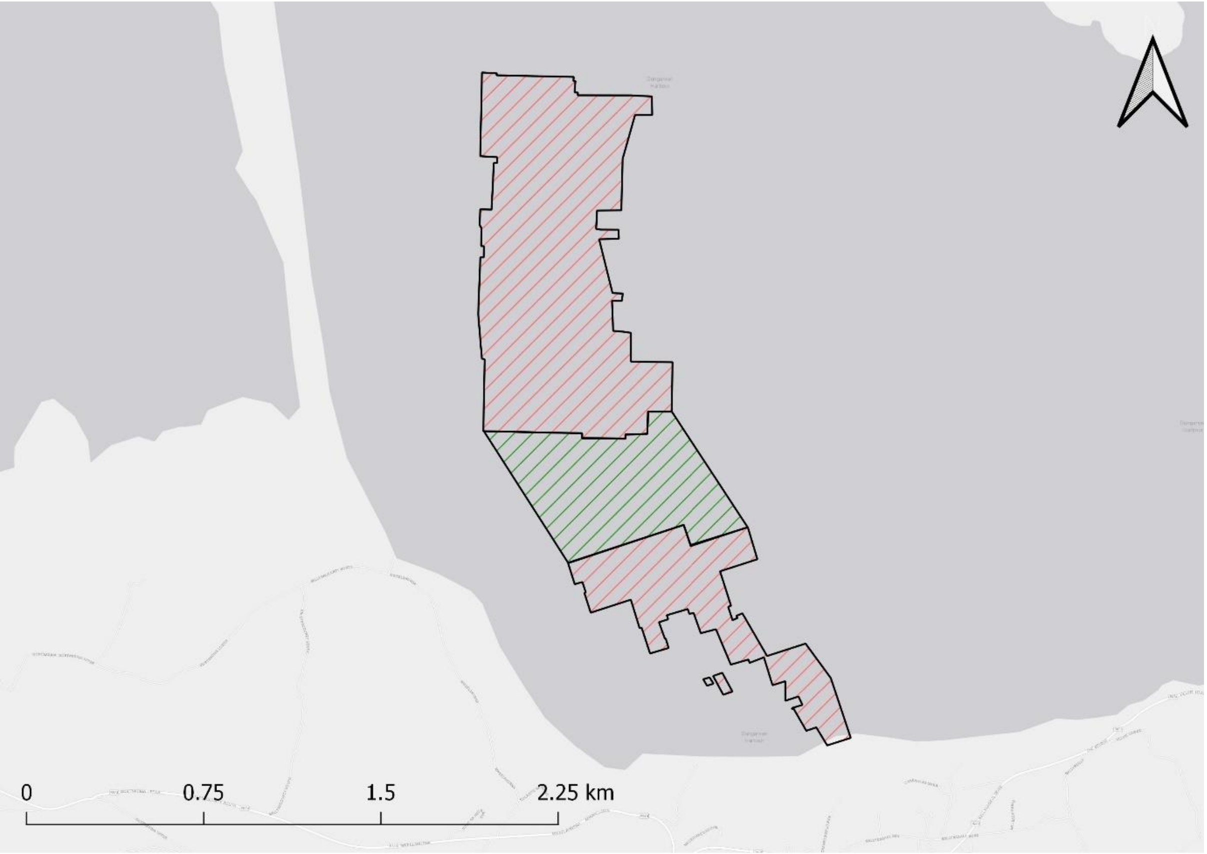


Figure 2. Boundaries of trestles (hatched red) and the 400m wide (39.8ha area; hatched green) Bird Corridor, based on survey undertaken by Marine Engineering Division (Dept Agr & Marine) in September 2020.



2.1a Through the tide counts

As with previous surveys (e.g. Gittings & O'Donoghue 2018a), and to ensure comparability of datasets across years, the through the tide surveys comprised counts at 30-minute intervals on both the falling (ebb) tidal phase and rising (flood) tidal phase on the Whitehouse Bank and the eastern side of the main Inner Harbour (adjacent to the Cunnigar). The primary objective of these counts was to achieve complete coverage of the Whitehouse Bank and the degree of movement of birds between the Whitehouse Bank and the eastern side of the Inner Harbour.

The count periods at 30-minute intervals are shown in Tables 1 & 2. Through the tide (TTT) counts were carried out on 10 dates between October 2019 and March 2020 (Table 3) , the last count being limited to the corridor area only at the end of March and inability of many of the project team to travel due to Covid-19 restrictions (Table 3). Counts were undertaken from shoreline vantage points aside from the low tide counts at Whitehouse Bank. Here the trestle blocks obscured birds feeding between trestles from shoreline vantage points and these counts were undertaken by counting from approximately 100m on the nearshore side of the trestles where this and previous surveys showed that birds were habituated to the presence of pedestrians and machines such that no significant disturbance was caused.

Table 1. Tidal count periods used for TTT surveys

Tidal stage	Count period	Start time	Finish time
Ebb (falling) tide	EBB1	- 04:00	- 03:30
	EBB2	- 03:30	- 03:00
	EBB3	- 03:00	- 02:30
	EBB4	-02:30	- 02:00
Low water	LT	- 01:30	+ 01:30
Flood (rising) tide	FLOOD1	+ 02:00	+ 02:30
	FLOOD2	+ 02:30	+ 03:00
	FLOOD3	+ 03:00	+ 03:30
	FLOOD4	+ 03:30	+ 04:00

Table 2. Count periods for BC monitoring

Tidal stage	Count period	Start time	Finish time
Ebb (falling) tide	EBB1	- 04:00	- 03:30
	EBB2	- 03:30	- 03:00
	EBB3	- 03:00	- 02:30
	EBB4	- 02:30	- 02:00
	EBB5	- 02:00	- 01:30
Low water	LT1	- 01:30	- 01:00
	LT2	- 01:00	- 00:30
	LT3	- 00:30	00:00
	LT4	00:00	+ 00:30
	LT5	+ 00:30	+ 01:00
	LT6	+ 01:00	+ 01:30
Flood (rising) tide	FLOOD0	+ 01:30	+ 02:00
	FLOOD1	+ 02:00	+ 02:30
	FLOOD2	+ 02:30	+ 03:00
	FLOOD3	+ 03:00	+ 03:30
	FLOOD4	+ 03:30	+ 04:00

Table 3. Timings of ebb, low and flood tide counts as undertaken for TTT and BC counts at Dungarvan October 2019-March 2020. Only BC counts were undertaken on 25/03/2020 due to Covid-19 restrictions on personnel travel. Ebb counts were not undertaken on two dates due to inclement weather (poor visibility and/or inability to travel due to snow/frost).

Date	Low tide		Count timings		
	Time	Height	Ebb	Low Tide	Flood
13/10/2019	12:10	0.6m	09:30-11:00	11:00-14:00	14:15-16:15
28/10/2019	11:26	0.1m	08:45-10:45	10:45-14:45	13:15-15:30
16/11/2019	13:40	0.6m	09:50-11:05	10:50-14:20	14:20-16:50
29/11/2019	13:08	0.5m	09:00-11:00	11:00-14:00	14:00-16:50
16/12/2019	14:18	0.6m	-	10:50-14:00	14:00-16:50
27/01/2020	13:10	0.6m	08:30-10:10	11:15-13:45	14:15-16:15
11/02/2020	13:16	0.1m	10:30-12:00	12:00-15:00	15:00-17:00
23/02/2020	11:39	0.7m	-	09:30-12:00	13:00-15:30
09/03/2020	11:25	0.3m	08:00-09:30	09:30-12:30	12:30-15:30
25/03/2020	12:20	0.5m	09:30-11:00	11:00-14:00	14:00-16:30

2.1b Bird Corridor monitoring

The primary purpose of this element of the study was to continuously monitor the 400m wide Bird Corridor (hereafter BC) throughout the period of tidal exposure. During these counts the numbers and distribution of waterbirds in adjacent areas of Whitehouse Bank was also recorded to better understand the way by which birds moved the entire area including the BC.

Counts of the bird corridor were carried out from either the Cunnigar car park or a shoreline vantage point to the SE, depending on the state of the tide. On each count, as with TTT counts, all species were counted (target and non-target) and their location noted onto maps, separating their location by count sector and sub-divisions of sector OY2. The behaviour of bird was recorded as feeding (F) or roosting (R; which includes all non-feeding behaviours), and counts were categorised as being within or outside trestle blocks, as well as their position relative to the tideline (subtidal, tideline or other inter-tidal habitat).

2.1c High and low water counts

Low-water and high water (I-WeBS Core) counts were undertaken using protocols outlined in Lewis & Tierney (2014) and Crowe (2005) respectively. Low tide counts across the entire site were undertaken on TTT count days during the period 1.5 hours either side of low water when the BC was under continuous monitoring but counts at 30-minute intervals ceased on the remainder of Whitehouse Bank and Inner Harbour (Main).

2.2 Examination of factors underlying waterbird distribution patterns

2.2a Sediment sampling

Measurement of food supply and how it varied across the estuary within-season (and influenced bird distribution) was beyond the scope of the current study. However, given the well-established relationship between sediment composition and macrobenthos (e.g. Azouzi *et al*. 2002, Choi *et al*. 2014) we aimed to efficiently examine variation in sediment characteristics in (a) the main zones of Dungarvan Harbour, especially Inner Harbour Main and, (b) in particular, within and outwith trestle blocks and (c) in the bird corridor. We sampled at 200m intervals using a N-S ordnance survey-based grid system, taking 55 samples from the points located using handheld GPS and shown in Figure 3 (Ballyrandle n=15; Inner Harbour Main n=15 & Whitehouse Bank n=25).

In October 2019 we sampled surface sediments using a corer to a standard 50mm depth (area 100m), labelled and bagged samples according to sampling points. These samples were dried to constant mass by oven-drying at 105 deg C for 24 hours and the size distribution of particles were determined in two categories through hand sieving – (a) > 1 < 2mm, and (b) < 630 microns. Particles in the 1-2 mmm range were weighed and the proportion of the overall sample which were 'fines' (</= 630 microns) in the following categories were used to classify the sample: sand (< 10% fines), muddy sand (10-29% fines), sandy mud (30-80% fines) and mud (> 80% fines). Mean particle size calculations and descriptions followed the protocols of Folk (1954) and Folk & Ward (1957).

Figure 3. Sediment sampling grid with sediment sampling points shown in black (mostly sandy) or grey (mostly sand but with muddier components) where cores were taken in October 2020. The black lines show the approximate location of the (trestle-free) bird corridor. The list of sampled points is shown in Appendix 1.

2.2b Measuring disturbance

On each count day the presence, type and severity/impact of potentially disturbing activities was recorded using protocols defined by Lewis & Tierney (2014). As in the previous studies (e.g. Gittings & O'Donoghue 2018a), we monitored the number of tractors using each sector of OY2 and OY1 in each of the 30-minute count periods, including the number within 250m of the edges of the BC. Other activity which may have impacted on counts was recorded – that included the dog walkers, horse-riders and the severity of the impact (none, moderate, severe), and its duration in each 30-minute black was recorded. This enabled us to identify counts whose quality was low due to disturbance.

2.3 GPS tracking target species

In order to further inform the utilisation of Dungarvan Harbour near continuously throughout the tidal cycle (including at night-time when observations were not possible) we used low-power high resolution GPS tracking devices to selected species. Of the two 2019/20 focal species, only Grey Plover had high enough body masses to be able to carry telemetry devices without considerably increased investment.

Birds were caught under licence in January 2020 using two approaches - a single bird was dazzled and GPS tagged on the Whitehouse Bank at 00:30 on the night of the 17th January and 14 were caught at a high-tide roost using a cannon-net at ca. 18:00 on 20th January, seven of which were fitted with GPS tags. The tags were type nano-Fix-GEO+RF GPS (Pathtrack Ltd.) weighing mean 2.8% (range 2.6 – 3.0) body weight (Table 4). Tags were fitted using approved temporary back glue-mounted methods using gauze and Loctite Superglue. Data downloads to fixed base stations were programmed for 2-hour intervals from deployment. Tags were programmed to acquire GPS positions continuously at 40-minute intervals thus providing up to 36 positions in each 24-hour period.

Table 4. Identity and biometrics of individually tagged Grey Plover at Dungarvan in January 2020.

Bird ID	Tag ID	Date fitted	Method	Wing (mm)	Mass (g)	Tag as % mass
AA	40911	17/1/2020 00:30	Dazzle	197	200	3.0
AC	40876	20/1/2020 19:00	Cannon-net	198	206	2.9
AN	40796	20/1/2020 19:00	Cannon-net	199	203	2.9
AP	40753	20/1/2020 19:00	Cannon-net	198	211	2.8
AU	40621	20/1/2020 19:00	Cannon-net	197	221	2.7
CA	40642	20/1/2020 19:00	Cannon-net	199	226	2.6
CC	40899	20/1/2020 19:00	Cannon-net	204	218	2.7
CH	40903	20/1/2020 19:00	Cannon-net	199	208	2.9

2.4 Statistical analyses

2.4a Long-term trends of selected species at Dungarvan Harbour

Preliminary analysis of I-WeBS data showed a pronounced step-change in overall counts around 2009, the period before and after having noticeably different total bird numbers. This was due to differential site coverage (the extent of coverage reduced slightly from 2009 onwards) and, for the purposes of the analysis presented here, we consider the data for the period 2009/10 to 2019/20 only.

Our preliminary analysis of I-WeBS bird count data was carried out using Generalised Linear Mixed Effect Models (GzLMMs) with a negative binomial error structure. The dependent variable was bird count and the independent variable was year. A more rigorous analysis (being done separately) will interpolate missing counts based on site, year and month factors by species for this site and across other sites in Ireland. This and all subsequent models reported here were fitted with the R (v3.6.3) language and environment (R Core Team 2012), using the package 'lme4' with the "bobyqa" optimiser (Bates *et al.* 2013). All model predicted plots were created using the "effects" package.

2.4b Analysis of TTT count data 2014/15 – 2019/20

Bird count data were analysed using Generalised Linear Mixed Effect Models (GzLMMs) with a Poisson error structure. The dependant variable was bird count. Table 5 shows the model factor levels. Species was fitted as a random factor. As the data were over-dispersed we also fitted an observational level random effect. Individual species models were analysed using the same model structure but without species as a random effect. We tested both negative binomial and poisson models; in most cases negative binomial models failed to converge and the poisson models were a better fit. We were unable to fit an offset term (to convert counts to densities) in many models due to model complexity but did so where possible.

Table 5. Model parameters for bird count analysis

Type	Name	Levels
Response	Bird Counts	Continuous
Fixed factor	Bird Corridor	2 levels: Bird Corridor; Not in Bird Corridor
Fixed factor	Zone	5 levels: Ballyrandle Sandflats, Inner Harbour, Inner Harbour (Main), Inner Harbour (Upper), Whitehouse Bank
	Tide	3 levels: Ebb tide, Flood tide or Low-tide
	Season	5 levels: five winters - 2014/15, 2016/17, 2017/18, 2018/19, 2019/20

2.4c Analysis of BCM count data 2019/20

Bird density models were fitted using General Linear Mixed Effect models with a gaussian error structure, using only the bird corridor monitoring data. The dependant variable was bird count. Fixed factors included in the model were Bird Corridor (2 levels; BC, NB), Sector (8 levels), Tide (3 levels; EBB, FLOOD, LT) & Season (4 levels; 2016/17, 2017/18, 2018/19, 2019/20).

2.4d Analysis of bird distribution in relation to co-variates (sediment & disturbance)

Sediment analyses were performed using Generalised Linear Mixed Effect Models (GzLMMs) with a Poisson error structure. Fixed effects (in separate models) were either sediment percentage 'fines' (6 levels) or Sediment Mean Particle Size (6 levels). Models also include an observational level random effect.

Disturbance models were performed using Generalised Linear Mixed Effect Models (GzLMMs) with a Poisson error structure. The fixed factor was "Tractor Time" fitted as a continuous covariate. Models also include an observational level random effect.

2.4e Analysis of movements of GPS tagged individuals

Individuals were recorded within the site boundaries (defined as below the HWM within all parts of Dungarvan Harbour) for 66.5 ± 4.7 % (mean ± standard error) of tracking locations (Table 5). Herein, we undertake all habitat selection analyses on Grey Plover tracking locations inside the site boundaries, only.

To assess whether Grey Plover use or avoid the trestle and corridor areas, we used resource selection models (Manly 2002). As a measure of available habitat, we randomly sampled 5 pseudo-absences per tracking location within the site boundaries. Habitat use (binary response variable; 1 = used, 0 = available) was modelled in response to a three-way interaction between (1) habitat type (categorical variable: trestles / corridor / other), (2) tidal height (numeric variable), and (3) day or night (categorical variable; defined using dawn and dusk times using the R package *suncalc* (Thieurmel & Elmarhraoui 2019)). We also included a two-way interaction between habitat type and bird ID, to account for potential differences in habitat selection between individuals. We included bird ID as a fixed effect instead of a random effect because of issues with singularity and convergence.

Models were run using the glm function of the R package lme4, with a binomial error structure and logit link (Bates *et al.* 2015). Used and available points were given weightings of 5 and 1 respectively, thereby weights were proportionally equal between all used and available locations (Barbet-Massin *et al.* 2012). We selected the most suitable random and then fixed effects structure based on corrected Akaike information criterion (AICc) values in backward stepwise selection (Table 7). We ensured model fit by calculating the area under the receiving operator characteristic curve (AUC) (Zweig & Campbell 1993), predictive power, sensitivity and specificity (Warwick-Evans *et al.* 2016; Table 8).

Table 6. Tracking locations recorded per individual, in total and within the site boundaries

Bird ID	Tag ID	Total no. of tracking locations	No. of tracking locations inside site boundaries	% of tracking locations inside site boundaries
AU	40621	22	20	90.9
CA	40642	146	103	70.5
AP	40753	1274	724	56.8
AN	40796	220	138	62.7
AC	40876	510	390	76.5
CC	40899	945	641	67.8
CH	40903	1264	613	48.5
AA	40911	480	279	58.1

Table 7. Model selection by AIC for random and fixed effects structures

Model	Fixed effects	AICc	Difference in AICc relative to most parsimonious model
Full model	Habitat type * Tidal height * Day or night + Habitat type * Bird ID	38454.65	0
Two-way interactions, only	Habitat type * Tidal height + Habitat type * Day or night + Habitat type * Bird ID	38481.31	26.66
Without habitat type * day or night	Habitat type * Tidal height + Habitat type * Bird ID + Day or night	38505.98	51.33
Without habitat type * tidal height	Habitat type * Day or night + Habitat type * Bird ID + Tidal height	38512.29	57.64
Without habitat type * bird ID	Habitat type * Tidal height + Habitat type * Day or night + Bird ID	38557.83	103.18

Table 8. Model validation of the full model, retaining all three two-way interactions.

Correct classification (%)	Positive Predictive Power (%)	Negative Predictive Power	Sensitivity	Specificity	Area under curve
25.1	18.2	99.3	0.99	0.10	0.55

3. Results

3.1 Low and HW counts and I-WeBS data

Complete waterbird counts were undertaken on four occasions at low or high water across the entirely of Dungarvan Harbour. The results are shown in Appendix 2.

Analysis of I-WeBS core count data for Dungarvan Harbour showed a pronounced change in counts (Figure 4) ascribed to changes in site coverage. Accommodating these changes was beyond the scope of the current study so, for the purposes of investigating bird trends at Dungarvan in broad terms, we restricted our subsequent analysis to I-WeBS data from 2009/10 to 2019/20. This showed marginally statistically significant increase in numbers of Grey Plover ($p < 0.05$) and no change in numbers of all waterbirds, Dunlin, Bar-tailed Godwit or Knot over the 10-year time period (Figures 5a-5e). These results should be interpreted with some caution but are likely to be representative of the true trends over the last decade at the site.

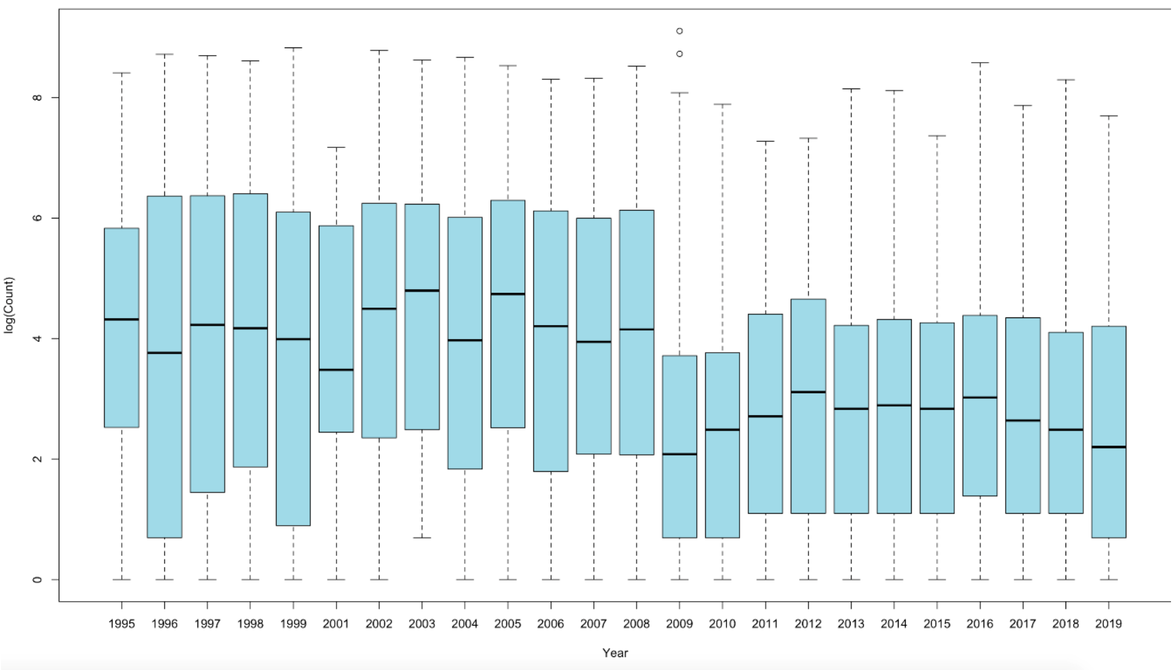


Figure 4. Plot of overall waterbird numbers (log scale) through time at Dungarvan Harbour. Data are I-WeBS Core Counts and no interpolation for missing counts has been carried out. This preliminary analysis reveals a step-change in counts after 2008/09 which indicates a change in site coverage at that point.

3.2 TTT counts

Our 'global' analysis (all species across the entire site 2014/15 – 2019/20) showed that numbers of all waterbirds combined were significantly lower in the BC than elsewhere and significantly higher ($p < 0.0001$) in Inner Harbour (Main). Numbers were generally lower at low-tide ($p < 0.0001$) and highest in 2016/17 and 2019/20 (both $p < 0.001$).

At a species level there were significant differences in abundance with numbers of Bar-tailed Godwit and Knot significantly higher (p < 0.05 in both cases) in 2019/20, whilst Grey Plover and Dunlin were more abundant in 2016/17 – 2018/19 (all $p < 0.001$). In most cases numbers were significantly lower on Whitehouse Bank at low and flood tides than at the ebb stage.

A similar analysis, but restricted to counts from Whitehouse Bank only, showed that densities outside the bird corridor were marginally higher than within with no single sector consistently being more important. Similar to the global analysis the numbers of birds overall were higher in 2016/17 and 2019/20.

3.3 Bird Corridor counts

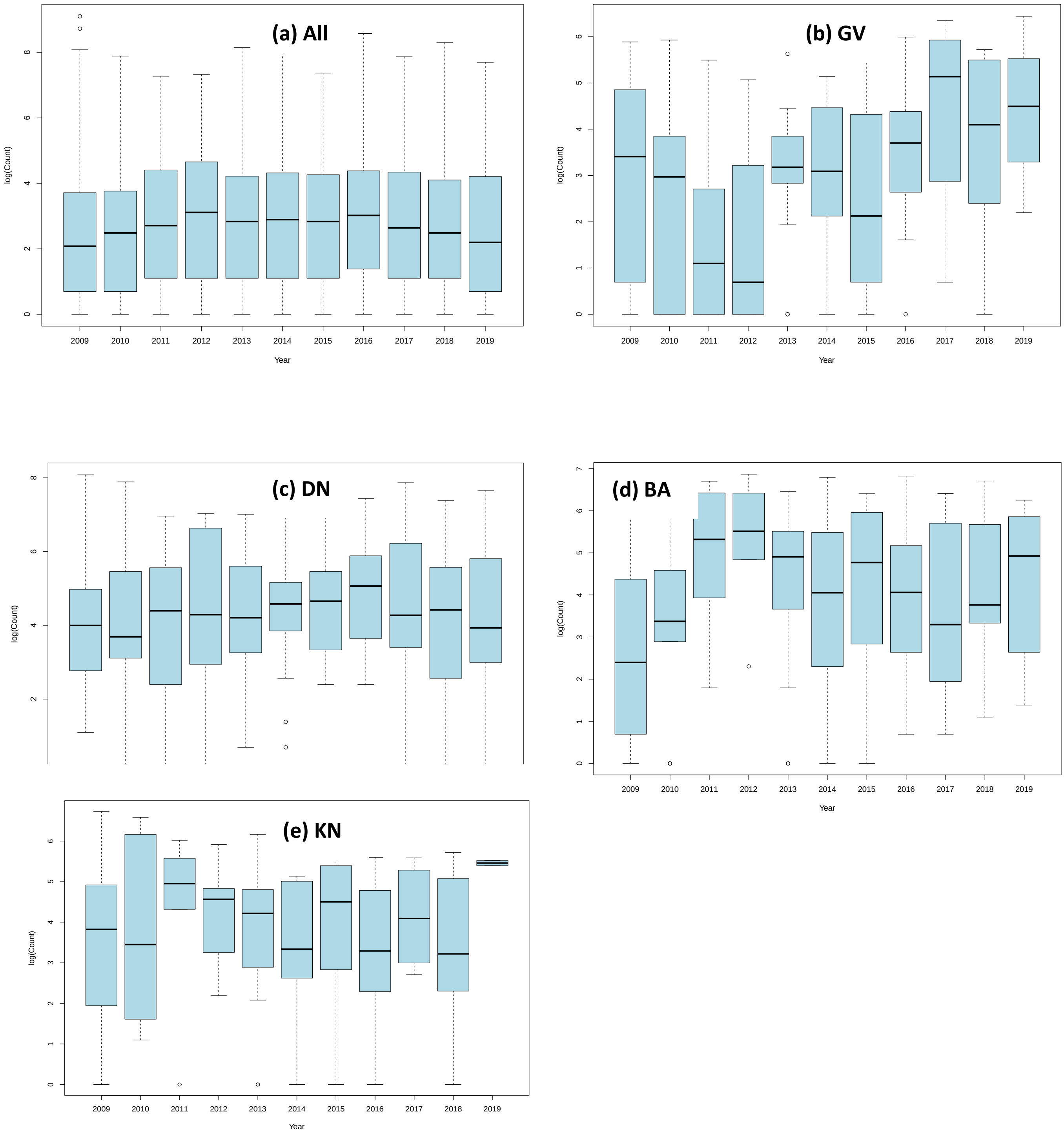
Only one of the four target species was observed in the BC during all the corridor monitoring counts – a flock of 314 dropping to 133 Bar-tailed Godwits present in a three hour time window in February 2020 (Table 9). Grey Plover were never recorded nor were Dunlin or Knot though there were small numbers in OY2 and OY3 but not within the corridor itself. Fewer than 5% of the total numbers of all species counted were in this area, despite it accounting for approximately 7% of the entire inter-tidal area of Whitehouse Bank (areas defined as areas between HWM and LWM). The effect of this single count has a disproportionate effect on the densities of bird utilising this area which typically and infrequently held small numbers of non-target species. The inclusion of this one flock indicates a higher density of birds using the corridor than the remainder of Whitehouse Bank (summed totals of all species / unit area), whilst its removal indicates lower densities.

Controlling for area, tidal state, season and year using the full data set (2014/15 – 2019/20) there was no significant difference in density of three of the four target species inside/outside the Bird Corridor (Whitehouse Bank data only). Only in the case of Bar-tailed Godwit was there a significantly higher usage of the Bird Corridor ($p < 0.001$). Counts in previous years showed similar sporadic use by medium to large flocks of this species and these high counts skew the analyses.

Table 9. Numbers of target (Grey Plover, Dunlin, Bar-tailed Godwit and Knot) observed during Bird Corridor monitoring surveys in 2019/20 in relation to tidal state and presence within or outwith the Bird Corridor (but within sectors immediately adjacent in OY2 and OY3). These counts only refer to corridor areas and immediately adjacent sectors on Whitehouse Bank. The large counts of Bar-tailed Godwit were made within the period 14:00-17:00 on February 11th 2020 only. Counts are overall peak counts by date (taken during 30-minute count blocks) shown as dd/mm.

Species	**Not within bird corridor**				**Within Bird Corridor**			
	EBB	**LT**	**FLOOD**	**(ALL)**	**EBB**	**LT**	**FLOOD**	**(ALL)**
Grey Plover	0	1 (13/10)	0	1	0	0	0	0
Dunlin	0	0	0	0	0	0	0	0
Bar-tailed Godwit	1 (28/10)	3 (16/12)	13 (11/02) 51 (25/03)	51	0	314 (11/02)	314 (11/02)	314 (11/02)
Knot	0	0	0	0	0	0	0	0

<u>Figure 5a – 5e.</u> Changes in the numbers of (a) all waterbirds, (b) Grey Plover (GV), (c) Dunlin (DN), (d) Bar-tailed Godwit (BA) and (e) Knot (KN) at Dungarvan Harbour 2009/10 – 2019/20. Counts are plotted on log scale and are derived from non-interpolated I-WeBS Core Counts. The results should be interpreted with some caution as do not account for missing monthly counts or coverage quality.



3.4 The role of sediment type and disturbance in influencing distribution

Sediment type varied relatively little across the entire site, with the overall particle size classification being 'very well sorted very fine sand' (Folk 1954). However, Ballyrandle and Inner Harbour Main sediments had a higher proportion (mean 2%) of fines (< 630 um), reflecting higher clay & silt components than Whitehouse Bank (mean 0.2%). Despite little variation, there was a significant relationship between sediment mean particle size and bird numbers. Bird numbers were significantly lower when mean grain sizes were > 748 microns ($p < 0.0001$) which were predominant at Whitehouse Bank (Figure 6). There was no significant difference in particle size or percentage fines between trestle and non-trestle areas, or between the Bird Corridor and other sampled areas within Whitehouse Bank.

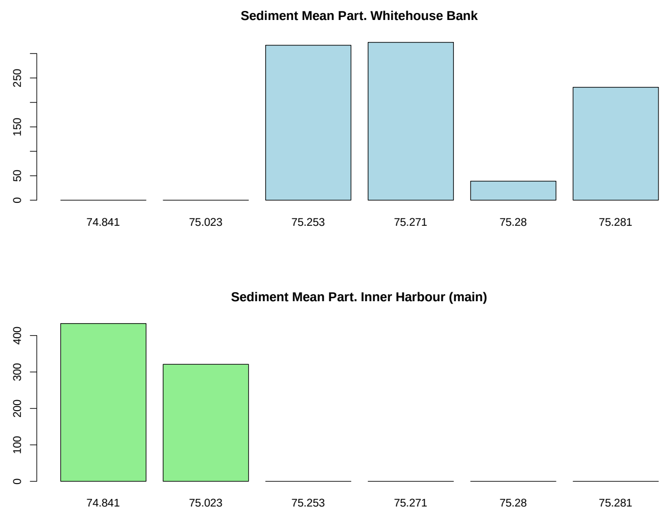


Figure 6. Mean particle size distribution of sediment samples taken at Whitehouse Bank (n=25) and Inner Harbour (Main; n=15) in October 2019. Larger particle sizes reflect sandier sediment types.

There was no evidence of an effect of tractor usage on overall bird numbers for all WB and Hbr Main or its constituent sectors ($p > 0.7$) nor of tractor hours within 250m of the corridor on bird numbers in the corridor ($p < 0.9$). On average tractors were present within 250m of the BC for 63.1 (SD $\pm$ 39.5) minutes, spending least time during November (< 45 minutes) and most in October (> 120 minutes; Figure 7). No vehicles were present at the end of March when presumably Covid-19 restrictions had temporarily lead to a cessation of aquaculture activity on the site.

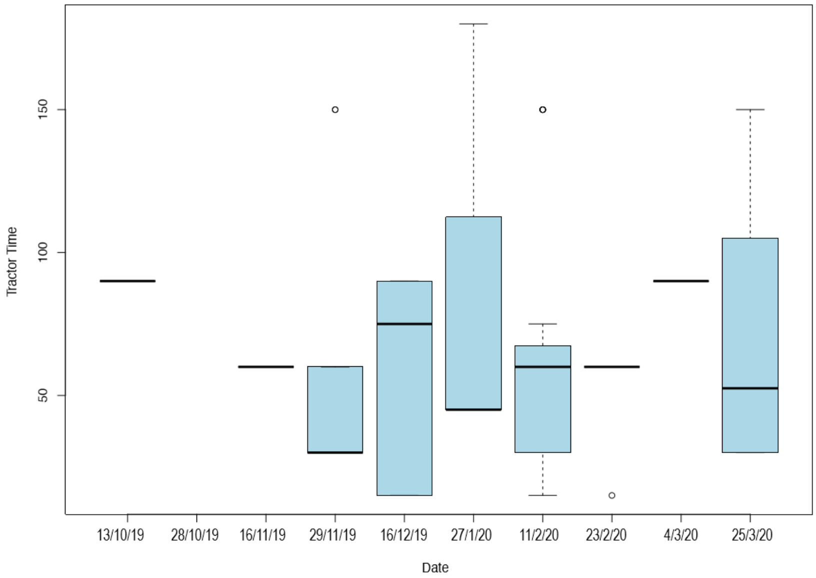


Figure 7. Cumulative tractor minutes within 250m of the Bird Corridor during 30-minute count blocks October 2019 – March 2020. Transient tractors were attributed 15 minutes, those that were stationary within the zone, 30 minutes within each 30-minute monitoring period per vehicle. The boxplot shows mean, range and SD of tractor minutes per survey day.

3.5 Movements of GPS tagged individuals within the site

We acquired 4,933 data points over an average of 18 days/bird (range 2 – 37 days) from 17th January until 25th February 2020. 72% of the total number of positions were acquired from three individuals (AP, CC & CH; Table 6). After filtering locations outwith the core bay, more than half of all positions of tracked birds were in the Inner Bay main west of the Cunnigar (sections OM427 (40.5%) & OM419 (12%)), with around 25% of positions being recorded on Whitehouse Bank. Figure 8 shows the density kernels for fixes for all 8 individuals, showing 'hotspot' areas of use and mostly on the Inner Harbour and based on the removal of outlier sites (outside Dungarvan Harbour and/or below low water mark). Just 16 positions on Whitehouse Bank were from the trestle or corridor areas (n=11 and 5, respectively). Three individuals occurred on trestles at high water on five different dates. Two individuals occurred within the corridor on four different dates – all during the day and at low water.

Several individuals used terrestrial sites, mainly at night at Helvick Head, ca. 2km inland SW of Dungarvan town and on the golf course at Ballinacourty (Figure 9).

Overall, across all states of the tide, Grey Plovers actively avoid areas trestles (within OY1-OY4 inclusive) and the corridor in-between by day and night (OY2; Figure 1, Figures 10-11) and this was similar across all individuals (Figures 12). Model selection supported the full model, retaining all two-way interactions between habitat type and tide, day or night, and Bird ID (Table 7).

Figure 8. Kernel density map showing the main locations of all GPS tracked individual Grey Plovers in January / February 2020 at Dungarvan Harbour. Data has been filtered to remove sites which lie outwith the site boundaries and including those above HWM. Pale blue shades indicate relatively few positions whilst white and red colouration indicate the highest densities of positions. Of 2908 fixes from within the site, 726 (24.9%) were on Whitehouse Bank and the majority (64%) occurred within Inner Harbour (Main). Of these only 5 fixes were on trestles (at high water), 11 were in the bird corridor and the remainder were all in sections CS1-CS4.

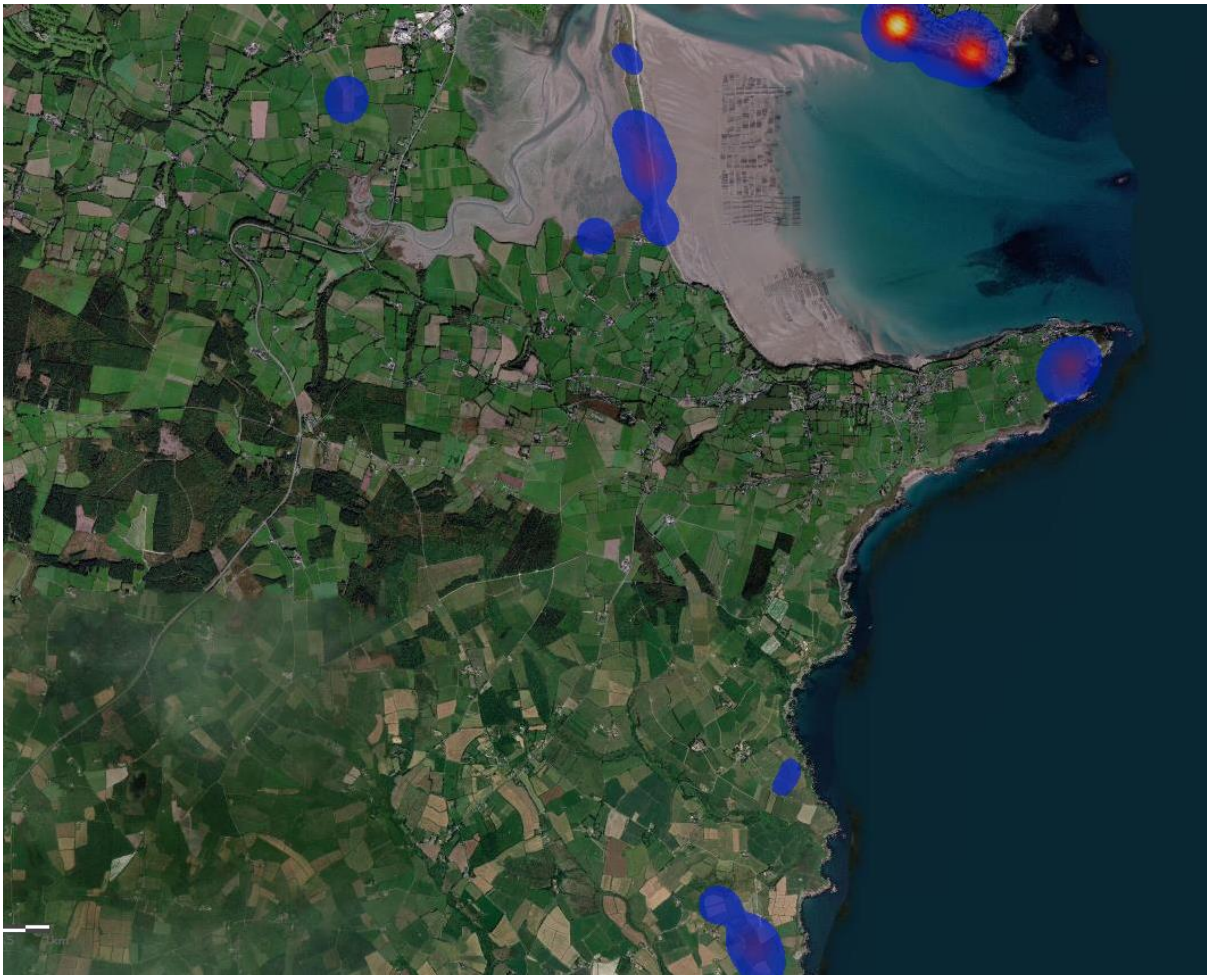
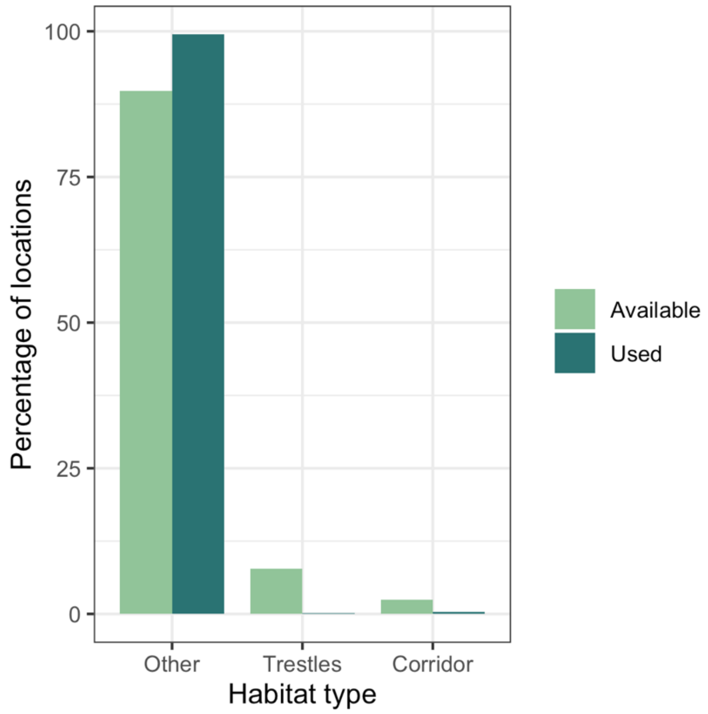


Figure 9. Use of areas outwith the core Dungarvan site by GPS tagged Grey Plovers during January/February 2020. The use of inland areas at the Gold Coast Golf Course, SW of Dungarvan at Ring and ca. 8km SW of Ring towards Ardmore is unexpected. Overall 43.5% of fixes of the tracked birds came from sites outwith Dungarvan Harbour itself.



<u>Figure 10.</u> Percentage of GPS locations within site boundaries both available to and used by tagged Grey Plover. All caught birds were fitted with unique engraved field-readable plastic leg 'flags'/rings, BTO metal rings and 8 individuals were tagged using glue-mounted remote download UHF 4g GPS tags – all under appropriate licences from NPWS and BTO.

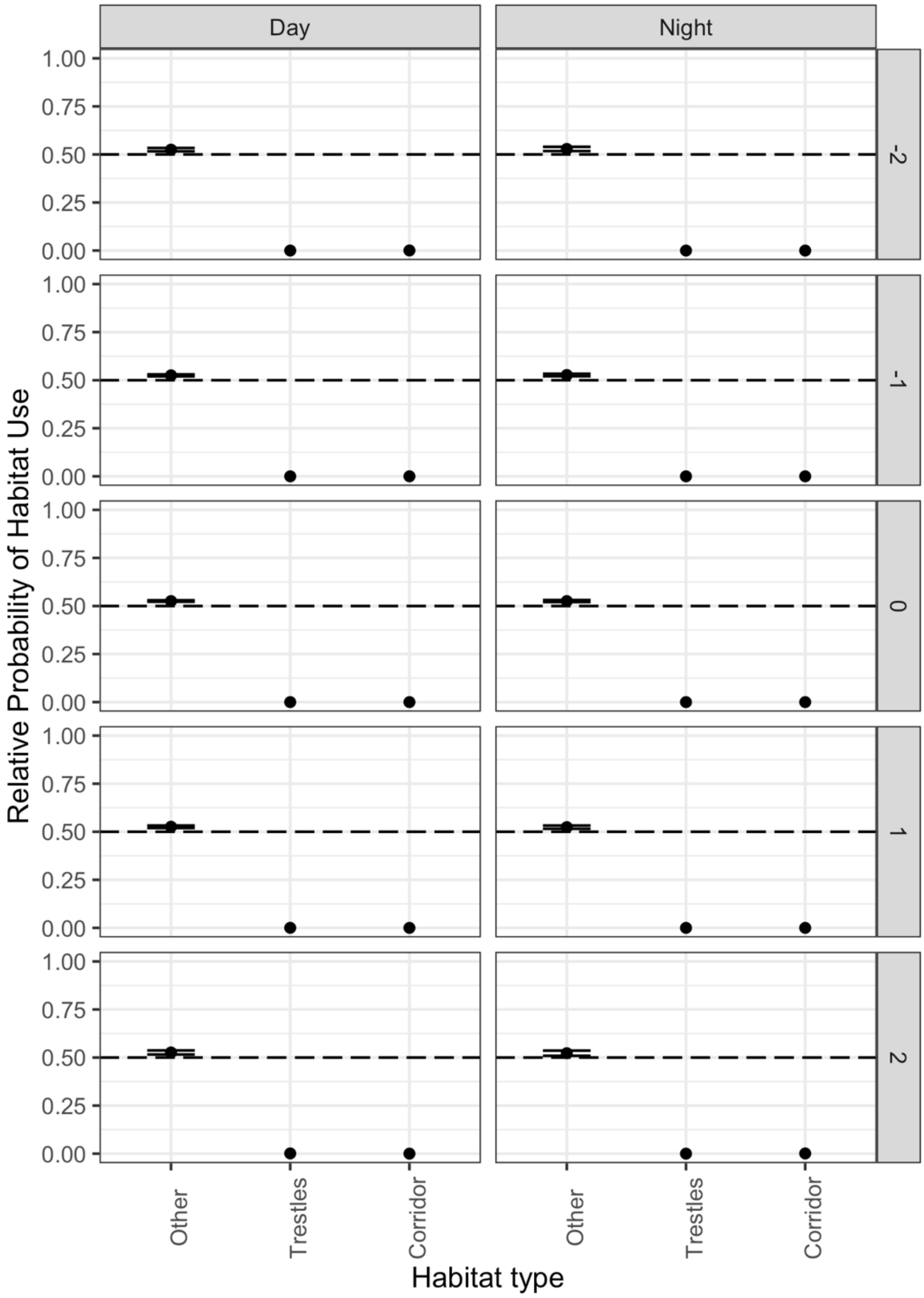


Figure 11. Habitat selection by grey plovers for habitat within site boundaries, across the tidal cycle (tidal height between -2m: low tide; and 2m: high tide) and during day and night. Error bars show standard error. Dashed line shows probability of habitat use that would be expected by chance, i.e. in line with availability. All parameter estimates for other habitats are above the dashed line indicate preference for this habitat, whereas all parameter estimates for trestles and the corridor are below the dashed line indicating avoidance for these habitats at all stages of the tide and times of day.

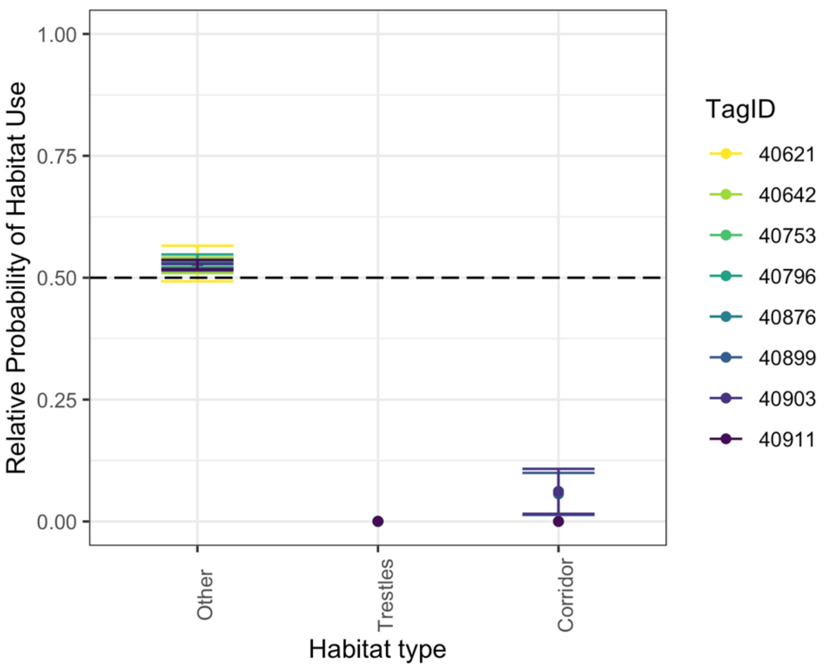


Figure 12. Habitat selection by 8 individual grey plovers for habitat within site boundaries. Error bars show standard error. Dashed line shows the probability of habitat use that would be expected by chance, i.e. in line with availability, showing avoidance by all individuals.

4. Discussion

Our preliminary analysis of long-term I-WeBS data was necessarily restricted to a 10-year time series due to apparent coverage changes after 2009/10. It is beyond the scope of the current project to analyse this rigorously and further processing may be required (e.g. interpolation of missing values and accounting for count quality and completeness) to describe trends with absolute confidence. Nonetheless, having ignored clear differences in the data time series (removing data pre-2009/10) and because count accuracy is likely to be high since 2009/10, it is likely that the trends for the site are reflective of the true picture at the site. The overall trend has shown no significant change in abundance of all waterbirds at in the time period and, of the target species, the only significant change has been a marginal increase in Grey Plovers. This is contrary to the overall long-term (1994/95 – 1998/99; -54.3%) and short-term (2006/07 – 2010/11; -5.8%) declines in Grey Plover numbers in Ireland as a whole (Burke *et al*. 2018). A detailed analysis of trends at Dungarvan relative to wider regional and national scales which is underway will present definite findings for these species and species groups.

Within Dungarvan Harbour we found numbers were generally higher on the Inner Bay (within the Cunnigar) and there is some evidence that this is due, in at least part, to the likely higher invertebrate food densities in the muddier sediments. We were unable to process invertebrate samples within the timescales of the project, but did analyse sediments across the sectors and, since there is a well-established relationship between sediment type and invertebrates (wader food resources higher in muddier sediments) we suggest this is a useful proxy. We suggest that this overall variation in waterbird abundance within the site is largely attributable to sediment composition. Given the considerable volume of bird counts and other work now undertaken (and reported here) at the site, consideration could be given to a dedicated invertebrate study which is last main data component required to enable the development of an Individuals Based Model (IBM) for this site (see Durrell *et al*. 1995). In the absence of an opportunity to experimentally test the effects of the trestles on bird numbers and distribution (which ideally would comprise a before-after-control-intervention study), the development of an IBM is probably the best mechanism for estimating the population level consequences of the displacement effects of aquaculture structures on the target and other species.

We found no evidence of significant effects of disturbance on waterbird distribution across the site. It appears likely that most species are well habituated to aquaculture activities and thus the movements of workers and vehicles has limited, short-term effects. The site has considerable recreational pressures (especially on the upper outer Cunnigar shore – primarily horse-riding and dog-walking) which appear to have only short-term disturbance impacts.

Occasional non-aquacultural disturbance occurred within the corridor also and its location adjacent to the Cunnigar made it relatively accessible to pedestrian traffic. More so than, for example, were there a similar 400m wide buffer further north (e.g. at the top of sections OY3 or OY4) where recreational activity is much more infrequent.

Using a combination of GPS telemetry and observations, Grey Plover made negligible use of the trestle areas and only did so at high water. This is borne out of the previous years' counts where our analysis has shown that numbers of this species are significantly lower at low tide (probably reflecting the dispersal of this species across and beyond the site) and almost totally avoid using within-trestle blocks during low water. Counts and telemetry in fact indicate that, at least in mid-winter 2020, the primary diurnal feeding areas are in the Inner Harbour (Main). Usage of Whitehouse Bank accounted for a considerable (25%) proportion of fixes but these were restricted to the upper shore (sections CS1 – CS4) and whilst used on both ebb and flood tides, a higher proportion of GPS positions of tracked birds and counts were during the ebb tidal phase. It seems likely that the presence of the trestles is reducing available habitat for foraging Grey Plovers during the ebb-low-flood period but it is not possible to be sure this is the case nor robustly assess the impact if this were the case. Our analysis has shown that Grey Plover actively avoid trestles and the bird corridor at all stages of the tide and time of day. While a number of studies have shown usage of inland feeding areas by Grey Plover around the world (Byrkjedal & Thompson 1998), we are unaware of any observations of inland feeding previously in Ireland. The usage of these outlying terrestrial sites was at night-time and since the species feeds both at night and day we suggest that these are nocturnal feeding (not roosting) birds, most likely joining foraging flocks of Golden Plover and/or Lapwing which we did observe in some of these areas during some night-time ringing. The extent of night-time feeding is probably under-recorded as this can only really be quantified using tracking techniques and the species has never been GPS tagged in the UK or Ireland prior to this study.

Dunlin were not observed using the bird corridor at any point during the bird corridor monitoring work in 2019/20. The only one of the target species using the Bird Corridor to any degree, as in previous years, was Bar-tailed Godwit. These sporadic counts of relatively large flocks are probably short-lived and it is difficult to argue that the Bird Corridor is providing valuable food resources for these birds. In 2019/20 Bar-tailed Godwits made considerable use of the Inner (Upper) Harbour parts, in particular OM416 and OM417 which were only counted at low and high tide count periods. We were particularly aware of consistent use of these areas by large numbers in January during an intense observation week while trying to catch Grey Plover on the inner side of the Cunnigar. Overall there is little evidence that the corridor is serving any valuable function for waterbirds at this site in its current form.

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6. Appendices

Appendix 1. List and location of sediment sampling points. 0 or 1 refers respectively to negative or affirmative.

Zone	Sample No.	Sector	Trestles (0,1)	Bird Corridor (0,1)
BR	182	CN4-U	0	0
BR	144	CN1-L	0	0
BR	164	CN1-L	0	0
BR	143	CN1-L	0	0
BR	165	CN1-L	0	0
BR	122	CN2	0	0
BR	121	CN3-L	0	0
BR	120	CN3-U	0	0
BR	140	CN3-U	0	0
BR	141	CN3-U	0	0
BR	142	CN4-L	0	0
BR	184	CN4-L	0	0
BR	161	CN4-U	0	0
BR	203	CN5	0	0
BR	204	CN5	0	0
INN(Main)	257	OM418	0	0
INN(Main)	259	OM419	0	0
INN(Main)	324	OM419	0	0
INN(Main)	282	OM419	0	0
INN(Main)	303	OM419	0	0
INN(Main)	238	OM419	0	0
INN(Main)	279	OM419	0	0
INN(Main)	321	OM419	0	0
INN(Main)	302	OM419	0	0
INN(Main)	320	OM427	0	0
INN(Main)	322	OM427	0	0
INN(Main)	388	OM427	0	0
INN(Main)	280	OM427	0	0
INN(Main)	345	OM427	0	0
INN(Main)	342	OM427	0	0
WB	434	CS1	0	0
WB	391	CS2	0	0
WB	455	CS2	0	0
WB	412	CS2	0	0
WB	454	CS2	0	0
WB	370	CS2	0	0
WB	433	CS2	0	0
WB	307	CS3	0	0
WB	328	CS3	0	0
WB	349	CS3	0	0
WB	309	CS4	1	0
WB	289	CS4	0	0
WB	458	OY2	0	1
WB	435	OY2	0	1
WB	437	OY2	0	1
WB	456	OY2	0	1
WB	457	OY2	0	1

WB	479	OY2	1	0
WB	436	OY2	0	1
WB	414	OY3	1	0
WB	393	OY3	0	0
WB	373	OY3	1	0
WB	308	OY4	1	0
WB	351	OY4	1	0
WB	67	OY4	1	0

Appendix 2. Low and High tide count data

Species Code	Species Name	Count type			
			Low tide		High tide
		Oct-19	Nov-19	Jan-20	Jan-20
PB	Light-bellied Brent Goose	145	482	919	1368
SU	Shelduck	2	34	180	26
WN	Wigeon	68		42	96
MA	Mallard	87	26	44	4
T.	Teal	86	62	86	52
RM	Red-breasted Merganser		3	4	
LG	Little Grebe		5	1	1
GG	Great Crested Grebe	1	12		1
OC	Oystercatcher	547	209	162	284
L.	Lapwing	131	517	1326	739
GP	Golden Plover			800	
GV	Grey Plover	24	7		33
RP	Ringed Plover	220		73	
CU	Curlew	746	235	489	429
BA	Bar-tailed Godwit	5	616	111	697
BW	Black-tailed Godwit	673	469	484	448
TT	Turnstone	10		5	4
KN	Knot	12	476	175	
SS	Sanderling			62	
DN	Dunlin	16	324	658	1550
SN	Snipe	2			
RK	Redshank	549	323	456	369
GK	Greenshank	3	2	5	14
BH	Black-headed Gull	443	198	115	103
CM	Common Gull	56	3	35	48
GB	Great Black-backed Gull	18	2	12	1
HG	Herring Gull	4	1	105	15
LB	Lesser Black-backed Gull	15	6	38	20
H.	Grey Heron	9	6	6	7
ND	Great Northern Diver			1	
CA	Cormorant	11		10	2
ET	Little Egret	27	10	2	4
	Total	**3910**	**4028**	**6406**	**6315**