Kirk Arrow Spit

Morphological Overview 2020

EASTERN SOLENT | COASTAL PARTNERSHIP

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CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

The present understanding of Kirk Arrow Spits morphological evolution is limited. Theories suggesting its periodic function as a source of sediment to Selsey's beaches may be elucidated upon by observations of changing patterns in its extent and volume. This study assesses available aerial photography, LIDAR and hydrographic survey data to gain an overview of changes in the spit's volume and extent over the last 80 years. It then uses these observations to infer a hypothesis as to the mechanism behind observed dynamics.

Key findings from this report include:

- The current location of the spit to be substantially further east than its 1947 position.
- The southern section of the spit appears to be diminishing whilst the northern section has grown in size.
- The proximity of the spit has moved landward since 2007.
- The spit reduced in extent between 2004 and 2006 however steadily increased between 2007 to 2016.

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1. INTRODUCTION

The Kirk Arrow Spit is a mobile gravel bank located around 300-500 m offshore from Selsey Bill which is exposed at low water (see Figure 1). Owing to interactions between waves and accelerated tidal currents induced by the promontory of the Bill, the bank displays a dynamic morphology and is known to have fluctuated significantly in both extent and volume over the past 100 years (Jolliffe and Wallace 1973).

The SCOPAC Sediment Transport Study (2012) summarises the history of the feature as follows. It is currently supposed that the spit periodically functions as a source of material for Selsey's adjacent beaches (Lewis and Duvivier 1977; Wallace 1990; Posford Duvivier, 2001). Evidence for this, however, is mainly circumstantial, based primarily on reported observations and inferences from aerial photography. It was concluded by Lewis and Duvivier (1977) that feed to the shore occurs in pulses which are separated by intervening periods of erosion, however as these high magnitude, low frequency pulses have proved difficult to measure and monitor any attempts for quantitative estimates of this are considered as medium in reliability.

Gaining a better understanding of changes to the spit's shape and volume may help to shed further light on its dynamics, potentially offering insights into the periodicity of its capacity to function as an onshore sediment feed.

Though data coverage of the spit is sporadic and variable in resolution and quality, Aerial photography, LIDAR and Bathymetric surveys taken over the last 69 years do offer a number of snapshots by which the morphological state of the spit through time may be captured. This study aims to assess this data in order to gain an overview understanding of the spit's long-term dynamics.

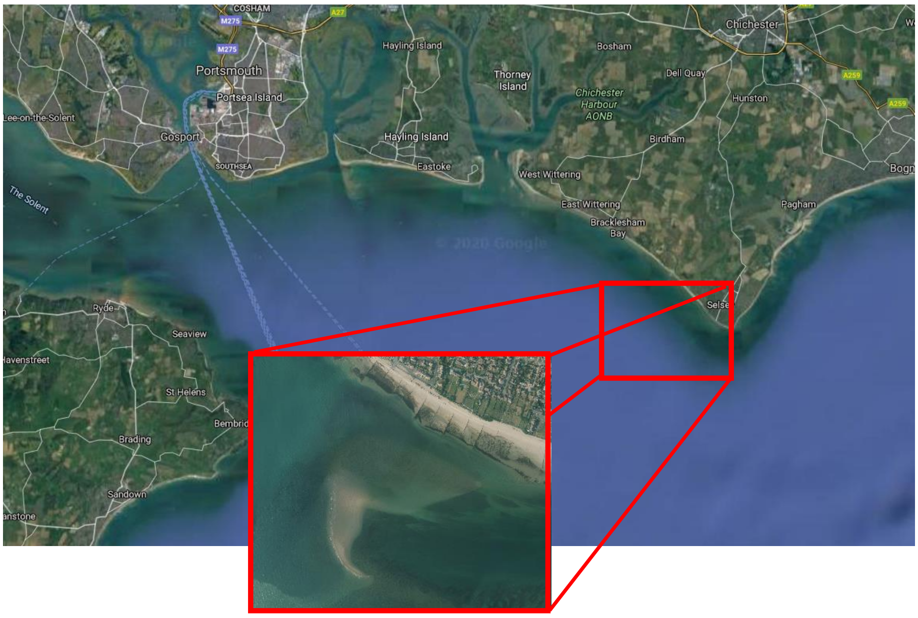

Figure 1: Map of Selsey Showing location of Kirk Arrow Spit (Google Earth, 2020)

2. DATA AND METHODS

The following section outlines the data and methods used to map and analyse morphological changes at Kirk Arrow Spit.

2.1 Data

Tables 2, 3 and 4 summarise the aerial photography, bathymetry and LIDAR respectively for all data assessed.

Aerials

Year	Notes
1945	Spit not visible
1946	Spit not visible
1947	Full Coverage
1963	Spit not visible
1986	Spit not visible
1991	Partial Coverage of spit only
1994	Spit not visible
2000	Spit not visible
2001	Spit not visible
2002	Spit not visible
2004	Spit not visible
2005	Spit not visible
2008	Spit not visible
2013	Full coverage
2016	Full coverage

Table 1: Aerial photography assessed

Bathymetry

Date	Instrumentation and Survey type	Notes
16/10/2004 to 17/10/2004	Navisound Enhanced single-beam ES / Reson Single beam	Full coverage
06/10/2006 to 07/10/2007	Odom Hydrotrack Single beam	Full coverage Survey split across the two years due to bad weather.
06/06/2016	EM3002D Multibeam	Full coverage

Table 2: Bathymetric Surveys assessed

Lidar

Year	Notes
2015	Coverage restricted to spit only, not inclusive of surrounding seabed.

Table 3: LIDAR coverage assessed

2.2 Methods

Aerials

Aerials which included coverage of the spit were used to discern the outline of its exposed area. Additionally, the clarity of the water evident in the 2013 and 2016 aerials made it possible to discern underwater changes in coloration indicative of the submerged boundary of the spit with the surrounding seabed. These outlines were digitised to produce a sequence of extents by which areal changes in the spit's extent could then be compared.

Hydrographic Data and Lidar

Bathymetric and Lidar data was interpolated to create a sequence of digital terrain models (DTMs). The Mean low water spring contour (taken as -2.1m OD) was then digitally extracted and the DTMs were then digitally compared to produce a sequence of difference plots which display changes in elevation. This was conducted both for year on year change, as well as each year consecutively from the earliest available data. The volume of the spit was calculated using the difference between the recorded surface elevation and Mean Low Water Springs at Selsey (-2.1 OD).

Descriptive Terminology

To aid description the spit has been divided into three separate geomorphological sections; These will be referred to as the northern lobe, central hinge and the southern arm (see Figure 2).

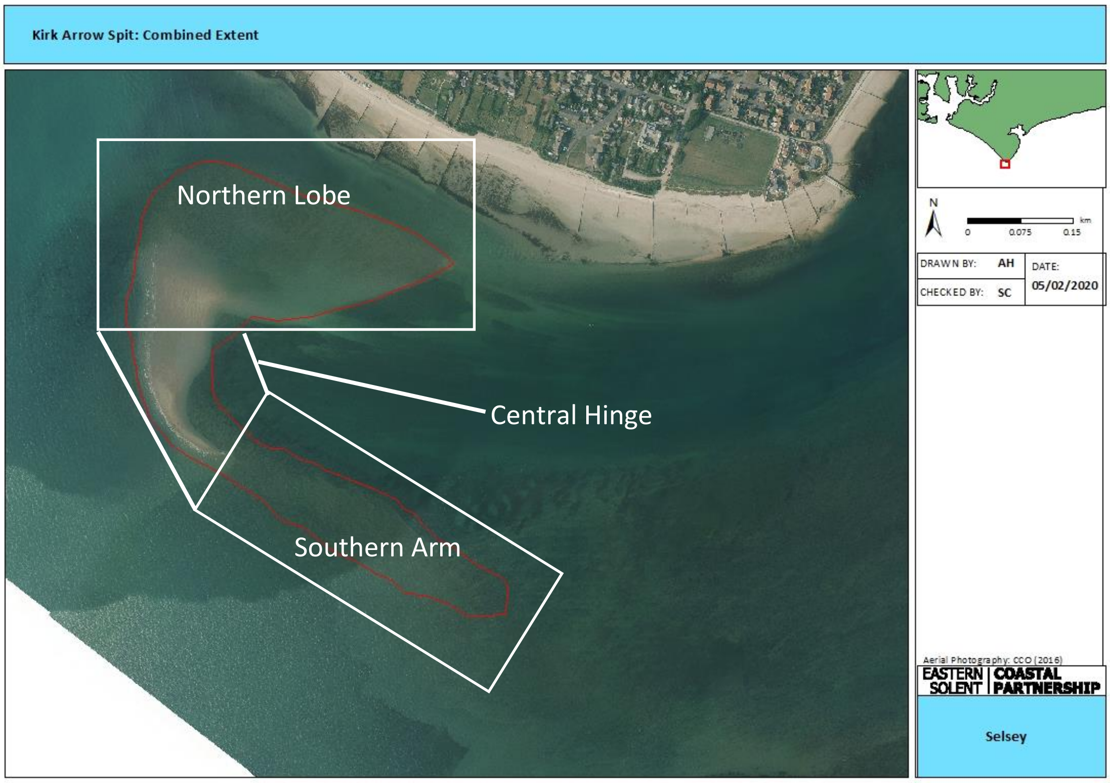

Figure 2: Terminology of spit characteristics used to aid description.

3. RESULTS

The following section presents the GIS analysis of the aerial photography digitization and contour extraction analysis from the bathymetry and LIDAR.

3.1 Aerials

This section compares changes in extent indicated by digitisations of aerial photography.

1947

A small area visible however it appears that this photo was not taken at low water it is therefore likely that the actual extent of the spit during this period is much larger (figure 3).

Figure 3: Spit extent (above waterline) digitised from aerial photography 1947

1991

Only the northern section of the spit is captured by the photography. This takes a narrow linear form and is orientated in the north east to south west direction (figure 4).

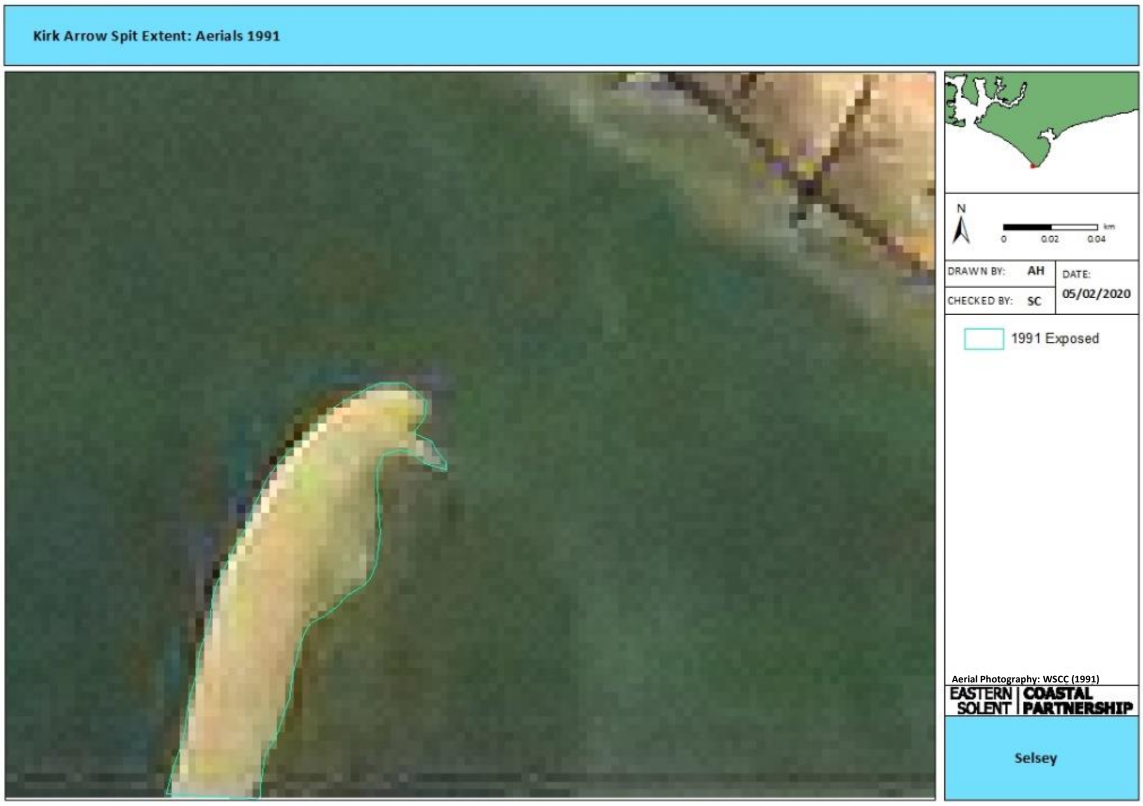

Figure 4: Spit extent (above waterline) digitised from aerial photography 1991

1991-1947

The visible portion of the spit in 1991 appears to be located some 383m to the north west of its 1947 position. **NOTE:** these photos were taken at different tidal states and so this measurement cannot be considered exact (figure 5).

Figure 5: Spit extents (above waterline) digitised from aerial photography 1947-1991

1991-2013

Whilst the 1991 Aerial was taken on a higher tidal state and therefore extent cannot be comparable with 2016, the exposed area of the spit evident in 2013 shows the northern edge of the northern lobe to be in a more southerly position then it was in 1991, however, it has expanded significantly in area with its distal point hinging to a more easterly position. The southern arm is clearly visible in the 2013 imagery and can be seen curving to the south east (figure 6).

Figure 6: Spit extents (above waterline) digitised from aerial photography 1991-2013

When the spit extent below the waterline is discerned it includes the appearance of two plumes which appear to stretch shoreward from the spit. Notably the position of the more eastern plume coincides with a promontory on the beach (figure 7).

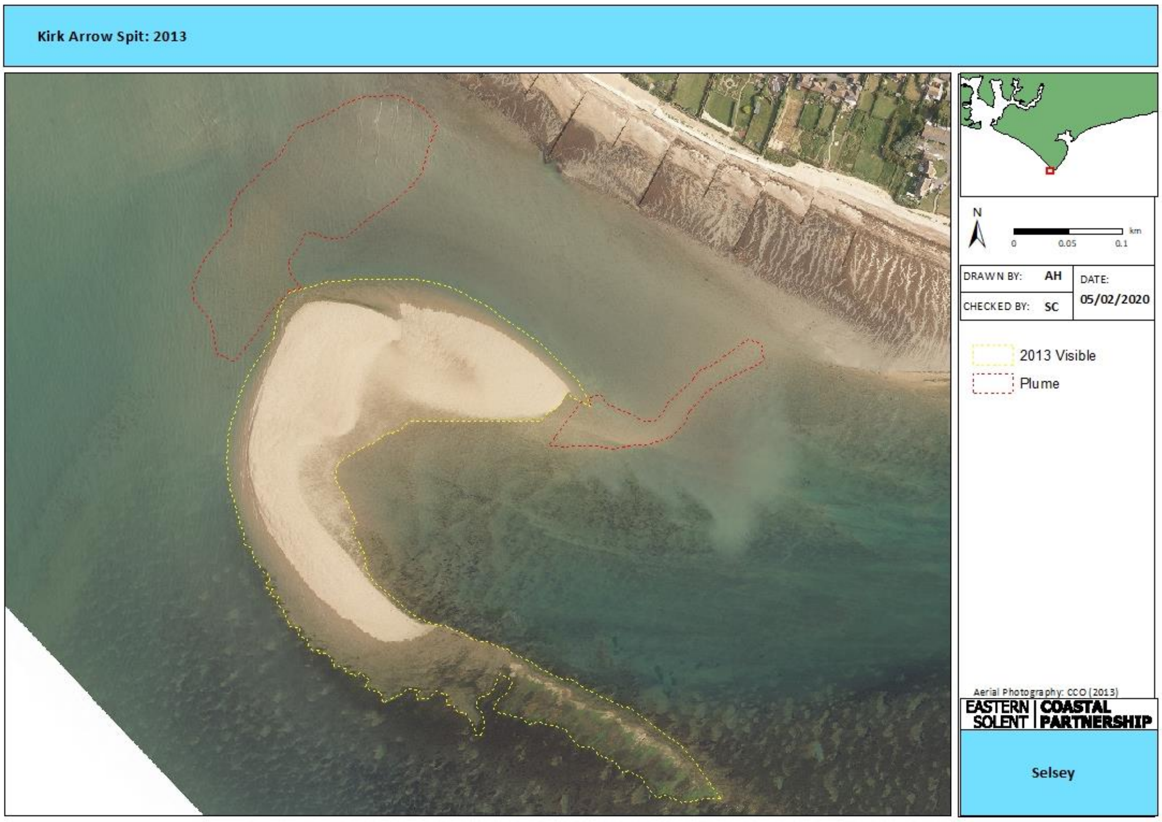

Figure 7: Spit extents (all visible) digitised from aerial photography 2013

2016

2016 shows a comparatively lower area exposed above the waterline than was seen in the 2013 aerial, however this may be the result of the tidal state rather than a true reflection of the size of the spit as a significantly larger area can be observed underwater (figure 8). When this is considered the northern lobe appears to be significantly larger than it was 2013 with the distal point of the spit moving much further to the east most east and considerably closer to shore and bringing it in general closer proximity to the shoreline promontory observed in the 2013 aerial (figure 9).

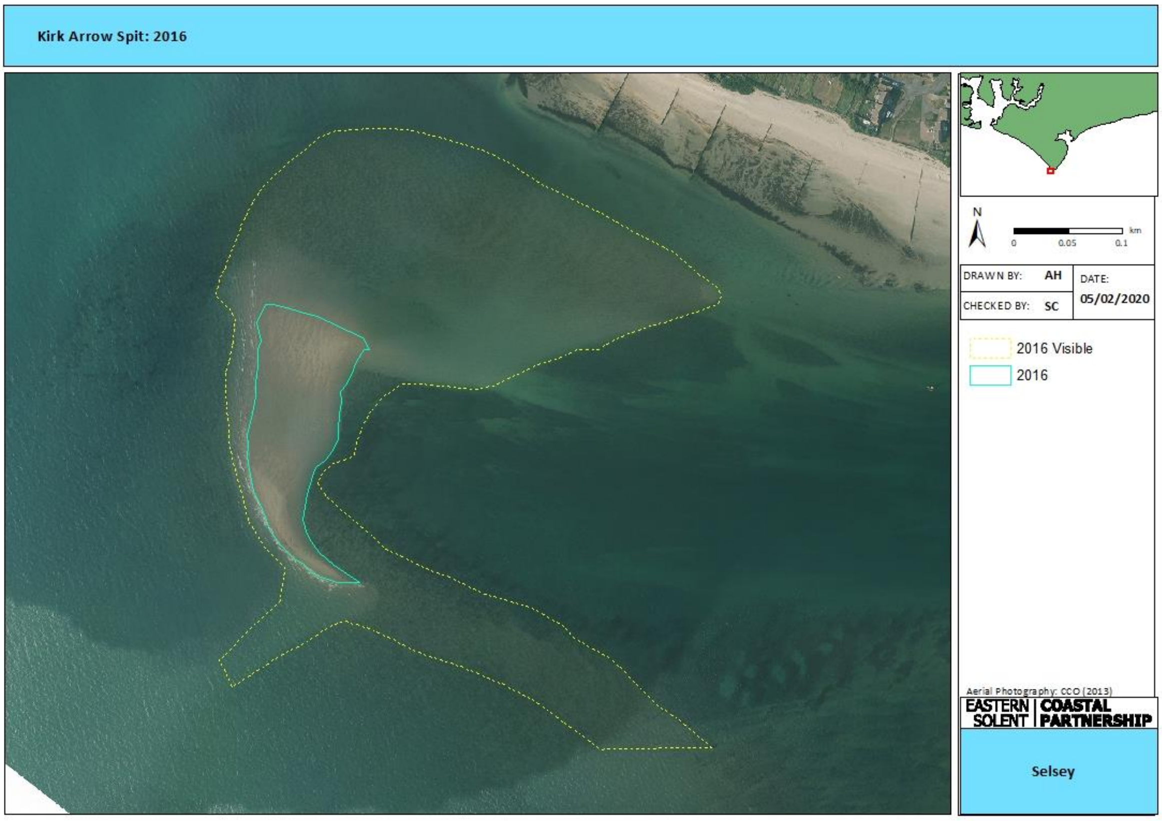

Figure 8: Spit extents (exposed above low water and all visible) digitised from aerial photography 2016

Figure 9: Spit extents (exposed above low water and all visible) digitised from aerial photography 2013-2016

1947-2016

Figure 10: Spit extents digitised from aerial photography 1947-2016

3.2 Mean Low Water Springs Contours 2004-2016

NOTE: Due to the low-resolution data available from the 2004 and 2006/7 single-beam surveys the corresponding extents can only be considered approximate and all inferences drawn should be considered approximations.

When all extracted Mean Low Water Spring contours are viewed together there is generally an observable diminishment of the southern arm. This coincides with a corresponding increase in the northern lobe as well as a clear westerly migration of its eastern extent.

Figure 11: Mean Low Water Springs Contours (-2.1 OD) 2004-2016

Mean Low Water Spring Contour Area

Between 2004 and 2006/7 the area of the spit decreased by 28,495m2. This divided by the 3-year interval in between gives an average reduction rate of 9,498m2 per annum.

Conversely, between 2006/7 and 2015 area almost tripled increasing by 35130 m2. This divided by the 6 years in between this gives an approximate annual growth rate of 4,391 m2 per annum. Between 2015 and 2016 the spits area increased by 7,027 m2 (table 4 and figure 12).

Year	Area (m^2)
2004	47,389
2006-2007	18,894
2015	54,024
2016	61,051

Table 4: Area above Mean Low Water Springs, taken from bathymetric surveys 2004-2016

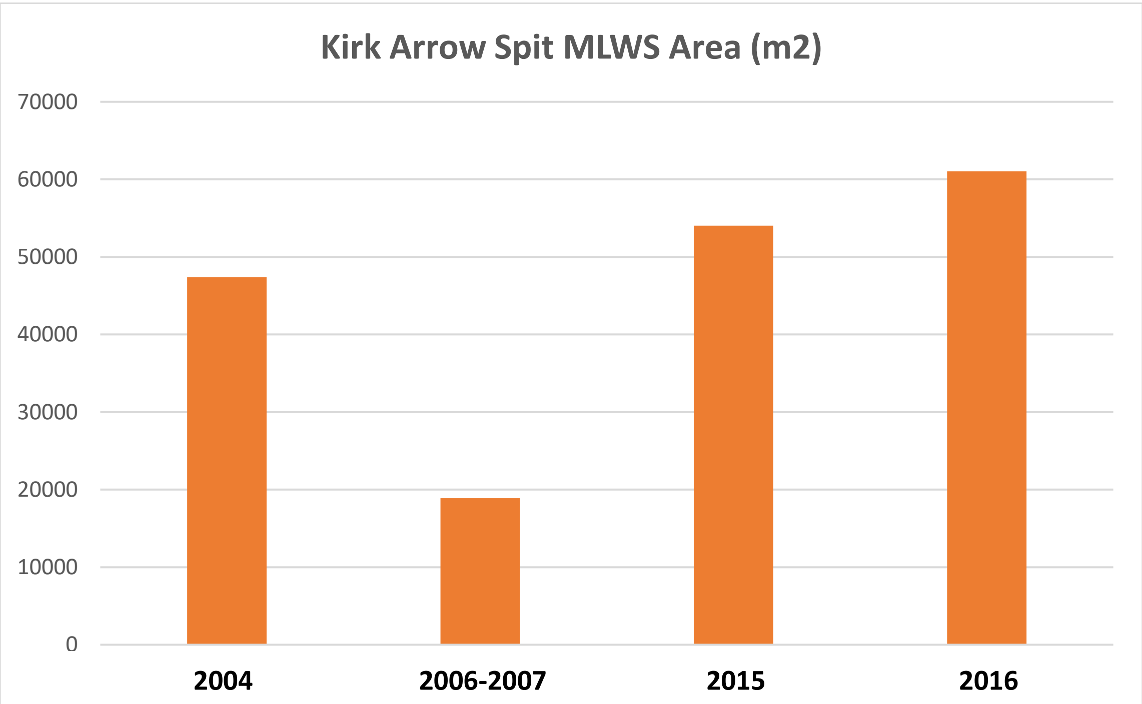

Figure 12: Bar chart showing area above Mean Low Water Springs, taken from bathymetric surveys 2004-2016

Mean Low Water Springs contours combined with Aerial Extents

Mean Low Water Spring contours (figure 13) when viewed in combination with the extents digitised from aerial photographs (see figure 7) support the general trend of north and eastward growth of the northern lobe and diminishment of the southern arm. The closest that any part of the spit gets to its original 1947 position is the most recent 2016 survey.

Figure 13: Mean Low Water Springs contours combined with extents digitised from aerials 1947-2016.

Distance from shore

Measurements taken between the closest point of the spit to shore show a clear trend, with distance increasing between 1947 and 2004 2006/7 before decreasing to its closest position to shore in 2016 (table 5 and figure 14).

Year	Distance (m)
1947	100
1991	150
2004	270
2006-2007	230
2013	155
2015	105
2016	77

Table 5: Nearest distance of spit from shore.

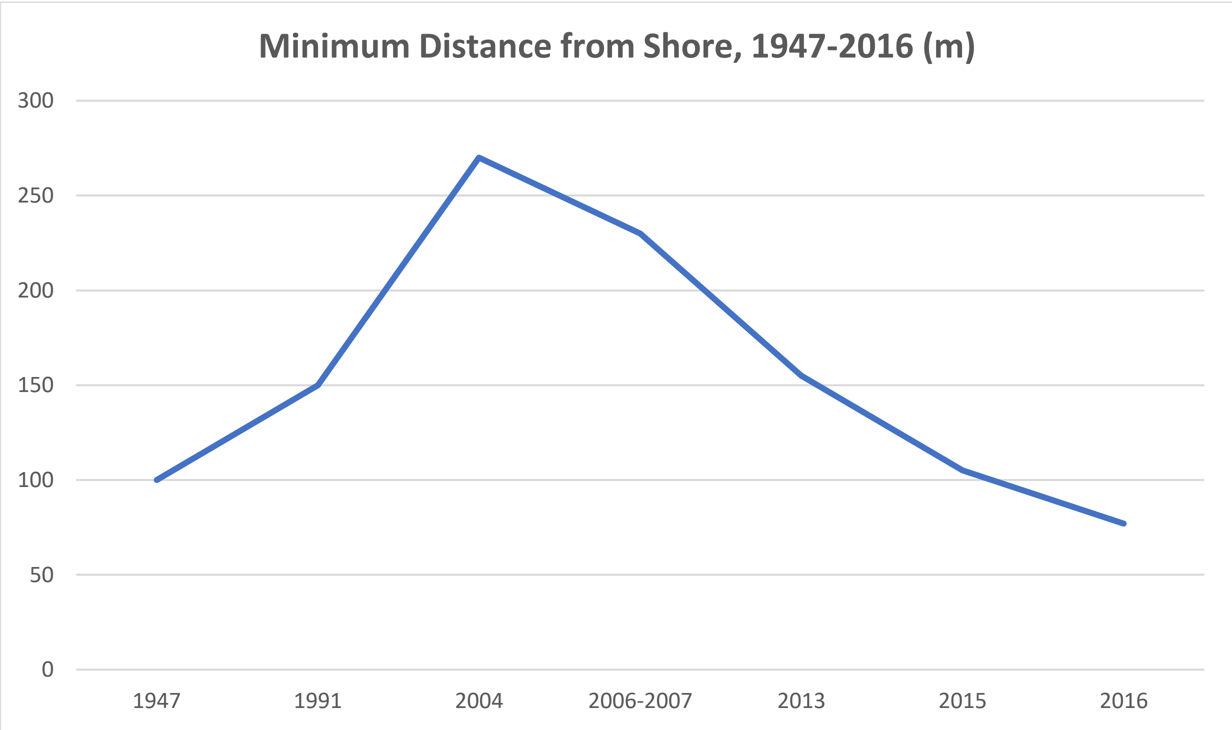

Figure 14: Line graph showing nearest distance of spit from shore.

3.3 Difference Plots

2004-2006/7

Between the 2004 and 2006/7 surveys the southern arm is dominated by erosion, however, a clear zone of accretion is evident on the northern lobe (figure 15).

Figure 15: Difference plot showing elevation changes between 2004 and 2006/7.

2004-2015

Between the 2004 and 2015 surveys the zone of accretion on the northern lobe can be seen to cover a much larger area than observed in the 2004-2006/7 difference plot. The eastern MLWS boundary also be observed to have migrated further eastward. There is erosion evident along much of the southern arm however a band of accretion has appeared at a depth below MLWS, along the north eastern edge of its 2004 position (figure 16).

Figure 16: Difference plot showing elevation changes between 2004 and 2015.

2004-2016

Between 2004 and 2016 the northern lobe displays further accretion with an increased eastward reaching of the MLWS contour. This is concurrent with the large patch of accretion at this location as well as accretion patches which lie at its eastern extent. There is further erosion evident on the southern arm, which is concurrent with its general areal diminishment, however the zone of accretion can still be observed located along the north eastern boundary of its 2004 position (figure 17).

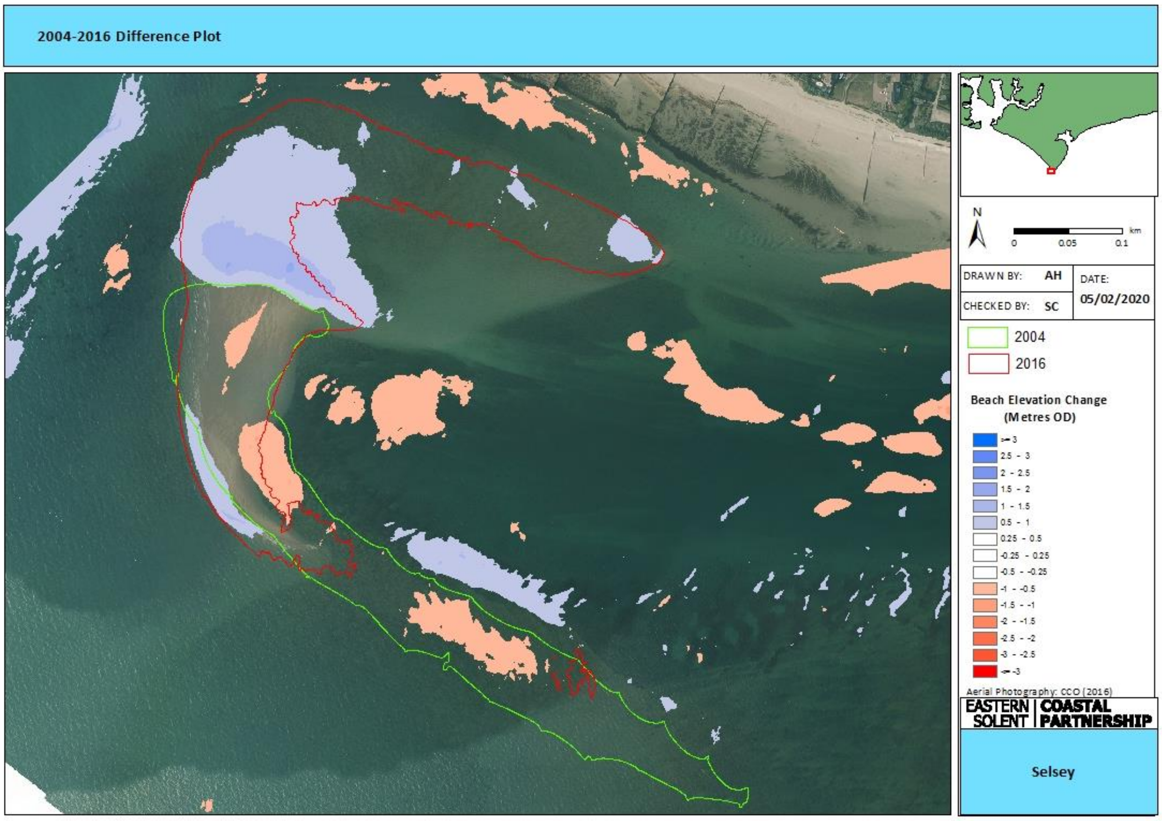

Figure 17: Difference plot showing elevation changes between 2004 and 2016.

2006/7- 2015

Between the 2006/7 and 2015 survey periods the spit showed general overall accretion. Accretion on the northern lobe is concurrent with large north and westward growth of its area.

A band of accretion is observed just north of the previous position of the southern arm. A location which lies beneath mean low water springs (figure 18).

Figure 18: Difference plot showing elevation changes between 2006/7 and 2015.

2015-2016

Changes between 2015 – 2016 show a slight reduction of the southern arm with further north and westward growth of the northern lobe. Patches of erosion can be seen across the spit with the exception of small zones of accretion on the east and west sides of the central hinge (figure 19).

Figure 19: Difference plot showing elevation changes between 2015 and 2016.

3.5 Volumes

Between the 2004 single-beam survey and the 2006/7 single beam surveys volume decreased by approximately 13,341.2 m3. Dividing this increase by the 3-year interval between yields a yearly rate of decrease of 4,447 m3 per year. Between 2006/7 and 2015 volume increased by 15,132 m3. This divided by the 8-year interval in between gives an accretion rate of 1891.5 m3 per annum. Between the 2015 Lidar survey and 2016 multibeam, volume decreased by 4280.5 m3. The decrease in volume shown between 2015 LIDAR and 2016 multibeam is in contrast to the areal change observed over the same period which showed growth (see table 6 and figure 20).

Year	Volume (m^3)
2004	16010
2006-2007	2669
2015	17802
2016	13521

Table 6: Spit volumes above Mean Low Water Springs 2004-2016.

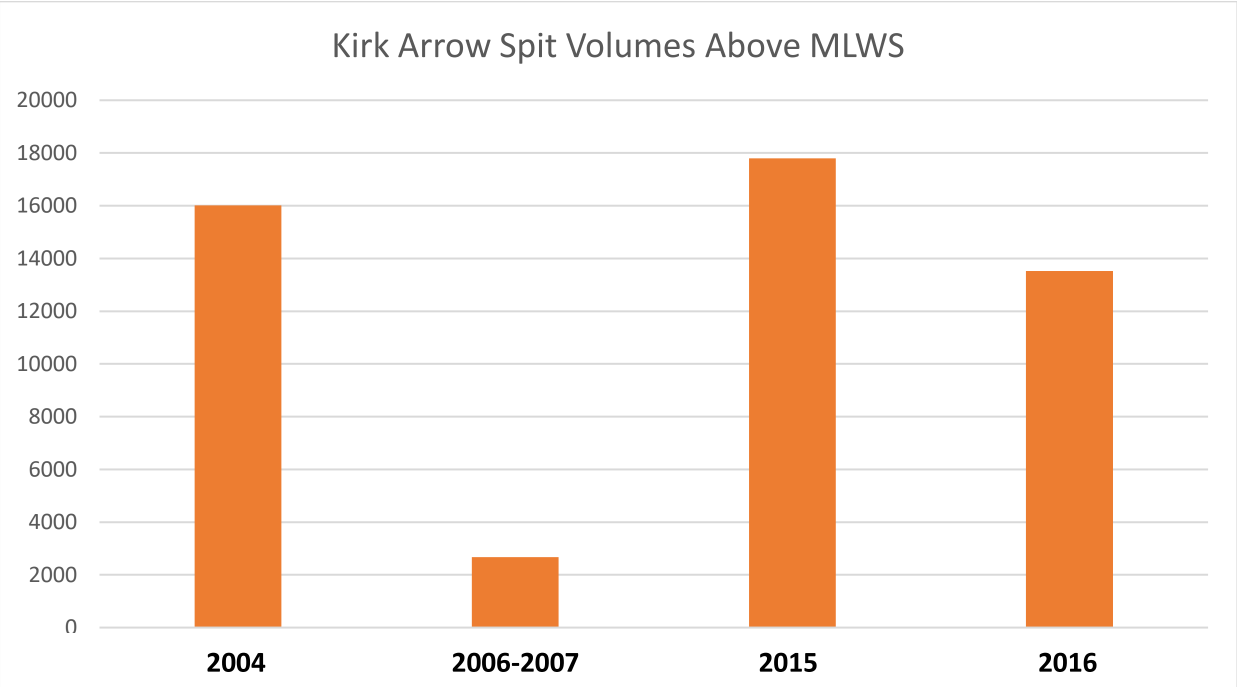

Figure 20: Bar chart showing spit volumes above Mean Low Water Springs 2004-2016.

4. DISCUSSION AND HYPOTHESIS

The evolution of Kirk Arrow spits extent since 1947 can be summarised by a general northward diminishment of the southern crescent arm occurring coincidentally with a northward and westward growth of the northern lobe. The westward growth of the northern lobe has resulted in its 2016 location reaching closer to the spits original 1947 position than at any other point indicated by the data available. Whilst it is accepted that the temporal coverage of data maybe too short or too sparse to infer concrete conclusions, this behaviour could be interpreted as an indicator of a cyclic process. The following considers observed erosion and accretion trends in combination with changes to the spits positioning and extent to propose a speculative hypothesis as to the dynamics of how this cycle may operate.

Given the general diminishment and eroding tendency of the southern arm and corresponding growth and accretion of the northern lobe, it is conceivable that the eroding arm functions as a sediment source for the northern lobe resulting in its gradual growth. This increasing proximity with the shore and thus its capacity to function as an onshore sediment feed (a function which is supported by the shoreward plumes seen in the 2013 aerials and the general proximity to the shoreline promontory seen in the 2016 aerial). The general diminishment displayed by the southern arm suggests that in time its capacity to function as a feed to the northern lobe may become exhausted, resulting in the northern lobe diminishing in size as it migrates further to the east. The reduction in volume coincident with an increase in area seen between 2015 and 2016 combined with the switch from erosion to accretion exhibited by the northern lobe in the 2015-2016 difference plot suggests that this phase may have began in 2016.The next phase of the cycle may be indicated by the zone of accretion which can be observed just to the north east of the southern arm. Though this area is currently submerged at MLWS, should its current supply of material continue it is conceivable that it will continue to accrete until it becomes exposed, in this way this feature could be interpreted as a reforming southern arm, closing the cycle. A conceptual diagram of this hypothesis can be seen below in figure 21.

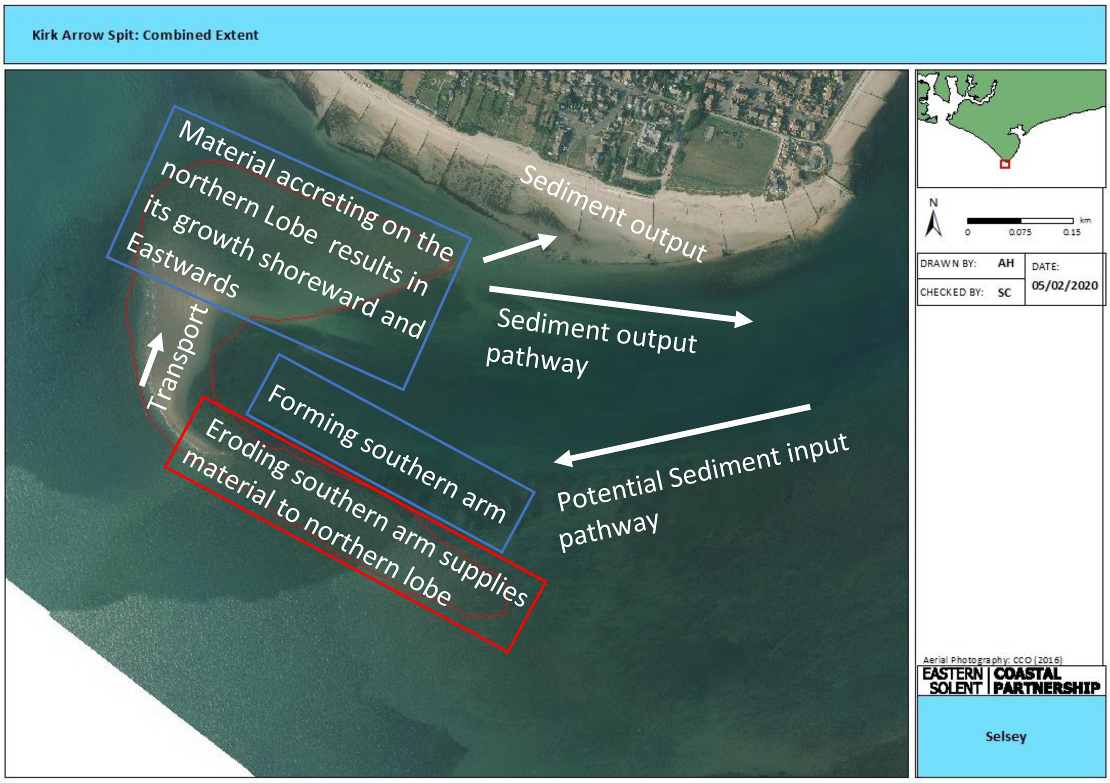

Figure 21: Conceptual Diagram of material input zone accretionary lobe and shoreward joining location.

Whilst this hypothesis is based on patchy information requiring a great level of assumption and thus should be considered as speculative in nature, future surveys of the spit may offer an opportunity to test its robustness. Its application infers the prediction that the northern lobe will start to dissipate, decreasing in size as it moves eastwards towards the spits original 1947 position whilst the southern arm will continue to diminish. A new crescent arm may become evident in a slightly north westerly position then has been previously evident.

The above has implications for the capacity of the spit to feed Selsey's beaches as it suggests that potential for the spit to supply sediment to the shore periodically increases and decreases as the size and position of the northern lobe changes. To elucidate on this further future studies should incorporate analysis of the topographic and volumetric beach changes which occur concurrently with the observed changes displayed by the spit. Whilst outside the scope of this study, it should also be noted that the manner in which material from the spit is distributed across Selsey's beaches will be affected by the location of the feed in relation to a transient drift divide known to exist on the mainland adjacent to the spit (NFDC,2012). Any future interpretations made on the relationship of the spits condition and feed of material to the shore would therefore need to consider this.

5. RECOMMENDATIONS

To improve general understanding of the spit's morphological behaviour and function and its related function as a sediment source the following recommendations are proposed.

- The undertaking of a sediment budget of the spit and adjacent shoreline to quantify its volumetric change as well as its relationship with volumetric changes onshore.
- The undertaking of an RFID tracer study on the shoreline to identify sediment pathways which would likely be taken by any onshore supply from the spit.
- Hydrodynamic modelling of the coastal dynamics around Selsey Bill and Kirk Arrow Spit to increase understanding of the drivers behind the spits morphological change.
- Acquisition of further topographic and photogrammetric data to update longitudinal records of spit morphology.
- Periodic reassessment of all available GIS compatible data as this becomes available to assess or confirm changing theories on morphological trends.

6. REFERENCES

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