Dynamic Adaptive Pathways

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Executive Summary

The dynamic nature of coasts and the anticipated, yet uncertain, changes to coastal processes because of climate change, mean that traditional, engineered coastal management alone is no longer a sustainable option. Dynamic Adaptive Pathways are flexible tools that can be used to make current and future decisions to accommodate coastal change and associated uncertainty[1]. They highlight the preferred, or anticipated, path to adaptation, while recognising that other alternative pathways exist and may have to be taken in the future.

As well as the traditional management, they should identify opportunities to work with natural processes, enhance the environment and include necessary supportive steps to create space (e.g., accommodate erosion through land safeguarding) in preparation for inevitable future sea level rise and associated increases in erosion and flooding.

The Dynamic Adaptive Pathways presented for West Beach and East Beach at Nairn focus on the management of coastal change, i.e., erosion. The Dynamic Adaptive Pathways include 1) an **Anticipated Pathway** that focusses on coastal management and identifies the most appropriate/ preferred pathway based on the current understanding of risk; and 2) a **Supportive Pathway** that should be delivered in parallel, that focusses on land-based management, and acknowledges that the desired management pathways may not be achievable in the future for a variety of reasons.

Based on the results of the Coastal Resilience Assessment report[6], these Dynamic Adaptive Pathway phases, management approach and initial actions are recommended:

West Beach = Phase 1:

- Anticipated pathway: Enhance Natural Features
- Supportive pathway: Create Space

Phase 1 Actions: 1) vegetation planting; 2) dune access arrangements; 3) sand recycling; 4) understand land ownerships.

Monitoring – every year.

East Beach = Phase 0:

- Anticipated pathway: No Intervention
- Supportive pathway: N/A

No current Actions required.

Monitoring – every 2 years.

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[1] Scottish Government (2023) Coastal Change Adaptation Plan Guidance – Interim
https://www.dynamiccoast.com/files/ccapg_2023feb.pdf

1 Introduction

This report presents the Dynamic Adaptive Pathways developed as part of the Nairn coastal adaptation study. The Dynamic Adaptive Pathways presented here focuses on the management of coastal change, i.e., erosion. The dune system plays an important role in coastal flood protection so maintaining the dune system is integral to reducing coastal flood risk to Nairn. Coastal flood inundation is also possible via the river channel. This flood risk has been quantified in the Nairn flood risk appraisal[2]. Ultimately coastal change and flooding management at Nairn need to be linked as it is illogical to manage the coast and not the river (or vice versa). This document is to be read in conjunction with the Methodology[3], the Baseline Survey[4], Historic Change[5] and Coastal Resilience Assessment[6] reports.

The coast at Nairn is dynamic and, throughout history, has responded to storms and other climate variables. Changes of the Nairn coastline will continue and become more pronounced in response to future climate change. With the rise in sea levels already being experienced, and further sea level rise committed to in the coming decades, Nairn's coastal edge will, in many places, retreat landwards. This means that places that are on land today may be flooded or eroded in the future. This will inevitably lead to loss of land and pressure on assets and amenity space; ultimately changing the relationship the Nairn community have with their coast.

As a result, we cannot rely on traditional, engineered, coastal risk management approaches alone to protect communities against these risks in the future. Instead, we must become more resilient and adapt to our changing coast through combined coastal risk management and climate resilient development planning. Coastal change adaptation aims to improve the climate resilience of the ecosystems, communities, infrastructure, and human well-being, supported by the natural coastal environment.

In this report, initial Dynamic Adaptive Pathway are presented that aim to support The Highland Council (THC) facilitate adaptation of the dune system along the coast at Nairn.

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[2] IGZ-JBAU-00-00-RP-HM-0001-S4-P05-Nairn_Flood_Risk_Appraisal
[3] IGZ-JBAU-XX-XX-RP-MO-0001-S3-P02-Coastal_Change_Adaptation_Methodology
[4] IGZ-JBAU-XX-XX-TN-MO-0001-S3-P02-Baseline_Survey
[5] IGZ-JBAU-XX-XX-TN-MO-0002-S4-P02-Historic_Change
[6] IGZ-JBAU-XX-XX-TN-MO-0003-S3-P01-Coastal_Resilience_Assessment

2 Dynamic Adaptive Pathways - Approach

Dynamic Adaptive Pathways are flexible tools that can be used to make current and future decisions across all involved sectors to accommodate coastal change and associated uncertainty[7]. They highlight the preferred, or anticipated, path to adaptation, while recognising that other alternative pathways exist and may have to be taken in the future.

As well as the traditional management, they should identify opportunities to work with natural processes, enhance the environment and include necessary supportive steps to create space (e.g., accommodate erosion through land safeguarding) in preparation for inevitable future sea level rise and associated increases in erosion and flooding.

Ultimately, a Dynamic Adaptive Pathway should be developed with an associated Action Plan to enable delivery (development, financing etc.) of local coastal management actions and land-based decisions.

Planning for adaptation involves establishing pathways and a process that enables selecting the preferred pathway and/or shifting from a type of pathway to another. To provide a solid structure to the adaptation approach, the following are defined:

- *Adaptation Framework*

  The mechanism to support moving from one pathway to another.

- *Dynamic Adaptative Pathway*

  Several pathways will have to be defined that may (or may not) be the chosen management option as the coast, climate and community changes through time. To allow for present and future considerations, pathways are defined for a range of temporal phases. These are Current, Short-term, Medium-term and Long-term.

2.1 Adaptation Framework

The adaptation framework supports the delivery of the Dynamic Adaptive Pathways, representing the process necessary to be undertaken for consideration of moving to a new pathway. Figure 2-1 provides a sketch of the steps involved in the process.

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[7] Scottish Government (2023) Coastal Change Adaptation Plan Guidance – Interim https://www.dynamiccoast.com/files/ccapg_2023feb.pdf
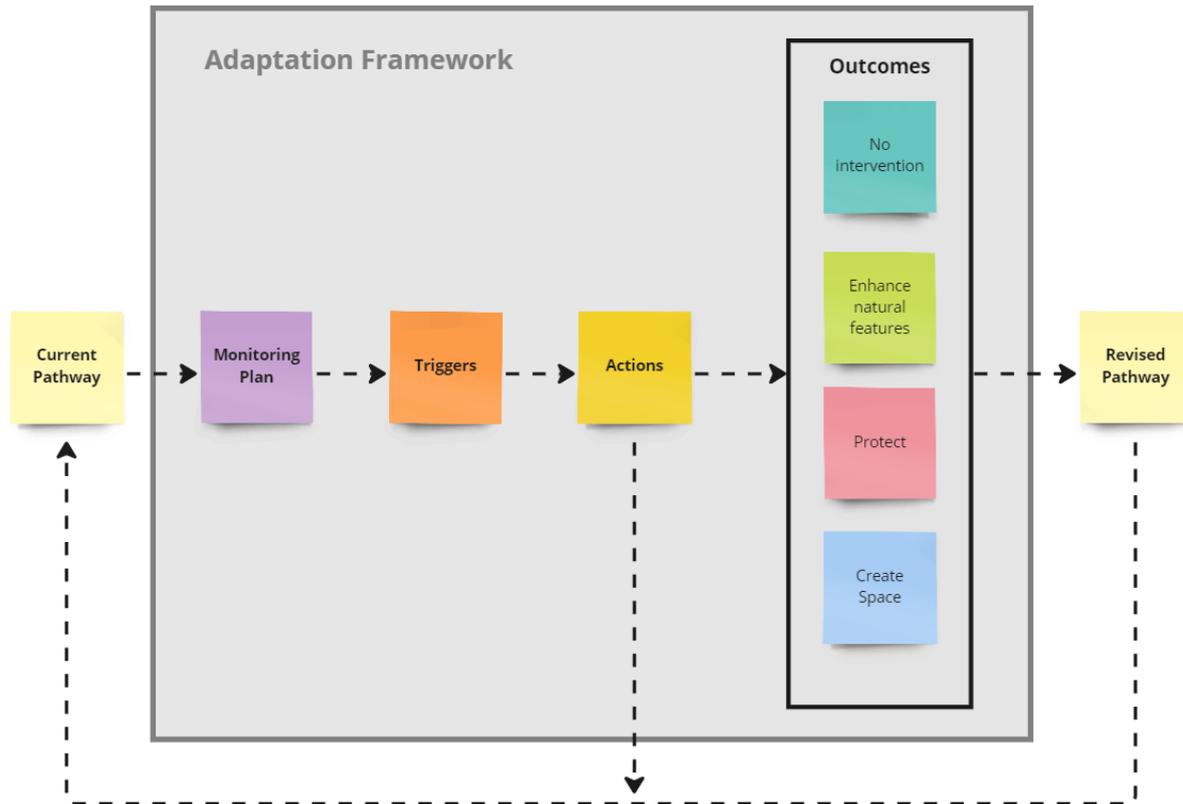
Figure 2-1: High Level Adaptation Framework.

The **Adaptation framework** has three stages:

1) Monitoring and Triggers

2) Actions

3) Outcomes

The outcome of the Adaptation Framework determines what path will be followed within the Dynamic Adaptive Pathway when moving to a new phase. Outcomes are the potential type of intervention measures that will be implemented after a trigger is realised and the associated actions have been undertaken.

There are four possible **outcome** categories:

1) No intervention:

   Do nothing and allow erosion processes to occur.

2) Enhance natural features:

   Improve the protection provided by natural features, i.e., dunes, beach.

3) Protect:

   Maintain/improve/introduce protection provided by engineered built structures.

4) Create space:

Accommodating erosion through the creation of space where erosion can safely occur and assets can be relocated.

The complete Adaptation Framework is presented in Appendix A.

2.2   Dynamic Adaptive Pathway

Outcomes of the Adaptation Framework link to the Dynamic Adaptive Pathways. A sketch of the Dynamic Adaptive Pathway is presented in Figure 2-2. This is formed of current and future phases. Moving from one Phase to the other depends on triggers. Each Phase outlines alternative pathways.
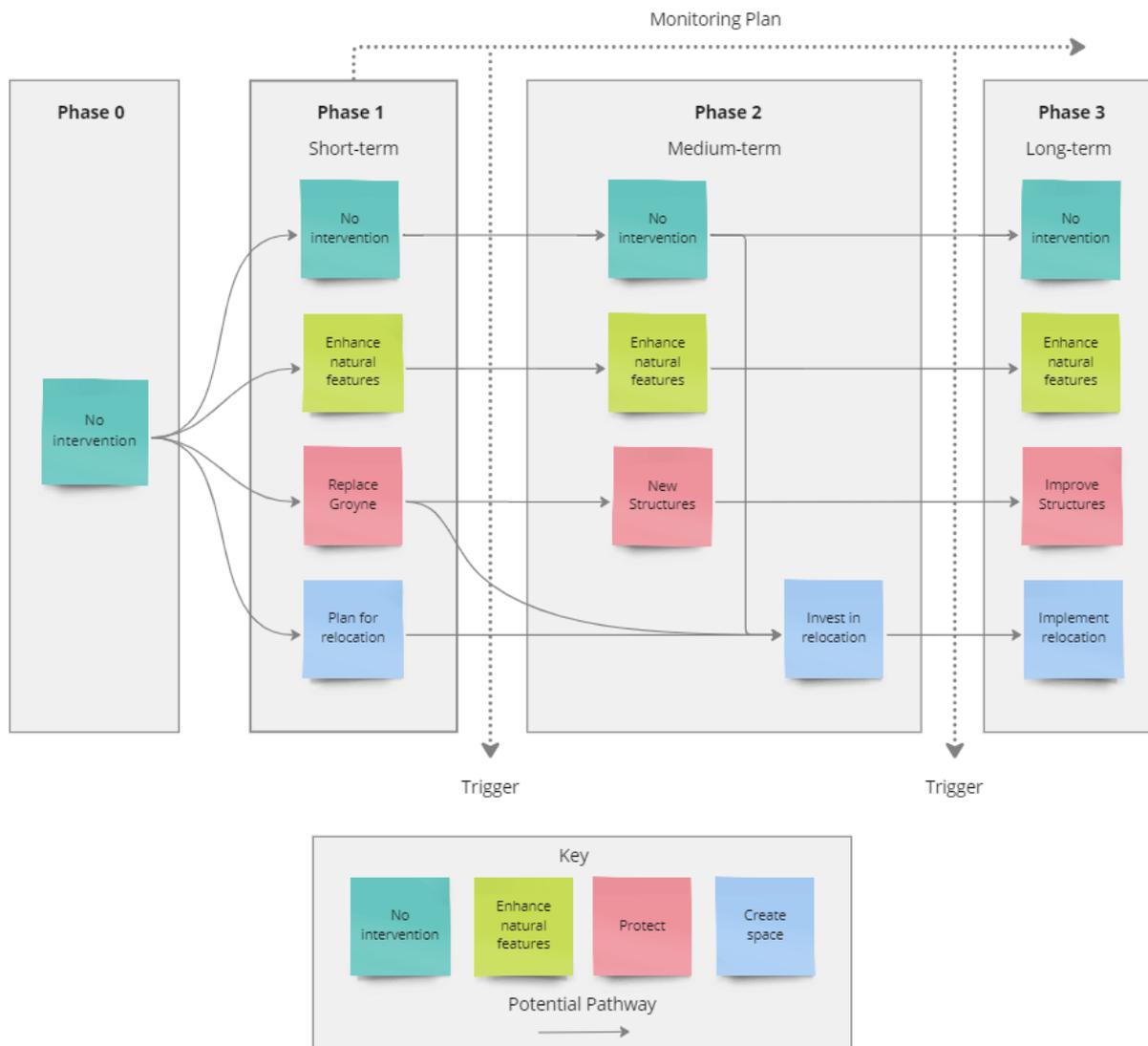
Figure 2-2: Example Dynamic Adaptive Pathway.

2.2.1 Phases

Phase 0 of the Dynamic Adaptive Pathway (1st column, Figure 2-2) represents the current management action taken by THC.

For the Dynamic Adaptive Pathway to move to **Phase 1** (2nd column in Figure 2-2 containing potential outcomes), a decision to change the management approach must be made. At this stage the chosen management option at Phase 1, or anticipated pathway, is based on results from the Coastal Resilience Assessment for Nairn[6].

For the Dynamic Adaptive Pathway to move to **Phase 2** (3rd column containing potential outcomes) a pre-defined trigger must be realised. Then, depending on the outcome of any actions, this may or may not result in a change to the future management approach adopted. The direction of the pathway from Phase 1 onwards is dependent on the trigger realised and associated actions and outcomes undertaken.

The **timescales** for outcomes implemented at each phase are summarised below:

- Phase 1 = Short-term

- Phase 2 = Medium-term

- Phase 3 = Long-term

However, the timing of each phase is ultimately dictated by when a trigger is met, so these timescales are not definitive.

2.2.2 Triggers and thresholds

Triggers are used in Dynamic Adaptive Pathway to signal when the current management approach should be reviewed, and possibly changed, in response to updated information or change of circumstance i.e., resilience has decreased. In other words, triggers associated with the Dynamic Adaptive Pathway require local authorities to make decisions in the coastal change management approach; to adapt to climate change at both short-term and long-term timescales.

The next phase of the Dynamic Adaptive Pathway is instigated once a Trigger has been realised. Triggers specific to the risk are formed of two levels (Figure 2-3):

- Trigger:

    - Instigate change and planning

A trigger signals an increase in risk and that increased monitoring and an assessment is required. The assessment should determine on the most appropriate intervention option to take once the threshold has been met.

- Threshold:

    - The risk limit - implementation

A threshold signals that risk has increased beyond the manageable limit and therefore, a change in management approach is needed. The chosen and planned intervention option (established after a trigger is met) should be implemented.
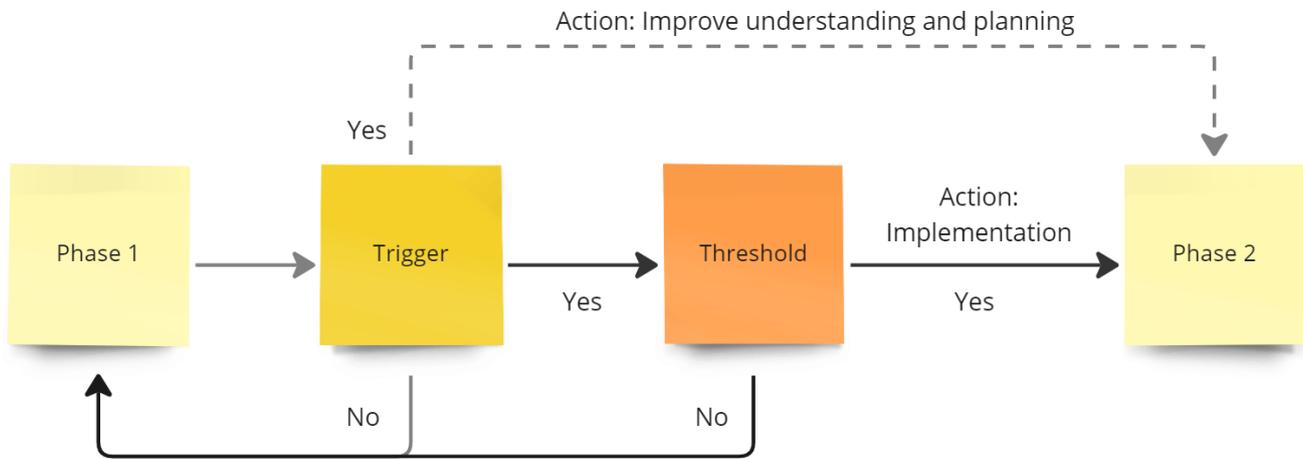
Figure 2-3: Example implementation of a change in Dynamic Adaptive Pathway phase.

2.3 Coastal Management Units (CMUs)

To facilitate the development of the pathways, the Nairn coast has been divided into two distinct Coastal Management Units (CMUs) (Figure 2-4). The different nature and characteristics of these mean a separate Dynamic Adaptive Pathway to reflect the specific risks and relevant management approaches at each CMU:

- West Beach (section 3)
- East Beach (section 4)

While different management approaches may be adopted for each area, the decisions made will impact the resilience of the whole coast. Therefore, a whole systems approach should be taken at Nairn when making management decisions at the two CMUs, as well as Nairn Harbour.

On a similar note, the management decisions made for coastal change, as considered in this report, need to link with decisions made for flood risk management (FRM) on the River Nairn. A trigger that considers any updates made in relation to the River Nairn FRM approach is included in Appendix B.

Figure 2-4: CMU areas: West Beach and East Beach at the Nairn coast.

Through the Coastal Resilience Assessment report[6], and then the following assessments taken at initial trigger levels (section 3.4.2 West Beach, section 4.4.2 East Beach), an appropriate outcome for each CMU and associated direction of the Dynamic Adaptive Pathway will be established.

3 West Beach

3.1 Summary of Risk

Coastal change risk and associated resilience at West Beach is presented in the Baseline Survey[2], Historic Change[3], Coastal Resilience Assessment[6] reports. The analysis conducted strongly relies on the available datasets. However, availability of historic topographic data is limited in Scotland. Thus, it should be noted that the conclusions made on the coastal change risks at West Beach are based on two main sources of topography data, a decade apart from one another (2011 and 2023).

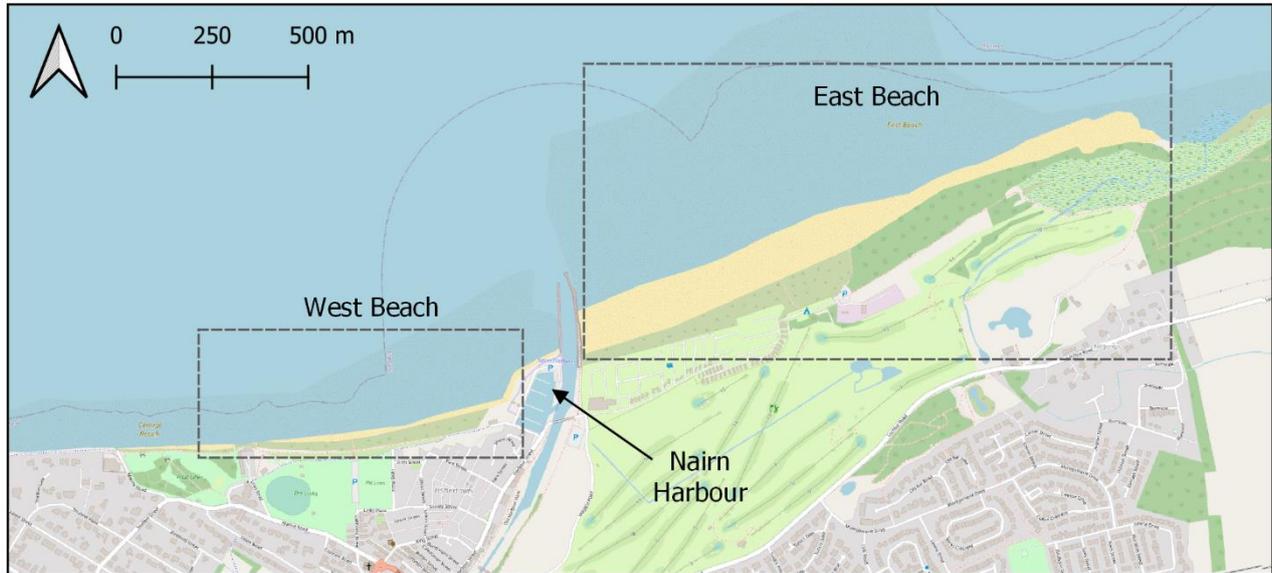The Coastal Resilience Assessment report developed a Coastal Resilience Index (*CRI*) to understand the overall resilience of the dune system at Nairn. A low *CRI* is reflective of low resilience, in other words, vulnerability to coastal change, whereas a high *CRI* is reflective of high resilience, in other words, less vulnerable to coastal change.

The summary of risk presented below is based on the available data and methods used in the *CRI* calculation. The findings from the Coastal Resilience Assessment are summarised below:

Overall Coastal Resilience:

- West Beach is less resilient than East Beach.

- Low to lowest *CRI* scores are located to the west of West Beach, with lowest scores located close to the groyne (Figure 3-1).

- Between 2011 and 2023, *CRI* scores have decreased across the west of West Beach.

Dune and beach morphology:

- Minimum distance from shoreline to asset (footpath at rear dune) = **14 m**, located at west of West Beach.

- Minimum dune volume = **18 m^3 / m**, located at the west of West Beach[4].

- Maximum percentage of dune volume loss because of a 1 in 200-year storm event = **41%**, located at west of West Beach.

- Maximum shorelines change by 2050 because of Sea Level Rise (SLR) = **-23 m** (erosion), located at west of West Beach.

Vegetation:

- Resilience in relation to vegetation species and cover is lowest to the west of West Beach

Key areas and assets located within the Dynamic Coast 2100 erosion vicinity zone:

- 53 residential properties

- 8 non-residential properties

- West Links – greenspace, leisure facilities

- The Links – greenspace leisure facilities

- Coastal footpath

- Marine Road, Links Road, Links Place

- Links Car Park, West Links Car Park

Coastal resilience at West Beach is shown with transects coloured by *CRI* scores, as well as key assets within the Dynamic Coast 2100 erosion vicinity zone and maximum shoreline change in 2050 due to sea level rise (23 m of erosion) Figure 3-1.
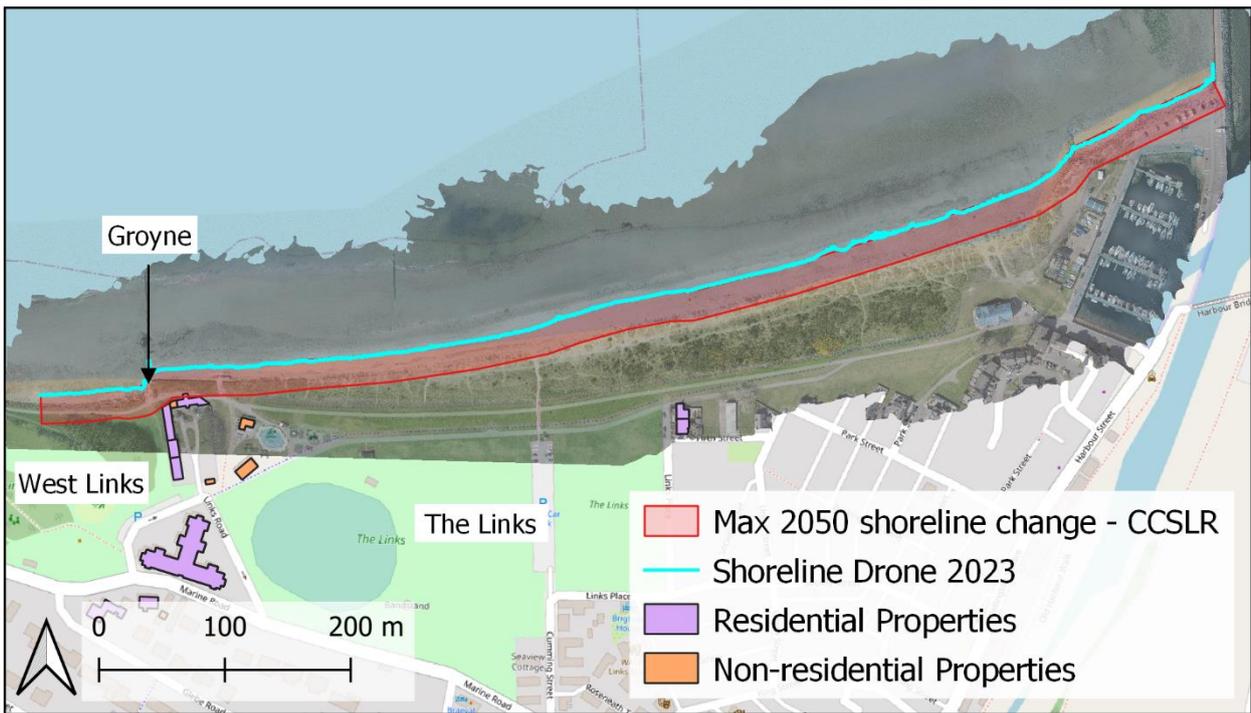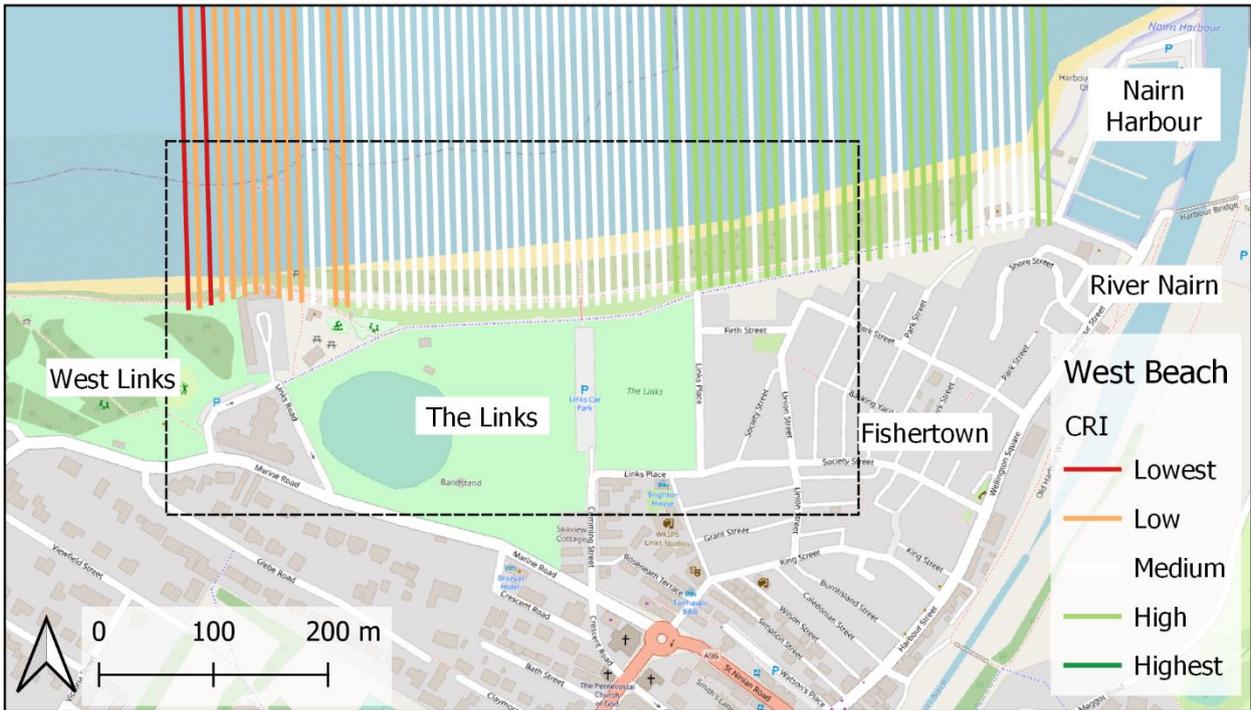
Figure 3-1: West Beach *CRI* transects from Coastal Resilience assessment report[6]; key assets within the Dynamic Coast 2100 High Emission Scenario (HES) erosion vicinity; maximum shoreline change in 2050 (-23 m) based on CC_{SLR} results[6].

3.2 Dynamic Adaptive Pathway

The Dynamic Adaptive Pathway for West beach is presented in Figure 3-2.

West Beach shows areas of low to lowest resilience scores, low dune volume, close proximity of shoreline to assets and risk of storm and sea level rise-induced erosion. At this stage, the risk is not considered extreme to instigate immediate protective measures. This is justified because risk is not present in the short-term (maximum 23 m of erosion by 2050) (Figure 3-1) and because the dunes are modelled to have the capacity to withstand a one-off extreme event (maximum 41% dune volume loss due to a 1 in 200-year storm). Furthermore, the area where risk is greatest is located close to the groyne; risk here is therefore complex and needs to be understood better before protective intervention.

A proactive and sustainable approach that could slow down disruptive changes in the longer term should be considered. Thus, the current management option (**Phase 0**) of No Intervention should be changed.

As a result, the Dynamic Adaptive Pathway at West Beach should enter **Phase 1**. The chosen coastal management option at Phase 1, or **anticipated pathway**, is to **Enhance Natural Features**. This pathway is chosen as there is potential to increase the protection provided by the natural system at West Beach by increasing the resilience of the dunes and correspondingly reducing risk. In other words, the current predictions of risk are such that there is potential that these could be managed though enhancing the beach and dune system.

From Phase 1 onwards at West Beach, the specific Enhance Natural Features outcome is dependent on which trigger is met (see section 3.4.2) and how coastal resilience is improved through the associated action. The anticipated pathway is also subject to change in relation to which triggers are met.

As well as coastal management options, land-based management options should be addressed with a supporting pathway, delivered in parallel. This acknowledges that the desired management pathways may not be achievable in the future for a variety of reasons (e.g., technical, economic, legislative etc).

The **supporting pathway** at West Beach is to **Create Space**, which means plans for potential relocation and re-development should start at Phase 1. The aim of this is to understand the maximum potential land loss and accommodate this though development and implementation of proactive planning and land use policies. The pathway to Create Space should be supported with No Regret Actions (see section 3.4.3).

Specific coastal management options to Enhance Natural Features and land-based management options to Create Space are included in the **Action Plan** (section 3.3).

The Phase 1 Dynamic Adaptative Pathway approach at West Beach is summarised below:

- **Anticipated path = Enhance Natural Features**

- **Supportive path = Create Space**
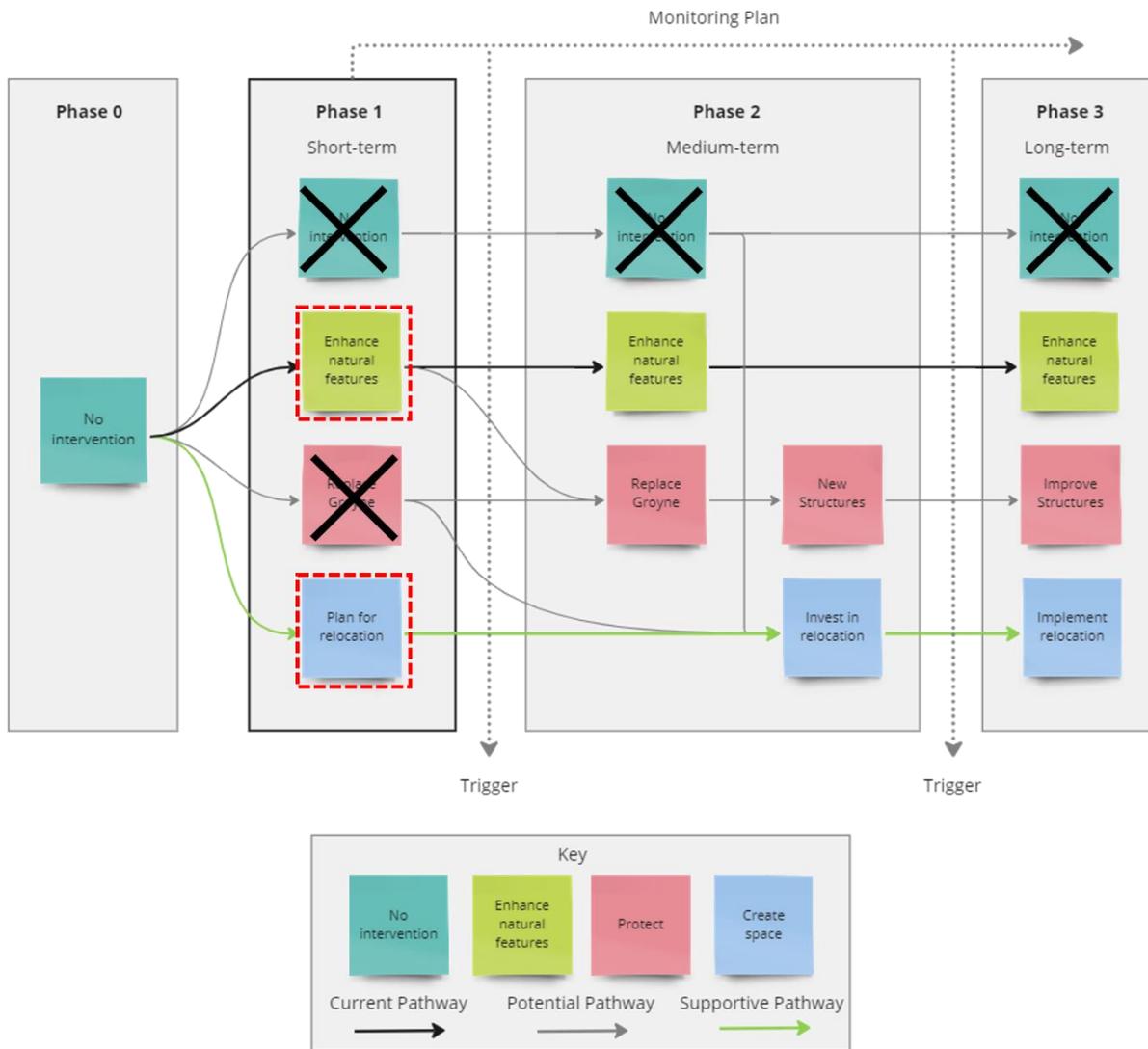
Figure 3-2: Dynamic Adaptive Pathway for West Beach. Grey lines show all possible pathways for coastal management; the black line shows the current anticipated or preferred pathway; the green line shows the supportive pathway; black crosses show options that are no longer viable based on current management decisions; and the red box shows the recommended option to be implemented at the current phase of the Dynamic Adaptive Pathway.

3.3   Action Plan

The Action Plan for Dynamic Adaptive Pathway implementation at West Beach is included in Table 3-1. Actions presented in the Action Plan are JBA's recommended Actions based on the current understanding of risk. It is important to consider other Actions that may become more appropriate as understanding improves through implementation of a monitoring plan (section 3.4.1).

The Action Plan includes short (phase 1), medium (phase 2) and long-term (phase 3) coastal management actions to support the current anticipated pathway at West Beach,

which is to **Enhance Natural Features**. If a trigger is realised and a change in management approach is required, i.e., Enhance Natural Features is no longer appropriate, a new action plan will need to be developed to support the different outcome (e.g., protect).

As well as coastal management actions, short, medium, and long-term land-based management actions are included to support the supportive pathway at West Beach, which is to **Create Space**.

Table 3-1: Action Plan, including short, medium and long-term coastal and land-based management options for West Beach.

West Beach Action Plan	Anticipated Pathway (Coastal Management)	Supportive Pathway (Land-based management)
Adaptation Plan: Short term (Phase 1) (noting uncertainty, actions after first decision point)	Continue to **monitor & plan multiple options** - Vegetation planting/ translocation - Review and change dune access arrangements - Sediment recycling	Continue to **monitor & plan multiple options** - Understand land and assets at risk ownerships - Engagement with public, stakeholders and planners - Discussions with legal teams - Review of Scottish Government resilience strategy (when available)
Adaptation Plan: Medium-term (Phase 2) (post decision point 2 noting uncertainty – subject to change if anticipated pathway or risk changes from current understanding)	Continue to **monitor & plan multiple options** - Continue sand recycling and dune re-profiling to improve resilience to storms - Maintain current position using sand recycling	Continue to **monitor & plan multiple options** - Move public footpath - Make changes to greenspace - Investigate compulsory purchase options for properties - Land purchase for re-development for properties
Adaptation Plan: Long-term (Phase 3) (noting uncertainty - subject to change if anticipated pathway or risk changes from current understanding,	Continue to **monitor & plan multiple options** - Dune/beach recharge to maintain re-profiled shape	Continue to **monitor & plan multiple options** - Property relocation

West Beach Action Plan	Anticipated Pathway (Coastal Management)	Supportive Pathway (Land-based management)
actions after next decision point)		

3.3.1 Phase 1 Actions

Phase 1 actions at West Beach to support the **Enhance Natural Features** anticipated pathway:

- **Vegetation planting:**

  Development of a dune planting programme that focuses on vegetation enhancement and coverage. Outcomes from the National Vegetation Classification (NVC) and *Coastal Resilience Index* (CRI) [6] are used to identify potential for vegetation translocation from "healthier" parts of the system. *CRI* inputs for vegetation species baseline Veg_0 and vegetation cover Veg_{h_cover} suggest that the vegetation at the east of East Beach is in a healthy and stable condition[6]. Translocation of vegetation from this area to West Beach could improve the resilience of the dune system toward the west of West Beach, where relative resilience is lowest.
  Marram Grass planting is often chosen as a method to reduce dune erosion through natural processes[8]. An on-site survey may be required to establish what areas at the west of West Beach are suitable for planting in order to increase the resilience of the dunes. Considerations need to be made for the exact location of planting. For example, Marram grass should be located above the high tide mark to avoid saltwater submersion[8]. An area of West Beach with lowest resilience is suggested as a target area for Marram Grass planting (Figure 3-3).

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[8] Clean Coasts (2015) A Practical Guide to Marram Grass Planting: A Natural Coastal Defence, https://cleancoasts.org/wp-content/uploads/2015/04/A-Practical-Guide-to-Marram-Grass-Planting-.pdf
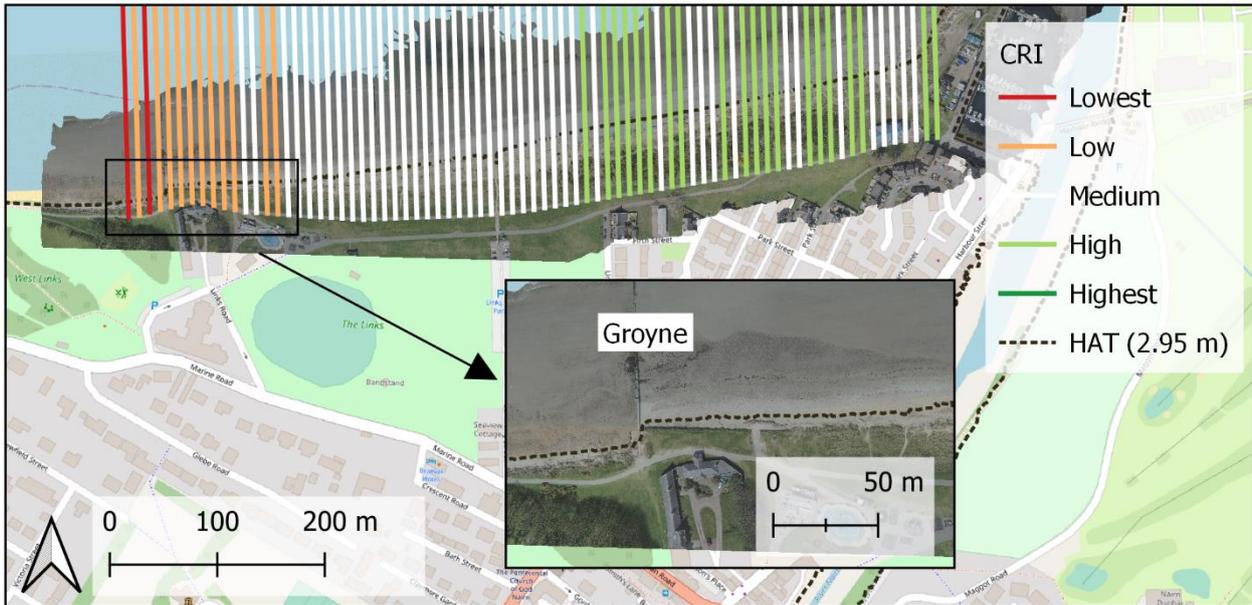
Figure 3-3: Area of West Beach with lowest resilience highlighted as a possible location for Marram Grass planting. Planting should be located above the Highest Astronomical Tide (HAT) elevation (2.95 m).

- **Dune access arrangements:**

    Conduct data collection on the location and condition of current beach and dune access points, including footpaths and the location of carparks etc. Highlight where access points are causing disruption to dune stability/ enhancing erosion of the dune. Opportunities for new beach and dune access points should also be explored and developed. Implement revised access point relocation away from vulnerable areas. Also, forbid the public from crossing dunes (installing signages and possibly fencing) to allow low resilience areas to recover naturally through a reduction in vegetation disturbance. Consideration should be given to formalise beach access where resilience is highest.

    Access points through the dunes in the low resilience area at West Beach are highlighted in Figure 3-4. Potential relocation of these access points could help reduce further erosion and disturbance to vegetation in these areas.
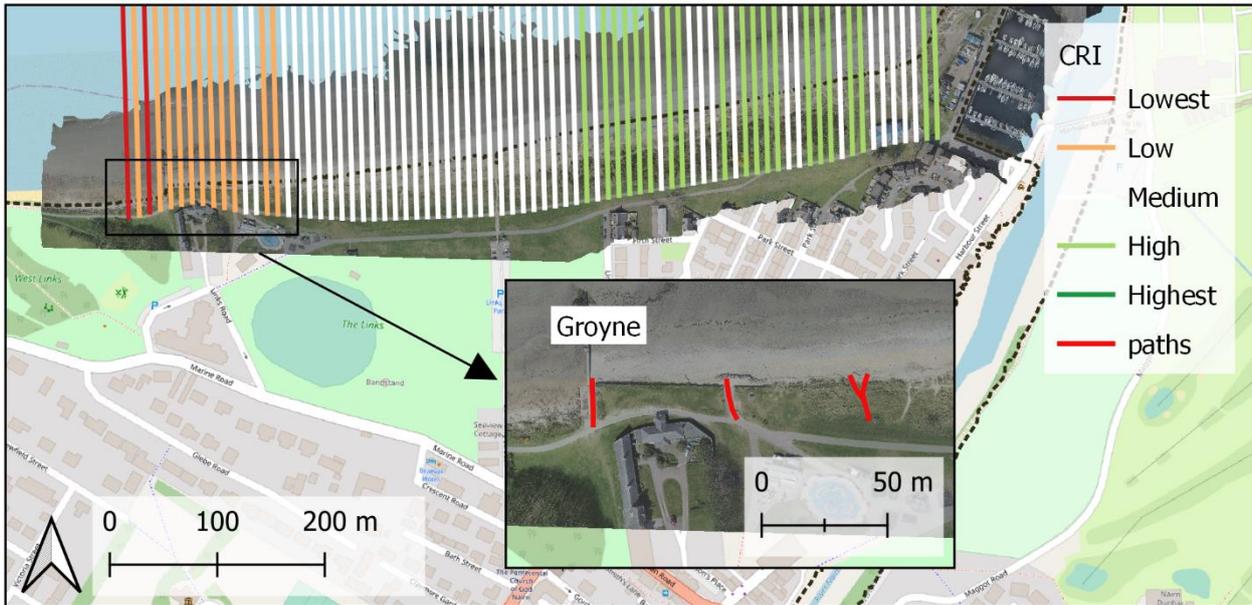
Figure 3-4: Area of West Beach with lowest resilience highlighted and location of present access points. Potential relocation of these footpaths could help reduce further erosion and disturbance to vegetation in these areas.

- **Sand recycling:**

  Investigate opportunities for sand recycling to achieve consistency across the dunes in terms of capacity and shoreline position. Consideration should be given to

  - Beneficial Use of Dredged Sediments – from Nairn Harbour
  - Recycling from within West Beach – from areas with highest resilience
  - Borrow pits and transport of sediment from East Beach – with areas of highest resilience.

Phase 1 actions at West Beach to support **Create Space** supportive pathway include:

- **Understand land and asset ownerships:**

  Establish a database ownerships for land and assets with close proximity to the coast at West Beach (section 3.1).

- **Engagement with public, stakeholders and planners**
- **Discussions with legal teams**
- **Review of Scottish Government resilience strategy**

3.4 Delivery

Triggers are realised through monitoring of available data that informs the resilience of the dune system at Nairn.

Specific triggers require information as these triggers are assigned quantified thresholds which need to be regularly monitored by THC. Specific triggers have associated actions, which should be implemented if the trigger is realised.

As well as specific triggers, generic triggers may not require direct monitoring by THC and are associated with updates to data/information provided by third party data and information, data that THC already hold/collect, or from external pressures. These generic triggers are applicable across the whole of Nairn coast. Generic triggers and associated actions and the monitoring required for both CMUs are included in Appendix B.

Some specific triggers are recognised by means of the *CRI* which should be updated following THC monitoring of required data. *CRI* inputs and the overall *CRI* score, calculated in May 2023 are included in the Coastal Resilience Assessment report[6] and can be used as the baseline to monitor changes in dune resilience and associated triggers at Nairn. Examples of how the *CRI* tool can be used to monitor specific triggers are included in Appendix C.

3.4.1 Monitoring plan

Specific triggers identified at Phase 1 of the Dynamic Adaptive Pathway for West Beach, which are to be monitored by THC include:

1) **Vegetation Cover**

2) **Erosion**

3) **Dune volume loss**

4) **CRI**

5) **Coastal engineered structure condition**

It is recommended that THC considers **monitoring** of specific triggers, that is, data collection on vegetation cover, erosion and built structure condition. Ideally if budgets allow, surveys would be conducted **at least annually** at **West Beach**. The exception is the dune volume loss trigger, where data collection should occur after a storm occurrence as well as annually.

A more detailed monitoring plan, including the monitoring of triggers and thresholds is included in Appendix D.

3.4.2 Triggers and threshold

All triggers that require THC monitoring at West Beach are summarised in Table 3-2.

When a trigger is met an assessment is required to better understand changes to risk following a trigger. The assessment should determine on the most appropriate intervention option to take once the threshold has been met:

- **Trigger** met:
  Action: Increase monitoring and undertake assessment
- **Threshold** met:

Action: Implementation of chosen intervention and continue monitoring plan

Assessments associated with each trigger are summarised below:

Vegetation cover assessment:

- Use *CRI* tool to test Marram Grass planting/ translocation.
- Assess options for changes to dune access arrangements.
- Resource/ cost of fencing
- Ecology consultants to consult on best options for and develop Marram Grass planting/ translocation methodology

Erosion assessment:

- Use *CRI* tool to test beach replenishment/ sand recycling.
- Assess options for changes to dune access arrangements.
- Resource/ cost of fencing
- Detailed risk assessment with new information about when risk may be realised and associated economic damage. Options appraisal should be conducted following relevant guidance and best practice with a preferred management option identified.

Dune volume loss assessment:

- Same as erosion assessment

CRI assessment:

- Consider all assessments associated with vegetation cover, erosion and dune volume loss triggers

Condition assessment:

- Detailed risk assessment with new information about when risk may be realised and associated economic damage. Options appraisal should be conducted following relevant guidance and best practice with a preferred management option identified.

Table 3-2: West Beach Triggers and Thresholds.

Trigger Type	Trigger	Threshold
Vegetation Cover	Vegetation cover = low resilience (2) across >= 500 m of frontage	Vegetation cover = lowest resilience (1) across >= 200 m of frontage
	Vegetation cover decreases one resilience level (e.g., 3 to 2) within one year	Vegetation cover change decreases one resilience level (e.g., 3 to 2) within one year
Erosion	Distance between shoreline and asset (D_{S-A}) = low resilience (2) across >= 100 m of frontage	Distance between shoreline and asset (D_{S-A}) = lowest resilience (1)
Dune volume loss	Coastal change due to storms (CC_{Storm}) = lowest resilience (1)	Coastal change due to storms (CC_{Storm}) = lowest resilience (1) across >= 100 m of frontage
CRI	CRI = lowest resilience (1) across >= 100 m of frontage	CRI = lowest resilience (1) across >= 200 m of the frontage
Built structure condition*	Defence condition Grade 4	Defence condition Grade 5
* Grades of coastal defence condition according to the EA and Defra condition assessments[9] are associated with the groyne at West Beach. These specific condition triggers assume structures are currently Grade 3 but this should be reviewed upon completion of the No Regret Action for engineered structure condition (section 3.4.3).		

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[9] Environment Agency (2013) Practical guidance on determining asset deterioration and the use of condition grade deterioration curves: Revision 1.

3.4.3 Supportive steps and No Regret Actions

Supportive steps are required to help deliver the Action Plan. The nature of adaptation means that future decisions and directions are unknown and will be affected by external changes not necessarily under THC influence. It is critical that proactive supporting steps and No Regret Actions are undertaken to enable effective decision making in the future.

No Regret Actions is anticipated to provide a net benefit regardless of other actions or inactions without first undergoing rigorous analysis. Undertaking these can therefore only have a positive impact on supporting adaptation or increasing resilience.

1) Establish coordinated and consistent dune and beach monitoring plan

Monitoring of data and information is essential to the success of coastal change adaptation. Establishing a coordinated and consistent dune and beach monitoring plan will improve both the reliability and quality of monitoring data and information that can inform coastal resilience at the Nairn coast.

Information should be collected through monitoring that is specific to support future risk assessments and compared to specific erosion and dune vegetation triggers. It should focus across the entire Nairn coast but increase in frequency and detail where predicted risk associated with erosion and coastal change is greatest. Potential elements of a monitoring plan at West Beach are discussed below.

- **Built Structure condition**

Establish and standardise defence asset condition database, including a mechanism for updating this and for identifying triggers in advance. This No Regret Action is specific to the groyne at West Beach and supports monitoring of the coastal engineered structure condition trigger (section 3.4.2). Additionally, a second groyne, previously covered by the beach was exposed on West Beach after a storm event between the 27th and the 29th of October 2023 caused beach levels to lower should also be included in the asset condition database.

2) Exploring automated and remote monitoring and integration of data options

Examples of potential monitoring technologies and data are described below but are subject to available budget from the Council for both the equipment and the resources for data analysis.

- **High resolution satellites**

Investigate opportunities for monitoring data using high resolution satellites at the Nairn coast. High resolution satellites are an example of Earth Observation (EO) data and can be used to collect data on shoreline change and vegetation coverage as demonstrated in the Historic Change report[5]. In the Historic Change report, freely-available satellite imagery was used to explore a low-cost option, but low spatial resolution caused high uncertainty in the data collected[5,6]. High resolution satellites have the potential to provide low-uncertainty, autonomous and easily processed data to allow for effective coastal change monitoring at Nairn. The viability of using high-resolution satellites, including

costing, frequency of images required etc. should therefore be investigated. If found suitable consideration should be given to remote monitoring and analysis to reduce the burden on council staff time carrying out field measurements. Extraction and analysis of EO data is currently a specialist skill so training in how to use the data would be required. As the availability, quantity and quality of EO data increases it is not unreasonable to assume that a user friendly interfaces will be developed at some point in the not too distant future.

- **Camera system**

A camera system set up at the Nairn coast is another example of an autonomous, and effective monitoring tool for coastal change. Photographs taken at a constant and known frequency by a fixed camera can provide reliable data on shoreline position, dune toe and crest position, and wave runup. The cost, frequency of images needed, and appropriate location of the camera system, budget permitting, could be investigated to decide whether this is a viable monitoring option for Nairn.

3) Land safeguarding for asset relocation

Creating Space is a supportive pathway for West Beach, which means plans for relocation and other place making opportunities need to start now to accommodate land loss in response to inevitable future erosion and flooding.

To work with natural processes and make space for coastal change it is inevitable that existing land will be lost to make space for natural systems such as beaches to dynamically adjust to climate change impacts such as sea level rise, and to continue to alleviate risks for people. To adapt effectively it is therefore important that a) planning is used to restrict new and existing assets that are increasingly at risk and b) to make space for the natural adjustment of the coast in response to coastal climate change drivers (e.g., sea level rise and storms). To do this, it is important that land and asset ownership is fully understood, to identify windows of opportunity to reduce impacts of coastal climate change on communities; thereby increasing the climate resilience of these communities to coastal change. This should feed into revisions of the wider Highland-wide Local Development Plan[10] (HwLDP).

Assets in need of consideration at West Beach include the key areas and assets located within the Dynamic Coast 2100 erosion vicinity zone (section 3.1)

4) Community Engagement and Awareness raising

Community Engagement is key in coastal adaptation to understand the community's priorities and what the community want their coast to look like and how to function in the future. Community engagement workshops should be held for groups including:

- **Places:** Involves local Nairn groups, such as local Councillors and affected community groups.

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[10] The Highland Council (2012) highland-wide Local Development Plan

- **Practice:** Involves third party stakeholders, such as SEPA, Scottish Government, Nature Scot etc.
- **Asset:** Includes private engineered structures, harbours and utilities

5) CoastSnap

THC is undertaking an assessment on the appropriate location for installation of a CoastSnap[11] citizen science station to support monitoring and community engagement. Similar to the camera system, photographs can be collected freely to obtain qualitative records and extract shoreline and/or dune toe/crest position. CoastSnap has the added advantage of engaging the community and increasing awareness of coastal change and climate change impacts at the Nairn coast: an essential component to coastal change adaptation.

6) Beneficial Use of Dredging Sediment (BUDS)

The harbour at Nairn has been dredged twice in the last 20 years. A study should be undertaken to explore the potential for the dredge sediment to be used in a beneficial way, by depositing the dredged material on (or near) West Beach to increase resilience of the dunes. An analysis on the dredged sediment would be required to determine if suitable for a potential recharge. West Beach is the proposed site for deposited material due to lower dune volumes and closer proximity of assets to the shoreline in comparison to East Beach.

7) Control Invasive Non-Native Species

In the Baseline Survey report[4], several Invasive Non-Native Species (INNS), including Japanese Knotweed, Giant Hogweed and Japanese Rose were identified in the dune vegetation at Nairn. Establishing a monitoring and management plan to control the spread of these species will support the stability of the vegetation, and in turn, the stability of the dune system at Nairn.

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[11]CoastSnap (2023) UNSW https://www.coastsnap.com/

4 East Beach

4.1 Summary of Risk

Coastal change risk and associated resilience at East Beach is presented in the Baseline Survey[2], Historic Change[3], Coastal Resilience Assessment[6] reports. The analysis conducted strongly relies on the available datasets. However, availability of historic topographic data is limited in Scotland. Thus, it should be noted that the conclusions made on the coastal change risks at East Beach are based on two main sources of topography data, a decade apart one another (2011 and 2023).

The Coastal Resilience Assessment report developed a Coastal Resilience Index (*CRI*) to understand the overall resilience of the dune system at Nairn. A low *CRI* is reflective of low resilience, in other words, vulnerability to coastal change, whereas a high *CRI* is reflective of high resilience, in other words, less vulnerable to coastal change.

The summary of risk presented below is based on the available data and methods used in the *CRI* calculation. The findings from the Coastal Resilience Assessment are summarised below:

Overall Coastal Resilience:

- East Beach is more resilient than West Beach

- There are no areas of lowest or low *CRI* scores at East Beach

- Between 2011 and 2023, *CRI* scores have decreased across the east of East Beach

Dune and beach morphology:

- Minimum distance from shoreline to asset (footpath at rear dune) = **46 m**, located at the east of East Beach

- Minimum dune volume = **104 m³ / m**, located at the east of East Beach[4]

- Maximum percentage of dune volume loss as a result of a 1 in 200-year storm event = **11%**, located at the east of East Beach.

- Maximum shoreline change at 2050 as a result of Sea Level Rise (SLR) = **+4 m** (accretion), located at west of East Beach.

Vegetation:

- Resilience in relation to vegetation species and cover is lowest to the west of East Beach

There is no Dynamic Coast data on erosion or assets at risk of erosion at East Beach due to the complexities of the coast in this area.

Key areas and assets located with close proximity to the coast:

- Nairn Lochloy Holiday Park– greenspace, leisure facilities, tourism

- Nairn Dunbar Golf course – greenspace leisure facilities, non-residential properties

- RSPB Culbin Sands – greenspace, Special Protection Area (SPA).

Coastal resilience at East Beach is shown with transects coloured by *CRI* scores, as well as areas and assets with close proximity to the coast (Figure 4-1).

Figure 4-1: East Beach *CRI* transects from Coastal Resilience assessment report[6] and key areas with close proximity to East Beach at Nairn.

4.2   Dynamic Adaptive Pathway

The Dynamic Adaptive Pathway for East beach is presented in Figure 4-2.

East Beach shows medium to highest resilience scores, large dune volume, minimal assets and low risk of storm and SLR-induced erosion. Therefore, at this stage, there is no need to move from the current **Phase 0**, management option (No Intervention) to the next one. As a result, the Dynamic Adaptive Pathway at East Beach remains at **Phase 0** (section 2.2.1).

The chosen coastal management option at Phase 0, or **anticipated pathway** is **No Intervention**. This pathway is chosen as the present risk is minimal and therefore, currently requires no management interventions at East Beach.

From Phase 0 onwards at East Beach, the specific outcome is dependent on which trigger is met (section 4.4.2) and how coastal resilience is improved through the associated action. The anticipated pathway is also subject to change in relation to which triggers are met.

As well as coastal management options, land-based management options should be addressed with a supportive pathway, delivered in parallel. This acknowledges that the

desired management pathways may not be achievable in the future for a variety of reasons (e.g., technical, economic, legislative etc). As the Dynamic Adaptive Pathway at East Beach remains in Phase 0, there is no need to initiate a supportive pathway at this stage.

The Phase 0 Dynamic Adaptative Pathway approach at East Beach is summarised below:

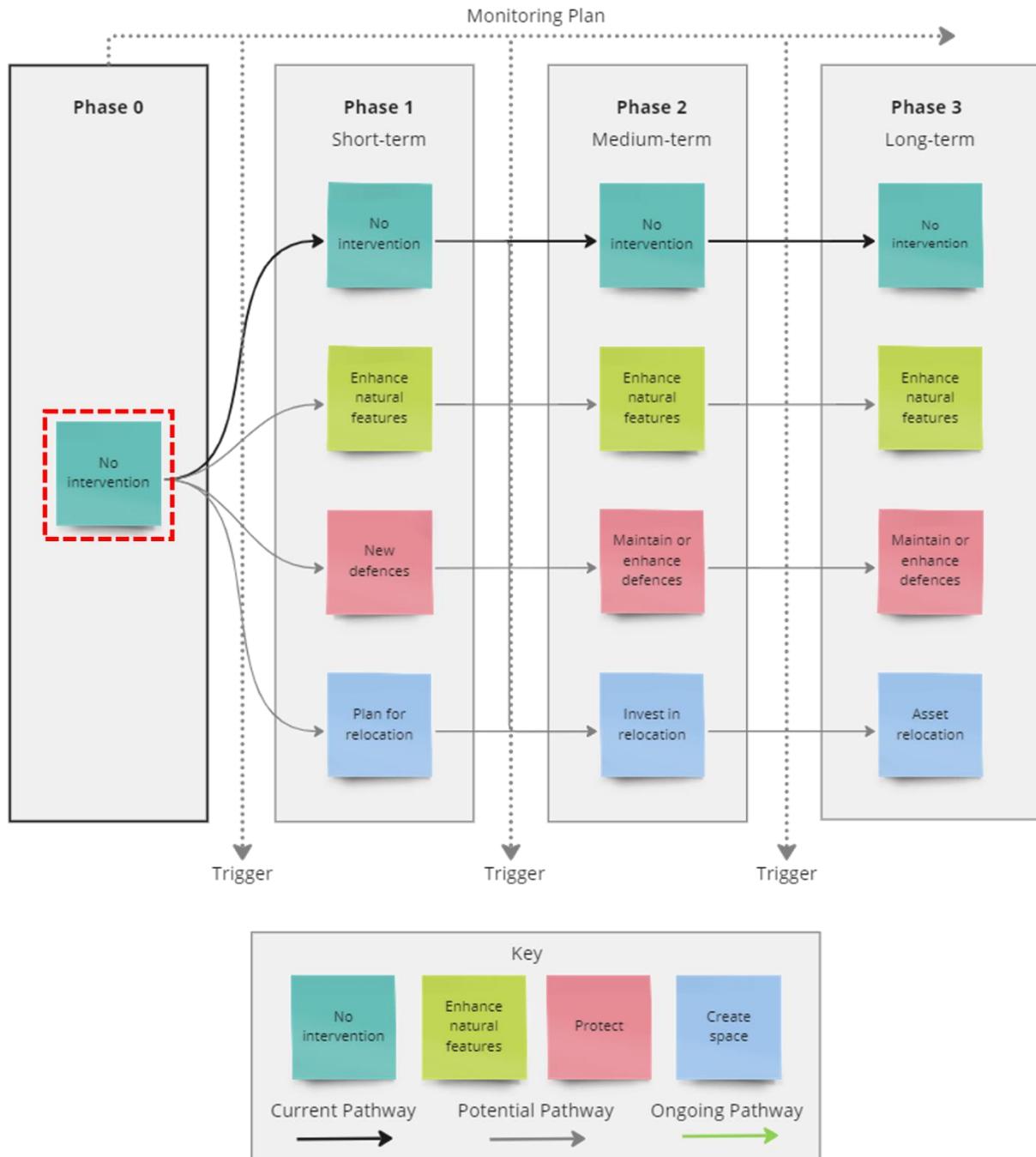- **Anticipated path = No Intervention**

Figure 4-2: Dynamic Adaptive Pathway for East Beach. Grey lines show all possible pathways for coastal management; the black line shows the current anticipated or preferred pathway; and the red box shows the recommended option to be implemented at the current phase of the Dynamic Adaptive Pathway.

4.3 Action Plan

As the Dynamic Adaptive Pathway for East Beach is currently at Phase 0 and an anticipated pathway has not been identified, an Action Plan is not yet required. Once the East Beach pathway transitions into Phase 1, an Action Plan will need to be established.

4.4 Delivery

Triggers are realised through monitoring of available data that informs the resilience of the coastal system at Nairn.

Specific triggers require particular information as these triggers are assigned quantified thresholds which need to be regularly monitored by THC. Specific triggers have associated actions, which should be implemented if the trigger is realised.

As well as specific triggers, generic triggers do not require direct monitoring by THC and are associated with updates to data/information provided by third party data and information, data that THC already hold/collect, or external pressure. These generic triggers are applicable across the whole of Nairn coast. Generic triggers and associated actions and the monitoring required for both CMUs are included in Appendix B.

Some specific triggers are recognised by means of the *CRI* which should be updated following THC monitoring of required data. *CRI* inputs and the overall *CRI* score, calculated in May 2023 are included in the Coastal Resilience Assessment report[6] and can be used as the baseline to monitor changes in dune resilience and associated triggers at Nairn. Examples of how the *CRI* tool can be used to monitor specific triggers are included in Appendix C.

4.4.1 Monitoring Plan

Specific triggers identified at Phase 0 of the Dynamic Adaptive Pathway for East Beach, which are to be monitored by THC include:

1) **Vegetation Cover**
2) **Erosion**
3) **Dune volume loss**
4) *CRI*

It is recommended that **monitoring** of specific triggers, that is, data collection on vegetation cover and erosion should be conducted **at least every 2 years** at **East Beach**. The exception is the dune volume loss trigger, where data collection should occur after a storm occurrence as well as every 2 years.

A more detailed monitoring plan, including the monitoring of triggers and thresholds is included in Appendix D.

4.4.2 Triggers and Thresholds

All triggers that require THC monitoring at East Beach are summarised in Table 4-1.

When a trigger is met an assessment is required to better understand changes to risk following a trigger. The assessment should determine on the most appropriate intervention option to take once the threshold has been met:

- **Trigger** met:
  Action: Increase monitoring and undertake assessment
- **Threshold** met:
  Action: Implementation of chosen intervention and continue monitoring plan

Assessments associated with each trigger are summarised below:

1) **Vegetation cover** assessment:

    - Same as West Beach (section 3.4.2)

2) **Erosion** assessment:

    - Same as West Beach (section 3.4.2)

3) **Dune volume loss** assessment:

    - Same as West Beach (section 3.4.2)

4) *CRI* assessment:

    - Same as West Beach (section 3.4.2)

Table 4-1: East Beach Triggers and Thresholds.

Trigger Type	Trigger	Threshold
Vegetation Cover	Vegetation cover = low resilience (2) across >= 500 m of frontage	Vegetation cover = lowest resilience (1) across >= 200 m of frontage
	Vegetation cover decreases one resilience level (e.g., 3 to 2)	Vegetation cover change decreases one resilience level (e.g., 3 to 2)
Erosion	Distance between shoreline and asset ($D_{S\text{-}A}$) = low resilience (2) across >= 100 m of frontage	Distance between shoreline and asset ($D_{S\text{-}A}$) = lowest resilience (1)
Dune volume loss	Coastal change due to storms (CC_{Storm}) = lowest resilience (1)	Coastal change due to storms (CC_{Storm}) = lowest resilience (1) across >= 100 m of frontage
CRI	CRI = lowest resilience (1) across >=100 m of frontage	CRI = lowest resilience (1) across >= 200 m of the frontage

4.4.3 Supportive Steps and No Regret Actions

Supportive steps are required to help deliver the Action Plan. The nature of adaptation means that future decisions and directions are unknown and will be affected by external changes not necessarily under THC influence. It is critical that proactive supporting steps and No Regret Actions are undertaken to enable effective decision making in the future.

No Regret Actions is anticipated to provide a net benefit regardless of other actions or inactions without first undergoing rigorous analysis. Undertaking these can therefore only have a positive impact on supporting adaptation or increasing resilience.

1) Establish coordinated and consistent dune and beach monitoring plan

Monitoring of data and information is essential to the success of coastal change adaptation. Establishing a coordinated and consistent dune and beach monitoring plan will improve both the reliability and quality of monitoring data and information that can inform coastal resilience at the Nairn coast.

Information should be collected through monitoring that is specific to support future risk assessments and compared to specific erosion and dune vegetation triggers. It should focus across the entire Nairn coast but increase in frequency and detail where predicted risk associated with erosion and coastal change is greatest. Potential elements of a monitoring plan at East Beach are discussed below.

2) High resolution satellites

Same as West Beach, section 3.4.3.

3) Community Engagement

Same as at West Beach, see section 3.4.3.

4) Control Invasive Non-Native Species

Same as at West Beach, see section 3.4.3.

5 Conclusion

This report presents the Dynamic Adaptive Pathways for the Nairn coastal adaptation study. The Dynamic Adaptive Pathways presented here are focussed on the management of coastal change, i.e., erosion. Dynamic Adaptive Pathways have been presented for West Beach and East Beach at Nairn. Based on the results of the Coastal Resilience Assessment report[6], these Dynamic Adaptive Pathway phases, management approach and initial actions are recommended:

West Beach = Phase 1:

- Anticipated pathway (coastal management): Enhance Natural Features
- Supportive pathway (land-based management): Create Space

Phase 1 Actions:

1) Vegetation planting
2) Dune access arrangements
3) Sand recycling
4) Understand land ownerships
5) Engagement with public, stakeholders and planners
6) Discussions with legal teams
7) Review of Scottish Government resilience strategy (when available)

East Beach = Phase 0:

- Anticipated pathway (coastal management): No Intervention
- Supportive pathway (land-based management): N/A

The delivery of the Dynamic Adaptive Pathway is achieved through the monitoring of triggers, thresholds and implementing associated actions. A monitoring plan, specific triggers and actions for West Beach and East Beach have been suggested based on the current anticipated pathway:

West Beach monitoring – every year:

1) Vegetation cover
2) Erosion
3) Dune volume loss (after storm event)
4) *CRI*
5) Coastal engineered structure condition

East Beach monitoring – every two years:

1) Vegetation cover
2) Erosion
3) Dune volume loss (after storm event)
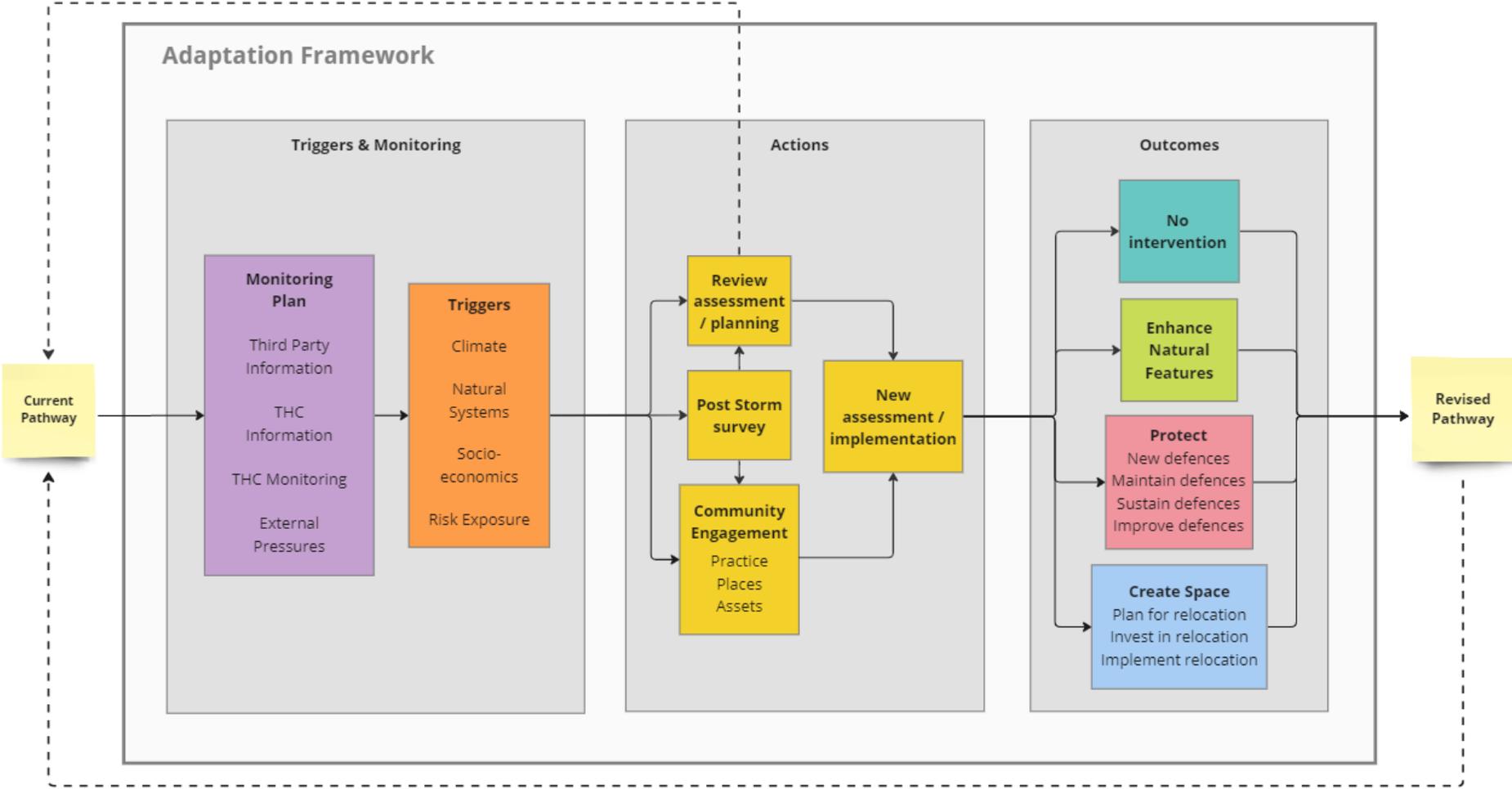4) *CRI*

A   Appendix: Adaptation Framework

Figure A- 1: Complete Adaptation Framework for coastal change adaptation at Nairn.

B Appendix: Generic Monitoring, Triggers and Actions

B.1 Monitoring

Required information for monitoring Triggers are grouped into categories, with some examples provided:

- **Third party data and information:**
1) Dynamic Coast
2) Scottish Government
3) Nature Scot
- **THC data and information:**
4) Highland-wide Local Development Plan
- **THC monitoring:**
5) THC monitoring should be directed at data collection that informs specific risk exposure triggers set for Nairn. These are further discussed for each CMU in sections 3.4.1 (West Beach) and section 4.4.1 (East Beach).
- **External pressure:**
6) Flood erosion event
7) Community pressure on changes, problems or structural condition

B.2 Triggers

Triggers, which signal when the current management approach should be reviewed, are categorised as:

- Climate triggers
- Natural systems triggers
- Risk exposure triggers
- Socio-economic triggers

For all CMUs there are **generic triggers**, where the information needed to assess the trigger is provided by third party data and information, THC data and information or external pressure. These generic triggers are applicable across the whole of Nairn coast and are summarised in Table B-1.

Table B-1: Categorised generic Triggers and associated monitoring required for the entire Nairn coast.

Category	Trigger	Monitoring required
Climate	Updates to climate change guidance	Third party data and information
	Storm occurrence	Third party data and information

Category	Trigger	Monitoring required
	Flood erosion event	External Pressure
	Updates to SEPA data	Third party data and information
	River Nairn FRM approach	THC data and information
Natural Systems	Changes to Greenspace	THC data and information Third party data and information
Socio-economic	Scottish Government funding	Third party data and information
	Community pressure	THC data and information External pressure
	Land use/ owner change	THC data and information
	Asset ownership/ location change	THC data and information
	Changes to Tourism	THC data and information
Risk exposure	Updates to Dynamic Coast	Third party data and information
	Updates to the SEPA flood warning system	Third party data and information

B.3 Actions

As well as trigger-specific actions, generic actions can also be applied to the entire Nairn coast. These generic actions are detailed below.

Review risk assessment:
- Involves a review of available data and associated risk assessment, which includes recalculation of the *CRI*[6]. Increased monitoring, planning, and implementing an assessment, and planning for intervention as a result of the realised triggers are included in the review risk assessment action.

Community engagement:
- **Places:** Involves local Nairn groups, such as local Councillors and affected community groups.
- **Practice:** Involves third party stakeholders, such as SEPA, Scottish Government, Nature Scot etc.
- **Asset:** Includes private engineered structures, harbours and utilities

Post storm data collection:
- Involves community engagement, surveys, photographs etc.

New risk assessment:
- Following a review of the current risk assessment and/or community engagement, a new risk assessment may be required. Should a new assessment be deemed necessary this should follow appropriate guidance[12] and include all necessary components to develop a preferred Dynamic Adaptive Pathway associated Action Plan for delivery. E.g., risk, economics, social, environment, engineering, land use planning etc.

Actions bridge the gap between Triggers and Outcomes and define what processes need to be implemented before the most appropriate Outcome is recognised and delivered. Actions linked to specific triggers and relevant areas at the Nairn coast are included in Table B-2.

Table B-2: Trigger categories, generic triggers and associated generic actions for West Beach and East Beach.

Category	Trigger	Action
Climate	Updates to climate change guidance	Review risk assessment, community engagement (places)
	Storm occurrence	Review risk assessment, community engagement (places, asset), post-storm data collection
	Flood erosion event	Review risk assessment, community engagement (places, asset), post-flood data collection
	Updates to SEPA data	Review risk assessment, community engagement (practise)
	River Nairn FRM approach	Review risk assessment Community engagement (places, practise)
Natural Systems	Changes to Greenspace	Review risk assessment, community engagement (places, practise)

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[12]Scottish Government. 2016. Flood protection appraisals: guidance for SEPA and responsible authorities https://www.gov.scot/publications/guidance-support-sepa-responsible-authorities/pages/2/

Category	Trigger	Action
Socio-economic	Scottish Government funding	Community engagement (practise)
	Community pressure	Review risk assessment, community engagement (places)
	Land use/ owner change	Community engagement (places)
	Asset ownership/ location change	Community engagement (asset)
	Changes to Tourism	Community engagement (places)
Risk exposure	Updates to Dynamic Coast	Review risk assessment, community engagement (places)
	Updates to the SEPA flood warning system	Review risk assessment, community engagement (places, practice)

C Appendix: Actions supported by the CRI tool

CRI calculations can be used to support the magnitude and location of chosen Actions. The *CRI* can be used to assess whether and where an Action will improve the overall resilience of the beach and dune system. Likewise, *CRI* can be used to assess whether and where an Action may negatively impact the resilience, such as translocation of vegetation from one area to another. As a result, *CRI* can be used, at an initial planning stage, to mediate management decision so that any Actions taken are viable and do not critically decrease the resilience of the coast at Nairn.

Two examples are provided to highlight how the *CRI* tool can support Actions taken at the Nairn coast:

1) Beach replenishment

2) Vegetation planting/ translocation

C.1 Beach replenishment

Beach replenishment is tested with the *CRI* tool by increasing dune volume by 20% and moving the shoreline position seaward by 10 m between transects 8–15 from the 2023 baseline inputs[6] (Figure C-1). As a result of beach replenishment, the *CRI* results show the resilience at the west of West Beach has increased from the lowest resilience score (1) to a low resilience score (2).

If the resilience at the west of West Beach is to be increased further (to medium or high resilience) the magnitude of beach replenishment may have to increase, or other implementation measures may need to be actioned as well as beach replenishment. A detailed study is required to fully understand the viability of beach replenishment used to improve resilience at West Beach.
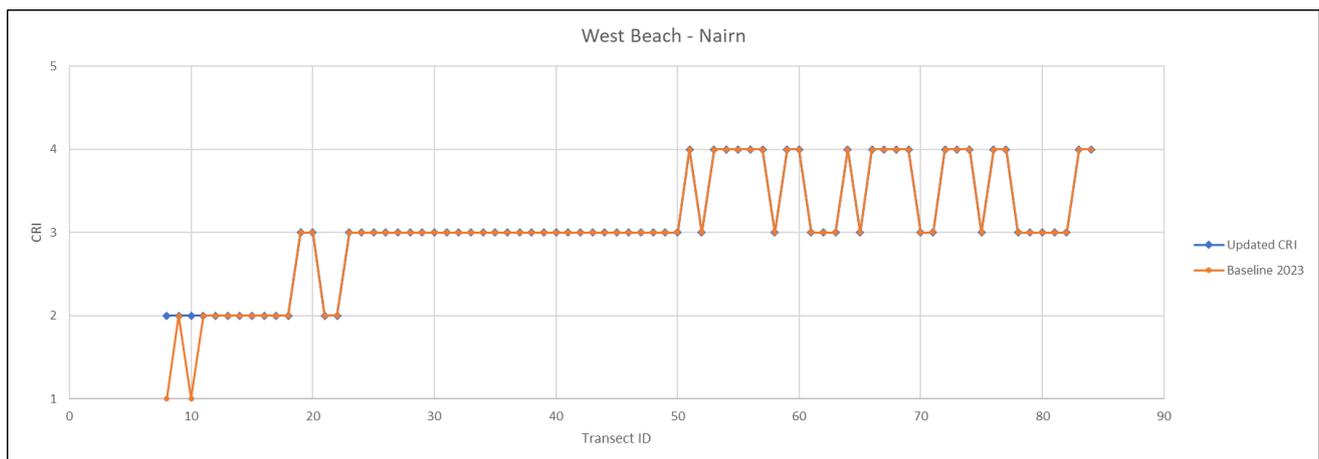

Figure C-1: CRI tool results testing for beach replenishment at West Beach.

C.2 Vegetation planting/ translocation

Vegetation translocation is tested with the CRI tool by removing Marram Grass at East Beach between transects 180–190 and planting Marram Grass at West Beach between transects 8–18 from the 2023 baseline inputs[6] (Figure C-2). As a result of vegetation translocation, the *CRI* results show the resilience at the west of West Beach has increased from the lowest resilience score (1) to a low resilience score (2). Correspondingly, the resilience between transects 180–190 at East Beach where Marram Grass was removed has decreased from the highest resilience score (5) to a high resilience score (4). A detailed study is required to fully understand the viability of vegetation translocation used to improve resilience at West Beach.
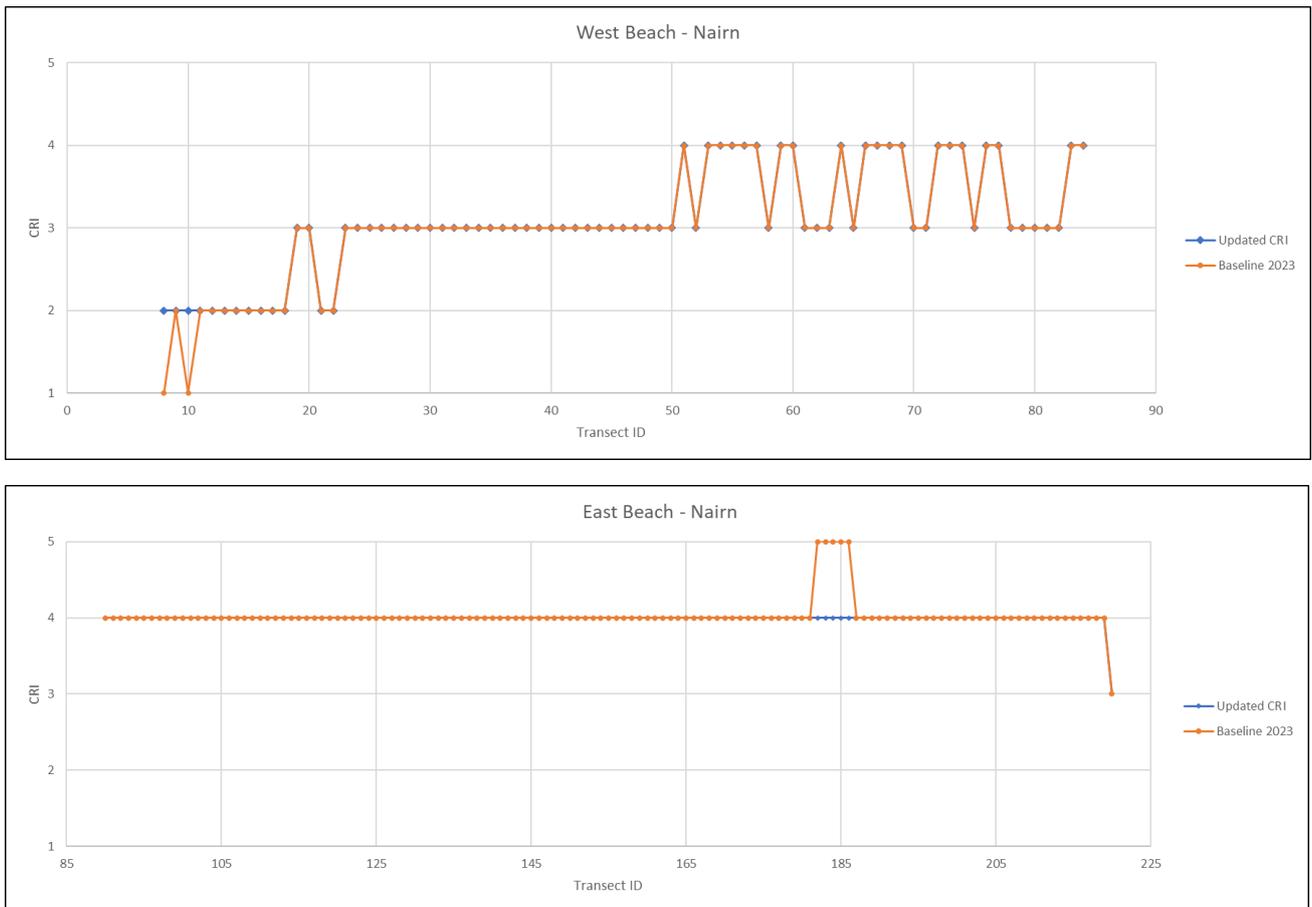

Figure C-2: *CRI* tool results testing for vegetation translocation at West Beach and East Beach.

D   Appendix: Monitoring Plan

Specific triggers identified at Phase 1 of the Dynamic Adaptive Pathway for West Beach and East Beach, which are to be monitored by THC include:

1) **Vegetation Cover** trigger monitoring:

   - Vegetation coverage can be monitored by use of Earth Observation (EO), aerial imagery or through vegetation surveys.
   - Vegetation cover and vegetation cover changes can be categorized into the different resilience levels using the intervals used in the Coastal Resilience Assessment report[6].

2) **Erosion** trigger monitoring:
   - Shoreline or dune toe position
   - Asset position
       o In the Coastal Resilience Assessment report[6], the rear point of the dunes, which closely followed the footpath was used as the asset position.
   - Distance between shoreline and asset

3) **Dune volume loss** trigger monitoring:

   - Shoreline or dune toe position
   - Dune crest height
   - Dune volume

4) *CRI* trigger monitoring:

   - All monitoring associated with vegetation cover, erosion and dune volume loss triggers/
   - The *CRI* tool can be used to track changes to the *CRI.*

5) **Coastal engineered structure condition** (West Beach only) trigger monitoring:

   - Grade of structure according to the EA and Defra condition assessments

   - Any other detailed structural assessments undertaken by THC.

JBA consulting