JNCC Report 748

Technical assistance programme for effective coastal-marine management in the Turks and Caicos Islands (DPLUS119)

WP2: Status assessments for marine/coastal habitats within TCI territorial waters – Sensitivity assessments

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Summary

This Work Package of the Darwin Plus *'Technical assistance programme for effective coastal-marine management in the Turks and Caicos Islands'* was aimed at identifying the priority marine habitats of the Turks and Caicos Islands, which human activities and their associated pressures occur in these habitats, and how sensitive these habitats are to the identified pressures.

The priority habitats and human activities were determined through discussions with relevant stakeholders including the Joint Nature Conservation Committee (JNCC), the Turks and Caicos Government Department of Environment and Coastal Resources (DECR) and the South Atlantic Environmental Research Institute (SAERI). The pressures were identified using a JNCC Pressures-Activity Database, and then further discussed at a workshop with project partners and advisory group to compile a finalised list of seven pressures for the sensitivity assessments.

Sensitivity assessments were undertaken on the top three priority habitats identified (coral reefs, seagrass and sand habitats) for the seven priority pressures (Physical loss of habitat, physical change to another sediment type, abrasion of the surface of the seabed, penetration of substrate below the surface of the seabed, smothering and siltation, organic enrichment, and introduction of microbial pathogens) using a Marine Evidence-based Sensitivity Assessment (MarESA) method developed by the UK's Marine Biological Association.

The outputs from the sensitivity assessments are being used in the creation of a vulnerability assessment which is covered in a separate report of this project.

Contents

Acronyms and abbreviations

TCI	Turks and Caicos Islands
JNCC	Joint Nature Conservation Committee
DECR	Department of Environment and Coastal Resources (TCI government)
SAERI	South Atlantic Environmental Research Institute
PAD	Pressures-Activities Database
PAG	Project Advisory Board
SCTLD	Stony Coral Tissue Loss Disease
MarESA	Marine Evidence-based Sensitivity Assessment
MarLIN	Marine Life Information Network
RPP	Risk Profiling of Pressures

1 Introduction

1.1 Project background

This technical assistance programme is a three-year Darwin Plus funded project to improve the evidence base in marine and coastal environments to support sustainable coastal marine management in the Turks and Caicos Islands (TCI). An international partnership, consisting of the Joint Nature Conservation Committee (JNCC), the TCI Government Department of Environment and Coastal Resources (DECR) and the South Atlantic Environmental Research Institute (SAERI), will be working together to improve the evidence base.

The aim of this project is to provide foundations for strategic, sustainable management of TCI's marine and coastal environment through provision of practical tools and enhanced capabilities to consider biodiversity, conservation, and understand natural capital approaches by decision-makers and local communities.

This part of the project (Work Package 2) will improve understanding of the extent and condition of marine and coastal habitats within TCI. This will be used to support the development of suitable monitoring metrics to detect change to coastal and marine natural capital, and longer-term development of a monitoring programme.

1.2 Project aims, objectives and tasks

The aim of WP2 is to use existing data and evidence on human activities occurring in TCI to, firstly, identify the pressures occurring on marine and coastal habitats in TCI and the associated sensitivity of these habitats to pressures; and secondly, to undertake vulnerability assessments to assess the extent and condition of these habitats.

The key objectives are to:

1. Undertake a desk-based study to obtain existing data on marine asset condition.
2. In collaboration with TCI stakeholders, identify the key activities occurring in the coastal/marine environment, and develop a list of pressures associated with these activities.
3. Undertake a systematic literature review to examine the sensitivity of a priority set of coastal/marine habitats in TCI to priority pressures.
4. Complete a vulnerability assessment for these priority coastal/marine habitats, based on data collated through Work Packages 1 and 2, to make informed conclusions on habitat condition (Work Package 1 of the project was aimed at enhancing the natural capital evidence base and developing a range of tools for decision makers and communities to help manage marine resources).
5. Deliver a knowledge exchange programme to share outputs and provide training to staff within DECR and TCI Government on sensitivity and vulnerability assessments to enable them to update assessments and conclusions on habitat condition in the future.

This report focuses on objectives 1 to 3 of Work Package 2. Subsequent reports detail the outputs from objectives 4 and 5.

2 Methods for marine asset condition assessment

2.1 Selection of priority habitats

Prior to commencing a desk-based study on marine asset condition, a selection of priority coastal/marine habitats to focus on was needed. These would also be used for sensitivity assessments under objective 3. Marine habitat maps, provided by The Nature Conservancy Caribbean Division Science Team (Schill *et al.* 2020, November 2020 update), were reviewed, alongside associated benthic habitat class and sub-class descriptions (Table 1.) These descriptions categorise habitats into broad groups (e.g. Reef, Seagrass) and then identify sub-class based on biological and geomorphological factors.

Priority habitats were initially selected based on:

1. Best available evidence on elements of the habitat required to undertake sensitivity assessments, such as details on physical habitat and functional, structural and characteristic species.
2. Initial understanding of more highly sensitive habitats based on similar habitat assessments from UK waters.
3. Understanding of the habitats' capacity to deliver varied levels of ecosystem services based on evidence from Work Package 1.

This exercise identified three possible priority habitats: coral reefs, seagrass, and sand.

A meeting between JNCC and DECR was held to discuss the proposed priority habitats and to make a final decision. Through this discussion, coral reefs and seagrass were agreed upon, however sand underwent further deliberation. Algal plains were put forward as an alternative priority to sand due to the prevalence of the habitat in TCI, their importance for conch and lobster juvenile settlement, and the presence of known impacts from ongoing pressures in the areas where these habitats occur. However, upon further consideration there were insufficient available data to map algal plains. It was therefore agreed that the project would progress with sand as the third habitat, which would include an assessment of associated algal communities as indicated by the benthic habitat class description (Table 1). The algal plain habitat is, however, identified as a key gap in the current habitat map and would be a priority for future assessment.

Table 1. Habitats selected for assessment on marine asset condition and sensitivity, alongside benthic habitat class descriptions as provided by The Nature Conservancy Caribbean Division Science Team (Schill *et al.* 2021).

Habitat		**Benthic habitat class description**
Reef	Coral/ Algae	Includes fringing, patch, and deeper bank/shelf reefs. General coral reef class for areas not within a reef crest formation. Coral/Algae can exist in depths up to 25 m, depending on water column clarity, with a median depth of 7 m. Presence of live coral colonies or structure that is extensive or patchy with or without a living coral veneer. Could also be coral rock (old *Acropora sp.* or *Orbicella sp.*) framework. Gorgonians, sponges, and sparse seagrass and/or algae dominate the substrate between coral colonies. In sections fringing the shore, eroded reef framework with fossils of reef organisms might be observed in shallowest, intertidal sections. A sparse mixed assemblage of crustose coralline algae, encrusting species of algae and coral and macroalgae may occur in deeper sections. Patch reef and fringing reefs are typically dominated by a variety of macroalgae such as *Dictyota spp*., *Lobophora* spp., *Chaetomorpha spp.* Hard and soft corals commonly found include *Acropora cervicornis, Montastrea cavernoa, Oribicella spp., Pseudodiploria strigosa* and *Diploria labrynthiformis* along with sea plumes and sea fans. The community group of secondary dominance is relatively evenly split by hard corals and sponges.
	Reef Crest	Found in shallow water break zones of barriers and fringing reefs (with the reef flat typically occurring at a depth of less than 2 m), between back and fore reef with low to medium relief and creates a shoreward lagoon. The structure is typically dominated by a variety of macroalgae species that seem to vary with depth and location (distance from shore, exposure to wave energy and substrate type) and commonly includes green algae genera: *Avrainvillea spp*.; brown algae genera: *Dictyota spp*. There is co-dominance by hard corals such as *Millepora spp*., *Psuedodiploria clivosa*, *Porites astreoides*, *Acropora palmata*, *Siderastrea siderea, Porites porites*; the zooanthids *Palyothoa caribaeorum* or *Zoanthus sp.* and sometimes sea fans and small gorgonians. Typically, dead *Acropora palmata* dominate the structure.
	Reef Back	Shallow zone 2–3 m depth then transitions into lagoon, for fringing and barrier reefs going shorewards or shallow zone on the more sheltered part of the reef crest towards the centre of atolls. Typically found on the sheltered margins landward of the reef crest – has low relief from skeletal coral rubble and intact dead corals bonded by coralline algae to form a semi-consolidated framework, dominated by macro-algae. More dominant macroalgae species include: *Ulva spp., Chaetomorpha spp , Caulerpa* and *Avrainvillea*. Could also be a mosaic of shallow coral heads or patch reef with seagrass interspersed (dominantly *Thalassia testudinium,* and often mixed patches of *Syringodium filiforme, Halodule wrightii*). The community group of secondary dominance is relatively evenly split by hard corals, sponges, encrusting coralline algae and sea fans. This habitat may also be found surrounding, or atop, carbonate frameworks.

Habitat		Benthic habitat class description
Reef (continued)	Reef Fore	Typically found on the exposed seaward slope of the reef crest - area of high slope, then transitions into mixed assemblages greater than 8 m depth. This habitat has a median depth of 11 m but can typically be found between 5–25 m. Moderately rugose frameworks are characterized by sparse coral cover (typically less than 10%) and sandy substrate. Colonies are predominantly small (sub-meter) in size and are composed primarily of *Siderastrea spp., Orbicella annularis., Pseudodiploria spp.*, *Agaricia spp.* and *Colpophyllia spp.* Crustose coralline algae and fleshy algae (*Sargassum spp., Dictyota spp.*) along with gorgonians dominate the remainder of the reef framework. The community group of secondary dominance tends to be sponges, followed by hard corals, gorgonians, macroalgae and encrusting coralline algae.
	Spur and Groove	Characterized by medium-high relief, reef framework substrate with a medium to dense living stony coral community cover. Average depth of the substratum tends to start at about 10 m dropping to depth reaching about 25 to 30 m. There are alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically have a high vertical relief compared to pavement with accumulating sand channels and are separated from each other by 1–5 m of sand or bare hardbottom (grooves), although the height and width of these elements may vary considerably. The dominant community group in this habitat class is almost always hard coral with frequent co-dominance by macroalgae and gorgonians in many Caribbean area islands. The community group of secondary dominance may be relatively evenly split by hard corals, macroalgae, gorgonians, encrusting coralline algae and sponges. Coral species commonly include massive corals, *Orbicella annularis, Siderastrea siderea, Meandrina meandrites, Agaricia spp.;* branching corals, *Porites spp., Madracis spp.,* and rarely *Acropora spp*. Species of algae include brown algae genera: *Dictyota spp.*; red algae genera: *Galaxaura spp*.
Seagrass	Dense	Found in shallow lagoons or relatively sheltered zones at a depth of 2–10 m, characterized by a low relief, sand substrate with dense living community cover with (greater than 50% cover). Living cover is dominated by a mix of seagrass species: *Thalassia testudinum, Syringodium filiforme, Halodule wrightii* and *Halophila decipiens*; and commonly associated with green algae genera: *Ulva spp.*, *Chaetomorpha spp , Caulerpa* and *Avrainvillea* or some coral rubble habitat. There may also be some brown algae (*e.g.* benthic *Sargassum spp., Dictyota spp*.). These areas represent a darker spectral response when compared with spare seagrass.

Habitat		Benthic habitat class description
Seagrass (continued)	Sparse	Found in shallow lagoons or relatively sheltered zones at a depth of 2–10 m, characterized by a low relief, sand substrate with sparse-medium living community cover (less than 50% cover). Living cover is dominated by a mix of seagrass species: *Thalassia testudinum, Syringodium filiforme, Halodule wrightii* and *Halophila decipiens*; and commonly associated with green algae genera: Ulva spp. *Chaetomorpha* spp, *Caulerpa* and *Avrainvillea* or some coral rubble habitat. In the Eastern Caribbean is commonly dominated by invasive *Halophila stipulacea*. There may also be some brown algae (e.g. benthic *Sargassum* spp., *Dictyota* spp.). May be located adjacent to open patches of sand or dense seagrass. Cyanobacteria often form dense mats between macroalgal stalks covering the underlying sandy substrate. There may also be small patches of encrusting hard coral species fast growing and resistant to sand/sediment clouds (e.g. *Siderastrea radians*). These areas represent a lighter spectral response when compared with dense seagrass.
Sand	Sand	Characterized by a low relief, sand substrate with a bare to sparse living community cover (less than 10%). Typically covered by a layer of cyanobacteria and commonly includes green algae genera: *Halimeda,* and *Caulerpa*. The dominant community group in this habitat class is almost evenly split by cyanobacteria and macroalgae. The community group of secondary dominance is relatively evenly split by sponges and macroalgae. This habitat has a median depth of 15 m but can be found anywhere in the visible areas of the satellite imagery (0–30 m in depth).

2.2 Marine asset condition and sensitivity review

Following the selection of priority habitats, a rapid evidence review was undertaken to provide an initial overview of asset condition. It was also decided to use the exercise as an opportunity to collate initial data sources and evidence on habitat sensitivity to support objective 3. Due to the time available, the review was limited to evidence on corals that had previously been collated for a JNCC project to develop a TCI coral action plan, and a selection of terms was prepared to search for evidence on seagrass and sand (Table 2), with 3 to 4 papers per pressure selected.

Table 2. Search terms used to identify literature on seagrass and sand habitats.

Habitats	Search terms
Seagrass	• "Turks and Caicos" AND seagrass OR Thalassia • (Caribbean OR "Turks and Caicos") AND seagrass OR Thalassia AND pressures (in each case, specific pressures were used as detailed in Appendix 1 of Tyler-Walters *et al.* (2018), excluding those not considered high priority for TCI waters) • (Caribbean OR "Turks and Caicos") AND seagrass OR Syrongodium AND pressures

Habitats	Search terms
Seagrass (continued)	• (Caribbean OR "Turks and Caicos") AND seagrass OR Thalassia OR Syrongodium AND sensitivity • (Caribbean OR "Turks and Caicos") AND seagrass OR Thalassia OR Syrongodium AND pressures • (Caribbean OR "Turks and Caicos") AND "seagrass sensitivity assessment" OR "seagrass pressure impacts"
Sand	• (Caribbean OR "Turks and Caicos") AND "infralittoral sand" • (Caribbean OR "Turks and Caicos") AND sand -terrestrial -dunes -beach • (Caribbean OR "Turks and Caicos") AND sand AND subtidal • (Caribbean OR "Turks and Caicos") AND "infralittoral sand" OR "marine sand habitat" • (Caribbean OR "Turks and Caicos") AND sand OR "marine sand habitat" OR "reef sand"

Once papers had been selected, these were reviewed for evidence on habitat condition and sensitivity and collated into a proforma. The proforma detailed:

- Availability and type of evidence on condition, either 'empirical', 'proxy' or 'none'
- Availability and type of evidence on sensitivity, either 'empirical', 'proxy' or 'none'
- An initial assessment of asset condition, either 'damaged', 'good' or 'unknown'
- Brief description of evidence on condition (if available)
- Brief description of evidence on sensitivity (if available)
- Confidence in the condition assessment on a scale of High, Moderate, Low (Table 3)
- Rationale for the confidence score
- A list of relevant pressures for the sensitivity evidence

Table 3. Confidence categories used to assess asset condition.

Evidence confidence	Definition
High	There is good information on the condition of the feature. The assessment is well supported by the scientific literature
Moderate	There is some specific evidence or good proxy information on the condition of the feature.
Low	There is limited or no specific or suitable proxy information on the condition of the feature. The assessment is based largely on expert judgement.

Outputs of the asset condition review were used to support the next stage of WP2 on vulnerability assessments to assess habitat extent and condition. The outputs of the sensitivity review were used to provide an initial indication of available literature on sensitivity of the habitats to pressures for the more detailed sensitivity assessments (see Section 5). The proforma outputs are provided as supplementary material in Appendix 1.

3 Methods for activities data collation and pressures evidence

3.1 Activities list and data gathering

The next stage of the project undertook a review of marine and coastal human activities data within the TCIs to create a list of key activities occurring in TCI waters and to enable collation of activities data to use for the vulnerability assessments. Work Package 3 (Marine Indicators) of this project conducted a literature review of indicators (Britton *et al.* 2021), and information provided on available activities data were used as the basis for the data gathering. Further online searches of publicly available information in grey and scientific literature were conducted, particularly for human activities datasets. Data archives or sources searched included the TCI Tourist Board Statistics Report, World Resources Institute and the TCI Data Portal. The latter was developed by a Darwin Plus funded project (DPLUS094) "Developing Marine Spatial Planning (MSP) tools for Turks and Caicos". Relevant datasets were downloaded or requested where not directly downloadable. The data search resulted in a list of activities known to occur in TCI, alongside available datasets (Table 4).

Table 4. Provisional list of activities occurring in TCI and associated datasets.

Activity name	Activity dataset
Ferry routes	TCI ferry routes 2020 (TCI data portal)
Moorings	Mooring sites (TCI data portal)
Artificial structures (e.g. breakwater, bridge, causeway, pier, marina, beach and sea wall)	Shoreline artificial structures (TCI data portal)
Cruise ships	Tourism Board statistics
Lobster and conch fishing	Likelihood and range data for conch and lobster (TCI data portal)
Sport fishing/fishing tours/overfishing	Threats to reef/TCI fishing zones/marine activities (TCI data portal)
Sewage runoff	Marine activities (TCI data portal)
Boating/boat rides/sailing	Marine activities/Hobie cat boats/parasailing (TCI data portal)
Dredging	Marine activities/artificial shoreline structures (TCI data portal)

3.2 Activity-pressure associations

Once a list of activities was identified, the next step was to determine which pressures were caused by these activities. This was required to enable sensitivity assessments to be undertaken (see Section 5). Marine pressures can be defined as, "the mechanism through which an activity influences any part of the ecosystem. The nature of the pressure is determined by activity type, intensity, and distribution" (Robinson *et al.* 2008).

The initial determination of relevant pressures was done using JNCC's Pressures-Activities Database (PAD) (Robson *et al.* 2018). This database provides evidence from literature reviews for the relationships between human activities and marine pressures in the UK, and the subsequently identified pressures were then reviewed by JNCC staff and stakeholders at the Pressures Workshop (Section 4). An activity can result in one or more pressures, and most pressures will be caused by multiple different activities (see example in Table 5).

Table 5. Example of Pressure-Activity Database (PAD) Activity-pressure relationship.

PAD Activity Category	PAD Activity	Pressure
Transport	Vessel movements	Above water noise
		Underwater noise changes
		Visual disturbance
	Vessel moorings	Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion
		Physical change (to another seabed type)
		Physical change (to another sediment type)
	Vessel berths	Abrasion/disturbance of the substrate on the surface of the seabed
		Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion
		Physical change (to another seabed type)
		Physical change (to another sediment type)
	Vessel anchorages	Abrasion/disturbance of the substrate on the surface of the seabed
		Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion

3.2.1 Pressures list

The TCI activities identified in Table 4 were first correlated to equivalent activity categories and activities within the PAD (Table 6) and their associated pressures were then noted.

Table 6. PAD human activity categories and activities for use in the Pressures workshop.

PAD activity category	PAD activities
Coastal infrastructure	All coastal infrastructure activities in PAD (e.g. Port and Harbours operation)
Coastal management	Land reclaim
Extraction (and disposal) of non-living resources	Capital dredging Maintenance dredging

PAD activity category	PAD activities
Extraction of living resources	Diving (incl. removal of living resources) Line fishing Pelagic fishing (or fishing activities that do not interact with sea bed)
Other man-made structures	Cultural and heritage sites (e.g. wrecks, sculptures, foundations, etc.)
Recreation and leisure	Powerboating or sailing with an engine: Mooring and/or anchoring Sailing without an engine: Mooring and/or anchoring
Transport	Vessel anchorages Vessel berths Vessel moorings Vessel movements
Waste management	Sewage disposal

Risk Profiling of Pressures (RPP) scores are used in the PAD to indicate the general risk the pressures pose to the environment under normal conditions. Medium-high risk RPP scores indicate where a 'pressure is commonly induced by an activity at a level that needs to be considered further as part of an assessment' (Robson *et al.* 2018). Initially, only pressures showing ‘medium-high’ risk for RPP scores were selected for this project, the RPP score was used as a simple method to screen out pressures that were likely to pose a lower risk to the marine habitats of TCI.

The RPP scores are designed to be used in conjunction with available site-specific information, and in some cases low risk pressures can be considered medium-high risk depending to site-specific factors. Therefore, once the medium-high risk pressures had been selected, these were reviewed by JNCC pressures experts and any pressures with low RPP scores were considered in relation to TCI specific data. This resulted in the addition of the pressure ‘Introduction or spread of invasive non-indigenous species’, as the risk was considered medium-high due to available evidence, to create a provisional list of pressures.

This provisional list of pressures was then refined to select those with the highest potential impact on benthic habitats for more focussed consideration at a workshop with the Project Advisory Board (PAG) and other invited stakeholders. This refinement was based on initial evidence from the marine asset condition and sensitivity rapid evidence review (Appendix 1). From this review, the following eight pressures for consideration at the workshop were selected:

- Abrasion/disturbance of the substrate on the surface of the seabed
- Changes in suspended solids (water clarity)
- Habitat structure changes - removal of substratum (extraction)
- Introduction or spread of invasive non-indigenous species (INIS)
- Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion
- Physical change (to another seabed or sediment type)
- Removal of non-target species
- Smothering and siltation rate changes (Heavy and Light)

The following four climate change pressures were not included in the PAD but were also considered of relevance to TCI waters:

- Ocean warming
- Ocean acidification
- Marine heatwaves
- Sea level rise

Including climate change pressures in the sensitivity assessments is more complex as they require multiple benchmarks for sensitivity because of different climate change emission scenarios. As such, running these sensitivity assessments would take more time. Potential implications of this on the project timetable were also discussed at the workshop.

A final review of the activity types, activities data, and list of pressures was undertaken by the PAG at the Pressures Workshop (see Section 4).

4 Outputs of pressures workshop

4.1 Aims and delivery

Following the development of the list of activities and pressures, JNCC organised a pressures workshop with the Project Advisory Group (PAG) to:

1. Review and finalise a list of key human activities occurring in TCI waters and to confirm availability of existing datasets for these activities to support the assessment of habitat condition under WP2.
2. Agree a finalised list of priority marine pressures occurring from these activities, against which to assess the sensitivity of marine habitats in TCI waters.

The Pressures Workshop was held as an online event on 18 August 2021. It was delivered by JNCC staff to the PAG which included representatives from TCIG, Turks and Caicos Fishing Cooperative, Turks and Caicos Reef Fund, SAERI and eftec.

JNCC summarised the work being undertaken by WP2, and presented the lists of activities, activities datasets and pressures to attendees. Discussions then took place between meeting attendees, whereby any additional activities and pressures were identified, and agreement reached as to the list of pressures to be considered within the sensitivity assessments.

4.2 Outcomes

4.2.1 Activities list and datasets

The workshop identified several additional activities, including water sports; coastal activities, and threats from future activities such as sand mining. It also highlighted recent impacts from Sargassum seaweeds arriving at the TCI from other Caribbean locations, and the potential impacts and locations of landfill sites were discussed in relation to organic enrichment and the growth of algal blooms. Some smaller-scale activities were noted including small oil spills from ships. The activities list was therefore updated, and the final list of activities is displayed below (Table 7).

Table 7. The final list of activities occurring in TCI for the purpose of pressure identification.

Activity name
Ferry routes
Moorings
Artificial structures (e.g. breakwater, bridge, causeway, pier, marina, beach and sea wall)
Cruise ships
Lobster and conch fishing
Sport fishing/fishing tours/overfishing
Sewage runoff
Boating/boat rides/sailing
Dredging
Diving/snorkelling

Activity name
Jet ski/flyboards
Floating Bars
Coastal activities (picnics/litter)
Removal of terrestrial cover
Sand mining
Landfill sites
Oil spills

Workshop attendees also reviewed the available activity datasets. Additional datasets for lobster morphometrics, scale fish morphometrics and fishing licence registers, and recent information on fishing activity and location were requested following these discussions, but it was not possible for these data to be provided within the timeline of this project. A report containing summary data of Stony Coral Tissue Loss Disease (SCTLD) in TCI was provided but the raw data, and data on lionfish, were unable to be delivered within the project timeframe. It was not possible to obtain GIS data on landfill sites further to the coastal landfill indicated in the marine activities' dataset (Table 4).

4.2.2 Pressures list

The selection of pressures was discussed with the workshop attendees and the 'Introduction of microbial pathogens' pressure was identified as a further priority due to the recent arrival of SCTLD to the TCI from other Caribbean areas. Furthermore, discussion around organic enrichment and the growth of algal blooms at landfill sites from the activities data discussions, organic enrichment was also considered as a higher priority pressure. Other pressures considered included removal of target species (specifically conch and lobster), pressures known to reduce the reefs and seagrasses' abilities to provide storm protection, and chemical contamination.

The removal of target species pressure was initially suggested; however, this pressure is very specific to the removal of characterising species of a habitat (e.g. seaweed collection from seaweed beds). Whilst lobster and conch are associated with specific habitats, they are not a characteristic species of those habitats, and therefore the habitat sensitivity assessment would not review the impacts of the loss of these species. To address pressures that would impact lobster and conch species, JNCC suggested the inclusion of 'physical loss to freshwater or terrestrial habitat' in addition to the existing 'physical change (to another seabed or sediment type)' pressure. Both pressures represent loss or change of habitat from activities such as land reclaim, coastal infrastructure or navigational and maintenance dredging. Additionally, these pressures are also known to reduce storm protection also which was a high priority.

The chemical contamination pressures were considered more challenging to undertake sensitivity assessments for. These require benchmark levels of the pressure to be determined to assess sensitivity against (see Section 5.2). However, the benchmarks (see Section 5) for the chemical contamination pressures are currently undergoing a major revision in the UK under the MarLIN project, and even these revised benchmarks are unlikely to be appropriate for a tropical environment. They could, however, be considered in the future once the benchmarks have been updated and thoroughly reviewed to ensure that they are relevant for TCI and if not, new Caribbean specific benchmarks are created.

The final list of pressures to be used for the sensitivity assessments was therefore agreed and displayed below (Table 8).

Table 8. Final list of pressures for sensitivity assessments.

Pressure
Physical loss (to land or freshwater habitat)
Physical change (to another sediment/seabed type)
Abrasion/disturbance of the substrate on the surface of the seabed
Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion
Smothering and siltation changes (depth of vertical sediment overburden)
Organic enrichment
Introduction of microbial pathogens

The complete list of activities identified through the literature search and feedback from the workshop (along with relevant datasets), the activity-pressure links, and full list of associated pressures, is available in supplementary material provided as Appendix 2.

5 Methods for sensitivity assessments

5.1 Introduction to MarESA method

The sensitivity assessments for the project were based on a standard method used to assess the sensitivity of marine habitats and species in UK waters. The MarESA (Marine Evidence based Sensitivity Assessment) method was developed through the UK Marine Biological Association's MarLIN project. This aims to assess the sensitivity of marine biodiversity as a product of the likelihood of damage to a species or habitat from a pressure, known as '**resistance**', and the rate of recovery once the pressure is removed, known as '**resilience**'. A full method description can be found in Tyler-Walters *et al.* 2018, but this is briefly summarised below and displayed in Figure 1.

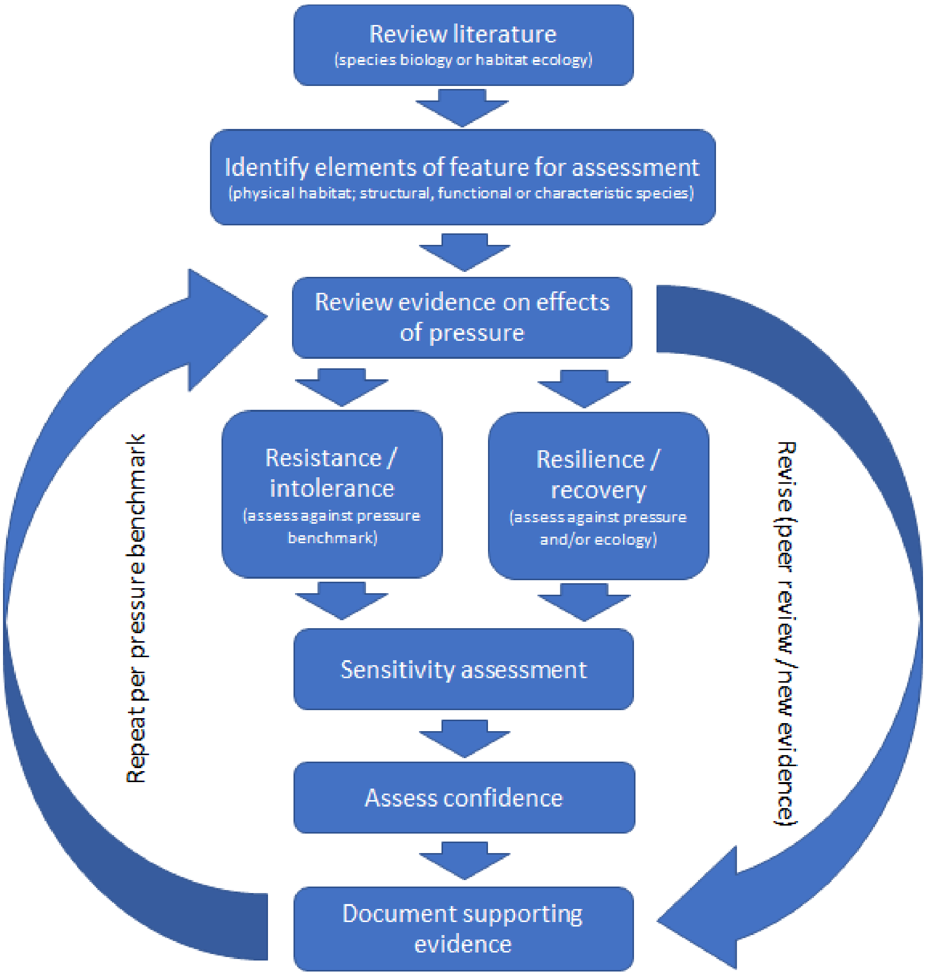

Figure 1. Summary of MarESA method for habitat sensitivity assessments (taken from Tyler-Walters *et al.* 2018).

The initial stage, when applying the MarESA approach to habitats, involves identifying and defining the important or characterising species. These are the species which play key structural or functional roles within the habitat, either by providing habitat for associated species or by maintaining community structure through their interactions with other species. Characterising species are those which characterise the habitat by their dominance and frequency, and if they were lost would result in a change in habitat classification. After these species are identified, a literature review is conducted to form an evidence base upon which the assessment is based. The literature review enables the scoring of the two key sensitivity parameters – resistance and resilience. Evidence from the literature is used to assign a ranked score to each parameter per pressure, which is then combined to produce a final habitat sensitivity score.

The **resilience** assessments score the **rate of recovery** of the habitat after the pressure has been removed or abated. This assessment relies on evidence regarding life history traits of the key and characterising species, such as reproduction and population dynamics, as well as information on community succession and habitat-specific factors, such as impacts to biogenic structures. Recovery is assessed as the time taken for the habitat or community to return to the state it was in prior to the impact from the pressure, termed '**Full recovery**' (Table 9). In the case of habitats this does not necessarily require that all species which were present return in the same frequency or distribution, as long as the relevant functional and structural components are present. **Resilience** is scored independently of resistance and is based on the **scoring system** shown in Table 9, ranging from 'Very Low' to 'High'.

Table 9. Summary of resilience scores and their descriptions (from Tyler-Walters *et al.* 2018).

Resilience	Description
Very low	Negligible or prolonged recovery possible; at least 25 years to recover structure and function
Low	Full recovery within 10–25 years
Medium	Full recovery within 2–10 years
High	Full recovery within 2 years

Resistance is assessed individually for each pressure against 'benchmark' levels using the available evidence. The benchmarks create a standard level of pressure to assess against, which incorporates both a quantitative and qualitative aspect (Table 10). Resistance is determined based on evidence of the effects of the pressure on the key and characterising species or physical condition of habitat (Table 10). This takes into consideration the effects of the pressure in comparison to the benchmark and the level of damage to key elements (e.g. mortality of species, decrease in biodiversity, amount of habitat lost). Where the evidence specifies the scale or frequency of the pressure and the extent of the impact, this can be directly compared to the benchmark and the relevant resistance category.

If there is no direct evidence on the specific habitat and the associated key and characterising species, then proxies are used. These can be closely related species in similar habitats or the same species living in different geographical locations.

Table 10. Summary of resistance scores and their descriptions (from Tyler-Walters *et al.* 2018).

Resistance	Description
None	Key functional, structural, characterizing species severely decline and/or the physico-chemical parameters are also affected (e.g. removal of habitats causing change in habitats type). A severe decline/reduction relates to the loss of 75% of the extent, density or abundance of the selected species or habitat component (e.g. loss of 75% substratum - where this can be sensibly applied).
Low	Significant mortality of key and characterizing species with some effects on physico-chemical character of habitat. A significant decline/reduction relates to the loss of 25–75% of the extent, density, or abundance of the selected species or habitat component (e.g. loss of 25–75% of the substratum).

Resistance	Description
Medium	Some mortality of species (can be significant where these are not keystone structural/functional and characterizing species) without change to habitats relates to the loss
High	No significant effects to the physico-chemical character of habitat and no effect on population viability of key/characterizing species but may affect feeding, respiration, and reproduction rates

The **overall sensitivity score** is determined by combining the resistance and resilience scores for each pressure (Table 11). For example, where a habitat or species has a 'High' resistance and 'High' resilience at the benchmark level, it is assessed as 'Not sensitive'. It is possible that the characterising species of a habitat may be sensitive to the pressure at greater intensities or frequencies than specified in the benchmark.

There are also some cases where a sensitivity assessment is not possible. A pressure may be **Not relevant** if the evidence suggests that there is no direct interaction between the pressure and the habitat or species, or if the interactions are unlikely to occur at present or in the future. **No evidence** is used where is not sufficient evidence available to support an assessment. A pressure is **Not assessed** when there is extremely limited or no evidence available.

Table 11. Overall sensitivity scores, based on resistance and resilience (from Tyler-Walters *et al.* 2018).

Resilience	Resistance			
	None	**Low**	**Medium**	**High**
Very low	High	High	Medium	Low
Low	High	High	Medium	Low
Medium	Medium	Medium	Medium	Low
High	Medium	Low	Low	Not sensitive

The resilience and resistance scores are each accompanied by three **confidence scores** for the quality of the evidence, the degree to which the evidence is applicable, and the degree to which all the evidence agrees (on the magnitude and direction of the impact), with each score scaled from low to high. The confidence scores for each category are combined for the resilience and resistance for each pressure to give the confidence in the sensitivity score (see Tyler-Walters *et al.* 2018) for detailed description of confidence scoring).

5.2 Summary of pressure benchmarks

The benchmarks for each pressure act as a standard level to assess resistance against, by defining it in terms of magnitude, extent, duration, and frequency and may be either quantitative or qualitative depending on the pressure. The pressure definitions and benchmarks were developed by the Marine Biological Association but were created for UK sensitivity assessments and therefore some of the thresholds use evidence specific to UK national waters (Tyler-Walters *et al.* 2018). To ensure that the sensitivity assessments completed in this project were relevant to TCI, the benchmarks were reviewed and only one, the 'Organic Enrichment' pressure, required alteration. The pressures and benchmarks used in this project are detailed in Table 12. A full list of the MarLIN pressures can be found on their website. To date, the priority pressures identified in the workshop (see Section 4) have been assessed. Further resources will be required to assess the full suite of pressures identified. It is hoped that training which will be provided to TCIG staff as part of WP2 will enable these further assessments when resources become available.

In some cases, sensitivity assessments to pressures are always assessed in the same way. For example, the physical loss (to land or freshwater habitat) pressure is defined as the permanent loss of saline habitat. As such, all marine species and habitats have a resistance of 'None' and a resilience of 'Very low' as they are unable to recover. Therefore, wherever this pressure occurs the sensitivity is 'High' with a 'High' confidence despite no specific evidence. Full details of these specific cases can be found in Tyler-Walters *et al.* (2018).

Table 12. Summary of pressures selected for sensitivity assessment and their benchmarks.

Pressure	Benchmark
Physical loss (to land or freshwater habitat)	Permanent loss of existing saline habitat within site
Physical change (to another sediment/seabed type)	Change in sediment type by one Folk class (based on UK SeaMap simplified classification)
	Change from sedimentary or soft rock substrata to hard rock or artificial substrata or vice-versa.
Abrasion/disturbance of the substrate on the surface of the seabed	Damage to seabed surface features (species and habitats)
Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	Damage to sub-surface seabed
Smothering and siltation changes (depth of vertical sediment overburden)	'Light' deposition of up to 5 cm of fine material added to the seabed in a single, discrete event
	'Heavy' deposition of up to 30 cm of fine material added to the seabed in a single discrete event
Organic enrichment	Total Organic Carbon (TOC) greater than 1.67 mg/L (Water monitoring from TCI reported TOC of 1.67 mg/L (Rachman *et al.* 2014); in the absence of other available data, the benchmark was set as anything greater than the naturally occurring TOC of TCI)
Introduction of microbial pathogens	The introduction of relevant microbial pathogens or metazoan disease vectors to an area where they are currently not present.

5.3 Summary of assessments undertaken

The sensitivity assessments were undertaken on three benthic habitats, coral reef, seagrass, and sand. These habitats were chosen through discussion with project partners to identify the key habitats of the TCI, as described in Section 2.1.

5.3.1 Coral reef

The coral species described in the Reef benthic habitat classes (Schill *et al.* 2020, November 2020 update) were first categorised by morphology type. As several species exhibit morphological plasticity to enable various growth forms dependant on specific environmental conditions, the species were assigned categories based on their dominant morphology as described in evidence from the literature review.

A majority of coral species were dominantly massive growth forms, followed by branching species (Table 13). Sensitivity of corals were grouped by morphology and the assessment for Reef was focused on the ‘coral/algae’ benthic habitat class as the species within this class represented the dominant morphology types found on TCI reefs.

Table 13. Morphologies of the species within the Coral reef classes in The Nature Conservancy benthic classification.

Massive	**Branching**
Montastraea cavernosa	*Acropora cervicornis*
Orbicella spp.	*Millepora* spp. (Hydrozoa)
Diploria strigosa	*Acropora palmata*
Diploria labrynthiformis	*Madracis* spp.
Pseudodiploria clivosa	*Acropora* spp.
Porites astreoides	
Siderastea siderea	
Porites porites	
Siderastrea spp.	
Orbicella annularis	
Pseudodiploria spp.	
Agarica spp.	
Colpophylli spp.	
Meandrina meandrites	

A literature review was carried out on the key species specified in the coral/algae class, specifically, the branching *Acropora cervicornis,* and the massive *Montastraea cavernoa, Orbicella* spp., *Pseudodiploria strigosa,* and *Diploria labrynthiformis*. The macroalgae specified in the class descriptions were not included in this assessment as they are likely to respond differently to the pressures due their different morphology and life histories.

The literature review identified evidence of the impacts of each pressure on the key species to assess resistance. A large amount of the evidence came from other Caribbean areas as data from the TCI was sparse. The sensitivity assessments were carried out using the MarESA method detailed above, using available evidence for the characterising species. Where evidence was not available for the TCI, evidence from other areas or using proxy species was used; however, this resulted in lower confidence scores for the assessments.

The resilience of the characterising species was assessed based on evidence detailing growth rates and reproductive strategies of these, or similar, species. Generally, the coral species are slow growing and reproduce via broadcast spawning, however *Acropora cervicornis* has a relatively fast growth rate and the ability to reproduce asexually by fragmentation.

Detailed resistance assessments are available in supplementary material provided as Appendix 3, and briefly summarised in Table 14.

Table 14. Resistance, Resilience, and Sensitivity scores for the assessed pressures for the Coral habitat.

Pressure	Resilience	Resistence	Sensitivity
Physical loss (to land or freshwater habitat)	N	VL	H
Physical change to another seabed type (e.g. soft rock to hard rock)	N	VL	H
Physical change to another sediment type (change in 1 Folk class)	NR	NR	NR
Abrasion/disturbance of the substrate on the surface of the seabed	N	VL	H
Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	N	VL	H
Smothering and siltation changes (depth of vertical sediment overburden) - Light	M	L	M
Smothering and siltation changes (depth of vertical sediment overburden) - Hard	N	VL	H
Organic enrichment	M	L	M
Introduction of microbial pathogens	L	VL	H

5.3.2 Seagrass

The seagrass assessment involved an initial search of the MarLIN database for existing sensitivity assessments for proxy seagrass species, followed by a literature review for evidence for seagrass species specified in the seagrass benthic classes in TCI such as *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule wrightii*. The quantity of evidence specific to the TCI was limited and the majority of evidence came from other areas such as Florida Keys, Mexico and Southern Caribbean. Where evidence for the seagrass species found in TCI waters was deficient, studies on other tropical species from the same genus were used. The sensitivity scoring was determined based on the methods detailed above and the available evidence. The use of evidence from other areas or species resulted in lower confidence scoring.

Similarly, to coral reef species, the resilience of the characterising seagrass species was assessed based on the evidence detailing growth rates and reproduction or recolonisation of seagrass populations. From the three seagrass species, *Thalassia testudinum* is the largest species with relatively slower growth rates compared to *Syringodium filiforme* and *Halodule wrightii*, meaning that *T. testudinum* might be more robust and less impacted by certain pressures than the other two species, but once significantly disturbed, *T. testudinum* beds might take longer to recover. *Halodule wrightii*, on the other hand, is the smallest and fastest growing seagrass in TCI and is considered a pioneer species taking over the community after disturbance events.

Detailed resistance assessments are available in supplementary material provided as Appendix 4, and briefly summarised in Table 15.

Table 15. Resistance, Resilience, and Sensitivity scores for the assessed pressures for the Seagrass habitat.

Pressure	Resilience	Resistence	Sensitivity
Physical loss (to land or freshwater habitat)	N	VL	H
Physical change to another seabed type (e.g. soft rock to hard rock)	N	VL	H
Physical change to another sediment type (change in 1 Folk class)	N	VL	H
Abrasion/disturbance of the substrate on the surface of the seabed	L	M	M
Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	L	M	M
Smothering and siltation changes (depth of vertical sediment overburden) - Light	L	M	M
Smothering and siltation changes (depth of vertical sediment overburden) - Hard	L	M	M
Organic enrichment	M	M	M
Introduction of microbial pathogens	L	L	H

5.3.3 Sand

The sand assessment was focused on the genera of green alga specified in the benthic class and cyanobacteria. Communications with the DECR of the TCI Government suggested that *Laurencia* sp. was also included in this assessment as a prevalent species associated with sand habitats. However, during the initial literature review it became clear there was very little evidence for these genera in TCI. As a result, most of the assessment is based on evidence for *Halimeda* sp. and *Caulerpa* sp. from other Caribbean areas and the Mediterranean.

Detailed resistance assessments are available in supplementary material provided as Appendix 5, and briefly summarised in Table 16.

Table 16. Resistance, Resilience, and Sensitivity scores for the assessed pressures for the Sand habitat.

Pressure	Resilience	Resistence	Sensitivity
Physical loss (to land or freshwater habitat)	N	VL	H
Physical change to another seabed type (e.g. soft rock to hard rock)	N	VL	H
Physical change to another sediment type (change in 1 Folk class)	N	VL	H
Abrasion/disturbance of the substrate on the surface of the seabed	H	H	NS
Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion	H	H	NS
Smothering and siltation changes (depth of vertical sediment overburden) – Light	M	H	L
Smothering and siltation changes (depth of vertical sediment overburden) – Hard	M	H	L
Organic enrichment	H	H	NS
Introduction of microbial pathogens	Nev	NEv	NEv

6 Caveats and limitations

Several caveats and limitations have been highlighted following the first stage of Work Package 2, as detailed below:

- The current habitat maps and benthic class descriptions for the TCI have been mainly based on remote sensing data, with limited groundtruthing. These habitat maps are required for WP2, as spatial data is needed to enable condition assessments to be undertaken. However, it was highlighted to JNCC by DECR that some mapped habitats are incorrect, particularly areas of seagrass that should be mapped as algal plains. Without groundtruthed, up-to-date habitat maps and associated habitat descriptions, it wasn't possible to include algal plains within the sensitivity assessments. However, an assessment for this habitat could be undertaken later, using the methods described here, if the maps and associated descriptions are refined.
- There is a good understanding of the range of activities occurring in TCI waters, however there were few spatial datasets available showing the location and extent of these activities. Although this did not impact on the ability to identify key pressures to assess sensitivity of habitats against, the lack of spatial data will affect the next stage of WP2, to undertake condition assessments for specific habitats.
- The identification of priority pressures was based on a UK database, and therefore required review thorough stakeholder engagement to address potential data gaps and provide local knowledge to support understanding of priority pressures. There are, however, some key pressures that are, as yet, unassessed.
- The sensitivity assessments have been undertaken in a time limited fashion and, as such, a fully comprehensive search of all available literature has not been undertaken. In many cases direct evidence from TCI were not available within the literature and literature from other parts of the Caribbean/world has been used to support the assessments. There are also instances where similar species to those listed within the habitat definition have been used as a proxy where no direct evidence was available.
- Literature on habitat sensitivity was not always found for all pressures at the benchmark levels. This is common in sensitivity assessment work and is reflected in the confidence scores. It is therefore important that these confidence scores are taken into account when using the sensitivity assessments in any further work.

7 Recommendations for future work

7.1 Improved habitat descriptions

To improve upon the sensitivity assessments, it is recommended that further work be done to develop and refine habitat descriptions. Sensitivity assessments are based upon available literature associated with the species listed in the habitat definitions. This is particularly true of any information on infauna which might be present which is entirely missing from current descriptions.

7.2 Additional habitat sensitivity assessments

Only three habitats were selected to undertake sensitivity and condition assessments on. Further work could be completed in the future to assess the sensitivity of other mapped habitats, to enable a more complete understanding of habitat condition in TCI coastal and marine waters. However, improvements to the habitat descriptions are recommended to be completed first.

7.3 Additional priority pressures

As noted in Section 6, there likely remain some key pressures acting on TCI habitats that have not yet been assessed in terms of habitat sensitivity but could be completed in the future. Pressures caused by contaminants were suggested at the workshop. However, at this point in time, work is still ongoing within the MarLIN project to update the sensitivity benchmarks for these pressures. Once these are available, future work could include sensitivity assessments for these pressures.

7.4 Review of pressure benchmarks

The sensitivity assessments require pressure benchmarks to have a threshold to measure resistance against. In this project the benchmarks or the priority pressures were reviewed, and the ‘Organic Enrichment’ pressure modified to use TCI data to form a more accurate benchmark. However, for future sensitivity assessments which include a greater range of pressures, the complete list of pressure benchmarks will require thorough review and modification where necessary so that benchmarks do not rely on UK specific data or environmental conditions.

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