PILBARA PORTS AUTHORITY

MANGROVE REHABILITATION GUIDELINES

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EXECUTIVE SUMMARY

The Western Australian (**WA**) Environmental Protection Authority (**EPA**) recognises the intrinsic value of mangroves in the Pilbara as the largest unit of relatively undisturbed tropical arid zone habitats in the world. Permanent mangrove loss is considered a key threat to the maintenance of a healthy marine ecosystem and the EPA provides guidance for assessment of cumulative loss. However, while there are guidelines for permitted irreversible loss of mangrove area, uncertainty is associated with the concept of reversible loss where, for example, mangroves are removed for a temporary access corridor or construction envelope and would be expected to return within five years of the infrastructure removal. This has recently been addressed by the provision of Environmental Conditions that require developments to rehabilitate mangroves when they have been temporarily removed.

These guidelines were developed to provide further certainty around mangrove rehabilitation for developments within ports and harbours temporarily removing mangroves, specifically:

- A description of the mangrove communities likely to be encountered within coastal areas of the Pilbara;
- Suggested approaches for baseline condition assessment survey methods to ultimately inform completion criteria;
- Suggested considerations for infrastructure installation and removal;
- General principles of rehabilitation and suggested methodology to achieve it; and
- Suggestions for completion criteria targets and their demonstration.

Appropriate baseline surveys will provide the benchmark that rehabilitation aims to achieve. Field mapping, using appropriately scaled digital imagery and division of the area into various habitat categories, can be approached first. The appropriate number of representative sites can then be selected for characterisation and assessment. Condition assessment may utilise a number of quantitative and qualitative assessment methods, the most important being a topographic survey of the target area, as it will be necessary to reinstate this after construction. A number of general principles can be considered by the contractor responsible for infrastructure installation and removal that will aid in site rehabilitation, apart from minimizing the area impacted. There are also a number of constructions and operational management measures that will prevent indirect impacts and the primary factor dictating rehabilitation success will be the reinstatement of the topographic profile when infrastructure is removed.

The primary rehabilitation goal in the Pilbara is to return the habitat to its pre-disturbance state and successful rehabilitation will initially involve site reinstatement, frequent monitoring of sediment stability and enhancement of natural recolonisation. After two years, an assessment can be made as to whether natural recolonisation allows a prediction that will achieve the target species mix and density, and whether additional planting is warranted.

Completion criteria, which may use a five-year milestone as a decision point, can focus upon the ability to predict a favourable (and acceptable) recovery trajectory, based upon:

- Parameters such as species presence, stem diameter, density and height;
- Flowering/propagule production - assuming that the species that are becoming established within the rehabilitation site would flower within the first five years under natural conditions; and
- Evidence that natural recruitment is occurring.

An example is given of the use of these criteria and it will be valuable to measure appropriate reference site/s for comparison with the rehabilitation area, to take account of broader natural changes to the habitat.

APPLICABILITY OF GUIDELINES

While these guidelines were developed by Pilbara Ports Authority (**PPA**) and apply to the mangrove environments within its ports, the principles are applicable to the broader coastal Pilbara region.

Many of the considerations within the guidelines specifically address mangrove rehabilitation related to the removal of temporary infrastructure and associated construction envelopes. Key principles for mangrove rehabilitation are also provided that can be applied to planning rehabilitation from other potential impacts to mangroves that may occur and that have not been specifically addressed in these guidelines.

1. INTRODUCTION

The WA EPA recognises the intrinsic value of mangroves in the Pilbara region as the largest unit of relatively undisturbed tropical arid zone habitats in the world (EPA 2001). Accordingly to minimise, for example, mangrove loss associated with development, the authority divided the coast into regions (or categories) depending upon the perceived significance of the mangroves within them. The EPA Technical Guidance (EPA 2016) for the protection of benthic communities and habitats (BCH) (which includes mangroves as a BCH type) addresses thresholds of cumulative loss for BCH type for the purposes of environmental impact assessment. While the cumulative loss thresholds provided in the EPA's Technical Guidance for the protection or BCH are intended as guidance only (i.e. not criteria that must be achieved) it is implied that should a threshold be exceeded then further investigation into the ecological consequence is triggered and if determined not significant then the greater loss may be accepted by the EPA. In these circumstances, the term 'permanent loss' is defined as "direct removal or destruction of benthic communities and their associated habitats.".

While there are guidelines for permitted irreversible loss of mangrove area (e.g. EPA 2016), uncertainty is associated with the concept of reversible loss where, for example, mangroves are removed for a temporary access corridor or construction envelope and would be expected to return within five years of the removal of the infrastructure. This has recently been addressed by the provision of Environmental Conditions that require developments to rehabilitate mangroves when they have been temporarily removed.

1.1 PURPOSE OF GUIDELINES

These guidelines have been generated to provide more certainty around mangrove rehabilitation and to suggest current best practice methods to maximise the chances of success. They are divided into a summary of the mangrove communities likely to be encountered along the Pilbara coastline; baseline condition assessment survey approaches (to inform completion criteria targets); possible methods of infrastructure installation and removal; general principles of rehabilitation and suggested methodology to carry it out; and finally, example completion criteria targets and demonstration.

2. MANGROVE HABITATS

Detailed descriptions of the mangrove communities in the Pilbara are available from various sources (e.g. Paling and Erftemeijer 2013).

2.1 SPECIES

Seven species of mangroves are widely accepted as occurring along the Pilbara coastal region. These are (in order of commonality); *Avicennia marina*, *Rhizophora stylosa*, *Ceriops australis*, *Aegialitis annulata*, *Aegiceras corniculatum*, *Osbornia octodonta* and *Bruguiera exaristata* (see also Paling et al. (2001) and Pedretti and Paling (2001)).

2.2 ASSOCIATIONS

Paling et al. (2003) listed nine mangrove associations in the Port Hedland harbour area (Table1, Pedretti and Paling 2010). These associations in general occur throughout the Pilbara region with rare exceptions related to freshwater input such as the De Grey River and the Turner River delta (SKM 2012a).

Table 1: Mangrove associations that generally occur in the Pilbara region

MANGROVE SPECIES ASSOCIATIONS	
1	Closed canopy woodland of *Rhizophora stylosa*
2	Closed canopy woodland of *R. stylosa* and *Avicennia marina*
3	Closed canopy woodland of *A. marina* (seaward fringe)
4	Closed canopy woodland of *A. marina* (landward margins)
5	Low open woodland of *A. marina* on saline flats
6	Low scattered *A. marina* and scattered samphires
7	Low, dense *Aegiceras corniculatum*
8	Low open *Ceriops australis*
9	Low dense *Aegialitis annulata*

In general, however the associations can be reduced for practical reasons and a simplified mangrove vegetation classification was proposed by Paling et al. (2003) as most useful for mapping via GIS, is generally used in all Pilbara mangrove studies (Table 2) and the most likely to be encountered in areas that may need rehabilitation.

Table 2: Mangrove associations classified by Paling et al. (2003).

SIMPLIFIED MANGROVE SPECIES ASSOCIATIONS	
1	*Avicennia marina* (closed canopy, seaward edge)
2	*Rhizophora stylosa* (closed canopy)
3	*Rhizophora stylosa/Avicennia marina* (closed canopy)
4	*Avicennia marina* (closed canopy, landward edge)
5	*Avicennia marina* (scattered)

A further description of these categories is given below:

1. *Avicennia marina* (closed canopy, seaward edge) – a forest comprising large, mature, multi-stemmed *Avicennia marina* on the seaward edge of the main channels and sheltered small bays.

2. *Rhizophora stylosa* (closed canopy) – a forest/scrub comprising a relatively narrow zone, often only a few trees wide, behind the seaward *Avicennia marina* fringe and lining steep banks on small channels.

3. *Avicennia marina/Rhizophora stylosa* (closed canopy) – a forest/scrub comprising a transitional zone between closed canopy forest close to the seaward edge of main channels and extending to landward along small channel banks.

4. *Avicennia marina* (closed canopy, landward edge) – a forest/scrub comprising the typical zone of mangroves immediately behind the mixed association of *Avicennia marina* and *Rhizophora stylosa* and often up to 100 m in width or more and characterised by a decrease in vegetation height with increasing height (above Mean Sea Level (MSL)) on the shore.

5. *Avicennia marina* (scattered) – comprising scattered landward individuals of the mangrove Avicennia marina, often with scattered samphires, but without high densities.

Several species associations may not be visible using standard GIS techniques due to their small extent or, in the case of landward *Avicennia marina/Ceriops australis* associations, often the inability of GIS to discern them from landward *A. marina*. These may be present in construction areas but will likely be low in coverage. These associations are:

Ceriops australis

Stands: These usually occur in small creek banks and are often only a few trees wide. They occur on steeply draining banks and are often associated with creek erosion.

Individuals: As in 'Stands' but consisting of one or two trees. Usually associated with creeks, occasionally occurring at the landward mangrove edge.

Avicennia marina/Ceriops australis

An uncommon mixture that may occur at the landward end of mangroves. Trees of both species are often 1 to 1.5 m high and are interspersed in equal proportions to an approximate total canopy density of 50%.

Aegiceras corniculatum

Will occur in depositing areas within (usually) smaller creek systems to seaward of the *A. marina*. Stands are usually no more than 5 m wide and are therefore not visible on satellite or (often) aerial imagery.

Aegialitis annulata

Occurs as above for *A. corniculatum* and will most often be associated with them to seaward. Occasionally will occur in sandy substrates to landward of *A. marina* (e.g. Port Hedland) or under sparse seaward mangrove trees directly on shorelines (e.g. Cape Lambert).

Osbornia octodonta

Most often occurring as individuals but occasionally in thin belts of a few trees wide and up to tens of metres long to landward on sandy, well drained substrates (e.g. Finucane Island). Usually an uncommon to rare species.

Others

Other species that may be encountered (and are defined as rare) include *Bruguiera exaristata*, which occurs either at, or adjacent to creek edges. Usually solitary but may be in groups of up to half a dozen trees among *R. stylosa*.

2.2.1 Tidal hydrology and salinity gradients in relation to the distribution of mangrove associations

Tidal exchange and flows are the dominant and prevailing processes that maintain the Pilbara mangroves as they regulate many of the physical, chemical and biological functions. Inundation by seawater during flood tides is the main recharge mechanism that regulates the intertidal zone with lower salinities occurring in mangrove areas of lower tidal elevation (e.g. lower reaches of tidal creeks and more seaward locations) where tidal inundation is frequent (daily) and higher salinities are recorded from the more landward closed canopy and open shrubland zones that receive less frequent tidal inundation. The salinity gradients influence both the occurrence of the different mangrove species (due to differing salinity tolerance limits) and the mangrove community structure.

Groundwater and sediment salinity gradients established across the tidal flats have produced recognisable structural and physiognomic zones or associations as described above.

2.3 BASELINE CONDITION SURVEYS

The primary function of baseline surveys is to provide the appropriate metrics to inform that habitat state which rehabilitation aims to achieve so that it may be considered complete and/or successful.

2.3.1 Field Mapping

An appropriately scaled (i.e. between 1:2,000 and 1:5,000) ortho-rectified base colour photograph can be generated for the area that may require rehabilitation. It may then be annotated with an overlay of the infrastructure that will be installed, including any construction buffer zones.

The mangrove habitat categories, at the minimum those listed in Table 2, can then be mapped upon the image to stratify and determine the extent (i.e. ha) of the areas where condition assessment will take place in the field. As there will still be mangrove variation within these categories, depending upon their topographic positioning in relation to tidal inundation, it is difficult to be prescriptive regarding the number of sites within a category that need assessment (a minimum of three sites per habitat category should be used as a guideline). An appropriate formula however can be derived by considering that the usual form of temporary construction are access corridors (i.e. construction roads and conveyer belt trestles) which in general are up to several kilometer's long and 30 to 50 m wide. In this case, sites 50 to 100 m apart, along the centre of the corridor, would provide sufficient information for habitat characterisation. It may be necessary to collect data on the perimeter of the corridor, depending upon its width, visibility in the field and habitat variation. Sites should be GPS-positioned to allow accurate return to the survey location/s.

The primary object of this exercise is to choose sufficient survey sites to assure valid habitat characterisation.

2.3.2 Condition Assessment

A number of parameters can be collected to determine the base condition and community structure of the mangroves. These parameters can also help define the completion criteria discussed in Section 6. These are a combination of qualitative and quantitative assessment methods and include:

- Topographic survey of the infrastructure area. This would cover the entire footprint of the temporary disturbance and be as accurate in the vertical dimension as possible (i.e. 1-5 cm height resolution);

- Species;
- Density (percent);
- Leaf area Index (LAI) and/or canopy density;
- Tree height (in a radius from the observation point ≤ 20 m), depending upon the area of potential impact;
- Tree condition (as defined by Duke et al. 2005);
- Presence of seedlings; and
- Photographic record from the survey point to all compass points (N, E, S and W). An assistant holding a surveyor's scale bar may be included in each image.

A practical Qualitative Assessment Framework (QAF) has been developed by Paling (e.g. SKM 2012b) which includes the above parameters and additional measurements.

3. CONSIDERATIONS FOR INFRASTRUCTURE INSTALLATION AND REMOVAL

While, in most circumstances, installation procedures are dictated by the particular facility being constructed, there are a number of general principles that may aid in the rehabilitation of the site and could be taken under consideration by the contractor. Potential acid sulphate soils (PASS) may also be taken into account at this stage. The primary principles would be to:

- Minimize the direct impact area, as this would reduce the area required for rehabilitation; and
- Ensuring that tidal flows into (and out of) mangrove areas are maintained and surface water is managed appropriately.

Secondary considerations need to be given to minimising the potential for indirect effects such as project related sediment deposition within adjacent mangroves.

3.1 MANGROVE REMOVAL

It is suggested that mangroves be removed by cutting stems/trunks at ground level. Where possible disturbance to subsurface sediments should be minimised to avoid the liberation of potential acid sulfate soils (PASS). The main Pilbara mangrove (*Avicennia marina*) has a known ability to resprout or coppice when under stress or when cut and such vegetative recovery may also potentially be beneficial in providing more stability for rehabilitation via natural recruitment of seedlings or human assisted plantings.

3.2 LIMITATION OF DISTURBANCE DURING CONSTRUCTION

Appropriate buffer areas within the approved disturbance boundary can be maintained to limit indirect disturbance (i.e. that outside of the allowable envelope). Construction and operational management measures to prevent indirect impacts include:

- Fencing or clearly marking the boundary limits to avoid disturbance outside the approved boundary;
- Environmental inductions for construction staff;
- Measures to address spillage and sediment containment;
- Where possible limit or avoid disturbance to the in-situ soil profile; and
- Regular audits during construction.

3.3 INFRASTRUCTURE REMOVAL

It is suggested that all infrastructure not associated with the primary construction be removed (including rock and sand fill) after the project is completed. Conveyor infrastructure will have piles remaining as fixed additions to the environment but temporary roads should have material imported for construction removed and/or re-profiled appropriately. The characteristics of imported material may be quite different to in-situ sediments, so re-profiling works need to consider both the practical limitations of undertaking such works and the effects of resulting soil type/s on potential mangrove recruitment and survival.

It should be noted that there are several areas in Port Hedland where infrastructure such as roads and levees constructed within mangrove and tidal flat areas have provided a propagule deposition area and, in combination with providing lower salinity conditions, they are areas where mangrove seedling recruitment commonly occurs. In some cases, this may be in areas where mangrove previously did not occur. For example, a substantial amount of seedling recruitment has occurred on high tidal flats adjacent to the base of Utah Point Road, Port Hedland in an area that was previously devoid of mangroves (see Plate 1). If such a scenario has developed within an area requiring rehabilitation, then where practicable, care should be taken during rehabilitation works not to damage these mangrove seedlings or existing coppiced mangroves, as it is anticipated that this vegetation will be beneficial in providing more stability for additional rehabilitation via recruitment of seedlings.

Plate 1 : Mangrove seedling recruitment on high tidal mud flats next to the Utah Point Road.

3.4 TOPOGRAPHIC REINSTATEMENT

Tidal hydrological conditions that maintain the various mangrove zones or associations are primarily based on ground level elevation and the corresponding tidal inundation period experienced in each zone (as described in Section 2.2.1). Hence the reinstatement of a landform to the appropriate ground levels is a critical factor driving successful rehabilitation of the site and its importance cannot be overstated. Failure to reinstate the original topographic profile may compromise successful rehabilitation or will result in a species assemblage different from that present originally. As noted in Section 2.3.2, topographic profile is the primary parameter to be measured in baseline assessment. This obligation may be made clear to contractors prior to construction and if it is not possible to re-instate the landform to the appropriate levels, then an assessment should be made on the implications of the new topographic profile on the potential for long term rehabilitation.

4. REHABILITATION PRINCIPLES AND METHODS

It is useful to clarify an understanding of the terms 'rehabilitation' and 'restoration' (e.g. Paling et al. 2009). 'Mangrove rehabilitation' is a general term with the sense of improving, augmenting or enhancing a degraded or affected area, with the expectation that there will be an improvement through return of mangroves and mangrove ecosystem function. The term 'restoration' conveys the meaning of a return to pre-existing conditions. Since this is acknowledged as being an unlikely outcome in practice, 'restoration' is usually interpreted as returning the ecosystem to a close approximation of its condition prior to disturbance (USNRC 1992). By that definition, structure and function of the ecosystem are approximately created, but still with the expectation of producing a natural, functioning and self-regulating system integrated with the ecological landscape. It is usual to assume that a reinstatement of the three-dimensional primary producer habitat structure will allow faunal colonisation to commence. Thus efforts are often focussed upon returning and monitoring vegetation rather than measuring faunal recolonisation.

4.1 PRINCIPLES

Worldwide, failures to successfully rehabilitate mangroves are almost invariably associated with the same issues (Paling and Erftemeijer 2013). These are; poor site selection, choice of wrong species, unsuitable hydrological regime, absence of clearly defined goals and a lack of follow-up monitoring and maintenance. Often, projects move immediately into planting of mangroves without determining first why natural recovery has not occurred.

The following ecological principles, considerations and practical suggestions are based on a well-established process called "Ecological Mangrove Restoration" (Lewis 2005), building on lessons learnt from rehabilitation attempts worldwide (Erftemeijer & Lewis 2000; Lewis 2001; Primavera & Esteban 2008) and supplemented with findings and recommendations from the most recent literature:

1. **Understand the individual species ecology** of the mangroves at the site, in particular their patterns of reproduction, propagules distribution and successful seedling establishment.
2. **Understand the normal hydrological patterns** that control the distribution and successful establishment and growth of (targeted) mangrove species. Determining the normal tidal hydrology of existing natural mangrove plant communities (at a reference site) in the area in which one wishes to do restoration is perhaps the single most important factor in designing a successful mangrove restoration project (Lewis 2005).
3. **Assess modifications** of the original mangrove environment that currently prevent natural regeneration (recovery after damage).
4. **Restore environmental conditions**, especially the tidal hydrology (for example through rehabilitation of creeks, removal of small dams or raised berms further inland or installation of culverts to ensure appropriate tidal inundation characteristics and sufficient freshwater flow towards the mangrove stands) and any other modification that prevents mangrove regeneration.
5. **Facilitate natural regeneration** (through step 4) of the mangrove vegetation by encouraging natural recruitment of mangrove propagules and successful plant establishment.
6. Only consider actual **planting** of propagules, field-collected seedlings, or nursery-reared seedlings after determining (through steps 1-5) that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilisation, or rate of growth of saplings established as objectives for the restoration project. Plant the proper mangrove species (i.e. comparable to those found in similar, nearby reference sites) at suitable locations and within “the window of opportunity” (Balke et al. 2011).

In terms of the application of these principles to mangrove rehabilitation in the Pilbara, the above principles should be addressed when developing mangrove rehabilitation plans for not only the removal of infrastructure and associated construction envelopes but also other potential impacts to mangroves that may occur, or have been known to occur, in the Pilbara region. For example:

- Modification of tidal flows to mangrove areas by the construction of roads and other infrastructure across tidal creeks;
- Modification to hydrological conditions in mangroves by the construction/operation of ponds - hydrostatic head/seepage effect (e.g. solar salt ponds or ponds containing dredge spoil);
- Sediment deposition/smothering of mangrove aerial root systems (pneumatophores) by erosion of nearby sources of unconsolidated or uncontained fill;
- Dust; and
- Hydrocarbon spills or other discharges (e.g. bitterns from solar salt ponds).

4.1.1 Key principles related to mangrove rehabilitation following removal of temporary infrastructure

Paling and Erftemeijer (2013) collated a number of ecological principles, considerations and practical suggestions for rehabilitation but in summary, the most important aspects are returning the site to its previous topographic state and hydrological regime, allowing for natural recolonisation, carrying out appropriate monitoring and implementing planting if necessary. In the case of most temporary clearing for access or construction of conveyers and temporary roads, it will be necessary to reinstate the original topography and sediment characteristics.

4.2 SUGGESTED METHODS

4.2.1 Site Reinstatement

Firstly, it will be necessary to remove unrequired infrastructure, and to reinstate the original topographic profile of the area or profile appropriately to create conditions conducive to mangrove rehabilitation. Where possible disturbance to subsurface sediments should be avoided to minimize the exposure of PASS materials. It is important that any reinstated gradients are smooth and there are no large ridges or depressions that will prevent tidal drainage. It is assumed that a resurvey of the area will take place in concert with this activity so that the height reinstatement can be confirmed. It will be important to monitor the site over several tidal cycles to ensure that adverse erosion or sediment deposition is not taking place and that the area is relatively stable.

For trenching associated with pipeline crossings, further considerations may be necessary that are associated with backfilling of trenches. Backfilling with rock material is usually done to provide stabilisation and protection of the pipeline, but application of a top layer of sediment (preferably the original material) back to the original substrate level is recommended, to facilitate recovery of mangrove vegetation following completion of the pipeline installation and trench backfilling works (Paling & Erftemeijer 2013).

4.2.2 0 - 24 Months – Natural Recolonisation and Target Species

In most cases, with a physical reinstatement of the original system, natural recolonisation will potentially commence when propagules are next released. These times along the Pilbara coast are:

- *Avicennia marina* (Jan-Apr);
- *Rhizophora stylosa* (Jan–Apr);
- *Ceriops australis* (Oct–Mar);
- *Aegiceras corniculatum* (Feb–Mar); and
- *Aegialitis annulata* (Jan–Mar).

The major habitats are comprised of *A. marina* and *R. stylosa* and it is recommended that these be the focus of recolonisation/rehabilitation efforts as, once established, these areas will provide the habitat structure for *Ceriops* and *Aegialitis* (an understory species) to subsequently colonise in to. Small physical structures may be installed to enhance the capture of seedlings, particularly *A. marina*. These might consist of small (<10 cm) banks, grooves/furrows or net structures installed perpendicular to the prevailing tidal direction (e.g. Proisy et al. 2009). Monitoring programs can commence at this point and will be sufficiently robust to determine that the site is stable, if seedlings are coming into the area, their survival (and growth) rates and any reasons they are failing or being lost from the site.

After two years, an assessment may be made as to whether natural recolonisation allows a prediction that will achieve the target species mix and density and whether additional planting might be warranted.

4.2.3 After 24 Months – Natural Recolonisation and Planting

If natural recolonisation processes are taking place these can be monitored, along with parameters chosen from the baseline survey to allow the prediction of achieving the rehabilitation targets such as stem density and diameter, and canopy density.

If planting is required, there are several sources of material; newly released propagules of *A. marina* or *R. stylosa*; small natural seedlings (wildings) from nearby areas where abundant supplies of accessible seedlings occur, and nursery grown plants. There are several references on planting techniques contained within Paling and Erftemeijer (2013). Of primary importance is conducting appropriate monitoring and correction of technique/survival failures. If it is considered that nursery-grown plants will be required, consultation can be made in advance from suppliers to ensure propagules are available at the appropriate times.

5. REHABILITATION TARGETS

In simplistic terms, the primary goal of rehabilitation in the Pilbara is to return the disturbed mangrove ecosystem to as close a state as possible to that before it was cleared - notwithstanding that all mangrove environments are, by their very nature, in a state of change. In practical terms this is to return the mangrove vegetation to that state, with the recognition that full ecosystem functioning (e.g. faunal colonisation) may take longer to return.

Therefore, the predicted time frames required for a successful and defensible endpoint depend largely upon its initial definition (Paling and Erftemeijer 2013). If the goal is simply to establish some vegetative cover, this may be achieved within three years. Rehabilitating mangrove habitat to recover fish populations back to similar species composition and density as reference sites can often be accomplished within about five years (Lewis 1992). Full ecosystem functioning, in terms of nutrient and carbon cycles, and full faunal biodiversity, may take from 10 to 30 years. Unfortunately, the limited mangrove rehabilitation experience in the Pilbara makes it difficult to predict the appropriate time frame for completion to be demonstrated. In light of this, a set of workable criteria is needed to demonstrate that a particular area is on a pathway (i.e. a return trajectory) to achieve appropriate mangrove cover in an appropriate timeframe. Given that the EPA's Technical Guidance for the protection or BCH considers a return of BCH within five years as a reversible loss, this may be an appropriate timing milestone.

Results from a mangrove planting trial along an artificial tidal creek at Port Hedland, Western Australia demonstrate that by creating appropriate environmental and hydrological conditions conducive to mangrove growth in areas with abundant propagule supply, mangrove seedlings will recruit naturally and establish themselves successfully, with significant survival after three years. The slow growth of the mangroves in this semi-arid region suggests that it may take well over a decade before the mangrove vegetation at this site would be comparable to that of adjacent natural creeks in Port Hedland (Erftemeijer, Wylie and Garnet 2017).

As a cover target, it is suggested that focus be placed upon natural recruitment resulting in the stem/trunk density and species mix of each particular habitat category (e.g. Table 2) that was present originally (i.e. measured at baseline). As plants are established, stem diameter and height can also be added as criteria. This will demonstrate that the habitats are returning at an acceptable rate.

6. COMPLETION CRITERIA AND THEIR DEMONSTRATION

6.1 THEORY / GENERAL PRINCIPLES

A suggested first completion criterion includes the following staged approach:

Stage 1: Confirmation that a stable landform has been achieved and appropriate ground levels reinstated. Survey ground levels along the re-contoured landform and adjacent mangroves to confirm that appropriate ground levels have been achieved to restore tidal hydrology.

Stage 2: Correct species have returned to the particular habitat category.

Following this, given the time frame for demonstration (five years) and the metrics suggested (stem density and diameter); a theoretical general return trajectory for one habitat category is illustrated in Figure 1.

It is possible the original stem density would return to the rehabilitated area quite rapidly in all habitat categories. Density may vary in the first few years due to competition and other factors. For example, more mangrove saplings may establish than at the original density (or possibly greater) and these may reduce once intra-tree competition stabilizes. Or the natural deposition of mangrove seeds (propagules) may be favored to occur in particular or localised areas within the overall rehabilitation area.

Given the time frame, stem diameter is only likely to return to the original value in those categories where trees are not very wide (e.g. scattered *A. marina* (Figure 1) or landward continuous cover *A. marina*). It is unlikely, in the first few years that seaward *A. marina* trees will gain the diameter originally present (in many cases from 30 to 80 cm). The most important aspect of this metric is that the (probably annual) measurements allow a reasonably accurate prediction of when they will reach that point, along with providing certainty that trees are healthy, and the trajectory is being followed. Other metrics that will assist in demonstrating return of function are height, LAI and canopy density (see also Section 2.3.2 for other parameters).

It should be noted that due to the current lack of documented mangrove rehabilitation projects from the Pilbara coast, the rehabilitation trajectory shown in Figure 1 is theoretical at this stage and would need to be reviewed in the future as further information becomes available.

6.2 MONITORING OF REHABILITATION PROGRESS

It is suggested that monitoring times be annual except for the first year, where it is important to be able to establish that sediments at the site are stable, appropriate ground levels have been reinstated and that natural recolonisation is taking place. This may occur every three months and/or coincide with seedling release from *Avicennia* and *Rhizophora*. Should planting take place, then monthly or three-monthly monitoring might be suggested. Natural recruitment of *Avicennia marina* seedlings (the dominant species) peaks during the annual fruiting and seed/propagule dispersal period (February to April) and hence monitoring should be included after this period to capture the annual infusion of propagules/seedlings (e.g. May-July).

Monitoring should include a range of parameters appropriate to the rehabilitation project and site conditions. Potential parameters include:

- Ground levels - a surrogate measure to confirm that tidal hydrology has been restored;
- Seedling/stem density, stem diameters species composition, heights;
- Tree condition/ canopy density;
- Extent of natural recruitment versus human assisted recruitment (if plantings were to occur); and

- Soil stability and sedimentation/erosion monitoring (relative ground levels or sediment heights recorded by using reference markers).

Photo monitoring: It is valuable to measure appropriate reference site/s for comparison with the rehabilitation area to take account of broader (i.e. system-wide) natural changes to the habitat (e.g. cyclones).

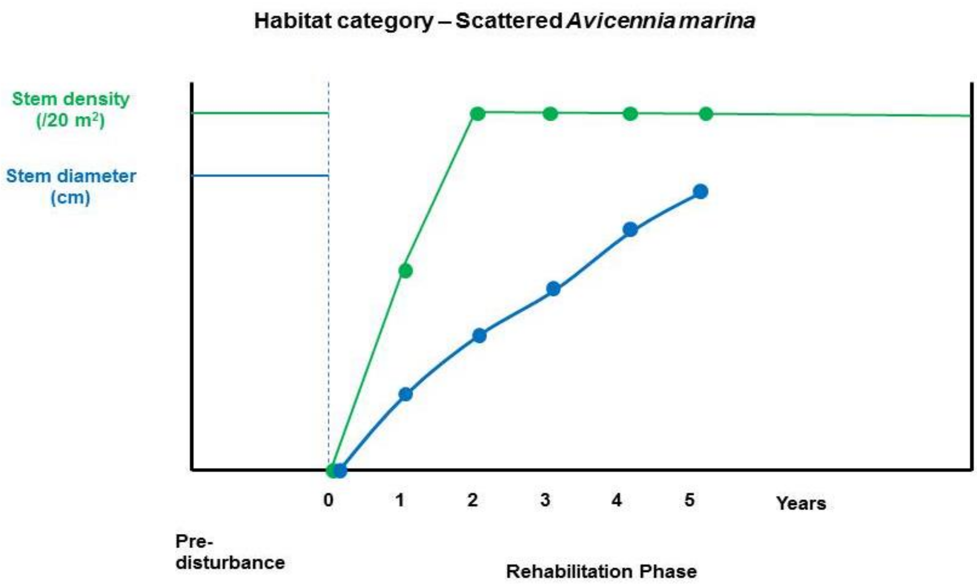

Figure 1: Theoretical rehabilitation trajectory for a disturbed mangrove habitat category in the Pilbara. The metrics suggested have illustrative units. For example, stem density might be in any convenient and measurable area. It would be envisaged that a mean and standard error would be quoted.

6.3 REGISTER OF MANGROVE REHABILITATION AND MANGROVE OFFSET CASE STUDIES

While there is an increasing range of literature and information available on mangrove rehabilitation/restoration from projects outside of Australia there is very little available for the Pilbara area on which to formulate rehabilitation plans. Environmental practitioners such as those associated with Pilbara ports, resource company developments and research organizations would have knowledge of mangrove rehabilitation and mangrove offset activities that have occurred on the Pilbara coast however, to date, this information has not been collated in a form that is accessible.

It is recommended that a register/database of mangrove rehabilitation and mangrove offset case studies from the Pilbara be established to help inform future rehabilitation/restoration/offset projects. Such a database could include information on:

- Descriptions of rehabilitation/offset scenarios;
- Type and scale of works undertaken to restore/rehabilitate existing mangrove habitat or develop new mangrove habitat;
- Extent and type of mangrove habitat that has been restored/developed (i.e. the development of the physical/chemical structural attributes that comprise suitable habitat for subsequent mangrove colonisation);

- Extent and type of mangrove vegetation that has developed within the restored or newly developed habitat (e.g. species, community type);
- Mode of seedling recruitment - natural recruitment and human assisted recruitment (i.e. propagule/ seed casting and transplanting seedlings);
- Timeframes involved to achieve the above; and
- Potential applicability of the rehabilitation/offset scenarios to future projects.

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