Biological assessment

Version: June 2018

Monitoring mangrove forest health

1 Purpose and scope

The scope of this document is to provide general guidance on a method that can be used to monitor mangrove forest health in Queensland. It is based on generic plot-based vegetation survey (Neldner et al. 2012) and vegetation condition assessment (Eyre et al. 2015) methods used in Queensland with additional measures e.g. litter trapping and crab burrow counting, which provide some indices on forest productivity. Alternative plotless methods may also be used, provided they are consistently applied and record the structural, floristic and productivity attributes of mangroves and evaluate change over time in these attributes.

In the case of harm to a mangrove ecosystem, it is recommended advice be sought from a mangrove expert.

2 Associated documents

Sampling design and preparation:

- *Permits and approvals*
- *Record keeping, including taking field photographs and videos*

Biological assessment: Background to monitoring mangrove forest health

3 Health and safety

Before following the methods contained in this document, a detailed risk management process (identification, assessment, control and review of the hazards and risks) must be undertaken. All work carried out must comply with the Queensland Work Health and Safety legislative obligations.

4 Permits and approvals

Permits and approvals may be required to conduct activities involving animals, plants and/or in protected areas (for example National Park/Regional Park, State Forest or State Marine Park). See *Permits and approvals* for more information on requirements.

5 Skills, training and experience

Skills, training and or experience required to understand and/or undertake this method include the ability to identify the different species of mangroves and other plants found in mangrove forests.

6 Equipment

See Appendix 1 for example equipment checklist.

7 Procedure

All the methods outlined in this procedure should ideally be used to fully assess the health of a mangrove forest, although a subset of methods may be used based on the objective of the study or investigation being

undertaken. Monitoring using all methods should, where possible, be undertaken in a single 50 x 10m plot (apart from the mangrove forest structure procedure where a number of 50 x 10m quadrats are surveyed). The alignment of this plot will depend on the width of the community being monitored but it is best to align the plot at right angles to the seaward edge of the mangroves if this is possible (Figure 1). Permanent markers, such as surveying pickets, should be used to identify the corners of the quadrat.

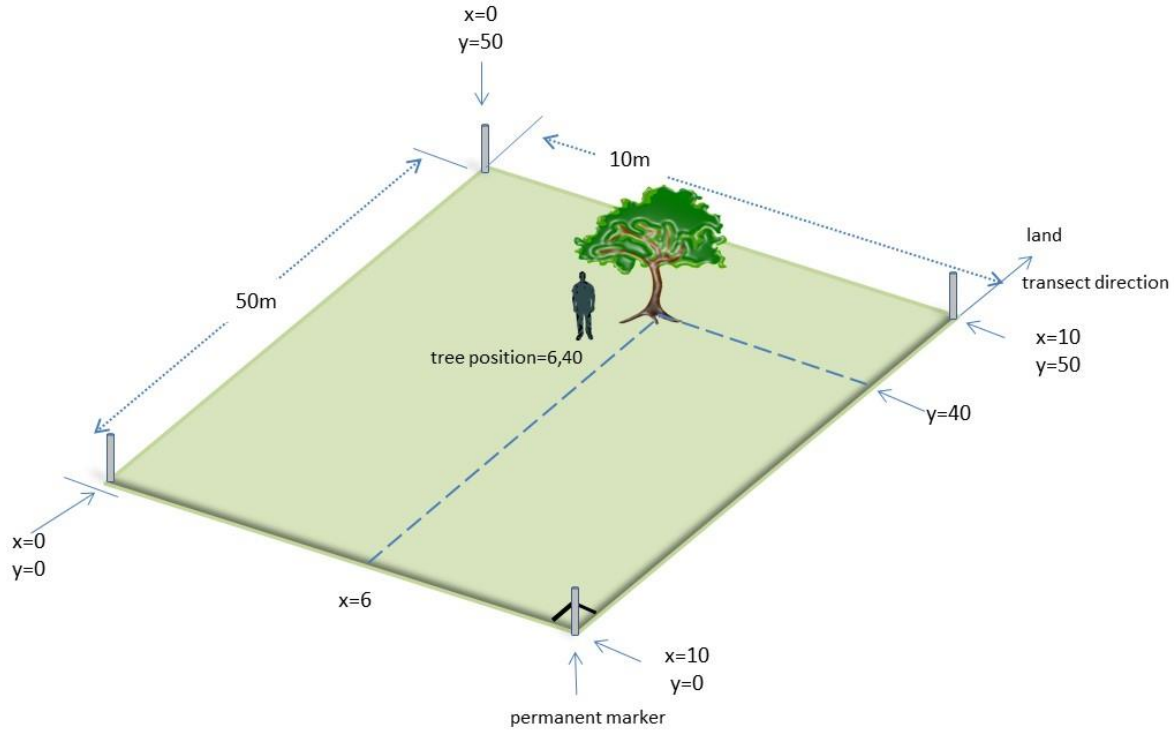

Figure 1: Setup of main sampling quadrat

7.1 Site selection

Though site selection will depend on the objectives of the monitoring program, in most instances it will be necessary to select sites that are representative of the mangroves in the area. Use recent aerial photographs to determine the size and extent of the site, and look for zonation patterns between the seaward and landward margins. Sites should be ground-truthed to confirm zonation patterns, and to ensure that they are representative. Select potential monitoring sites so they are representative of the mangrove community which you are trying to monitor.

As mangrove systems are diverse and can vary considerably in structure and floristics over short distances, a person of suitable experience should assist with this process.

Also note any evidence of unusual occurrences, such as deposition of rubbish, or other human-induced disturbances.

7.2 Mangrove litter trapping

Leaf litter traps are installed in a mangrove community and litter is collected monthly, sorted into different categories (leaves, twig, bark, flowers and propagules), oven dried, and weighed.

The dry weight of the litter is a measure of the productivity of the mangrove community.

Problems to be aware of include:

- significant disturbances (e.g. cyclones and storms) may damage sites and make it necessary to begin collecting data again for a time series

- traps can be interfered with
- climatic and biological differences in Australian mangroves make it difficult to compare data from different locations.

Within the forest:

1. Set up a transect running parallel to the tidal gradient (see Figure 2).
2. Put litter traps at 5m intervals along the centre line of the transect.
3. Install litter traps by attaching a nylon cord to each corner of the trap and hanging them evenly from mangrove branches (instructions for making a litter trap are in Appendix 2). Ensure that the bottom of the trap or chute is above the high tide mark (Figure 3).

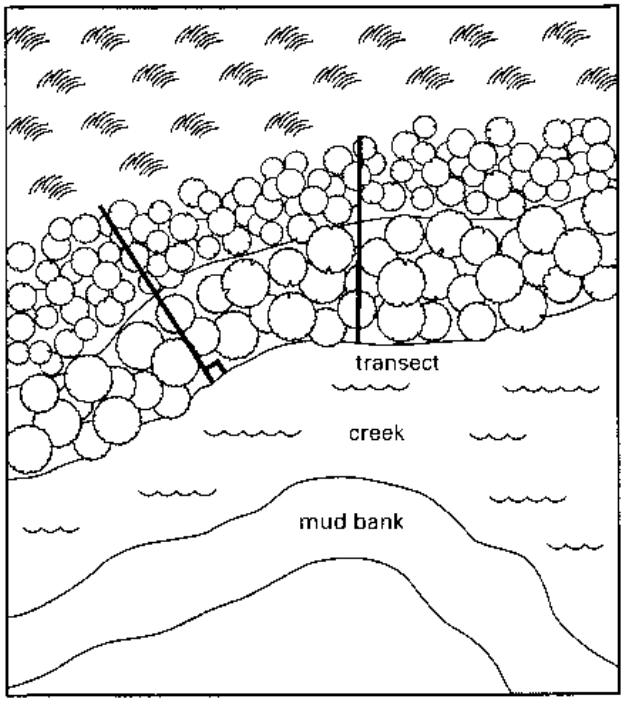

Figure 2: How to establish a transect

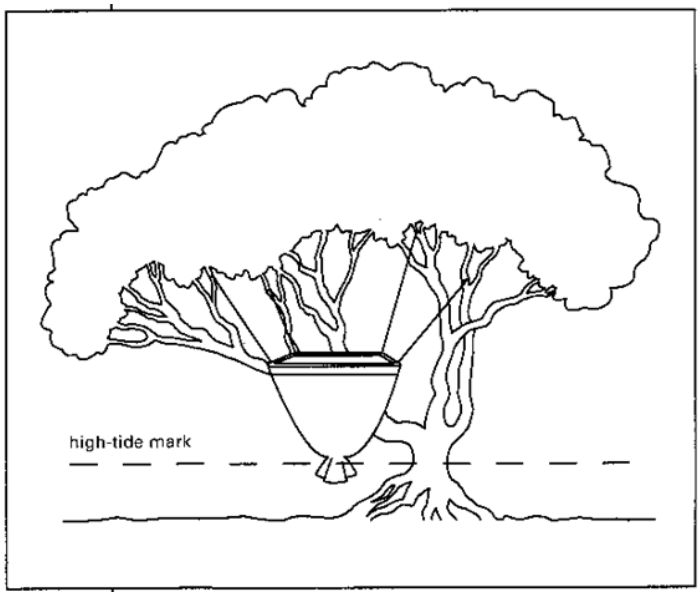

Figure 3: A litter trap in a mangrove forest

4. To empty a trap:

    4.1. Remove any large sticks and put them in a plastic bag labelled with the trap number.
    4.2. Put the bag under the chute.
    4.3. Untie the chute and empty the trap contents.
    4.4. Re-tie the chute securely.
    4.5. Proceed to the next trap.

Note: Traps should be emptied every month (every two weeks if measuring *Avicennia* spp.) to prevent leaf decay and to determine monthly trends.

On returning from the field:

1. Sort contents from each trap (do not mix content from different traps) into leaves, flowers, bark (include wood), seeds, stipules (if monitoring in a *Rhizophora* forest) and other items if they are present.
2. Count the number of leaves and stipules and record the result.
3. Place the sorted contents into smaller, labelled paper bags, and then put the datasheet and smaller bags in the large labelled plastic bag for transport to the drying ovens.
4. Dry the labelled paper bags in a drying oven at 70ºC for 72 hours.
5. Using laboratory scales, weigh the contents from each category in each trap separately.
6. Record the results (in grams, to three decimal places).

Note:

- Leaf litter contents can be kept in a refrigerator for up to a week before being dried.
- If there is insect damage, leaf dry weight is likely to be low, biasing estimation of leaf productivity. Therefore, leaf loss needs to be quantified by sorting leaves from each trap into the closest matching category, and correcting for this loss as detailed in Table 1 and Figure 4.

Table 1: Percentage loss categories of mangrove leaves

Category of leaf loss	Measured weight	Correction factor	Corrected weight
Full leaf		None (as measured)	
75% remaining		Multiply by 1.333	
50% remaining		Multiply by 2	
25% remaining		Multiply by 4	
		Total for Trap =	

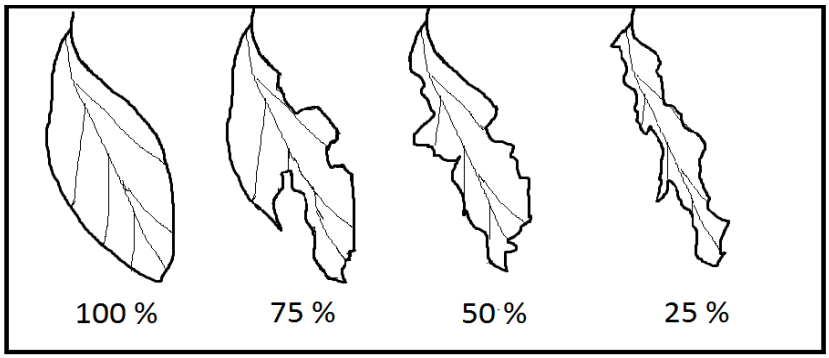

Figure 4: Leaf percentage loss

7.2.1 Data interpretation

Data is interpreted as mean dry weight of litter fall per square metre, per month (g/m^2/month). Ranges and standard deviations between traps should also be calculated.

Mangrove communities exhibit strong seasonal, annual and temporal variations in litter production, with peak fall occurring in summer in most locations, and varying with climatic conditions from year to year. It will also vary between regions due to different climate, rainfall, salinity and nutrient availability. For example, mangroves in the wet tropics are likely to produce more litter than those in more temperate climates. As different species also produce litter at varying rates, it is not usually appropriate to compare results between different regions and species.

Significant decline in leaf litter fall or reproductive effort in a particular mangrove community may indicate that it is under stress, so seek advice from relevant experts if such trends occur. If soil salinity is also being monitored, check data to see if unusual levels (high ones, in particular) have been recorded.

If comparing the stipules-to-leaves ratio in communities of *Rhizophora* spp., the ratio should normally be close to 1:1. Trends showing a higher ratio of leaves to stipules may indicate that the plants are shedding leaves, indicating possible stress.

For analysis of trends, data should be collected for at least three years, as some species of mangroves only produce propagules every two or three years.

7.3 Seedling regeneration

Seedlings should be monitored along the centre line of the plot at intervals of 10m in 1 x 1m plots.

The height and stem diameter of each seedling within the 1 x 1m plots are monitored every three months and used to calculate the growth rates of the seedlings. Stem diameters of seedlings will need to be measured at the same height above soil level on subsequent recordings.

Note: If seedlings are extremely dense the size of the seedling plots can be reduced to 0.5m^2.

7. Using the measuring stick, record the height of the seedling by measuring from the ground to the base of the uppermost apical shoot (Figure 5). Record the result on the datasheet.
8. Using callipers, measure the stem diameter of the seedling. This height will be determined by the height of the seedlings but 5cm above ground height would in most cases be an appropriate height.
9. For species that propagate using an elongated propagule rather than a seed (e.g. *Rhizophora* spp.) take the measurement at the base of the stem, just above the swelling of where the propagule meets the emerging stem (Figure 5).
10. Record density (number of stems per m^2).
11. Count the number of leaves on each seedling. If there are more than 25, record the result as more than 25 leaves. Leaf counts provide an indicator of seedling progress in the early stages of development.
12. Collect a sample of the substrate at the middle of the transect and classify it based on McDonald and Isbell (2009).
13. It is also advisable to record the salinity and pH of the sediment within the transect.
14. Draw a mud map of the gap showing its dimensions, an arrow representing north, the position of the transect, and the surrounding forest type.

When the site is re-surveyed all seedlings, including any new seedlings, should have their height, stem diameter and leaf number recorded. Seedlings will only be needed to be measured up to a height of 1m.

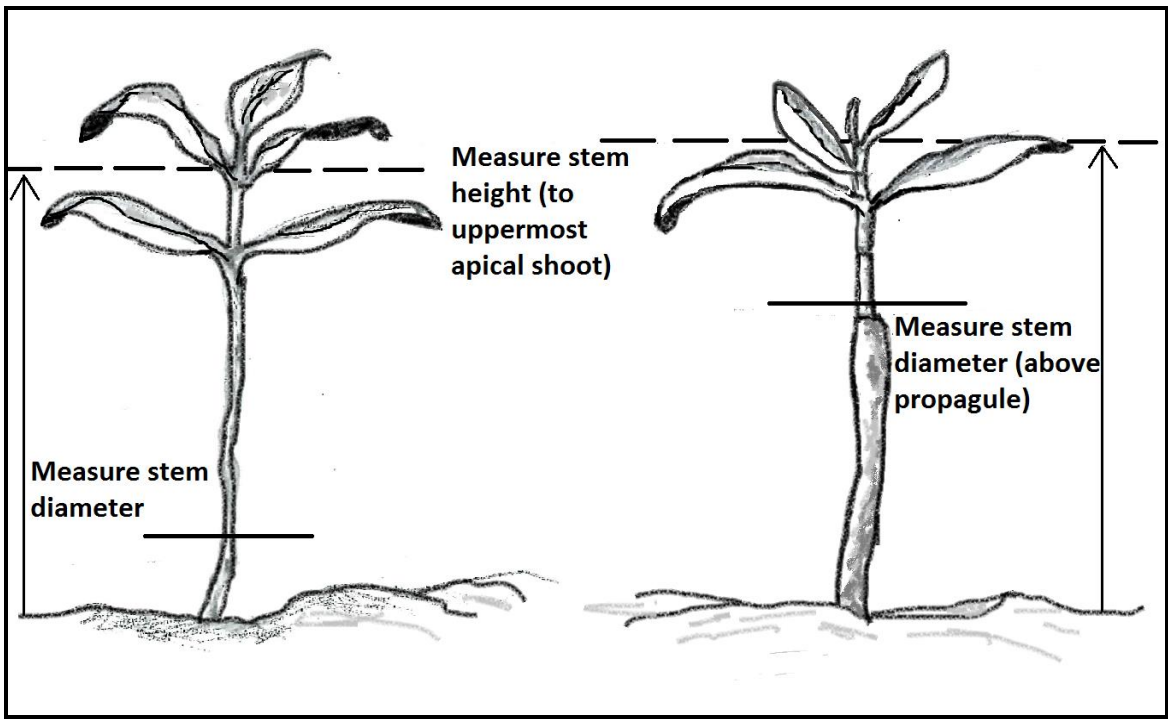

Figure 5: Where to take stem diameter and height measurement

7.4 Canopy cover and leaf area index

Light readings are taken in the sun using a light meter, outside the canopy of the mangrove community. A series of readings are then taken under the canopy, followed by a further series, again in the sun. Leaf area index (LAI) is determined by calculating the ratio of light under the canopy, to the light in the adjacent open space. The 50m x 10m quadrat is used.

Best timing is midday ±2 hours to ensure that the sun is as close to overhead as possible. Valid measurements can only be made on sunny days. LAI measurement is not suitable for fringing mangrove environments, as light penetration from the edges will bias the result (e.g. on narrow river fringes). For more extensive mangrove communities ensure there are at least 20m between the quadrat and forest edge to avoid light penetration.

7.4.1 Light Meter Readings

Either a lux or photosynthetic active radiation (PAR) meter is suitable; the choice of meter depends on the accuracy required. Lux and PAR readings are not easily comparable, so choice of meter is important. Lux meters are cheap and robust, measure total light intensity, can be used to detect and measure short-term changes to mangrove canopy cover but have some limitations. In contrast, PAR meters are expensive and fragile. However, PAR meters measure photosynthetic active radiation (light absorbed by plants during photosynthesis) and are therefore highly sensitive and able to detect much smaller foliage pattern changes than the lux meter can.

To use the meter:

15. hold the light meter in one hand and the sensor in the other, ensuring that the white surface of the sensor is facing upwards
16. turn on the light meter and select a range that is appropriate for the current light conditions
17. to take a reading: blink your eyes and record the first reading that you see when you open them
18. record the results, including the range setting of the light meter (e.g. 1x, 10x and 100x)
19. wipe down the meter with a moist cloth after each use, treating the sensor with extreme care.

Note: Always read instruction manuals for light meters, as some require the application of a correction factor.

Take the light meter readings:

20. Outside the canopy:

    20.1. turn on the light meter and set the range to 100x
    20.2. take five readings outside the canopy (multiplying each by 100 to adjust for range)
    20.3. record the results.

21. Within the quadrat:

    21.1. set the light meter to 1x or 10x
    21.2. walk along the boundaries of the quadrat taking a light reading every metre for 100 m
    21.3. record the results (adjusting for the range).

22. Repeat step 1 above.

Note: When a light meter is used under a forest canopy, readings will occasionally go off-scale. If this happens, switch to a higher range setting and record the measurement on the new scale. Return to the original scale and continue to take readings. It is important to complete each set of readings within 30 minutes.

7.4.2 Measurement of the zenith angle of the sun

An instrument called a clinometer is used to measure the zenith angle of the sun, which is its angle from the vertical (Figure 6). The closer it is to midday, the smaller this angle will be. If a clinometer is not available, insert a 1-2m pole into a flat area of sunlit ground, ensuring it is vertical. Measure the height of the stick and the length of its shadow.

$$\text{Zenith angle} = \frac{\text{arc tan (length of shadow)}}{\text{height of stick}}$$

Alternatively, the zenith angle for the site can be calculated from a nautical almanac, a suitable computer program or phone/tablet application, using the latitude, longitude (or GPS reading) and time of day.

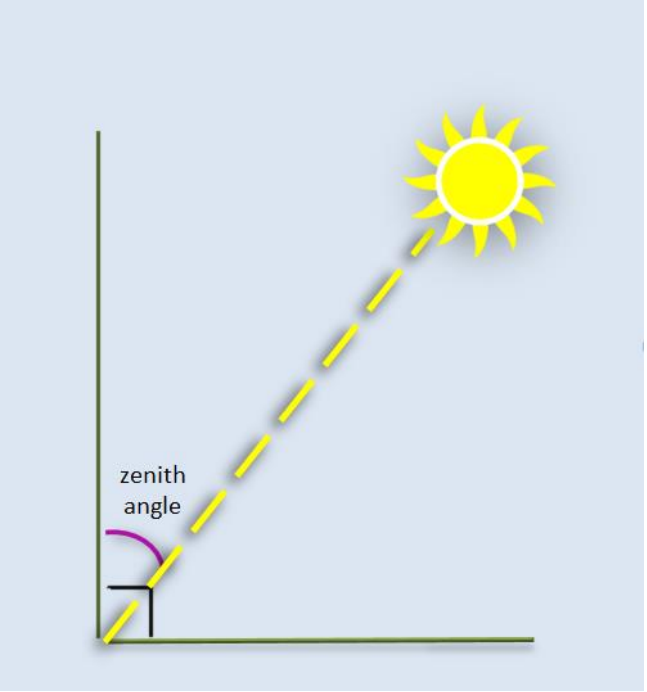

Figure 6: Zenith angle of the sun

7.4.3 Data interpretation

Calculate canopy cover and LAI of a plot using the following formulas:

$$\text{Canopy cover} = \frac{1 - \text{Average of canopy readings} \times 100}{\text{Average of open space readings}}$$

$$LAI = \frac{Ln\left(\frac{I_b}{I_0}\right)}{-k \times \cos\left(\frac{\infty\pi}{180}\right)}$$

Where:

Ln = Natural log of number

I_b = Mean value of light below the canopy

I_0 = Mean value of light above the canopy

k = Extinction coefficient that accounts for the angle and orientation of the foliage (a k value of 0.55 has been chosen as appropriate for mangrove stands).

∞ = Zenith angle of the sun

π = 3.14 (approximately)

Note: The k value quoted can be used in calculations for closed canopy forests of *Rhizophora*, *Bruguiera* and *Ceriops* spp. Due to the different structural characteristics of their canopies, it is **not suitable** for use in closed canopy forests of *Avicennia* spp., or in open forests. However, as no k value has, as yet, been calculated for *Avicennia* stands, the nominated value can be used to calculate LAI, but the data can be compared only with that from other *Avicennia* stands.

Forest LAI and canopy cover are the mean results from each plot. Data can be displayed on histograms as the LAI score, or as canopy cover per plot or forest over time. Median, range and standard deviations of readings are also calculated.

It is important to distinguish between natural and human-induced changes when interpreting data. As leaf area in canopies will naturally vary slightly from season to season, with a peak during the summer months, LAI can also vary naturally between sites and between different communities.

Large reductions in LAI are normally the result of disturbance or stress. If they are detected at a site, compare results from a control or other site (containing the same species) to determine if this reduction is local or more widespread. It is also recommended to return to the site to observe the forest closely for evidence of damage (e.g. storm damage, insect attack or stress).

7.5 Crab burrow counts

The number of crab burrows in a survey area is estimated by counting burrows within 50 x 50cm quadrats. Monitoring should occur every three months.

This method is normally used in association with other methods, but if establishing a new site, ensure that it is in an area representative of the surrounding forest.

23. Establish three parallel 10m transects through the site, 5m apart. Mark the beginning and end of each with a peg to assist in locating the site again later.
24. Starting at 0m, place a quadrat to the left of the transect and count the number of crab burrows within it. Burrows on the edge of the quadrat should be counted only if the centre of the hole is within the quadrat.
25. If crab holes are very numerous, use a 25 x 25cm area of the quadrat and multiply the results by four.
26. Replace the quadrat and count crab holes every 2m along the length of the transect.

7.5.1 Data interpretation

Data is interpreted as crab holes per square metre (holes/m^2).

Results may be highly variable between sites, so establish a baseline burrow density for each site. Long-term trends showing a significant decline in burrow numbers may indicate declining crab numbers and/or that the site is experiencing stress. Since crabs can have multiple burrow entrances and some species have been known to share burrows, the relationship is not linear.

Since crab hole abundance does not equate to absolute crab populations, significant changes in burrow counts

would need to be recorded to indicate changes in population. Crab holes can be covered by sediment plugs at low tide.

7.6 Mangrove forest structure

This method is used to:

- provide baseline data on the diversity and structure of a mangrove community at a particular site,
- monitor long-term changes and provide a quantitative measure of species composition, stem density, and basal area of trees.

This information can be useful for interpreting other parameters, such as leaf trapping ability and LAI. Changes to basal area, stem density and canopy cover can be indicators of ecosystem health. It is a time-consuming method and should only be used to study long-term changes to mangrove forests.

27. Establish a transect running at right angles from the sea to the land, with 10 x 10m quadrats in each forest zone along the transect.
28. Use the compass to establish the bearing to follow.
29. Identify the major forest types or zones along the transect
30. For each forest type, find an area to the left of the transect that is representative (in terms of floristics and structure) of that mangrove community.
31. Within each quadrat, record the canopy cover, species type, tree height, sapling/seedling number and stem diameter.

Note:

- If two quadrats are to be established, ensure that they are at least 20m apart.
- If monitoring a homogenous forest type or a narrow mangrove fringe along a creek, transects can be established parallel to the shoreline. Quadrats can be placed where the forest is representative of the mangrove community, or at regular intervals.
- If there are a large number of trees or shrubs in the plot and the canopy within the plot is even, only record half the plot (but note which side of the plot it is). For plots with very large numbers of trees/shrubs (e.g. *Aegiceras* communities) it may be necessary to reduce the plot size.

7.6.1 Estimation of canopy cover

32. Walk along the centre line and longest edges of the plot and record where the canopy starts and finishes along these lines. This includes recording breaks in the canopy along these lines.
33. Sum the distance that canopy covers along these lines.
34. Divide the figure by 3 and multiply by 2 to give a percentage cover for a 50 x 10m plot.
35. If the length of the plot is more or less than 50m you will need to adjust the figures accordingly.
36. If the canopy consists of more than one species of mangrove, estimate the percentage that each species contributes to the total canopy cover.

Note: Dominance is not the same as canopy cover; the total of all species must equal 100 per cent. For example, if there is a 70 per cent canopy cover and only one species, canopy dominance by that species is 100 per cent.

7.6.2 Measurement of stem diameter

37. Measure the stem diameter of each tree or shrub at breast height (1.3m above the ground) (Figure 7). Measure only those trees or shrubs with a height of 2m or more.
38. Record result as diameter at breast height (DBH) (Figure 7). A regular tape measure measures circumference only. Record this as circumference at breast height, and calculate DBH by dividing this result by π (approximately 3.14).
39. If carrying out long-term monitoring, hammer a galvanised nail (half of its length) into stems 10cm below where measurements have been taken, to provide a reference point for future measurements. Note this on the datasheet.

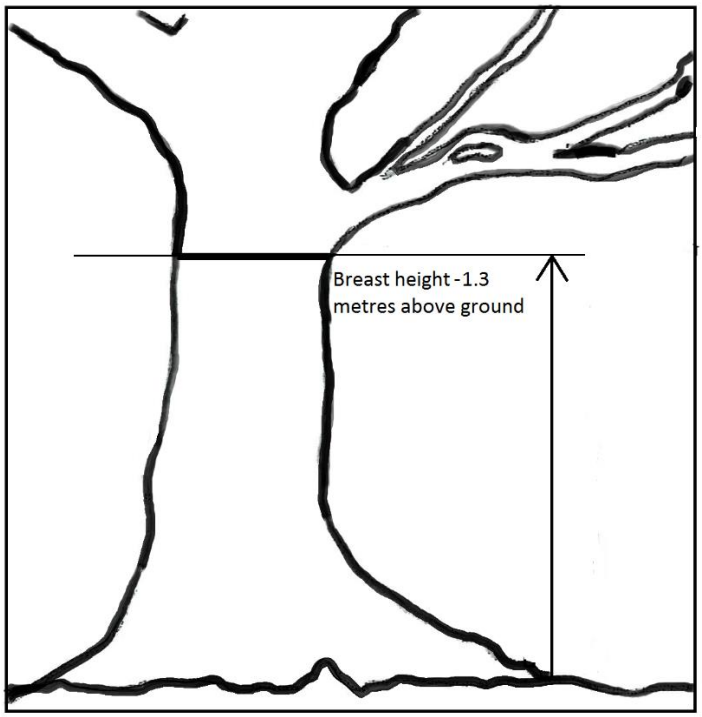

Figure 7: Measurements recorded at breast height

7.6.3 How to measure irregularly shaped trees

Irregularly shaped trees are very common in mangrove forests. If an irregularity occurs at breast height (Figure 8), use the following procedures to measure diameter:

- For multiple stems that fork below breast height; where stem diameter is 2.5cm or greater, measure the diameter of each stem at breast height, and record all results in the same box on the datasheet. Do not count each stem as a separate tree.
- For multiple stems that fork at breast height; take the measurement slightly below the swelling caused by the fork. For buttress roots, take the measurement 30cm above the uppermost prop root or buttress.
- For trunk swellings, take the measurement slightly above or below the swelling.

Some smaller mangrove forests may be naturally stunted or dwarf-like. In such situations these criteria are not suitable for determining growth status.

7.6.4 Saplings and seedlings counts

40. Count the number and record species type of seedlings and saplings within the quadrat.
    - 40.1. If plants are dense, use a smaller quadrat (size will depend on numbers, but 1 x 1m is a starting point), ensuring that the area sampled is representative of the larger quadrat.
    - 40.2. Estimate the number of seedlings/saplings within the 50 x 10m quadrat, based on the results of the smaller quadrat sampling.

7.6.5 Height estimation

To measure the height of each tree:

41. Stand the height pole up directly below the highest point of the tree (Figure 9).
42. Measure the height of the tree to the nearest 10cm, based on the known length of the pole.
43. Record the result.

Note: As this can be very difficult if the forest canopy is higher than 10m the use of a clinometer is recommended in such situations.

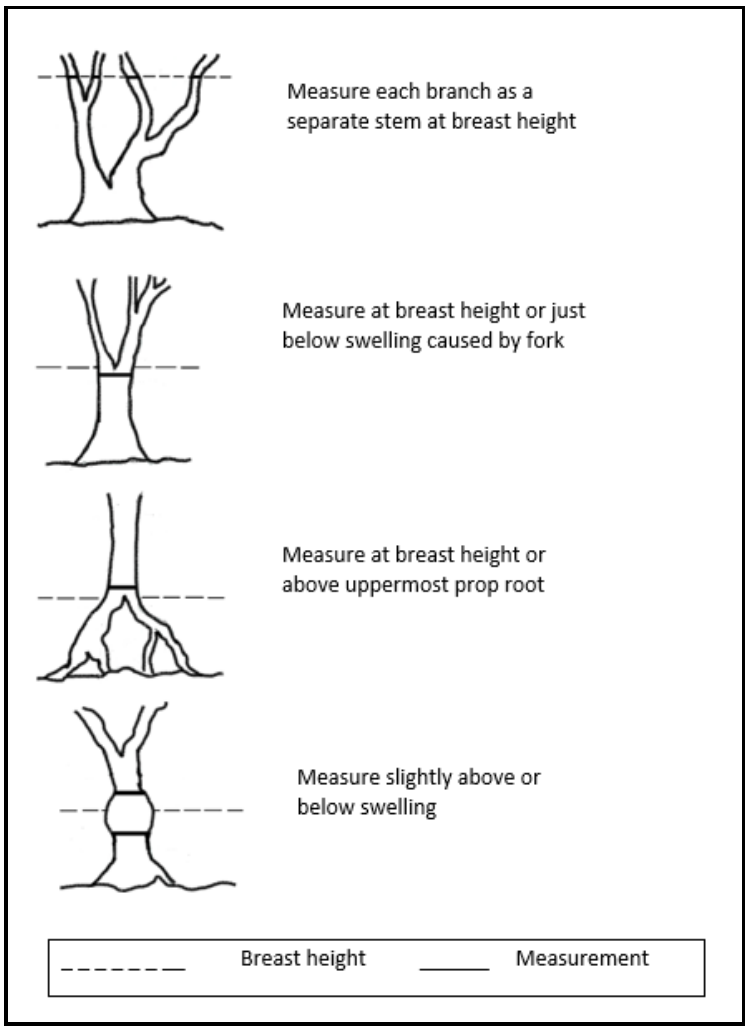

Figure 8: Measuring the stem diameter of irregularly shaped tree

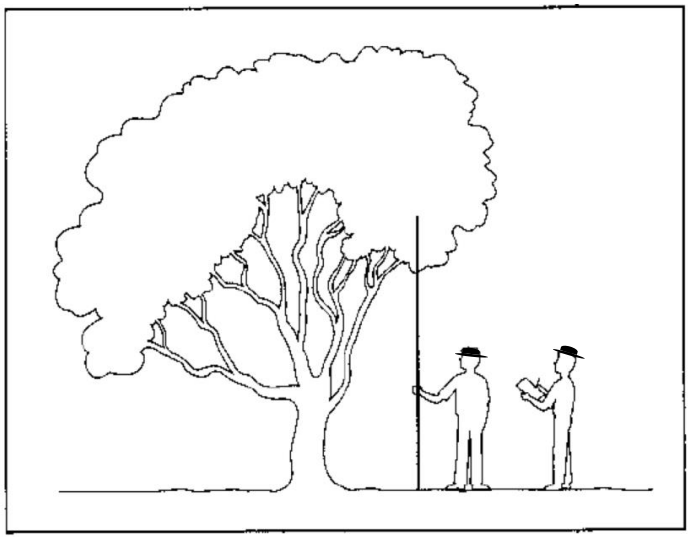

Figure 9: Using a height pole

7.6.6 Tag and record position of trees

Since branches can die during long-term monitoring of a plot, attach alloy or stainless steel tags to the main stem. Use nylon cable or stainless steel wire, ensuring that there is enough slack to allow for growth of the trees. The position of trees should also be recorded using a GPS.

7.6.7 Soils

Collect a sample of the substrate from the quadrat and rub it between your fingers. Record the sediment type based on its feel using the classification of McDonald and Isbell (2009). Other information such as pH and salinity can also be recorded.

7.6.8 Re-survey

As it is likely that a long time may have elapsed before repeat measurements are made, the original corner marker may have disappeared, but plot boundaries can be located using the tree tags. If new trees have become established, they should be assigned a new number.

7.6.9 Data interpretation

Formal measurements provide quantitative data on the structure or level of ecological development of a mangrove community. Data is expressed as:

- stems (living and dead) per hectare
- basal area (square metres per hectare)
- tree height.

Stems per hectare (stems/ha) is a measure of the density of living mangrove trees. It is calculated using the formula:

$$\text{Stems per hectare (stems/ha)} = \frac{\text{Number of living stems in plot} \times 10\,000}{\text{Area of the plot } (m^2)}$$

Stems per hectare should be calculated for each plot, together with the average for all the plots. The number of dead stems per hectare can also be calculated using the above formula, together with the overall ratio of dead to live stems (total dead stems versus total live stems).

Basal area (BA) of a plant refers to the cross-sectional area of its stem at 1.3m (breast height). The BA of a stand (stand BA) is the sum of all stem BAs in the quadrat, and is expressed as square metres per hectare (m^2/ha). BA is a measure of the size, biomass or level of ecological development of a mangrove community. Normally, the higher the BA, the greater the biomass and level of development of a mangrove community.

Basal area for an individual plant is calculated using the following formula:

$$\text{BA } (cm^2) = \pi r^2$$

Where:

r = radius of the stem (cm) = $\frac{\text{DBH (cm)}}{2}$

π = 3.14 (approximately)

If the plant has multiple stems, the basal area for the plant will be equal to the sum of the basal areas of the individual stems.

To calculate stand BA, use the following formula:

$$\text{Standard BA } (m^2/ha) = \frac{\Sigma \text{ BA for the plot } (cm^2)}{\text{Area of the plot } (m^2)}$$

Where:

Σ BA = sum of individual BAs

Increases in BA over time indicate that the community is still growing and developing. Increases in average canopy height will also help to confirm this. A significant decrease in BA may indicate that disturbance has occurred within the mangrove community. Average or median tree height can also be calculated to provide an indicator of canopy height and how the canopy is changing over time. Tree height measurements can also be used to track the progress of individual trees over time.

8 References and additional reading

Eyre, TJ, Kelly, AL, Neldner, VJ, Wilson, BA, Ferguson, DJ, Laidlaw, MJ and Franks, AJ 2015, *BioCondition: A Condition Assessment Framework for Terrestrial Biodiversity in Queensland. Assessment Methodology Manual, Version 2.2*, Queensland Herbarium, Department of Science, Information Technology and Innovation, Brisbane, viewed 9 December 2016, http://www.qld.gov.au/environment/plants-animals/plants/herbarium/publications/.

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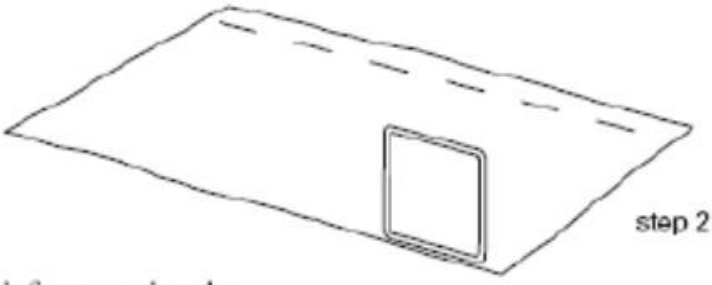
Neldner, VJ, Wilson, BA, Thompson, EJ and Dillewaard, HA 2012, *Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland*, *Version 3.2*, Queensland Herbarium, Queensland Department of Science, Information Technology and Innovation, Brisbane, 124 pp, viewed 9 December 2016, http://www.qld.gov.au/environment/plants-animals/plants/herbarium/publications/.

Appendix 1

Table 1: Equipment checklist

General equipment for sampling in mangroves	✓	**Mangrove litter trapping equipment**	✓
Recent aerial photographs Waders 50m tape measure and shorter tape measure Mangrove species identification books Datasheets Waterproof Marker Pens GPS Camera		Leaf litter traps Nylon cord Marker pens Labelled paper bags Large labelled plastic bag Drying oven Laboratory scales	
Seedling regeneration equipment		**Canopy cover equipment**	
Compass Stakes 1 x1m square Shorter tape measure Flagging tape Measuring stick Plastic callipers Soil salinity and pH measuring equipment (recommended)		Light meter Moist cloth Clinometer or a 1-2m pole or GPS	
Mangrove forest structure equipment		**Crab burrow counts equipment**	
Compass 4 x PVC poles Light meter or forest densitometer Hammer Galvanised nail Height pole or clinometer Alloy or stainless steel tags GPS Callipers, tree callipers or diameter tape depending on trunk size Soil salinity and pH measuring equipment (recommended)		50 x 50cm quadrats. Marker peg	

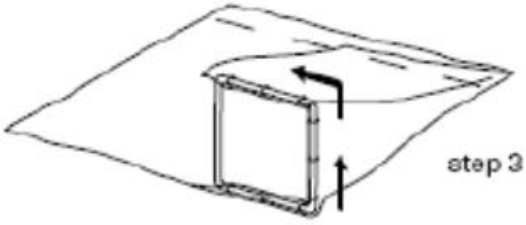
Appendix 2 Construction of leaf litter traps



step 2

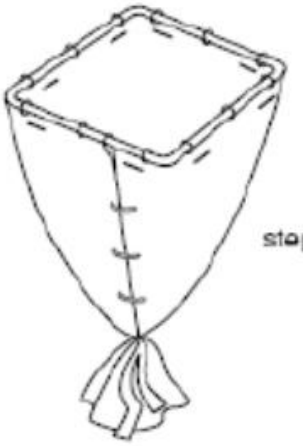
Step 1

Cut each frame so that the internal trap dimensions will be 50 cm x 50 cm.



step 3

step 4



step 5