Methods for Assessment of the Conservation Status of Coastal Dolphins in the Northern Territory

Report to the Northern Territory Department of Land Resource Management

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Background

This document recommends sampling and statistical methods for assessment of the conservation status of coastal dolphins in the Northern Territory. The project is part of an offset program developed by the Northern Territory Government through the Department of Land Resource Management (DLRM) to deliver robust scientific data to support the assessment of the regional conservation status of all species of coastal dolphins. The project will provide a framework for ongoing monitoring and management of dolphin populations and habitats in the Northern Territory, strengthen evidence-based decision-making, and assist in evaluating future environmental impact assessments.

The project will focus on the Australian snubfin dolphin (*Orcaella heinsohni*), Australian humpback dolphin (*Sousa sahulensis*) (Jefferson & Rosenbaum 2014) and the bottlenose dolphin (*Tursiops* sp.).
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Other species of interest include the false killer whale (*Pseudorca crassidens*) and the dugong (*Dugong dugon*).

The project is in line with the Australian Inshore Dolphin Research Framework (Department of the Environment 2013) and recommends similar methods to those recommended for the Framework (Brooks, Carroll and Pollock 2014).

The project has the following objectives:

1. Identify significant habitat and areas of high conservation value for coastal dolphin species
2. Assess the regional conservation status of coastal dolphin species in the Northern Territory waters
3. Improve data accessibility to relevant stakeholders

**Objectives of this report**

1. Conduct an analysis using survey data collected in Cobourg Marine Park to derive estimates of occupancy and detection under different survey scales and sampling effort, including a comparison of the efficacy of boat- and aerial survey platforms.
2. Develop a sampling design using simulation of different survey designs on occupancy modelling for three species of coastal dolphins for the coastal waters of the Northern Territory.
3. In addition to the occupancy design, develop methodology for estimating the relative abundance of coastal dolphins from the aerial survey data.
4. Produce a report outlining survey design, statistical analysis methodology, model assumptions and limitations, required sampling effort and precision.

**Sampling design**

**Background**

The geographic scale of the study, the remoteness of much of the area, and that all three species are relatively rare, represent constraints on the sampling design. In particular, the design needs to accommodate the expected low density and patchy distribution of the species, the difficulty of accessing survey sites and the cost of returning to re-sample them.
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**Presence/absence – occupancy and detection**

When detection is imperfect, ‘presence/absence’ data can only be interpreted as detection/non-detection data because, while detection indicates presence, non-detection cannot be taken to indicate absence. Statistical methods that use repeat surveys to provide information on detection probability and tease apart the occupancy and detection processes are required to estimate the proportion of sites that are occupied (MacKenzie et al. 2006).

The basic, ‘single season’ occupancy model (MacKenzie et al. 2002, Mackenzie et al. 2006 Chapter 4) models detection/non-detection data from set of repeat surveys on a sample of sites to estimate two parameters: the probability of site occupancy ($\psi$) and the probability of detection given occupancy ($p|\psi$) or simply ($p$). Covariates may be fitted to both parameters and suitable covariates are subsequently described. Here we indicate that covariation of estimates of the probability of occupancy with habitat variables is potentially a rich source of information on the distribution and habitat use of the species under study.

**Home ranges, core habitat and mobility**

Current knowledge indicates that Australian coastal dolphin sub-populations occupy relatively small home ranges that may often extend over less than 50 km of coastline (Cagnazzi et al. 2013). Sample sites defined over stretches of coast of about this size will overlap with home ranges to varying degrees depending on whether sub-populations are present in the areas, the locations of the cores (centroids) of their activities (core habitat) relative to the locations of the sites, and the actual home range sizes of local sub-populations.

We assume that, if a local population exists in the area, there is a non-zero probability of detecting the species on survey within a site defined over 40-50 km of coast. The probability of detection will vary with survey effort, sighting conditions and the density of the species on the survey site. The density of the species on a survey site will in turn depend on the size of a local sub-population and the extent of overlap between its home range and the survey area.

We are not aware of any reason to suppose that sub-groups of animals in a local population preferentially use different parts of its home range. Consequently, it’s reasonable to assume that samples taken in different areas within the same 40-50 km of coast are random.

**Groups, individuals and calves**

Snubfin, humpback and bottlenose dolphins typically travel in groups of varying sizes (1-20, mean = approximately 5: Parra et al. 2002; Cagnazzi et al. 2013) and a presence/absence study will aim to detect groups rather than individuals. Obviously, such groups need to be identified to species but,
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because conservation status assessment criteria, as specified the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) for example, are typically framed in terms of numbers of mature individuals, data are required on group sizes so that information on the abundance (or detection rates) of groups can be re-expressed as the abundance (or detection rates) of individuals. Information about fecundity is inherent in counts of calves within groups and these data should be estimated in the field along with group size.

Sampling efficiency

Many parts of the Northern Territory coast are remote and expensive to survey, and returning to re-sample very remote sites would add greatly to the cost of the project. While replication is required to separate the probability of occupancy (ψ) and the probability of detection in occupied sites (p|ψ) (MacKenzie et al. 2006), replication may be achieved during a single survey session extending over a relatively short period (a day or days), or spatially rather than temporally by selecting spatial sub-samples within sites (Nichols et al. 2008; Kendall & White 2009; Guillera-Arroita 2011). With spatial replication, the probability of detection is a combination of the probability of dolphins being present in a sub-sample at the time of survey and the probability that they are detected if present.

A purely spatial approach to replication implies a one-off, cross-sectional survey that would not permit modelling of the influence of temporally variable factors on a site-by-site basis. Information on this would be inherent, however, in across-site variation in the conditions prevailing at the time each site was surveyed. Replicate helicopter surveys on the same site would be typically be taken over a day or days however, permitting modelling of the influence of factors that may vary over relatively short time spans such as tidal state.

Temporally variable factors are unlikely to greatly affect estimates of occupancy for sites defined on the approximate scale of a sub-population home range although they may influence the rates of use of different habitat types within a site.

General approach to sampling

We recommend a general approach to sampling with 3 nested spatial levels:

- Primary sampling areas. Areas of 400 km$^2$ or more, extending over 40-50 km of coast and out to 10 km offshore, plus any inshore, estuarine area of at least 100 km$^2$
- Secondary sampling areas. Sub-areas (zones) defined within each primary sampling area to distinguish between broad habitat types
- Tertiary samples. Sets of transects run through each zone in each primary sampling area – each complete transect is a survey on a zone
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Each length of transect surveys an area of unknown width depending on how far from the transect line it is possible for a group to be detected and the probability of detecting a group within that width. We do not attempt to estimate the effective search width or the effective area surveyed here but it should be clear that the probability of detection is associated with the density of groups on the site.

**Primary sampling areas**

**Size**

We recommend that areas of approximately the expected size of a sub-population home range be selected as the primary sampling units for this research. In this situation, if such an area is occupied, it is reasonable to expect that members of the local sub-population will be present there at all times. Consequently, an estimate of the probability of occupancy of primary sampling areas defined on the approximately home range sized scale may possibly be interpreted as an estimate of the probability of residency. Smaller areas within a home range (e.g., zones) will be used with some frequency but may not be continuously occupied, and estimates of occupancy at this level should be interpreted as indicating rates of use rather than residency.

It is not necessary that all primary sampling areas be the same size, although operationally it is recommended that their sizes be similar. For primary sampling areas of varying sizes, it is necessary that each be spatially defined and its area calculated.

While the species of interest may range out to 20 km or further from the coast, they are coastal species nonetheless and individuals that may occasionally be seen further from shore are expected to be as likely or more likely to be found within 10 km from shore. Accordingly, we recommend that sampling not be undertaken further than 10 km from land to limit the total area to be surveyed and to better concentrate effort on the expected favoured habitat of the species. If part of a local sub-population is more than 10 km from land at the time of sampling, we expect this to reduce the probability of detection but not substantially affect the probability of occupancy.

Note that we do not employ water depth as a basis for defining sampling areas. As subsequently described, we recommend that depth be measured on transect (or derived from bathymetry maps), for use as a covariate.

In sum, primary sampling areas will typically extend over approximately 40-50 km of coast and out to 10 km from land, although their areas will vary depending upon the extent of within river (inshore, estuarine) area included.
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While it is proposed to define primary sampling areas on the approximate scale of sub-population home ranges, there is little information on their actual sizes and they may be highly variable. Consequently, it should not be assumed that an estimate of occupancy at the level of primary sampling areas will provide a reliable basis for estimating the number of sub-populations. It is possible that such areas could include members of more than one sub-population of the same species and likely that some sub-populations range over areas that are larger than the primary sample areas. The main objective of specifying areas on the suggested scale is to increase the probability that, if such an area were occupied, members of the local sub-population would be present and available for detection there at all times.

Location – Sites of type A (Estuarine sites) and B (Other sites)

The search area covers the entire Northern Territory coast, includes islands of at least (area) up to 35 km from the mainland and extends up to 10 km from land.

Ideally, each primary sampling area would be centred on a point of expected focal habitat (centroid of use) within a site. There is little information about this for any species however, and it will be necessary to select potentially arbitrary points on the coast to act as centres of primary sampling areas.

Rivers

While definitive information on the species’ preference for areas near river mouths is lacking across the range, there is evidence for this on the coast of Queensland (Parra et al. 2002, 2006). The locations of the mouths of major and minor rivers also offer a basis for identifying points around which primary sampling areas can be defined.

We recommend identification of river mouths to serve as focal points for defining most primary sampling areas, and that two broad site types are defined as follows:

A. Areas of type A. Estuarine sites. Sites centred on the mouths of major rivers and some additional focal points of comparable sites, such as large sheltered bays including ports and harbours, as described below. Criteria for an area of type A are that it includes at least 100 km$^2$ of inshore, estuarine area and that it has a distinctly embayed form.

B. Areas of type B. Other sites.

We recommend that large, sheltered bays, including harbours, be included among sites of type A. An example of a large, sheltered bay that supports a relatively large population of snubfin dolphins, and shares many of the features of a major river or estuary but without substantial freshwater inflow, is Port Essington on the Cobourg Peninsula, NT (-11.256, 132.150) (Palmer et al. 2014).
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A rationale for inclusion of these sorts of areas among sites of type A is that they may provide preferred habitat for dolphins and may also be attractive as sites for port or other coastal development.

A subset of the list of major rivers consisting of those that include at least 100 km² of inshore, estuarine area and a distinctly embayed form, supplemented with suitable bays and harbours, may be used to compose a sampling frame for sites of type A.

While adjacency to a river mouth is not a criterion for sites of type B, minor rivers are widely distributed around the coast and their locations might be employed as a basis for composing a list of potential points around which to define these sites. Only a small length of coast is greater than 50 km from the mouth of any river, large or small and exclusion of this area from the site selection process is unlikely to introduce systematic bias in the estimated probability of occupany.

A sampling frame for sites of type B may be composed by listing the minor rivers, perhaps supplemented with a subset of other arbitrary locations.

Secondary sampling areas and zone types

We recommend that zone types be defined within the primary sample areas to ensure reasonable coverage of the primary sampling areas, provide spatial and environmental coherence to each set of replicate surveys and to compose a broad-scale classification of habitat types.

It is necessary to define these zone types somewhat differently for primary sample areas of the different types because primary sample areas of type A include substantial areas of inshore, estuarine environment by definition, while areas of type B do not.

Zone types for primary sample areas of type A (Estuarine sites)

Three zone types for areas of type A are defined in reference to two distance from land lines and a virtual line across the river mouth or the ‘mouth line’ (a line demarcating the inshore, estuarine area from the oceanic environment):

1. Seaward from and within 5 km of the mouth line – the ‘near-shore’ zone
2. Seaward from and between 5 and 10 km of the mouth line – the ‘offshore’ zone
3. The inshore, estuarine zone (inside mouth line) – the inshore zone

Zone types for areas of type B (Other sites)

Only two zones types are defined for sites of type B:

1. Within 5 km from land – the near-shore zone
2. Between 5 and 10 km from land – the offshore zone
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The near-shore zone in estuarine sites will differ from the near-shore zone in other sites because they will generally be further from shore being located outside the mouth line rather than by distance from shore. Similarly, the offshore zone in estuarine sites may differ in character and probability of use by dolphins from the offshore zone in other sites being subject to the influence of a nearby estuary or major bay. For these reasons, the five zones in the estuarine and other sites might be considered as distinct and treated as a single factor in modelling.

Tertiary sampling units (replicate surveys)

Each level 3 unit is a length of transect through a zone and constitutes a replicate survey of it. It is recommended that each replicate survey be at least 40 km in length to ensure an adequate per replicate probability of detection in occupied level 2 areas (zones). Covariates on the probability of detection of the species will be measured at this level and, for factors that vary during the course of a transect pass, derived as the mean of least three measurements taken during the course of survey from the transect line.

Statistical models

The book by MacKenzie et al. (2006) is the core general reference for occupancy modelling. The development of occupancy models has been rapid since publication of the paper by MacKenzie et al. (2002). Occupancy models may be fitted in the software programs Presence (http://www.mbr-pwrc.usgs.gov/software/presence.shtml) and Mark (http://www.phidot.org/software/mark/).

While we have recommended a 3-level sampling structure, we focus on two-level models and analysis of the data at two levels in this report.

Two-level data may be derived under either of two scenarios:

1. Scenario 1 – treating the sample of secondary sampling areas (zones) as sites and the tertiary sampling units (replicate surveys) within each as surveys of each zone
2. Scenario 2 – treating the sample of primary sampling areas as sites and the tertiary sampling units (zones and their replicate surveys) within each as surveys of each primary sampling area

To allay future confusion, the software refers to ‘sites’ and ‘surveys’ where the surveys are replicates of the sites. We have attempted to make it clear in what follows which level of sampling area is being referred to as a site for the purposes of analysis. While the whole project may be conceived of as a survey, here we use ‘survey’ to indicate a replicate of a site whether the site is defined at the primary or secondary sampling area level.
Under scenario one, the effect of the spatial clustering of zones within primary sampling areas would need to be assessed and adjusted for if necessary. Judicious employment of covariates to distinguish among primary sampling areas may obviate the need for such adjustment. Advantages of this approach are a much larger sample of sites (here the zones) than under scenario two (there the primary sampling areas) and estimation of probabilities of occupancy for the zone types in addition to the site types. With zones being smaller than the species’ home ranges, the rates of use and the density of groups on zones would vary over time and the estimated probabilities of occupancy of zones should be interpreted as reflecting rates of use. Estimates with reasonable precision generally require at least 4 replicate surveys of each site (i.e., zone in this case).

Under scenario two, the variation among zone types would be reflected in differences between them in the estimates of the detection rather than the occupancy probability. As subsequently described, such differences in detection probabilities might be interpreted as reflecting differences in the density of groups in each zone type at the time of survey. If data with four replicate surveys per zone are collected with modelling under scenario one in mind, the number of repeat surveys per site (here primary sampling areas) would be greatly increased by modelling under scenario two (there zones). While this would be at the cost of reducing the size of the sample of sites (there are fewer primary sampling areas than zones), it may be useful if detection probabilities were too low from analysis under scenario one to obtain reliable estimates for a species. It would be possible under these circumstances to combine replicate surveys in pairs (aggregate over pairs of replicate surveys on a zone) to increase the detection probability while retaining a sufficient number of replicate surveys on the sites (primary sampling areas).

**The standard single season occupancy model**

An appropriate model under either scenario one or two is the standard single season occupancy model (MacKenzie et al. 2006; see Kendall & White 2009 and Guillera-Arroita 2011 for considerations relating to spatial rather than temporal replication), albeit with appropriate adjustment for the spatial clustering of zones in level 1 areas under scenario 1.

The parameters of the model are

\[
\{\psi, p\} \quad \text{where,}
\]

\[
\psi = \text{the probability of occupancy of sites, and}
\]

\[
p = [p | \psi] = \text{the probability of detection in occupied sites.}
\]

Covariates may be fitted to the probability of occupancy and/or the probability of detection. Suitable covariates are suggested below. It is anticipated that careful use of covariates will be necessary to
Methods for assessment of the conservation status of coastal dolphins in the Northern Territory ensure good fit of the model to data and that estimates their effects will important to conclusions about the conservation status and habitat use of the species.

In fitting this model under scenario one, site type (A or B) and zone type (inshore, near-shore, offshore) or their combination as five district zone types would be assessed as covariates on the probability of occupancy ($\psi$), along with other occupancy covariates. The mean sea state during the repeat survey and possibly other variables would be assessed as covariates on the probability of detection.

In fitting this model under scenario two, zone type (inshore, near-shore, offshore) would be assessed as a covariate on the probability of detection ($p$) to adjust for variation in rates of use among zone-types, along with the mean sea state during the replicate survey and possibly other detection covariates.

**Model assumptions**

MacKenzie et al. (2006) list the main assumptions of the single season occupancy model as “

1. The occupancy state of the sites does not change during the period of surveying
2. The probability of occupancy is equal across all sites
3. The probability of detecting the species in a survey, given presence, is equal across all sites
4. The detection of the species in each survey of a site is independent of detections during other surveys of the site
5. The detection histories observed at each location are independent.”

Assumption 1, or the closure assumption, requires that sites that are occupied remain occupied for the duration of the study, i.e., that there are no ‘local extinctions’ and that sites that are unoccupied remain unoccupied for the duration of the study, i.e., that there are no ‘local colonisations’. It is not necessary that the occupancy of sites be interpreted as the continuous presence of the species; it is sufficient that sites that are used by a species continue to be used by it and sites that are not used continue to be not used for the duration of the study (the ‘season’).

Assumptions 2 and 3 refer to homogeneity of the probabilities of occupancy ($\psi$) and detection ($p$) respectively. When covariates are included in the model, these assumptions apply subject to the effects of the covariates. For example, if there are significant differences in probability of occupancy between site types or zone types, when these factors are fitted as covariates on the probability of occupancy, assumption 2 applies within each class of the fitted covariates. Similarly, if the probability of detection varies with sea state, when this factor is fitted as a covariate on the probability of detection, assumption 3 applies within each class of the sea state factor.

Heterogeneity of detection probabilities is further discussed below.
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Assumptions 4 and 5 refer to independence among the replicate surveys on a site and that the surveys on different sites are independent respectively. The likelihood that these assumptions are met can be increased by the consideration given to them in sampling design and conformity to the specified sampling protocols. In this study for example, we recommend that consecutive surveys on a zone not be made by immediately turning around and retracing the same transects to avoid immediately detecting the same groups (see below, Comments on tertiary samples – replicate surveys of zones), and primary sampling areas are spaced relatively widely apart (see below, Selection from the sampling frame for sites of type A). The dependency that may arise from sampling zones clustered within primary sampling areas will need to be assessed and adjusted for with covariates or statistically when analysing under scenario one as described above.

**Heterogeneity of detection probabilities**

The probability of detection may be a function of the density of groups in the surveyed area (e.g., Royle and Nichols 2003, MacKenzie et al. 2006, Ch. 5) and vary with zone type or other covariates. In this case, detection probabilities would be heterogeneous and the probability of occupancy biased downwards unless a model that allows for density-dependent heterogeneity is fitted. Covariates may be found that account for variation in detection probabilities (e.g., zone type), but if not, models that account for un-modelled heterogeneity are available and should be assessed and fitted if required.

**An occupancy model for multiple species**

MacKenzie et al. (2004) describe a model for two species. The advantage of this model over separate models for each species is that it while it yields estimates of the probabilities of occupancy of the two species it also yields the probability of their co-occurrence, potentially yielding insight into sympatry and allopatry. While the primary objective of this project is to provide separate estimates for each species, this model was mentioned here as a possibility for supplementary analysis.

**Covariates for the probabilities of occupancy and detection**

Current knowledge identifies water depth as an important environmental feature associated with habitat selection, at least for snubfin dolphins (Department of the Environment 2013; Beasley et al. 2012) and may be important for other species, but it is not employed as a basic component of the sampling design in terms of site types, zone types and replicate surveys. Water depth and other environmental features may be measured on transect or extracted from available electronic sources such as bathymetry maps to distinguish among sampling units at each level and constitute a basis for modelling habitat selection.
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Covariates may be fitted to both the probability of occupancy and the probability of detection in occupied sites. Detection covariates would generally be measured at level three (replicate surveys) although, as described above, some covariates that may be fitted on the probability of occupancy when modelling under scenario one (e.g., zone type) where sites are zones would be fitted on the probability of detection when modelling under scenario two where sites are primary sampling areas.

**Covariates for primary sampling areas**

Covariates for primary sampling areas must measure characteristics of the areas as wholes. Principally, these are:

- Site type (A, B)
- Site area
- Areas of each of the zones defined for the site
- Season (date)

Other relevant covariates include:

- Areas of water < 10 m and < 20 m deep adjacent to site and between 10 and 20 km from land (as an indicator of the proportion of a local population that may be more than 10 km from land at the time of sampling)
- Type and extent of human use - recreation, fishing, onshore-offshore pollutant flow
- The typical level of boat traffic on a site - this may be associated with detectability through boat avoidance by populations with little exposure to boats
- Tidal range, minimum and maximum SST, ...

**Covariates for secondary sampling areas (zones)**

Covariates for secondary sampling areas (zones) must measure characteristics of the areas as wholes. Principally:

- Zone type
- Zone area
- Tidal state at time of survey

Most fine scale habitat covariates and covariates for detection probability will be measured at level three. Appropriate covariates for level two units may be calculated as totals or means of the values of covariates measured at level three:
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- **Occupancy covariates.** Mean depth, mean distance from shore, mean distance from nearest river mouth, mean tidal height, mean tidal state, ...
- **Detection covariates.** Total length of transect, mean sea state, mean glare factor, ...

**Covariates for tertiary sampling units (replicate surveys)**

Covariates used to define tertiary sampling units must apply to the units as wholes. This implies measurement of habitat and detection covariates for each transect (replicate survey) rather than simply at locations where groups are detected. These are presence/absence (strictly, detection/non-detection) data and covariate values are required for each replicate survey (transect) whether dolphins were or were not detected.

Two kinds of covariates are appropriate for replicate surveys, those that are potential predictors of occupancy and those that are potential predictors of detection when dolphins are present. These represent within-zone, within-day variation in habitat characters and sighting conditions.

**Habitat (occupancy) covariates (to be aggregated for zones)**

1. Distance from nearest river mouth
2. Water depth, tidal state, tide height, distance from land, time of day, ...

**Detection covariates**

3. Sea state (Beaufort), number of observers (if this varies), speed of travel, turbidity, glare factor, ...

The latitude and longitude of both the beginnings and ends of transect lines, and sightings should be recorded.

While one measure is required for each survey (transect), as described above, this may be derived as the sum or mean of three or more measurements taken (or estimated from external data such as bathymetry maps) along the transect length.

**Use of covariates**

The number of covariates data can support depends upon the sample size. In this study for example, a model fitted under scenario one would have many more sites than a model fitted under scenario two and could support more covariates on the probability of occupancy.

Covariates may be used for different purposes along with their general use to account for variation in parameter estimates. In this study for example, we have categorical covariates for site types (A and B) and zone types (inshore, near-shore, offshore) as well as positional and other information...
(e.g., distance from nearest river mouth, water depth) that may be measured as continuous variables. A model fitted in terms of site types and zone types may be more useful for expanding the estimates up to total areas of occupancy while a model fitted in terms of other covariates may be more useful for describing habitat preferences. Of course both types of variables may be fitted together in a model, but these different potential uses of the estimates should be kept in mind.

**Development of GIS**

A systematic process of spatial definition of the primary sampling areas (sites of types A and type B), and secondary sampling areas (inshore, near-shore and offshore zones) is necessary for calculation of the total areas of each type for expansion of the occupancy estimates up to an estimate of the total area of occupancy. This is to emphasise that sites and zones need to be defined on clear decision rules prior to sample selection so that it is possible to identify sites and zones that meet the rules but were not surveyed so that estimates from those that were surveyed can be applied across the range.

Identification and spatial definition of individual primary survey areas was made following a fine-scaled investigation of the coastline using the site-type descriptions above as a guide. Identification and spatial definition of the zone types (inshore, near-shore and offshore) within primary sample areas was made within the primary sample areas selected for sampling using the zone-type descriptions above as a guide.

The approach taken to this was to create buffers around the focal points of primary sample areas in the lists of all areas that meet the definition for areas of types A and B that extended 20-25 km either side of their focal points. While it was not possible to calculate the total area of sites of type A precisely as their inshore, estuarine areas are seasonally and tidally variable, and do not seem to be systematically mapped, a reasonably consistent basis was devised to derive estimates of the total area of the site types.

**Selecting sites for survey**

**A sampling frame for sites of type A (Estuarine sites)**

A sampling frame for sites of type A was constructed by beginning with a list of major rivers within the search range. A list of large, sheltered bays, ports and harbours was appended to the list of major rivers to make a list of potential sites of type A. Each site on the list of potential sites of type A was assessed to determine whether it met the criterion of at least 100 km² of inshore, estuarine area and a distinctly embayed form. The sampling frame for sites of type A was the subset of the list of
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potential sites of type A that met the minimum inshore, estuarine zone > 100 km$^2$ and distinctly embayed form criteria.

An initial list of sites of type A was built from the terminating points of major perennial waterways with a length of at least 25km of perennial inshore water (38). A relatively small number (16) of bays, harbours and ports was added subject to the condition that there was at least 100 km$^2$ enclosed within the embayed part of the coast.

**Selection from the sampling frame for sites of type A**

The sampling frame for sites of type A was sorted into random order. The first site on the ordered list was chosen for sampling. The next site on the ordered list was chosen subject to the condition that its focal point was not closer than 80 km from the focal point of the previously selected site, otherwise the next site was chosen from the ordered list. The process was continued until the target number of sites of type A was selected.

The minimum distance criterion was calculated on an ‘as the dolphin swims’ basis.

**A sampling frame for sites of type B (Other sites)**

A sampling frame for sites of type B was constructed from a list of minor rivers within the search range.

An initial list of sites of type B was built from a list of the terminating points of minor waterways (1108).

**Selection from the sampling frame for sites of type B**

The sampling frame for sites of type B was sorted into random order. The first site on the ordered list was chosen for sampling subject to the condition that its focal point was not closer than 55 km from the focal point of a site of type A. The next site on the ordered list was chosen subject to the condition that its focal point was not closer than 55 km from the focal point of any previously selected site of either type A or type B, otherwise the next site was chosen from the ordered list. The process was continued until the target number of sites of type B was selected.

The locations of a sample of 20 sites of type A and 20 sites of type B in the Northern Territory are mapped in Figure 1.
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Defining sites

Having selected a sample of primary sampling areas each needed to be partitioned into zones. For sites of type A this meant first defining the inshore, estuarine zone. This inevitably required judgement and was somewhat arbitrary and accordingly, it is advisable that sampling in the inshore zone be conducted clearly within the demarcation line. The near-shore shore zone was then located nearby outside the demarcation line within the 5 km from land buffer line and the offshore zone was located nearby between the 5 and 10 km buffer lines. The same process was applied to sites of type B except that no inshore zone was defined.
Occasionally, in some sites, one or more of the zones were not continuous in space and consisted of two or more areas, as might occur for example near a bifurcated river mouth with two embayments. The total area of each site and the areas of each of the zones within the sites were estimated.

**Comments on sampling in secondary sampling areas (zones)**

The total length of transect for each survey on a zone was estimated as the length required to yield adequate detection rates for analysis. The estimate was based on (a limited amount of) data available from prior research and a pilot study for this project conducted in Cobourg National Park (below).

Anticipating subsequent discussion of sighting rates and sample size estimation, 40 km should be considered to be a minimum target length of transect for a replicate survey on a zone. The principal data to be collected on a replicate survey of a zone is whether at least one group was detected or not. While covariate data and information on the location of each sighting should also be collected for potential use in modelling habitat selection, only the presence or absence of at least one group per replicate survey is required as the response variable in an occupancy model.

As described above, should the observed detection rates from replicate surveys be inadequate to support informative models for one species or another under scenario one, it would be possible to aggregate over pairs of replicate surveys and fit a models under scenario two.

**Comments on tertiary samples – replicate surveys of zones**

Each 40 km transect or replicate survey on a zone could be flown parallel to the coast and the set of replicate surveys within the zone could be flown at different distances from the coast. This would maximise variation for modelling habitat preferences in terms of the covariate values associated with the times and locations of group detections.

It is preferable that the set of replicate surveys on a zone not be completed in sequence by immediately turning around after each and that time is allowed between them to ensure that each is an independent replicate of the zone as a whole rather than of a time of day or tidal state, and for tides and other factors that may affect the presence of groups to vary to maximise covariate variation for habitat modelling.

One strategy may be to complete one replicate survey on each zone at a time, in a set of complete circuits each through all zones in a primary sampling area. Other strategies are possible without completing all surveys on a zone in sequence before surveying another zone.
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That coastal dolphins vary their rates of use of zones as a function of tidal state is a reasonable hypothesis which could be tested by treating tidal state as a covariate on the probability of occupancy if there were adequate replication of tidal states at the times of survey of each zone type, and better tested if as many individual zones as possible were surveyed during different tidal states.

Sample size estimation

Reliable estimates can only be obtained with suitable replication and detection rates. We present results from a simulation study in Appendix A) based on some available data on snubfin detection rates using the simple ‘single-season’ occupancy model in the software program Genpres (http://www.mbr-pwrc.usgs.gov/software/presence.html: Bailey et al. 2007). This model considers only two levels of replication, sites and surveys (replicates). As indicated above, two-level data may be derived under either of two scenarios:

1. Scenario 1 – treating the sample of secondary sampling areas (zones) as sites and the tertiary sampling units (replicate surveys) within each as surveys of each zone
2. Scenario 2 – treating the sample of primary sampling areas as sites and the tertiary sampling units (replicate surveys) within each as surveys of each primary sampling area

We employed the single-season occupancy model (MacKenzie et al. 2002) in our simulations to generate expectations under both scenarios.

A sample size for the study is recommended in light of the simulation results following estimation of the probabilities of detection from data collected in a pilot study in Cobourg National Park.

We present results from an initial set of simulations in Appendix A and from a more targeted set to more closely examine the expected results for the recommended sample size following presentation of the results of the pilot study below.

Pilot study on Cobourg National Park: The probability of detection given occupancy from boat-based and helicopter-based surveys

Boat based study

It was initially planned that the Northern Territory conservation status project would follow the sampling design and methods proposed for the National program (Department of the Environment 2013a). That program called for boat-based surveys with the proposed sampling design (Brooks, Carroll and Pollock 2014) being similar to that described in this report with the three-level sampling structure, estuarine and other sites defined at level one and inshore, near-shore and offshore zones defined at level two. Two 40 km replicate surveys were to be conducted in each of the three zones in
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Estuarine sites and three to be conducted in each of the two zones in others sites. Analysis was to be conducted under scenario two, with primary sampling areas as sites and zone-type assessed as a covariate on the probability of detection.

A boat-based pilot study was conducted according to this design in four primary sampling areas in Cobourg National Park over 23 days in late March/early April 2014. Some days were lost due to unsuitable weather and usable data were gathered on three estuarine and one other site from a total of 24 surveys each of 40 km in length in 12 zones in the four sites. On the 24 surveys, at least one humpback and one bottlenose group was detected on six (25%) and at least one snubfin dolphin group was detected on three (12.5%). One humpback and one bottlenose dolphin group was detected per 160 km and one snubfin dolphin group was detected per 320 km on a total transect length of 960 km.

While the estimates from models fitted to the data had very wide confidence intervals due to the limited number of sites at level one, they provide some insight into the probability of detection from boat-based surveys each of 40 km in length. Although models fitted according to scenario two with zone-type as a detection covariate identified some differences in usage rates among zone types, we report only the estimates from models with constant probabilities of occupancy and detection here.

Table 1 reports the number and percentage of repeat surveys on which at least one group was detected, the estimated probability of occupancy and the estimated probability of detection for humpback, bottlenose and snubfin dolphins.

Table 1. Boat-based surveys, results of analysis with primary sampling areas as sites: The number and percentage of repeat surveys on which at least one group was detected, the estimated probability of occupancy and the estimated probability of detection for humpback, bottlenose and snubfin dolphins

<table>
<thead>
<tr>
<th>Species</th>
<th>Detections</th>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>L95%CI</th>
<th>U95%CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humpback</td>
<td>6/24</td>
<td>psi</td>
<td>0.86</td>
<td>0.28</td>
<td>0.06</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>p</td>
<td>0.29</td>
<td>0.12</td>
<td>0.11</td>
<td>0.57</td>
</tr>
<tr>
<td>Bottlenose</td>
<td>6/24</td>
<td>psi</td>
<td>0.51</td>
<td>0.25</td>
<td>0.12</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>p</td>
<td>0.49</td>
<td>0.15</td>
<td>0.23</td>
<td>0.76</td>
</tr>
<tr>
<td>Snubfin</td>
<td>3/25</td>
<td>psi</td>
<td>0.75</td>
<td>0.54</td>
<td>0.01</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>12.5%</td>
<td>p</td>
<td>0.17</td>
<td>0.14</td>
<td>0.03</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Note models fitted under scenario two, with primary sampling areas (level 1) as sites

The probabilities of detection were adequate for modelling the data from a larger sample (i.e., > 0.2) for humpback and bottlenose but not snubfin dolphins.
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**Helicopter-based study**

While the sampling design was viable for boat-based surveys (estimated probability of detection given occupancy > 0.2) for two of the three species, the time and effort expended on gathering the data relative to the number of detections was considered excessive and a further pilot study was conducted from a helicopter for comparison.

The helicopter-based study was conducted in six primary sampling areas over 4 days in late May 2014. No days lost due to unsuitable weather and usable data were gathered on four estuarine and two other sites from a total of 27 surveys each of 40 km in length on 13 zones in the six sites. Only one survey was conducted in one of the sites.

On the 27 surveys, at least one humpback, one bottlenose and one snubfin dolphin group was detected on six (22%) and at least one dugong group was detected on nine (33%). One humpback, one bottlenose and one snubfin dolphin group was detected per 180 km and one dugong group was detected per 120 km on a total length of transect of 1080 km.

Analyses were conducted under scenarios two (with the six primary sampling areas as sites) and one (with the 13 zones as sites).

**Analyses under scenario two (primary sampling areas as sites)**

For the analyses under scenario two, models may in principle be fitted to assess the differences in the probability of occupancy between estuarine and other sites and differences in the probability of detection for the inshore, near-shore and offshore zones. Among these, we report only the estimates from models with the probabilities of occupancy and detection both constant.

Table 2 reports the results from analyses under scenario two with primary sampling areas as sites: the number and percentage of repeat surveys on which at least one group was detected, the estimated probability of occupancy and the estimated probability of detection for humpback, bottlenose and snubfin dolphins, and dugong.
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Table 2. Helicopter-based surveys, results of analysis with primary sampling areas as sites: The number and percentage of repeat surveys on which at least one group was detected, the estimated probability of occupancy and the estimated probability of detection for humpback, bottlenose and snubfin dolphins, and dugong

<table>
<thead>
<tr>
<th>Species</th>
<th>Detections</th>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>L95%CI</th>
<th>U95%CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humpback</td>
<td>6/27</td>
<td>psi</td>
<td>1.000</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>22%</td>
<td>p</td>
<td>0.222</td>
<td>0.080</td>
<td>0.103</td>
<td>0.415</td>
</tr>
<tr>
<td>Bottlenose</td>
<td>6/27</td>
<td>psi</td>
<td>0.605</td>
<td>0.240</td>
<td>0.176</td>
<td>0.916</td>
</tr>
<tr>
<td></td>
<td>22%</td>
<td>p</td>
<td>0.391</td>
<td>0.145</td>
<td>0.163</td>
<td>0.678</td>
</tr>
<tr>
<td>Snubfin</td>
<td>6/27</td>
<td>psi</td>
<td>0.682</td>
<td>0.287</td>
<td>0.138</td>
<td>0.966</td>
</tr>
<tr>
<td></td>
<td>22%</td>
<td>p</td>
<td>0.317</td>
<td>0.134</td>
<td>0.122</td>
<td>0.609</td>
</tr>
<tr>
<td>Dugong</td>
<td>9/27</td>
<td>psi</td>
<td>1.000</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>33%</td>
<td>p</td>
<td>0.333</td>
<td>0.091</td>
<td>0.183</td>
<td>0.527</td>
</tr>
</tbody>
</table>

Note models fitted under scenario two, with primary sampling areas (level 1) as sites

The probability of occupancy estimate was 1.00 for two species, a result which is probably due to the very small number of sites sampled. When the probability of occupancy is estimated at 1.00, the estimated probability of detection given occupancy is simply the observed detection rate (proportion of surveys on which groups were detected). In general however, the estimated probability of detection given occupancy is the observed detection rate/the estimated probability of occupancy. Consequently, given that it is unlikely that large sample estimates of the probability of occupancy would be 1.00 for any species, the estimated probabilities of detection for the two species above are likely to be minimal.

It is not intended that the data from the proposed survey be analysed under scenario two however, with this option being available as an alternative should the estimated probability of detection for one species or another be too small for analysis under scenario one. In that case, because there would be many more surveys per site under scenario two (primary sampling areas as sites, with zones and replicates on zones as surveys) than under scenario one (zones as sites, and replicates on zones as surveys), it would be possible to aggregate over pairs of surveys on zones to increase the estimated probability of detection while retaining sufficient replication for sites. The resulting increase would not typically be double however, but less than or equal to double depending on the number of pairs of surveys in which there were detections in both which would be reduced to single detections in the aggregated data. The extent to which the increase was less than by a factor of two would depend upon the extent to which groups were clustered in the same zones at the time of survey compared to more broadly distributed throughout the sites, with a larger increase for less, and a smaller increase for more clustering.
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Analyses under scenario one (zones as sites)
For the analysis under scenario one, models may in principle be fitted to assess the probabilities of occupancy of the site types and zone types, and probabilities of detection. Among these, we report only the estimates from models with the probabilities of occupancy and detection both constant.

Analysis under scenario one is only possible with suitable replication of each zone. We consider four repeat surveys per zone to be a sensible target for this for the proposed study. In the pilot study data however, there were at most three and an average of slightly fewer than two repeat surveys per zone. While this resulted in wider confidence intervals about the estimates than were four replicates available, analysis of the data under scenario one should provide a reasonable indication of the probabilities of detection per survey.

Table 3 reports the number and percentage of repeat surveys on which at least one group was detected, the estimated probability of occupancy and the estimated probability of detection for humpback, bottlenose and snubfin dolphins, and dugong.

Table 3. Helicopter-based surveys, results of analysis with zones as sites: The number and percentage of repeat surveys on which at least one group was detected, the estimated probability of occupancy and the estimated probability of detection for humpback, bottlenose and snubfin dolphins, and dugong

<table>
<thead>
<tr>
<th>Species</th>
<th>Detections</th>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>L95%CI</th>
<th>U95%CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humpback</td>
<td>6/27</td>
<td>psi</td>
<td>1.000</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>22%</td>
<td>p</td>
<td>0.222</td>
<td>0.080</td>
<td>0.103</td>
<td>0.415</td>
</tr>
<tr>
<td>Bottlenose</td>
<td>6/27</td>
<td>psi</td>
<td>0.962</td>
<td>0</td>
<td>0.962</td>
<td>0.962</td>
</tr>
<tr>
<td></td>
<td>22%</td>
<td>p</td>
<td>0.231</td>
<td>0</td>
<td>0.231</td>
<td>0.231</td>
</tr>
<tr>
<td>Snubfin</td>
<td>6/27</td>
<td>psi</td>
<td>0.740</td>
<td>0.466</td>
<td>0.024</td>
<td>0.997</td>
</tr>
<tr>
<td></td>
<td>22%</td>
<td>p</td>
<td>0.304</td>
<td>0.217</td>
<td>0.055</td>
<td>0.766</td>
</tr>
<tr>
<td>Dugong</td>
<td>9/27</td>
<td>psi</td>
<td>0.804</td>
<td>0.295</td>
<td>0.094</td>
<td>0.994</td>
</tr>
<tr>
<td></td>
<td>33%</td>
<td>p</td>
<td>0.421</td>
<td>0.184</td>
<td>0.142</td>
<td>0.761</td>
</tr>
</tbody>
</table>

Note models fitted under scenario one, with zones (level 2) as sites

For this analysis under scenario one, where there are more sites in the analysis than under scenario two, the probability of occupancy was estimated as 1.00 for only one compared to two in the data under scenario two. However, with fewer replicates per site, a zero standard error was estimated for both the probability of occupancy and the probability of detection for bottlenose dolphins. These ‘failures’ would not be expected with a larger sample of zones and more replicates per zone.

From these results, the survey design is viable with estimated probabilities of detection generally greater than 0.2 per 40 km survey for all species.
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Summary of the pilot studies
While the boat-based and helicopter-based studies were both conducted in Cobourg National Park and were reasonably comparable, the sites and zones surveyed were not the same or sampled at the same rates. However, the estimated probabilities of detection were broadly comparable for the boat and helicopter platforms. From these results, the survey design is viable with estimated probabilities of detection generally greater than 0.2 per 40 km survey for all species. Detection of dugong as well as the three dolphin species was a major advantage of the helicopter.

It should be noted that these estimates from the Cobourg National Park survey area may not be typical of the entire Northern Territory coast. While the confidence intervals about the estimates were very wide from these small studies, the probabilities of detection obtained were sufficiently high to indicate that surveys over 40 km of transect per repeat survey are likely to generate suitable data for analysis for each of the three species of dolphin from a boat or a helicopter and also for dugong from a helicopter.

With the probabilities of occupancy across the Northern Territory likely to be substantially less than one, the observed detection rates should translate into larger probabilities of detection given occupancy. For example, an observed detection rate of 0.22 would translate into a probability of detection of at least 0.3 for probabilities of occupancy of 0.74 or less.

While we have argued that the probabilities of occupancy on sites on the scale of the primary sampling areas should not vary greatly with season, the rates of use and probabilities of detection in zones may be much more variable, potentially varying over relatively short periods of time with not only season but also tidal state or other factors.

Recommended sample size
As the simulation results presented in Appendix A show, models with detection rates < 0.2 per survey are very unstable and should be avoided.

In order to obtain estimates of the probability of occupancy for both site types (A and B) and zone types (inshore, near-shore and offshore), we focus on estimation under analysis scenario one and comment on analysis under scenario two should it be necessary to aggregate over pairs of replicate surveys to achieve a probability of detection of at least 0.2 per survey.

Our interest here is primarily in estimating a minimum number of sites and number of replicate surveys per site required to provide estimates of the probability of occupancy of zones with relative standard errors (or coefficients of variation) of close to or less than to 0.2.
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Depending upon how typical the probabilities of detection found for the pilot study data on Cobourg National Park are of the Northern Territory coast, replicate surveys of at least 40 km in length should result in probabilities of detection of at least 0.2 and possibly as high as 0.4 per survey for the three species of dolphin and dugong.

Some balance needs to be made between sampling more sites less intensively and fewer sites more intensively. MacKenzie et al. (2006) recommend that, for rare species, it is more efficient to sample more sites less intensively. There are limits to how far the number of replicate surveys per site can be minimised however, and we consider four replicates per site as a sensible minimum. Numbers of replicate surveys that are divisible by two have the advantage that they can be aggregated in pairs to increase the probability of detection per survey should that be necessary.

The relative standard error of an occupancy estimate depends on the probability of detection, the number of sites, the number of surveys per site and the probability of occupancy; the greater each of these is, the smaller the standard error of the estimate. We have little idea about the probability of occupancy for these species and consider it prudent to conduct the simulations for relatively low probabilities of occupancy ($\psi \leq 0.5$).

It should be clear from the plots in Figure A1 that the probability of detection is a major factor in determining the standard error of the probability of occupancy estimate; strong decreases in the relative standard error of the probability of occupancy occur as the probability of detection increases from 0.2 to 0.4. Consequently, increasing the probability of detection per survey is a major priority. The most obvious and reliable way to increase the probability of detection is to increase the length of transect per survey (at additional fixed cost) but decreasing the speed of survey, increasing the sighting width or increasing the number and skill of observers may also make a useful contribution.

While the simulation results in Figure A1 indicate that with 90 sites and four surveys per site, the relative standard error of the estimated probability of occupancy is reasonable (~25%) with a probability of detection of 0.2 provided the probability of occupancy is as high as 0.5, it is less satisfactory when the probability of occupancy is smaller. Reasonable relative standard errors of the estimated probabilities of occupancy are obtained with a probability of detection per survey of 0.4 for 90 sites and four surveys per site for probabilities of occupancy as low as 0.2.

Given the level of uncertainty around probabilities of occupancy of the four species across the Northern Territory, these results are marginal and just viable. If all reasonable steps are taken to maximise the probability of detection per survey, a slightly larger sample of sites may be a reasonable target. Results are presented in Table 4 for 100 sites and four surveys per site based on
expected values for the combinations of each of the following parameter values: \( \psi \{0.3, 0.4, 0.5\}, p \{0.2, 0.3, 0.4\} \).

Table 4. Estimated relative standard error (RSE) and 95% confidence interval for the probability of occupancy of 100 sites and four surveys per site based on expected values for each combination of the parameter values \( \psi \{0.3, 0.4, 0.5\}, p \{0.2, 0.3, 0.4\} \).

<table>
<thead>
<tr>
<th>Probability of occupancy</th>
<th>Probability of detection</th>
<th>Statistic</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RSE</td>
<td>0.314</td>
<td>0.215</td>
<td>0.178</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95%CI</td>
<td>0.151 - 0.508</td>
<td>0.190 - 0.439</td>
<td>0.207 - 0.413</td>
</tr>
<tr>
<td>0.4</td>
<td></td>
<td>RSE</td>
<td>0.268</td>
<td>0.180</td>
<td>0.146</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95%CI</td>
<td>0.218 - 0.6158</td>
<td>0.271 - 0.545</td>
<td>0.293 - 0.518</td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td>RSE</td>
<td>0.235</td>
<td>0.154</td>
<td>0.122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95%CI</td>
<td>0.285 - 0.7155</td>
<td>0.353 - 0.647</td>
<td>0.383 - 0.618</td>
</tr>
</tbody>
</table>

The relative standard errors are reasonable (≤ 21.5%) for combinations of these values when the probability of detection per survey is 0.3 or greater even for probabilities of occupancy as low as 0.3. When the probability of detection is only 0.2 however, many more surveys per site (about eight) would generally be required (see MacKenzie et al. 2006, Table 6.1). This is to emphasise that effort should be directed to maximising the probability of detection per survey as described above.

While the estimated probability of detection from the helicopter survey in Cobourg National Park was only 0.22 per survey for humpback dolphins when the data were analysed under scenario one, this was equal to the observed detection rate because the probability of occupancy of zones (and primary sampling areas) was estimated as 1.00 in that small sample. It is very unlikely that the probability of occupancy for humpback dolphins would be 1.00 from an analysis of data on 100 zones and the probability of detection given occupancy would very likely increase from this in the larger sample.

Similar considerations also apply to the pilot study results for bottlenose dolphins. The probability of occupancy should in principle be greater for primary sampling areas than for zones, although the opposite was the case in the small pilot study results.

In sum we consider 100 zones each surveyed four times to be a reasonable estimate of the required sample size provided effort is directed to maximising the per survey detection rate and that four surveys are completed on all zones.

It is sensible to sample primary sampling areas of types A and B in equal numbers to maximise the probability of detecting a significant difference between them. A sample of 100 zones would be
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obtained from a sample of 20 primary sampling areas each of types A and B with three zones in each site of type A and two zones in each site of type B.

In the event that the probability of detection was too small to yield useful results from analysis for one species or another from the analysis under scenario one, the data from pairs of surveys could be aggregated to increase it to a suitable level for analysis under scenario two. The data to be aggregated would be the detections on four surveys on each of the three zones in sites of type A and four surveys on each of the two zones in sites of type B, or 12 surveys per site on sites of type A and eight surveys per site on sites of type B. Following aggregation, the data for analysis under scenario two would be six surveys per site of type A and four surveys per site of type B. Taking the average of these (5 surveys per site) and assuming slightly higher probabilities of occupancy in primary sampling areas than zones and probabilities of detection of at least 0.3 per survey, results are presented in Table 5 for 40 sites and five surveys per site based on expected values for the combinations of each of the following parameter values: psi \{0.4, 0.5\}, p \{0.3, 0.4\}. Results are also given for a probability of detection of 0.6 to evaluate the potential of modelling under scenario two even when the probability of detection from modelling under scenario one was adequate.

Table 5. Estimated relative standard error (RSE) and 95% confidence interval for the probability of occupancy of 40 sites and five surveys per site based on expected values for each combination of the parameter values psi \{0.4, 0.5\}, p \{0.3, 0.4\}

<table>
<thead>
<tr>
<th>Probability of occupancy</th>
<th>Probability of detection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RSE</td>
</tr>
<tr>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>95%CI</td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>95%CI</td>
</tr>
</tbody>
</table>

Assuming that the aggregated data yield estimates of the probability of detection of at least 0.3 and that the probability of occupancy of primary sampling areas is at least 0.4, we consider the estimated relative standard errors for analysis of the aggregated data on 40 sites with 5 surveys each under scenario two to be viable with relative standard errors of at most 24.5%.

Aggregation over pairs of replicate surveys and analysis under scenario two may be useful whether the estimated probability of detection from analysis under scenario one is smaller than 0.2 or not because the probabilities of occupancy of sites types would be estimated independently of the probabilities of occupancy of the zone types which may facilitate extrapolation from the estimates obtained from the sample to the total area of occupancy in the Northern Territory. This strategy may
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be of additional interest considering that the probability of occupancy of primary sampling areas is likely to be much more stable over time than the probability of occupancy of zones, and might be interpreted as more like an indicator of residency than rate of use.

As may be observed in Table XXX (above) and noted in our comments on the simulation results in Table A1 however, most of the gain in the precision of occupancy estimates occurs as the probability of detection increases from 0.2 to about 0.4 but gains are minimal with increases in the probability of detection after that and there appears to be little value in aggregating scenario one data on which the probability of detection was 0.3 or greater.

Evaluating the relative merits of boat and helicopter surveys

Sampling efficiency
Perhaps the most direct measure of sampling efficiency is the observed detection rate from each platform. While the boat-based and helicopter-based pilot studies were both conducted in Cobourg National Park and were reasonably comparable, the sites and zones surveyed were not the same or sampled at the same rates, it appears that the observed detection rates were broadly comparable for the two platforms.

Groups were detected on at least 22% of surveys from both platforms for all species except for snubfin dolphins from a boat (12.5%). This difference in the observed detection rate for snubfin dolphins is very unlikely to have been due to inherent differences between the platforms and much more likely to have been due to sampling variation between the pilot studies.

With the probabilities of occupancy across the Northern Territory likely to be substantially less than one, these observed detection rates should translate into larger probabilities of detection given occupancy. For example, an observed detection rate of 0.22 would translate into a probability of detection of at least 0.3 for probabilities of occupancy of 0.74 or less.

Given that the sampling period for a boat would be much longer than for a helicopter, it would spread over a much greater part of the year or years and consequently, sampling from a boat is much more likely to be subject to periods of unsuitable weather than sampling from a helicopter which could be targeted to a part of the year when the weather is expected to be suitable.

Fewer days are also likely to be lost to unsuitable weather for survey from a helicopter than a boat because, if a suitable day is selected for survey on a primary sampling area, the whole set of replicates on each zone should be completed in a day from a helicopter whereas the set of surveys is much more likely to be interrupted over the substantially longer time it would take to complete them by boat. A further potential saving of time lost to unsuitable weather may arise because a
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helicopter has greater capacity than a boat to move ahead of changing weather and may sometimes be able to continue sampling in another zone until the weather clears.

Crews report that detection from the air is apparently less affected by the sea state than detection from the surface; if this is correct, higher detection rates would be obtained on average and fewer days may be considered unsuitable for survey from a helicopter than a boat.

The capacity to detect dugong in addition to dolphins is a major advantage of the helicopter.

**Time**

Twenty four surveys were completed from a boat over a period of 23 days (about one day per survey), while 27 were completed from a helicopter in 4 days (about 0.15 days per survey or 7 surveys per day). These sampling rates depend to some extent on the number of days lost to unsuitable weather in the pilot studies in which more days lost for a boat than a helicopter, which may be in line with the expectations described above. If these observed rates are applied to 100 zones each surveyed four times, the estimated sampling time for the Northern Territory study is 400 days for a boat and 60 days for a helicopter.

If surveys were only conducted on days on which the weather conditions were suitable and not accounting for transport days, it should be possible to complete two 40 km surveys per day, or to complete the whole 400 surveys in 200 days from a boat. It should be possible to complete eight 40 km surveys (320 km) per day, or to complete the whole 400 surveys (16,000 km) in 50 days from a helicopter.

For survey from a boat, the best that might be expected, with no days lost to unsuitable weather, is to complete two 40 km surveys in a day. On this basis, it would take six days to survey each of the 20 primary sampling areas of type A (estuarine sites) and four days to survey each of the 20 primary sampling areas of type B (other sites) or 200 days to complete the surveys.

As described above, fewer days are likely to be lost for survey from a helicopter than a boat due to the capacity to target a shorter period of the year when the weather is expected to be suitable, the surveys on a primary sampling area can be targeted to a suitable day rather than a period of days during which the weather may change, and the ability to move ahead of approaching poor weather. Together, these considerations indicate that the number of days lost to unsuitable weather is not only likely to be many fewer but also more predictable for a helicopter than a boat.

Apart from the per survey time taken, the transport time between sites would be far less for a helicopter than for a boat.
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The capacity to complete the planned surveys in a much shorter time with the crew focused on the task is likely to result in more consistent application of protocols and better quality data being collected from a helicopter for which variation in crew membership is likely to be smaller and their concentration on survey is likely to be greater than from a boat.

Cost
An estimate of expected costs will be provided separately by NTDLRM.

Estimating the total area of occupancy
We assume that the occupancy analysis will be conducted under scenario one and that the estimated probabilities of occupancy will differ between the primary sampling areas of types A and B and the inshore (I), near-shore (N) and offshore (O) zones, and that the probabilities of occupancy in the near-shore and offshore zones will differ between the primary sampling areas of types A and B. The most straightforward way to obtain estimates of these probabilities of occupancy is to define five the zone types AI, AN, AO, BN and BO as a factor and fit it as a covariate on the probability of occupancy in the model. Models will be fitted separately for each species.

The estimated probabilities of occupancy of the five zone types would be

\[ \hat{\psi}_{AI}, \hat{\psi}_{AN}, \hat{\psi}_{AO}, \hat{\psi}_{BN}, \text{ and } \hat{\psi}_{BO} \]

respectively.

We also assume that the areas of each of these zone types within the Northern Territory search area, \( A_{AI}, A_{AN}, A_{AO}, A_{BN} \) and \( A_{BO} \), would be known from the GIS analysis.

The estimated occupied areas of each of the five zone types within the Northern Territory search area \( \hat{O}_{AI}, \hat{O}_{AN}, \hat{O}_{AO}, \hat{O}_{BN} \) and \( \hat{O}_{BO} \) may be calculated as

\[ \hat{O}_{AI} = \hat{\psi}_{AI} \times A_{AI}, \quad \hat{O}_{AN} = \hat{\psi}_{AN} \times A_{AN}, \quad \hat{O}_{AO} = \hat{\psi}_{AO} \times A_{AO}, \quad \hat{O}_{BN} = \hat{\psi}_{BN} \times A_{BN} \quad \text{and} \quad \hat{O}_{BO} = \hat{\psi}_{BO} \times A_{BO} \]

respectively.

The estimated total area of occupancy within the Northern Territory search area may be calculated separately for each species as the sum of \( \hat{O}_{AI}, \hat{O}_{AN}, \hat{O}_{AO}, \hat{O}_{BN} \) and \( \hat{O}_{BO} \). Standard errors for the estimates could be calculated by the delta method (Casella & Berger 2002).

While it is possible to follow the above process to calculate an area of occupancy, the estimates \( \hat{O}_{AI}, \hat{O}_{AN}, \hat{O}_{AO}, \hat{O}_{BN} \) and \( \hat{O}_{BO} \) do not appear to be subject to clear interpretation when the habitat is considered continuous (Efford and Dawson 2012).

As described above (see Primary sampling areas, Size), whereas the probability of occupancy of a zone type should be interpreted as a measure of its rate of use rather than continuous presence, the
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probability of occupancy of primary sampling areas is likely to be much more stable over time than the probability of occupancy of zones and might be interpreted as more like an indicator of residency. Even were the calculation to be made at the level of primary sampling areas with estimates of occupancy derived from a model fitted under scenario two however, we do not know the boundaries of home ranges, the extent to which they overlap with the primary sampling areas or the extent of exchange between adjacent populations. In short, while the habitat may not be completely continuous, it may be discontinuous only to the extent that there may be fuzzy boundaries between home ranges.

It should also be kept in mind that the estimates of occupancy from this research apply only within the sampling area which is unlikely to include the total area of use.

In sum, we do not consider estimates of the area of occupancy to be subject to clear interpretation and recommend that conclusions about the conservation status of the species be drawn primarily from the occupancy estimates themselves and their covariation with habitat variables.

**Estimating the relative abundance of species**

The proposal to attempt to estimate the relative abundance of the species was originally made in the context of the proposed national program (Department of the Environment 2013; Brooks, Carroll and Pollock 2014) of which the Northern Territory program was to constitute a substantial component. The national program called for intensive, long term, capture-recapture studies on a subset of around 12 occupied primary sampling areas. The plan was to investigate the relationship between estimates of the density of individuals and rates of sighting of groups and to employ an estimate of the density of individuals present as a function of the number of groups sighted per km to obtain an approximate estimate of the density of individuals present in non-intensively studied primary sampling areas from their observed group sighting rates. The density of individuals on an area may be multiplied by the size of the area to obtain an estimate of the number of individuals present on the area.

The resulting abundance estimates were expected to be loose approximations only, with unknown bias and precision.

The data available on which to base such estimates will be extremely limited in the context of the present project with data available from only one intensively studied site (the Darwin Dolphin Monitoring Program, Brooks and Pollock 2014). Further limitations in the context of the present study include that
The Darwin survey area is not included as a primary sampling area in the present occupancy study sample and it would be necessary to use group detection rates observed during the course of sampling within the capture-recapture study. The group detection rate observed under those conditions may differ from that observed under the conditions of the occupancy study.

The group detection rate observed under the conditions of the occupancy study from a helicopter may differ from that which might have been observed from a boat, despite that they appeared to be similar in the small pilot studies in Cobourg National Park.

There will be no estimate of the abundance of dugong from any primary sampling area and no basis for estimation under the proposed method.

If the limitations of the proposed method presented in the above discussion are treated seriously and suitable doubt is invested in the resulting estimates, it would be possible to derive the estimates as described below.

In order to proceed, it is necessary to assume that the group detection rates observed in Darwin from a boat under the conditions of the capture-recapture study are proportional to those observed from a helicopter under the conditions of the occupancy study. The proposal below might then be followed with respect to each of the three dolphin species.

- Estimate the density of individuals in Darwin in each primary sample \( i \) (\( \hat{D}_{DARWIN,i} \)) from the capture-recapture estimates of abundance (\( \hat{N}_{DARWIN,i} \)) and the Darwin sampling area (\( A_{DARWIN} \)) as \( \hat{D}_{DARWIN,i} = \frac{\hat{N}_{DARWIN,i}}{A_{DARWIN}} \).

- Calculate the observed group detection rate in Darwin in each primary sample \( i \) (\( d_i \)) from the total number of groups detected (\( g_i \)) and the total length of transect (\( l_i \)) as \( d_i = \frac{g_i}{l_i} \).

- Estimate the relationship \( \hat{\beta} \) between the estimated densities of individuals in Darwin in each primary sample (\( \hat{D}_{DARWIN,i} \)) and the observed group detection rates (\( d_i \)) by regressing \( \hat{D}_{DARWIN,i} \) on \( d_i \) through the origin.

- Assume that \( \hat{\beta} \) estimated from boat-based capture-recapture abundance estimates and \( d_i \) from boat-based transects (\( \hat{\beta}_{BOAT} \)) is proportional to \( \hat{\beta} \) as estimated from boat-based capture-recapture abundance estimates and \( d_i \) from helicopter-based transects on the same area (\( \hat{\beta}_{HELICOPTER} \)).
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- Calculate the relative abundance of species 1 to species 2 for a zone type in the Northern Territory search area as $\frac{\hat{O}_1 x d_1 x \hat{\beta}_{\text{BOAT},1}}{\hat{O}_2 x d_2 x \hat{\beta}_{\text{BOAT},2}}$.

- Calculate the relative abundance of the two species over all zone types as

$$\frac{(\hat{O}_{\text{AI1}} x d_{\text{AI1}} + \hat{O}_{\text{AN1}} x d_{\text{AN1}} + \hat{O}_{\text{AO1}} x d_{\text{AO1}} + \hat{O}_{\text{BN1}} x d_{\text{BN1}} + \hat{O}_{\text{BO1}} x d_{\text{BO1}}) x \hat{\beta}_{\text{BOAT},1}}{(\hat{O}_{\text{AI2}} x d_{\text{AI2}} + \hat{O}_{\text{AN2}} x d_{\text{AN2}} + \hat{O}_{\text{AO2}} x d_{\text{AO2}} + \hat{O}_{\text{BN2}} x d_{\text{BN2}} + \hat{O}_{\text{BO2}} x d_{\text{BO2}}) x \hat{\beta}_{\text{BOAT},2}}$$

An estimate of relative abundance rather than absolute abundance is provided here because $\hat{B}_{\text{HELICOPTER}}$ is unknown. An estimate of $\hat{B}_{\text{HELICOPTER}}$ might be obtained were an estimate available for the relationship between $\hat{\beta}_{\text{BOAT}}$ and $\hat{\beta}_{\text{HELICOPTER}}$. It would be possible to obtain an estimate of $\hat{B}_{\text{HELICOPTER}}$ by calibrating it against $\hat{\beta}_{\text{BOAT}}$ if, during at least one primary sample, a set of helicopter transects was run through the Darwin capture-recapture sample site. The ratio $d_{\text{HELICOPTER}} / d_{\text{BOAT}}$ could be calculated for this primary sample and used to adjust $d_{\text{BOAT}}$ to $d_{\text{HELICOPTER}}$ for each primary sample. The required estimate $\hat{B}_{\text{HELICOPTER}}$ could then be obtained by regression as described above.

It would then be possible to estimate the abundance of each species in the Northern Territory sample area as $(\hat{O}_{\text{AI}} x d_{\text{AI}} + \hat{O}_{\text{AN}} x d_{\text{AN}} + \hat{O}_{\text{AO}} x d_{\text{AO}} + \hat{O}_{\text{BN}} x d_{\text{BN}} + \hat{O}_{\text{BO}} x d_{\text{BO}}) x \hat{\beta}_{\text{HELICOPTER}}$.

We note that such estimates depend on the estimated area of occupancy which is not subject to clear interpretation and emphasise that they depend on numerous, untested assumptions and should be treated as loose approximations only with unknown bias and precision. The estimates would be more fragile for absolute than relative abundance because they would depend on a calibration step for which there would be limited data.

**General summary**

This summary is presented in terms of the Objectives of this report.

1. Conduct an analysis using survey data collected in Cobourg Marine Park to derive estimates of occupancy and detection under different survey scales and sampling effort, including a comparison of the efficacy of boat- and aerial survey platforms.

The results of analysis of the survey data collected in Cobourg Marine Park for the surveys conducted from a boat and from a helicopter in the section “Pilot study on Cobourg National Park: The probability of detection given occupancy from boat-based and helicopter-based surveys”. While
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A summary of the findings from these analyses was presented there, it was concluded overall that surveys of 40 km in length from either platform were likely to yield probabilities of detection of at least 0.22 per survey and adequate to provide reasonable estimates given appropriate numbers of sites and replicate surveys.

A separate section, “Evaluating the relative merits of boat and helicopter surveys”, was provided to move beyond these estimates towards a basis for deciding between the boat and helicopter platforms. There are many uncertainties in estimating the relative costs of the platforms due largely to the time likely to be lost to unsuitable weather but also to the nature of contractual arrangements with their providers, and cost estimation was left to NTDLRM. However, it was concluded overall that the time lost to unsuitable weather was likely to be much greater and less predictable for a boat than a helicopter; that data quality was likely to be better from a helicopter, with effort concentrated over a shorter period of time, than a boat; and that a major advantage of the helicopter over a boat was the ability to gather data on dugong in addition to the dolphins.

2. Develop a sampling design using simulation of different survey designs on occupancy modelling for three species of coastal dolphins for the coastal waters of the Northern Territory.

The results of a set of simulations of models fitted under a wide selection of assumed parameter values were presented as Appendix A. As shown there, the relative standard error of an occupancy estimate (a measure of precision) depends on the probability of detection, the number of sites, the number of surveys per site and the probability of occupancy; and that the greater each of these is, the smaller the standard error of the estimated probability of occupancy (or the narrower its confidence interval). As noted in Appendix A, estimation from data in which the probability of detection is less than 0.2 per survey is very unstable unless the number of surveys per site is very large, and that the relative standard error of the estimated probability of occupancy decreases strongly as the probability of detection increases from 0.2 to 0.4, especially when the number of surveys is fewer.

These conclusions were considered in the context of the present research in the section “Recommended sample size”. It was noted there that it was recommended by MacKenzie et al. (2006) that, for rare species, it is more efficient to sample more sites less intensively and judged that at least four surveys per site was a sensible minimum. These considerations, together with the results from Appendix A and the pilot studies were used to conclude that 100 sites each surveyed four times over a transect length of 40 km would provide a suitable sample for the present study. Simulations were run for analysis under scenario one for this sample under several assumed
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Parameter values as suggested by the previous discussion. Appropriate relative standard errors of the probability of occupancy of less than 21.5% were found under the reasonable expectation that the probability of detection given occupancy would be at least 0.3 per survey.

Simulations were also run for analysis under scenario two as an alternative modelling strategy should it be necessary to aggregate over successive pairs of surveys to increase the probability of detection to at least 0.2 per survey for one species or another. Simulations run on data collected on four surveys each on 100 zones and aggregated to surveys on 40 primary sampling areas for analysis under scenario two demonstrated that this strategy was viable with reasonable relative standard errors for the probability of occupancy of primary sampling areas.

3. In addition to the occupancy design, develop methodology for estimating the relative abundance of coastal dolphins from the aerial survey data.

Processes were described for estimation of the total area of occupancy within the sampling area in the section “Estimating the total area of occupancy” and for estimating the relative abundance of the species in the section “Estimating the relative abundance of species”. A process for estimating the approximate absolute abundance of each of the dolphin species was also described in that section.

The estimates that would result from these processes were all subject to strong caveats. We consider that the estimates of the total area of occupancy are not subject to clear interpretation, that the estimates of relative abundance not only depend on estimates of the total areas of occupancy but are also subject to further uncertainty, and that the estimates of absolute abundance are even more fragile because they depend on a calibration step for which there would be limited data.

As simple summaries, these estimates of apparently meaningful quantities are at risk of being extracted from the context in which they were associated with strong caveats and inappropriately used.

4. Produce a report outlining survey design, statistical analysis methodology, model assumptions and limitations, required sampling effort and precision.

The major components of the survey design were described in the section “General approach to sampling”. These include a hierarchical approach to sampling within the sampling area in which primary sampling areas of at least 400 km$^2$ were partitioned into zones, or secondary sampling areas, to ensure reasonable coverage of the primary sampling areas, provide spatial and environmental coherence to each set of replicate surveys and to compose a broad-scale classification of habitat
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types. Primary sampling areas were classified as sites of type A (estuarine sites) and type B (other sites); and the zones were classified into five types defined in terms of the type of primary sampling area, a distinction between ‘within estuary’ and ‘other’ areas and distances from land (0-5 km and 5-10 km). Replicate surveys of each zone were described as tertiary sampling units.

Processes were described for partitioning the total sampling area into potential primary sampling units and construction of a sampling frame for primary sampling areas of both types were also described in this section.

Statistical models for the analysis of data were described in the section “Statistical models”. A major feature of the approach to analysis was a distinction between two approaches to analysis, albeit using the same, ‘single season’ occupancy model, in which the data could be structured with zones as sites and surveys as replicates (scenario one) or with primary sampling areas as sites and zones and their replicates as surveys (scenario two). While scenario one was considered the primary approach, scenario two was to be available should the probability of detection from surveys of zones be too low for analysis under scenario one.

The assumptions of the model were also described in this section and interpreted in the context of their application in this project.

Covariates for the probabilities of occupancy and detection were described in the section “Covariates for the probabilities of occupancy and detection”. It was pointed out that whether some variables were to be fitted on the probability of occupancy or on the probability of detection depended on whether the model was fitted under scenario one or scenario two, specifically, that variables for the zones that may be fitted on the probability of occupancy under scenario one may be fitted on the probability of detection under scenario two. This was first mentioned in the section “Statistical models”.

It is anticipated that fitting covariates will be fundamental to the analysis and important to both the fit of models to data and the utility of the results. In particular, the effects of variables for primary sampling areas and zones on the probability of occupancy are expected to carry important information about habitat selection and relative rates of use of various habitat types. While variables describing zones may be fitted on the probability of detection rather than on the probability of occupancy in analysis under scenario two, their effects may carry information about the relative rates of use of zone types nonetheless because the probability of detection is likely to vary with the density of groups in sampled areas.

The sampling effort required was estimated from the pilot study data collected in Cobourg National Park and simulation as described above under objective two. Estimates of the expected precision of
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the estimated probability of occupancy from analysis of data from the proposed sample were described in the section “Recommended sample size”.

Concluding comments
Achievement of the expected results is conditional on strict adherence to the sampling regime, in particular that close attention is paid to maximising the probability of detection and that the complete set of four replicate surveys is run on each zone. Some specific comments were made on the importance of the size of the probability of detection in the section “Recommended sample size” and elsewhere. The speed, height and sighting width on survey, and the skill, coordination and attention of the observers are factors that could impact on the achieved probability of detection. With one group detected from a helicopter on between 120 km and 180 km of transect depending on the species, it is clear that every effort should be made to avoid non-detection of groups that may be present.

Given that we have doubts about the interpretation and accuracy of estimates of the total area of occupancy and the relative abundance of species, we recommend that conclusions about the conservation status of the species be drawn primarily from the occupancy estimates themselves and their covariation with habitat variables.

The data collected in this project are subject to forms of analysis other than occupancy modelling, although occupancy models are the primary focus. In particular, spatial distribution analyses using some form of generalized linear model may be very informative of habitat use. Different covariates may also be fitted within the occupancy framework for different purposes; while the primary sampling area and zone types would be the principal covariates on the probability of occupancy in the core analysis, other covariates such as water depth, distance from nearest river mouth and distance from shore may be more informative of the environmental factors accounting for habitat selection.
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References


Department of the Environment. 2013. Coordinated research framework to assess the national conservation status of Australian snubfin dolphins (Orcaella heinsohni) and other tropical inshore dolphins.


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Appendix A – Simulation study

The simulation set

We assumed a broad range of values for each of the number of sites, the number of surveys per site (replicates), the probability of occupancy, and probabilities of detection, specifically:

- Sites \( \{15, 30, 45, 60, 90\} \)
- Surveys per site \( (k) \) \( \{4, 6, 8\} \)
- Probability of occupancy \( (\psi) \) \( \{0.2, 0.3, 0.5\} \)
- Probability of detection \( (p = p | \psi) \) \( \{0.1, 0.2, 0.4, 0.6, 0.8\} \)

One thousand (1000) simulations were run for each of the 225 combinations (simulation sets) of these assumed true values. The results were summarised for each simulation set terms of:

- The number of models for which \( \psi \) was estimated as either 0 or 1. We considered these to be failed models. An arbitrary acceptable maximum of 5% was set as a target for descriptive purposes.
- The mean estimated probability of occupancy.
- The mean standard error of the estimated probability of occupancy.
- The relative standard error (mean coefficient of variation) of the probability of occupancy. An arbitrary acceptable maximum of 25% was set as a target for descriptive purposes.

The relative standard error from each simulation set is plotted by the number of sites surveyed, the number of surveys per site, the probability of detection per survey and the probability of occupancy in Figure A1. The red dotted lines show a relative standard error of 25%.

The proportion of failed models from each simulation set is plotted by the number of sites surveyed, the number of surveys per site, the probability of detection per survey and the probability of occupancy in Figure A2. The red dotted lines show a relative standard error of 5%. 
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Figure A1: Relative standard error by number of sites surveyed, number of surveys per site, probability of detection per survey and probability of occupancy. Note that the y-scale differs on some plots.

It may be seen in the plots in Figure A1 that the probability of detection is a major factor in determining the standard error of the estimated probability of occupancy; strong decreases in the relative standard error of the probability of occupancy occur as the probability of detection increases from 0.2 to 0.4, especially when the number of surveys is fewer.

While, for 90 sites and four surveys per site, the relative standard error of the estimated probability of occupancy is reasonable (~25%) with a probability of detection of 0.2 provided the probability of occupancy is as high as 0.5, it is less satisfactory when the probability of occupancy is smaller. Reasonable relative standard errors standard errors of the probabilities of occupancy are obtained for 90 sites and four surveys per site for probabilities of occupancy as low as 0.2 with a probability of detection per survey of 0.4.

It may be seen in the plots in Figure A2 that failed models occur in small data sets with few repeat surveys and low detection probabilities. These plots therefore indicate how minimal a study might be and yet reliably provide estimates. Simulations with probability of detection less than 0.2 per survey generally resulted in an unacceptable proportion of failed models, more so for fewer surveys in fewer sites and when the probability of occupancy is smaller.
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Figure A2: Proportion of failed models by number of sites surveyed, number of surveys per site, probability of detection per survey and probability of occupancy. Note that the y-scale differs on some plots.