Marine Biodiversity Hub

National Environmental Science Programme

# Progress Report:

## Spatial and temporal patterns in sea snake populations on the North West Shelf

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Project A8: Exploring the status of Western Australia's sea snakes
November 2017

*Research Plan v3 (2017) - Milestone 10*



Australian Government | Australian Institute of Marine Science

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# EXECUTIVE SUMMARY

This progress report provides details on fieldwork and analyses conducted for NESP project A8: '*Exploring the status of Western Australia's sea snakes*' between the period of May 2017 – December 2017. Snorkel, research trawl and baited remote underwater video station (BRUVS) surveys were conducted by Hub researchers and collaborators between May and October 2017 that were combined with existing datasets to update occurrence records and conduct spatial and time-series analyses.

Data from BRUVS were used to assess sea snake assemblages in multiple locations within Australian Marine Parks (AMPs) and in locations where repeated sampling was conducted to construct species distribution models (SDMs) for all sea snake sightings and three priority species (*Aipysurus apraefrontalis*, *A. foliosquama* and *A. fuscus*).

# 1. SURVEYS FOR SEA SNAKES IN THE NORTH WEST MARINE REGION IN 2017

## 1.1 Snorkel, SCUBA and spotlight surveys

Existing survey data (see Udyawer *et al.*, 2016) was updated by collating survey data from research conducted previously by other researchers within the North West Marine Region (Dr. Kate Sanders, University of Adelaide; Dr. Ruchira Somaweera, CSIRO). In addition, Hub researchers conducted two field surveys in April 2017 and May 2017, targeting sites within Exmouth Gulf and around the Murion Islands. These data consisted of date, time and coordinates of sea snake sightings with species identification (Fig. 1). Tissue samples were also collected from individuals encountered during surveys and will be used to verify species ID and conduct further population genetic studies.

## 1.2 Research trawl surveys

Two field trips using research trawl surveys were conducted by Hub researchers during April and July 2017 within coastal habitats between Exmouth Gulf and Broome. In addition, data on sea snake catch from two additional research trawl trips on the RV Naturaliste (DoF) and one trawl trip on the RV Investigator (CSIRO) were contributed by collaborators from the Western Australian Department of Fisheries (Dr. Rory McAuley & Mr. Mathew Hourston). These data expanded the spatial extent of existing research trawl records for this project (Udyawer *et al.*, 2016) and included three additional verified sightings of priority species. These data consisted of start and end trawl coordinates for each trawl where sea snakes were caught, with photographs of snakes used to identify individuals to species level (Fig. 1). Tissue samples were collected by DoF staff and will be used to verify species ID and will contribute to samples used for further population genetic studies.

## 1.3 Online data repositories

Records of sea snake sightings from one national (The Atlas of Living Australia) and one international (Reef Life Survey) data repository were collated to update existing occurrence database (Fig. 1).

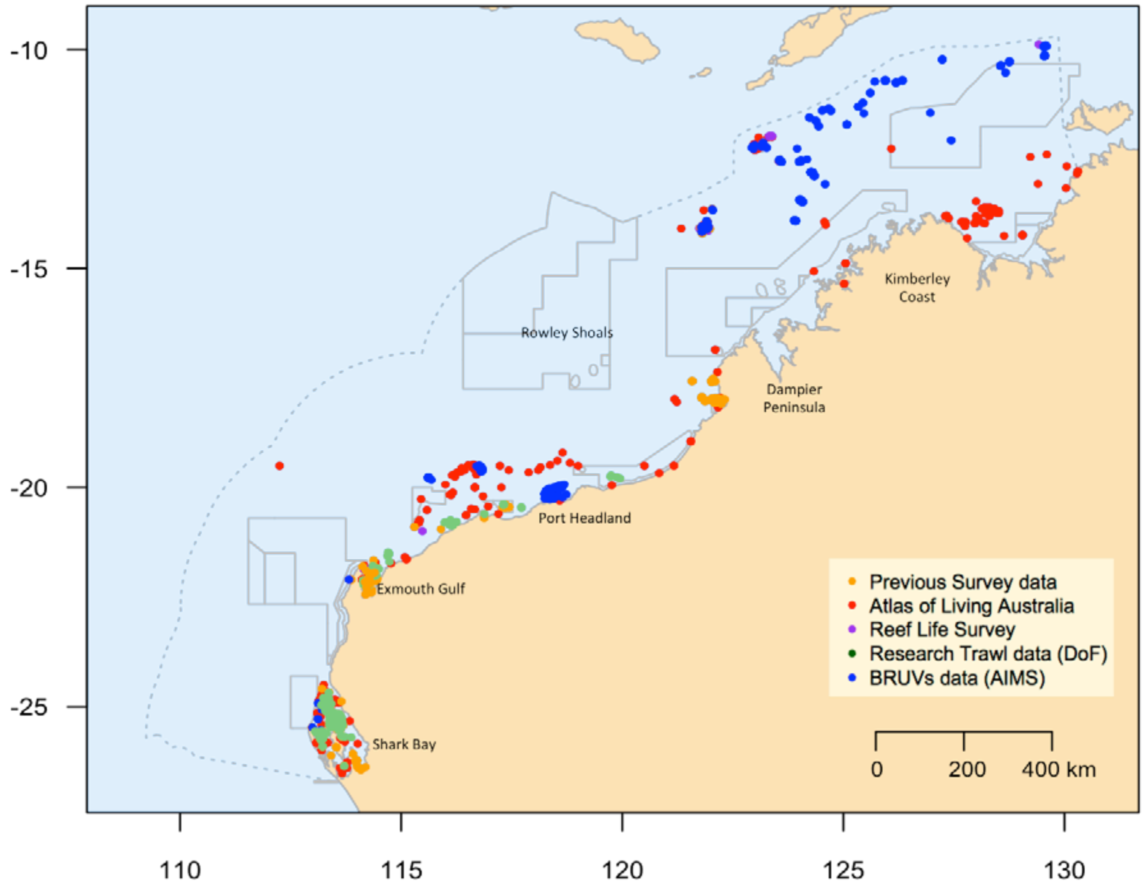


Figure 1. Locations of geo-referenced surveys conducted focusing on sea snakes between 1973 and 2017. Orange points indicate survey locations of snorkel and SCUBA surveys conducted by Hub researchers and collaborators (Blanche D'Anastasi, Kate Sanders, WA Department of Fisheries). Red points indicate locations of sea snake records from the Atlas of Living Australia used for SDMs. Purple points indicate locations of sea snake records from the Reef Life Survey database used for SDMs. Green points indicate locations of research trawls conducted by Hub researchers and collaborators (Department of Fisheries WA) used for SDMs. Blue points indicate locations of BRUVs deployments with sea snake sightings used for SDMs.

# 2. PROGRESS IN DATA ANALYSIS

## 2.1 Species Distribution Modelling

### 2.1.1 Methods

Confirmed sea snake sightings and occurrence data were used to construct species distribution models (SDMs) within the North West Marine region to assess the extent of occurrence of (a) all sea snake species, and three priority species (b) *Aipysurus apraefrontalis* (c) *A. foliosquama* and (d) *A. fuscus*.

Occurrence data were collated from five main sources (Fig. 1); Snorkel, SCUBA and spotlight surveys conducted by hub researchers and collaborators, verified records from the Atlas of Living Australia (https://www.ala.org.au); verified records from Reef Life Survey (https://reeflifesurvey.com), research trawls conducted by the Department of Fisheries WA and CSIRO, and verified sightings on BRUVs deployments conducted by AIMS.

Environmental, biophysical and habitat parameters used as covariates in SDMs were obtained from multiple data repositories (i.e. Geosciences Australia, Australian Ocean Data Network and ERDDAP-NOAA) (Table 1). Rasterised environmental data from within the North West Marine Region boundary was standardised to the highest resolution of data available (0.0083 degrees; 30 arc-seconds; ~ 1km/raster cell at the equator).

A Maximum Entropy (MaxEnt) model was used to create SDMs (Phillips & Dudík, 2008; Elith *et al.*, 2011) to assess patterns of species occurrence and identify other areas of occurrence within the North. This modelling approach compares the environment at occurrence localities to the environment at background localities. As sufficient true absence data was not available, the MaxEnt approach sampled 10,000 random points from within the North West Marine Region. To account for spatial biases in survey effort, background points were sampled at the same spatial density as occurrence data using a 'bias grid' approach (Fourcade *et al.*, 2014).

Sampling biases in the covariate space were also accounted for by pooling occurrence points within each raster pixel. This presence-only modelling approach includes assumptions that sampling within the model extent was relatively structured and that detection probability during the surveys was constant, but care must be taken when interpreting outputs of presence-only models.

The R library *ENMeval* (Muscarella *et al.*, 2014) was used for the species distribution modelling. Specifically, the function 'ENMevaluate' function (Muscarella *et al.*, 2014) was used to construct and tune MaxEnt models by testing all possible combinations of feature classes (determines the potential shape of the response curves) and regularization multipliers (determines the penalty for adding parameters to the model). The model with the best combination of settings was selected on the basis of lowest AICc score.

Table 1. Environmental, biophysical and habitat parameters used as covariates in SDMs.

| Environmental/Physical Parameter | Range | Mean ± SD |
|---|---|---|
| Depth (m) | 3.70 – 120 | 38.24 ± 20.34 |
| Aspect of bathymetry (degrees) | 0 – 360 | 225.82 ± 112.76 |
| Slope of bathymetry | 0 – 16.4 | 0.30 ± 0.57 |
| Relative distance alongshore (South -> North) | 0 – 1 | 0.58 ± 0.26 |
| Mean annual sea surface temperature (˚C) | 14.71 – 25.98 | 20.93 ± 0.97 |
| Annual amplitude of sea surface temperature (˚C) | 0 – 3.51 | 1.98 ± 0.48 |
| Mean annual sea surface salinity (psu) | 34.23 – 35.82 | 34.89 ± 0.31 |
| Annual amplitude of sea surface salinity (psu) | 0.05 – 0.45 | 0.22 ± 0.07 |
| Mean annual Chlorophyll a concentration (mg $m^{-2}$ $day^{-1}$) | 0 – 4.07 | 0.31 ± 0.35 |
| Proximity to the coast (m) | 0 – 248600 | 66470 ± 62613 |
| Proximity to reef systems (m) | 0 – 246900 | 45980 ± 67363 |
| Proximity to seagrass habitats (m) | 0 – 351400 | 124200 ± 106802 |
| Proximity to mangrove habitats (m) | 2340 – 295200 | 172900 ± 79030 |
| Proximity to freshwater source (m) | 4605 – 365600 | 213500 ± 98402 |
| Proportion of mud substrate (%) | 14.71 – 25.99 | 20.94 ± 0.97 |
| Proportion of gravel substrate (%) | 0 – 88.02 | 14.93 ± 11.85 |
| Proportion of sand substrate (%) | 2.76 – 99.79 | 61.57 ± 15.96 |

A random 5-fold cross validation method was used by partitioning occurrence data into five subsets, constructing a MaxEnt model on each subset (training set) and evaluating the created model using the remainder of the data (testing set). Area under the Receiver Operating Curve (henceforth AUC) score was calculated for each k-fold validation based on probability of true presence (for each of the 4 testing sets) falling on model predictions and reported as mean and variance of AUC between the 5 cross validations. The AUC ranges from 0 to 1, with an AUC of 0.5 indicating that model performance is equal to that of a random prediction and 1 indicating perfect discrimination between suitable and non-suitable habitat.

### 2.1.2 Results

MaxEnt models showed that coastal habitats within Shark Bay, Exmouth Gulf, Pilbara coast and Broome, and offshore reef habitats on Scott reef, Ashmore and the Mid-Shelf Shoals are areas with suitable habitats for all sea snake species (Fig. 2). Based on models of each priority species, most ideal habitats for *Aipysurus apraefrontalis* are within Exmouth Gulf and the Ashmore reef complex. This model predicts coastal habitats around Broome and Dampier Peninsula as newly identified suitable habitats for this species (Fig. 3). Models for *A. foliosquama* highlighted habitats within Shark Bay and Ashmore Reef complex as important habitats for this species. This model also predicted areas around the southern end of Barrow Island as newly identified suitable habitats for this species, which has limited support by a single record of this species within the Barrow and Montebello Island Marine Park (Fig. 4). Models for *A. fuscus* displayed a very restricted area of suitable habitat for this species within the North West Marine Region, limited to around the Ashmore Reef and Scott Reef Complexes. This model suggests areas of the inshore Kimberley region may have potentially suitable habitat for this species, however more data in this region is required (Fig .5). Model evaluation showed the model performed relatively well (Fig. 2 – 5). All models had high mean AUC scores with low AUC variance denoting a reliable prediction based on occurrence datasets.

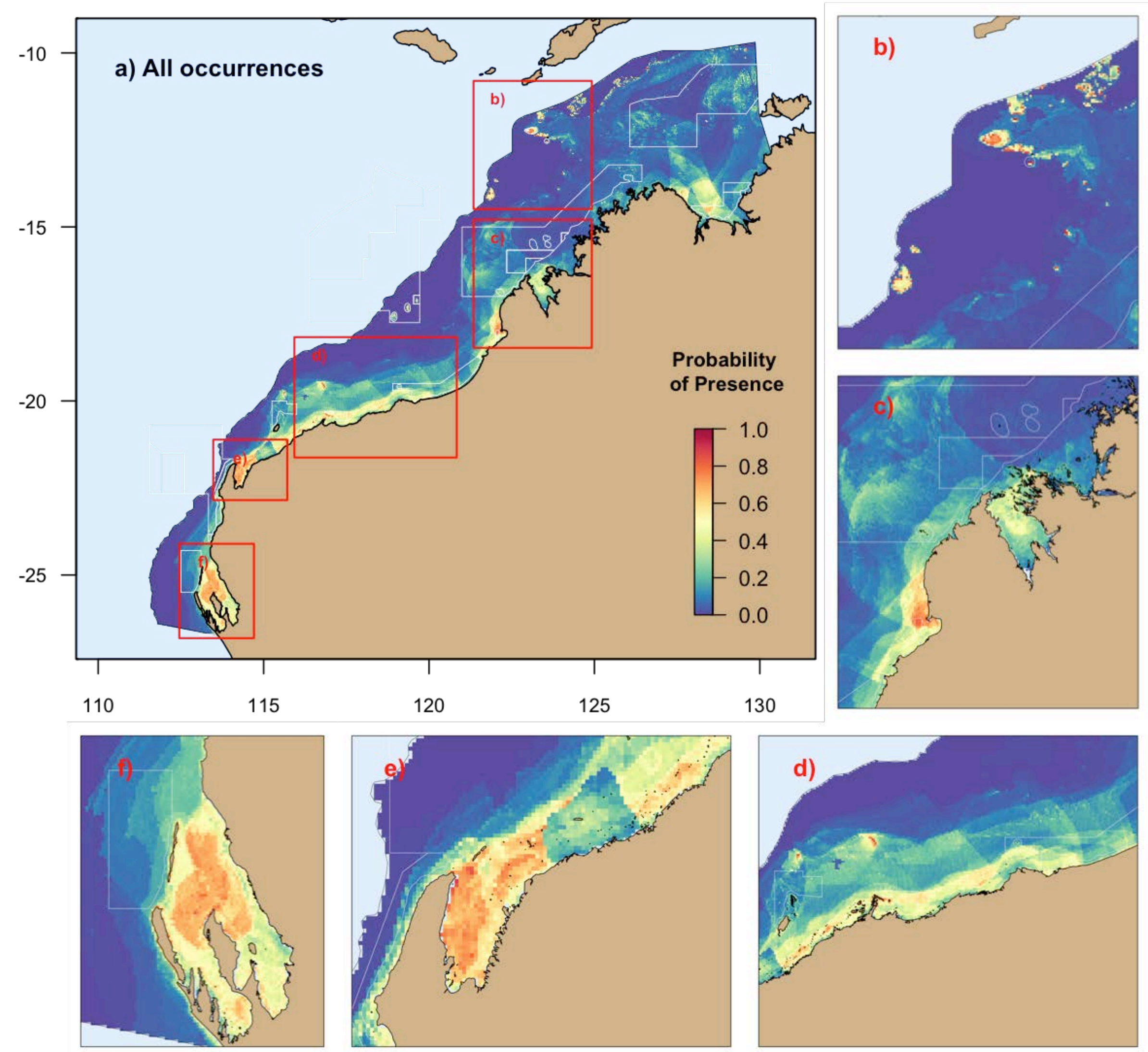


Figure 2. Species distribution model using Maximum Entropy models for all sea snakes sightings within the (a) North West Marine Region, restricted to shallow waters (> 1km bathymetry contour). Model outputs shown (b) around the offshore NW reefs, (c) Broome and Kimberley regions, (d) Pilbara coast, (e) within Exmouth Gulf and (f) Shark Bay. Model AUC = 0.91 ± 0.15.

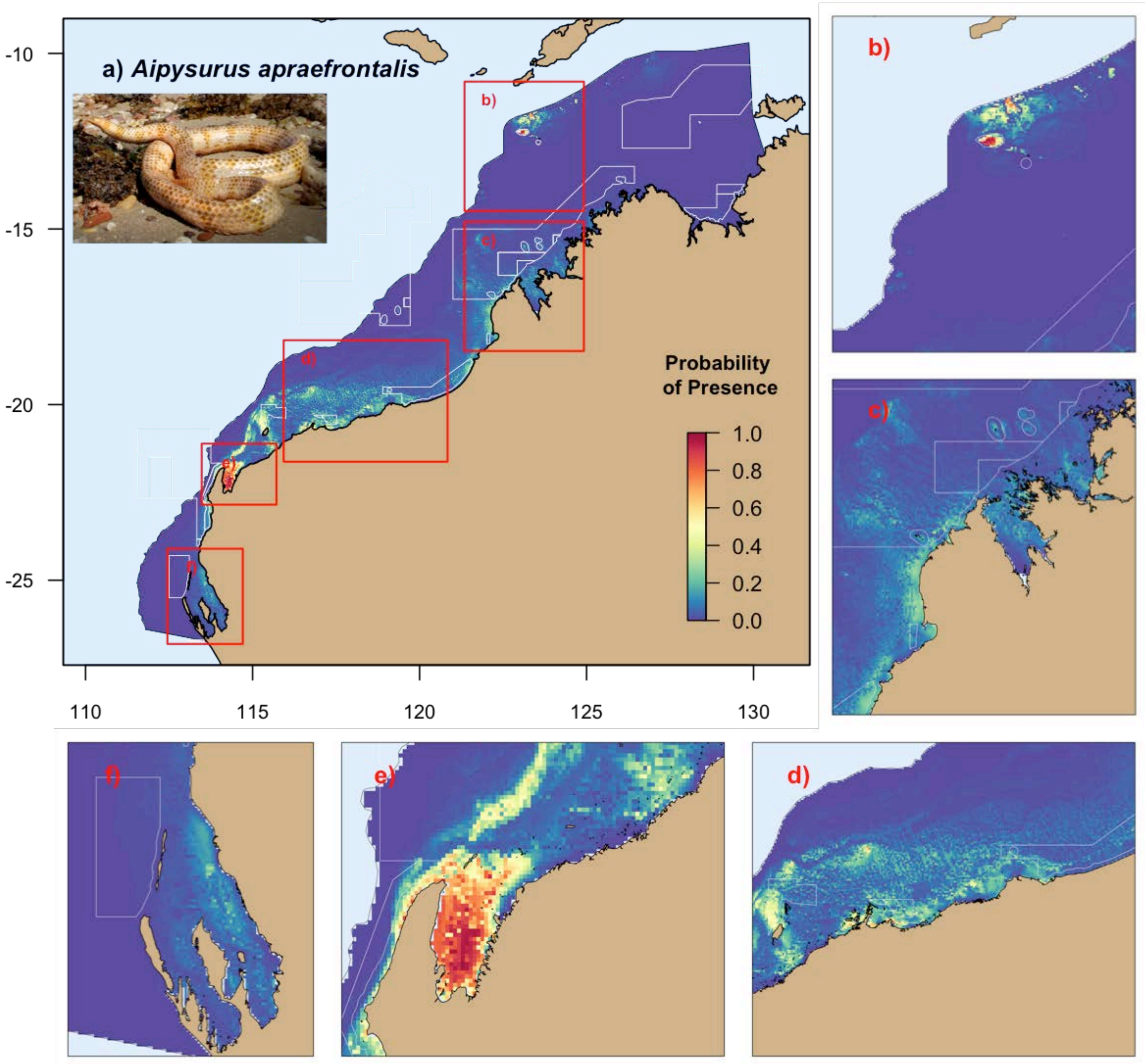


Figure 3. Species distribution model using Maximum Entropy models for *Aipysurus apraefrontalis* (Short-nosed sea snake) sightings within the (a) North West Marine Region, restricted to shallow waters (> 1km bathymetry contour). Model outputs shown (b) around the offshore NW reefs, (c) Broome and Kimberley regions, (d) Pilbara coast, (e) within Exmouth Gulf and (f) Shark Bay. Model AUC = 0.97 ± 0.02.

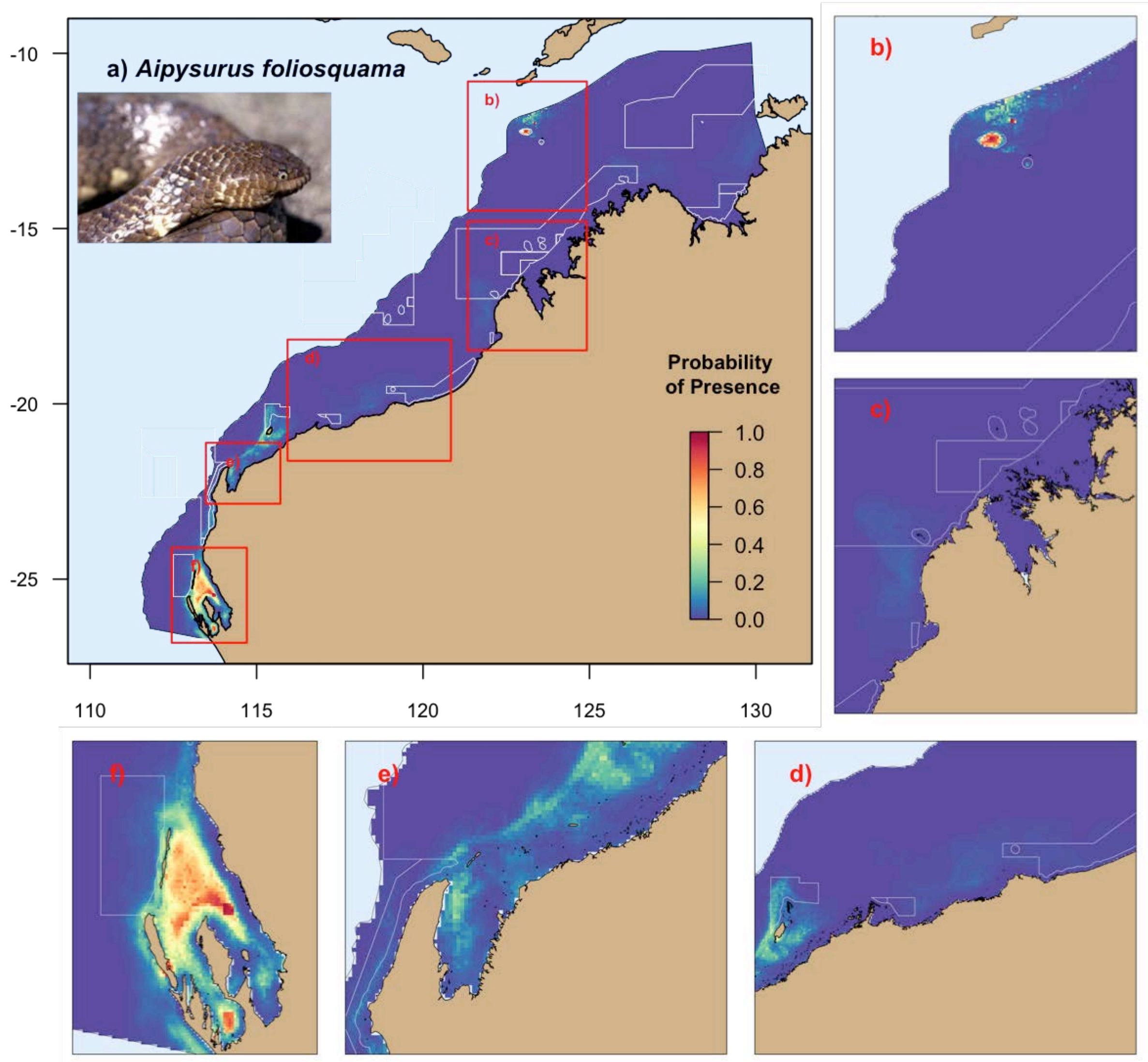


Figure 4. Species distribution model using Maximum Entropy models for *Aipysurus foliosquama* (Leaf-tailed sea snake) sightings within the (a) North West Marine Region, restricted to shallow waters (> 1km bathymetry contour). Model outputs shown (b) around the offshore NW reefs, (c) Broome and Kimberley regions, (d) Pilbara coast, (e) within Exmouth Gulf and (f) Shark Bay. Model AUC = 0.99 ± 0.02.

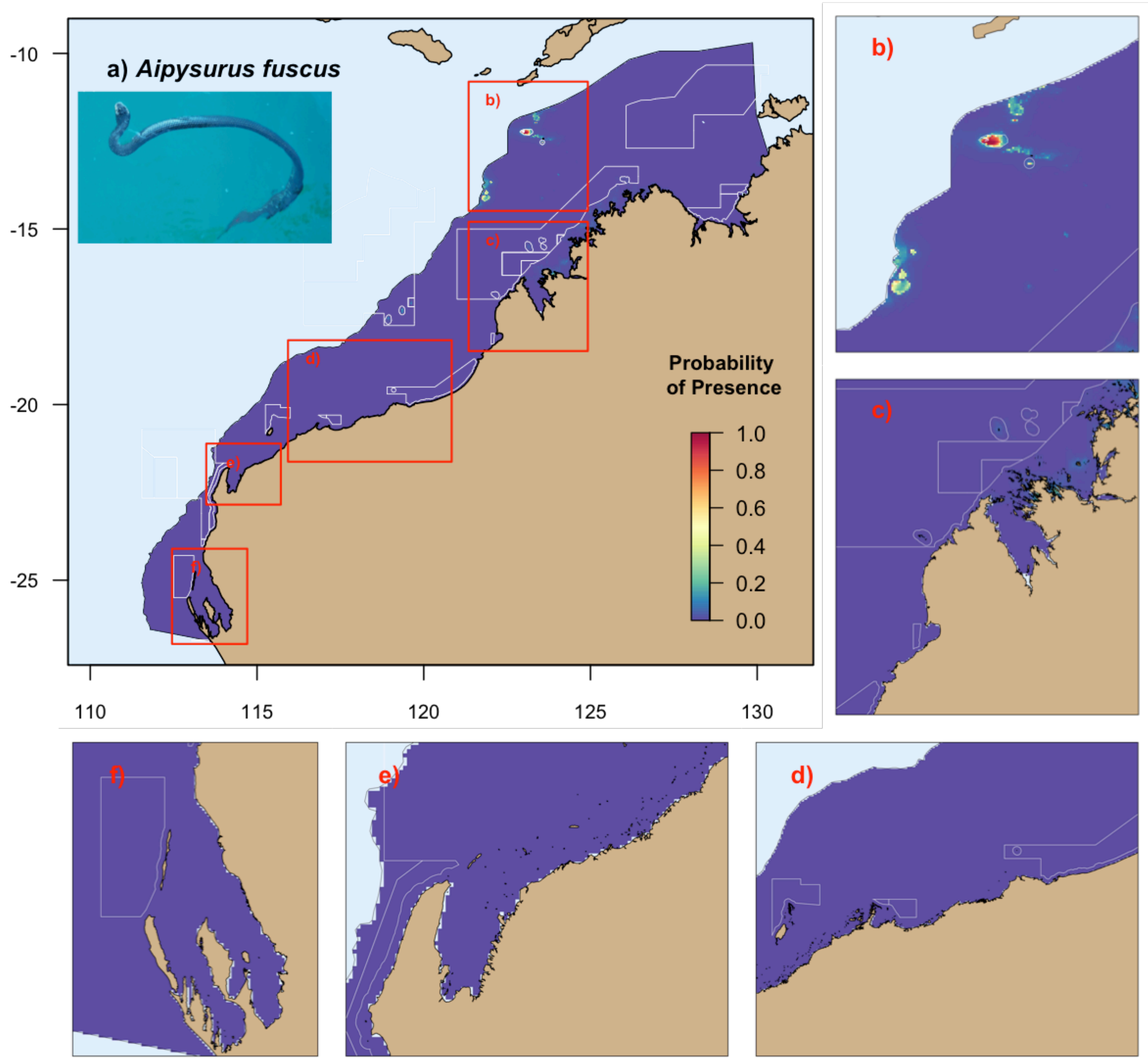


Figure 5. Species distribution model using Maximum Entropy models for *Aipysurus fuscus* (Dusky sea snake) sightings within the (a) North West Marine Region, restricted to shallow waters (> 1km bathymetry contour). Model outputs shown (b) around the offshore NW reefs, (c) Broome and Kimberley regions, (d) Pilbara coast, (e) within Exmouth Gulf and (f) Shark Bay. Model AUC = 0.99 ± 0.24.

## 2.2 Temporal trends in sea snake assemblages

Sighting records from BRUVs surveys conducted between 1999 and 2017 were used to assess spatial and temporal trends in sea snake assemblages within the North West Marine Region. BRUVs deployments covered a large portion of the remote North West shelf (Fig. 6), however coverage in coastal regions around Kimberley, Pilbara, Exmouth Gulf and Shark Bay were limited due to low visibility in coastal regions. Repeated sampling was conducted inside and outside Commonwealth Marine Reserves, and repeated sampling was conducted in 10 sites within the region (Fig. 7). Spatial analyses were conducted on BRUVs deployed within the Ashmore and Cartier Reefs (Fig. 6 and 7; red bounding box/bars).

Spatial and temporal analyses were also conducted for five sights where repeated sampling was conducted and where sea snakes were sighted in relatively high numbers (Fig. 6 and 7; purple and blue bounding box/bars). ‘Catch’ per unit effort (CPUE) was calculated for each BRUVs deployment by dividing the maximum number of sea snakes of each species sighted on video at any one time (MaxN; Cappo *et al.*, 2006) by the number of minutes each BRUVs was deployed for (unit: Snakes $min^{-1}$).

In total 687 sea snakes were sighted in all BRUVs footage, with *Aipysurus laevis* being the most commonly sighted species (56%) followed by *Emydocephalus annulatus* (11%) in the full dataset (Table 2). Of all sites with repeated sampling, Heywood Shoal displayed the highest sighting rates for all sea snakes (16% of all sightings; Table 2).

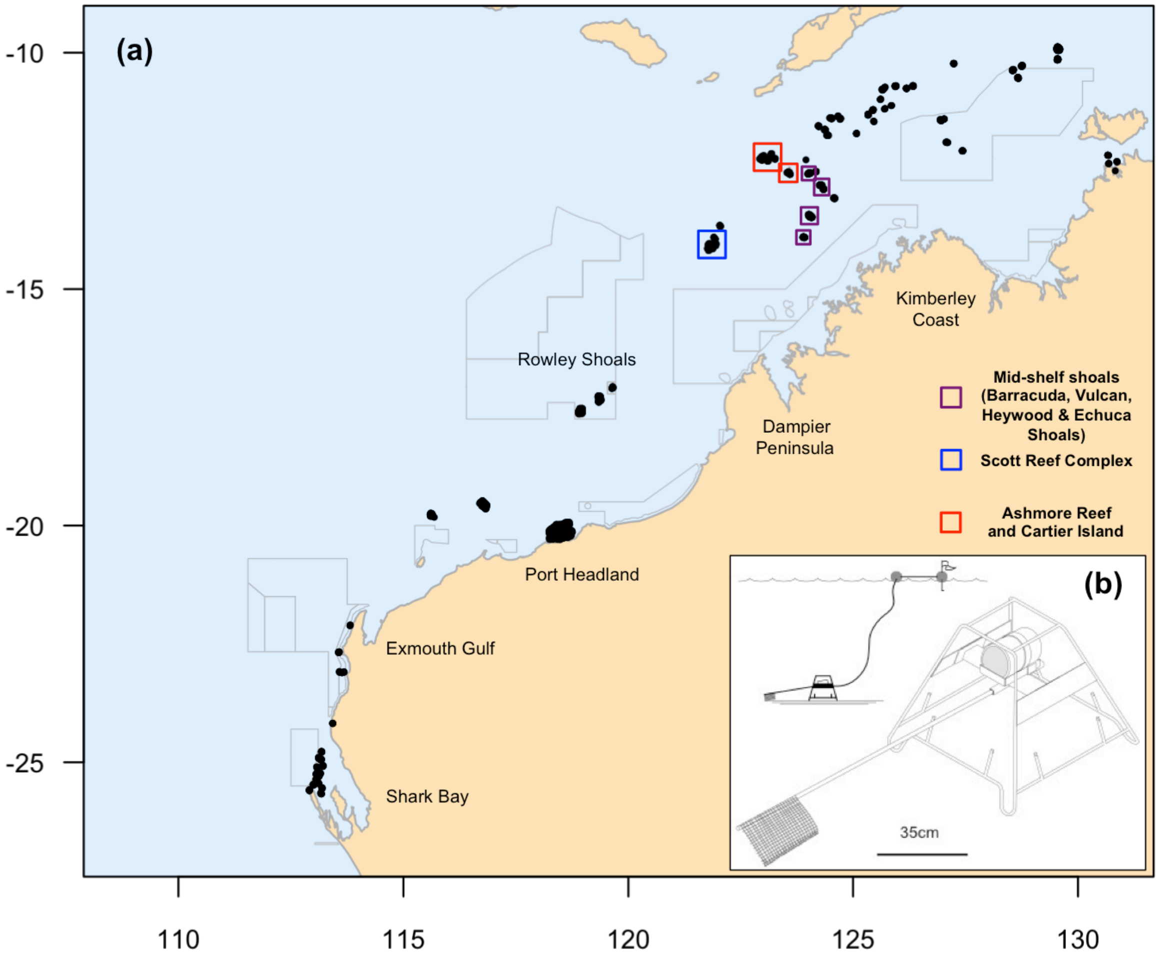


Figure 6. (a) Locations of baited remote underwater video station (BRUVS) deployments along the West Coast of Australia. Grey outlines within the marine region indicate Commonwealth Marine Reserve boundaries. BRUVs with coloured boxes represent sites used for further temporal analyses (b) A schematic of the set-up of single camera BRUVS used to sample the presence of marine fauna.

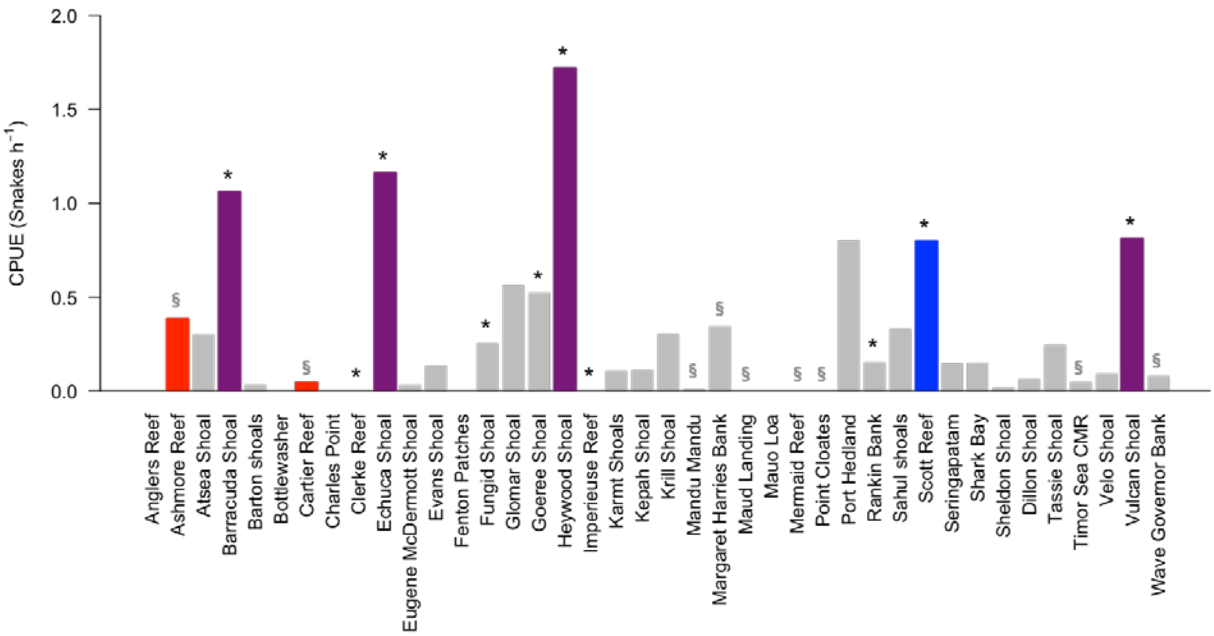


Figure 7. 'Catch' per unit effort (sighting rate) of sea snakes on BRUVs deployed in the North West Marine Region. Sites with '*' above bar represent sites with repeated sampling over multiple years. Sites with '§' above bar represent sites within AMPs. Coloured bars represent sites analysed further, colours correspond with sites on Figure 6.

Table 2. Number of snakes from each species sighted on BRUVs deployments within the North West Marine Region between 1999 – 2017.

| Species | Ashmore Reef | Cartier Reef | Barracuda Shoal | Echuca Shoal | Heywood Shoal | Scott Reef | Vulcan Shoal | All sites |
|---|---|---|---|---|---|---|---|---|
| *E. annulatus* | 2 | 1 | 9 | 9 | 7 | 2 | 7 | 78 |
| *H. coggeri* | | | | | | | | 3 |
| *H. curtus* | | | | | | | | 2 |
| *A. duboisii* | 1 | | | 3 | 4 | 1 | | 14 |
| *A. laevis* | 7 | 4 | 52 | 52 | 78 | 26 | 30 | 388 |
| *H. major* | | | | | 8 | 1 | 1 | 31 |
| *H. ocellatus* | | | 2 | | 2 | 1 | 3 | 24 |
| *H. peronii* | | | | 2 | 4 | 2 | | 18 |
| *A. pooleorum* | | | | | | | | 5 |
| *A. tenuis* | | | | 2 | 2 | 1 | 3 | 41 |
| Unidentifiable | 6 | 4 | 3 | 4 | 5 | 14 | 8 | 83 |
| All sea snakes | 16 | 9 | 66 | 74 | 110 | 48 | 52 | 687 |

### 2.2.1 Ashmore and Cartier Reefs

As only a single round of sampling was conducted at Ashmore and Cartier Reef in 2004, time-series analysis of sighting rates in these sites was not possible. However, the limited data available from BRUVs in this location indicate that *A. laevis* was the most sighted species within and outside AMPs at both sites with *E. annulatus* and *A. duboisii* also sighted at these reef systems (Fig. 8). Within Ashmore Reef, BRUVs samples on the East and West side of the reef identified relatively abundant snake populations whereas no snakes were sighted at the southern reef edge of Ashmore Reef. The northern and southern reef edges of Cartier Reef displayed higher sighting rates of sea snakes than sites on the western edge (Fig. 8). Both reefs were dominated with *A. laevis* sightings with *A. duboisii* absent at Cartier Reef (Fig. 8).

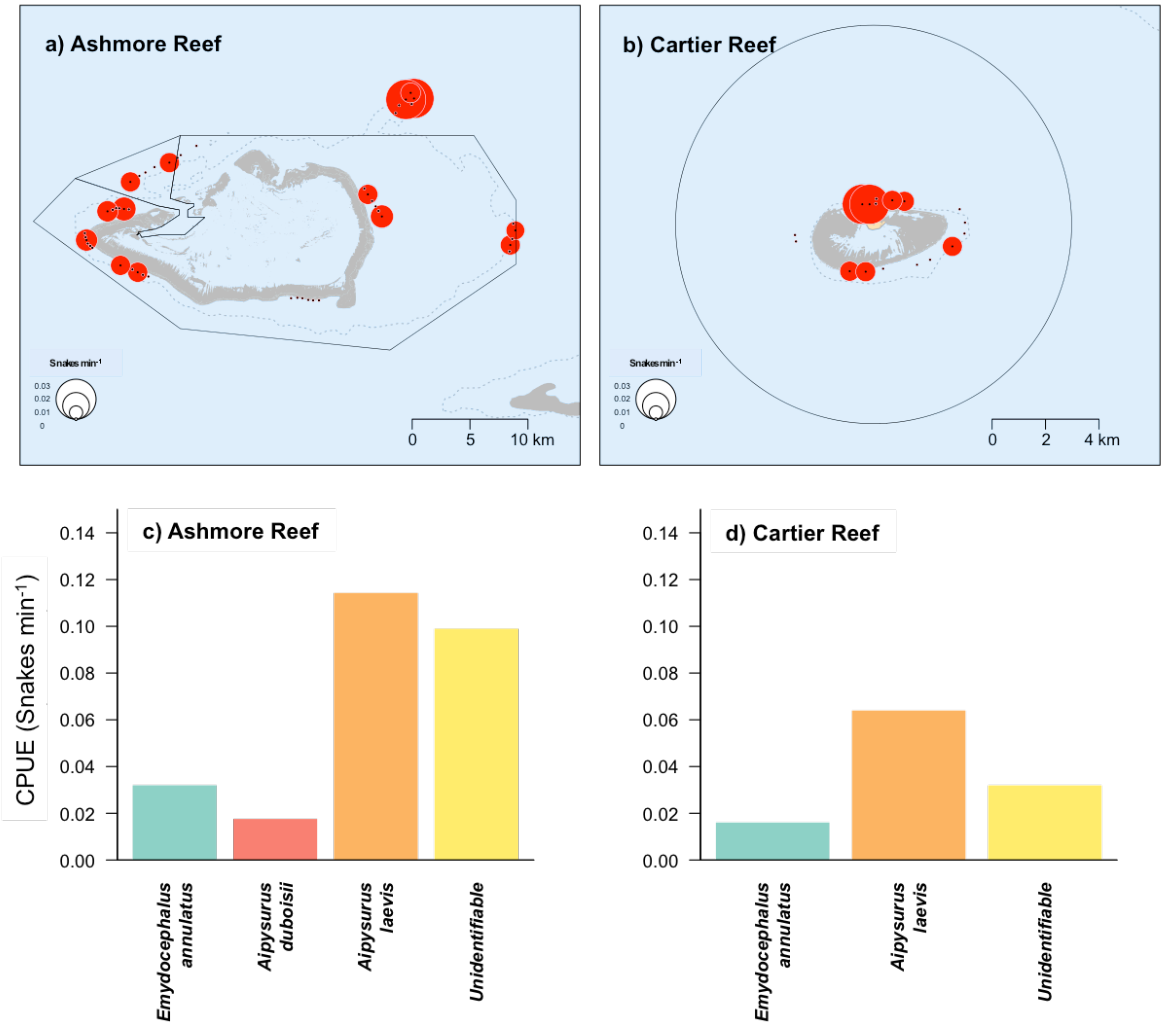


Figure 8. Spatial distribution of sea snake sightings on BRUVs at (a) Ashmore Reef and (b) Cartier Reef in 2004. Black points on maps show locations of BRUVs drops. Size of red circles represent sighting rate of sea snakes at each location. Species assemblage on (c) Ashmore Reef and (d) Cartier Reef determined by species identification on BRUVs footage.

### 2.2.2 Scott Reef

Five sampling rounds were conducted at Scott Reef in 1999, 2003, 2007, 2008 and 2014 (Fig. 9), with *A. laevis* being the most dominant species sighted on video footage during all five years of sampling (Fig. 10). Other species sighted at Scott Reef *included E. annulatus, A. tenuis, H. peronii, A. duboisii, H. major* and *H. ocellatus* (Fig. 10). Sighting rates of sea snakes peaked in 2008 with four identifiable species sighted that year (Fig. 10). Subsequently, in 2014 only a single species was sighted at much reduced rates, likely as a consequence of reduced spatio-temporal survey effort (Fig. 9 and 10).

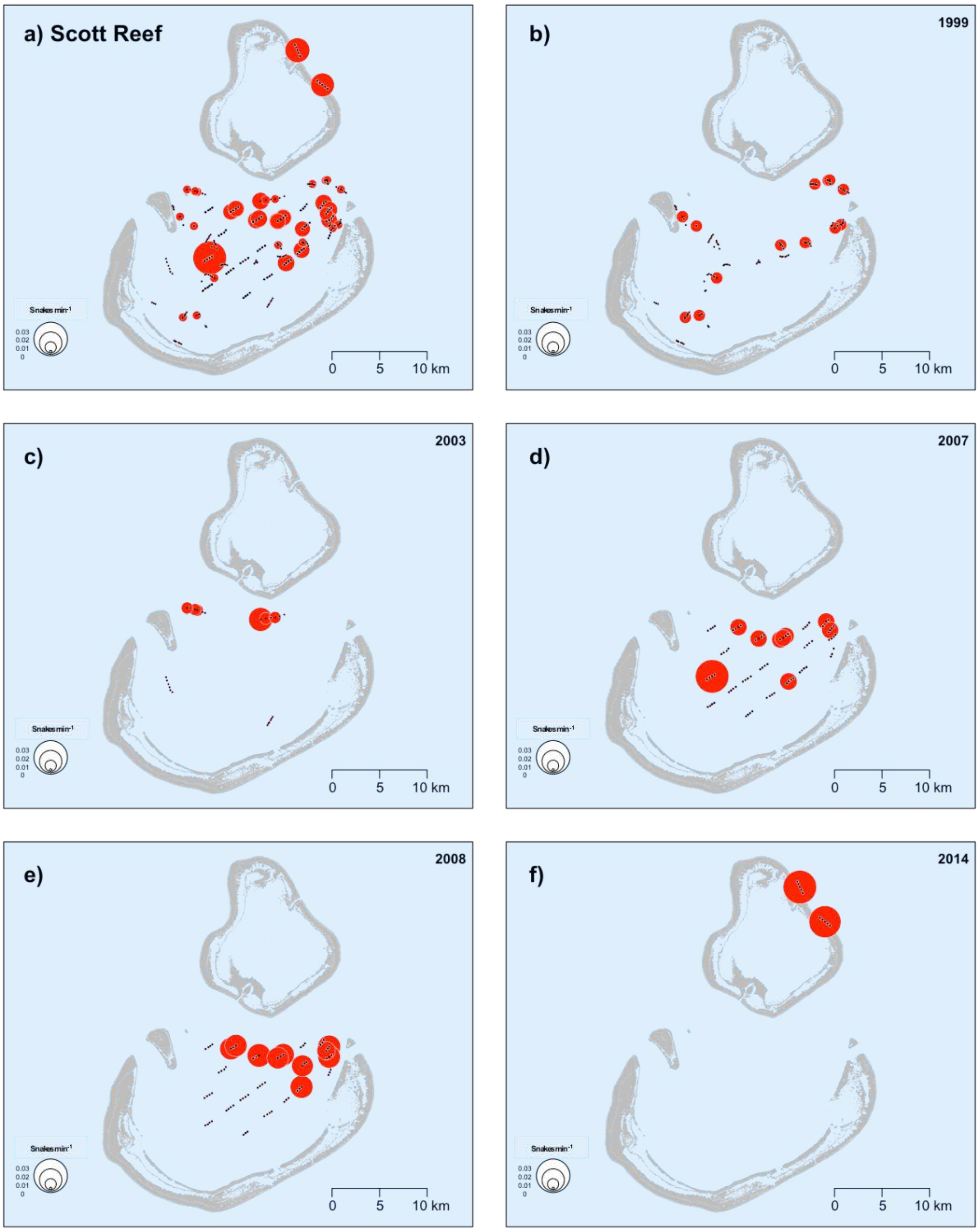


Figure 9. Spatial distribution of sea snake sightings on BRUVs at (a) Scott Reef and temporal patterns over five repeated sampling surveys in (b) 1999, (c) 2003, (d) 2007, (e) 2008 and (f) 2014. Black points on maps show locations of BRUVs drops. Size of red circles represent sighting rate of sea snakes at each location.

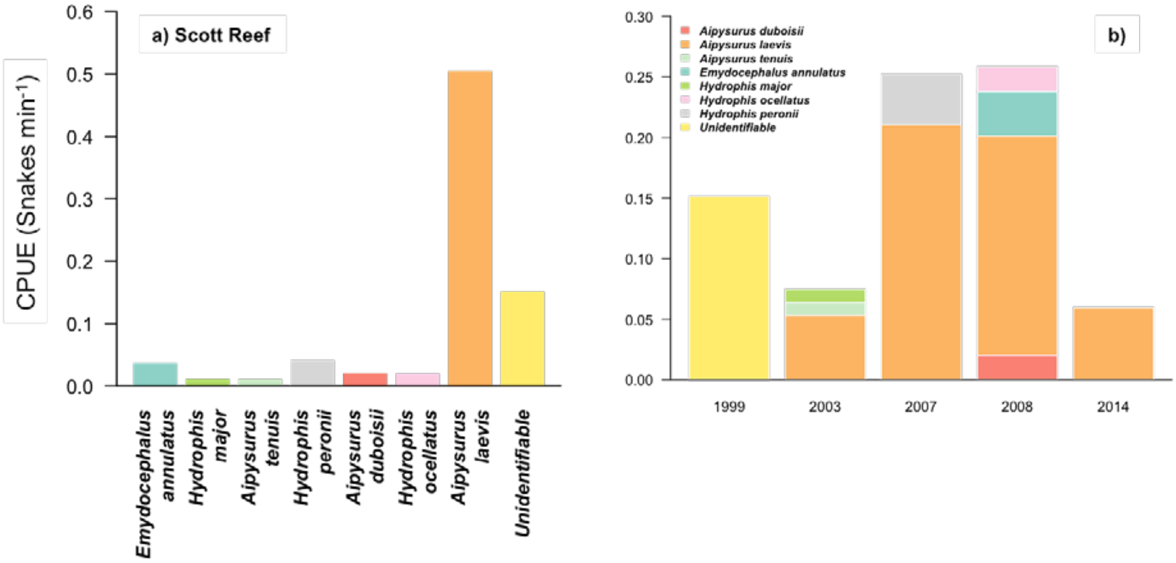


Figure 10. (a) Species assemblage and sighting rate of sea snakes at Scott Reef and (b) temporal trend in abundance and sighting rates of sea snakes across five repeated sampling trips.

### 2.2.3 Barracuda Shoal

Three sampling rounds were conducted at Barracuda Shoal in 2011, 2013 and 2016 (Fig. 11), with *A. laevis* being the most dominant species sighted on video footage during all four years (Fig. 11). Other species sighted at Echuca Shoal included *E. annulatus* and *H. ocellatus* (Fig. 13). Although the species assemblage in 2011 and 2013 remained constant at three identifiable species, the sighting rates of sea snakes drastically reduced between the two sampling years (Fig. 14). Subsequently in 2016, only *A. laevis* was sighted at Barracuda Shoal (Fig. 14).

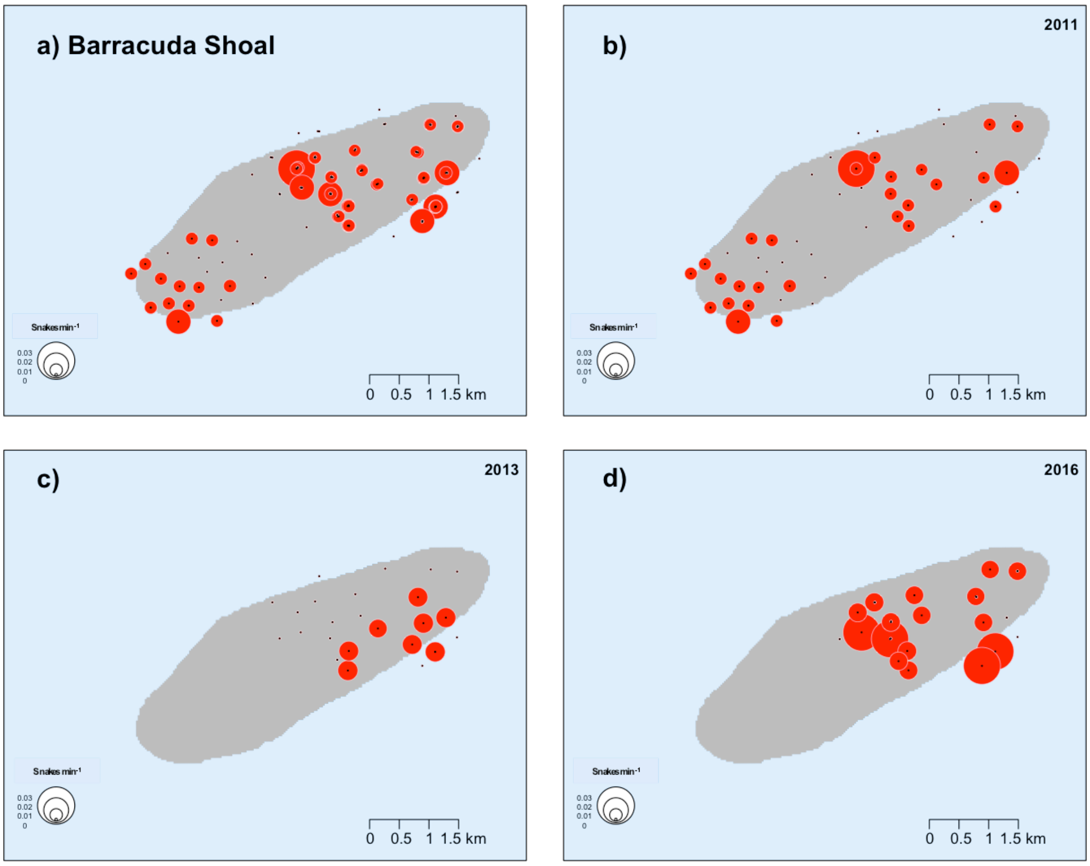


Figure 11. Spatial distribution of sea snake sightings on BRUVs at (a) Barracuda Shoal and temporal patterns over three repeated sampling surveys in (b) 2011, (c) 2013 and (d) 2016. Black points on maps show locations of BRUVs drops. Size of red circles represent sighting rate of sea snakes at each location.

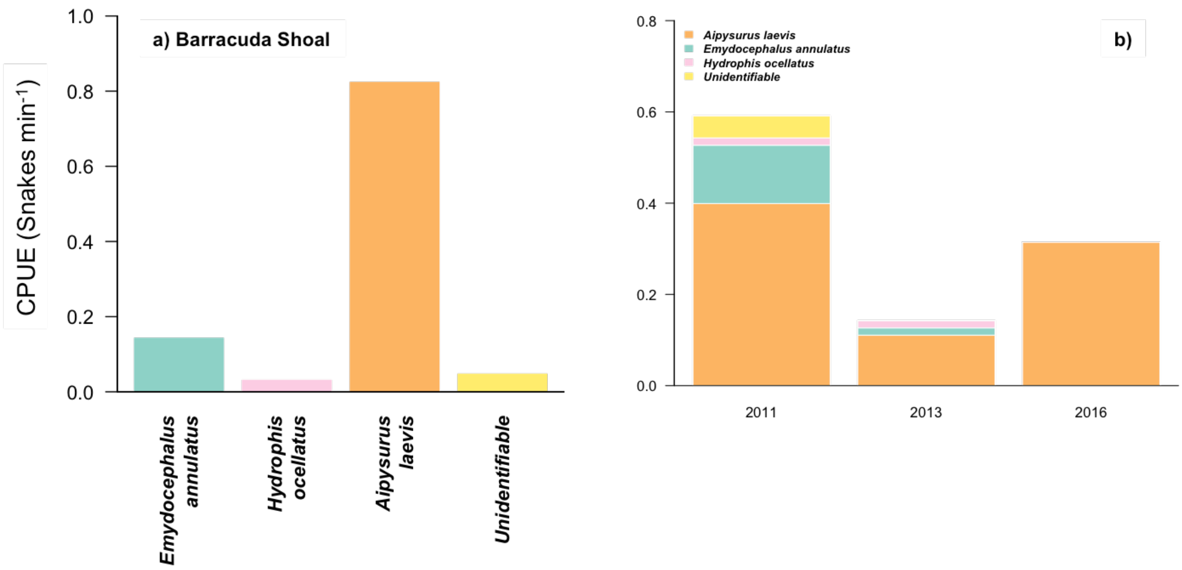


Figure 12. (a) Species assemblage and sighting rate of sea snakes at Barracuda Shoal and (b) temporal trend in abundance and sighting rates of sea snakes across three repeated sampling trips.

### 2.2.4 Echuca Shoal

Four sampling rounds were conducted at Echuca Shoal in 2011, 2014, 2015 and 2016 (Fig. 13), with *A. laevis* being the most dominant species sighted on video footage during all four years of sampling followed by *E. annulatus* (Fig. 14). Other species sighted at Echuca Shoal included *A. tenuis, H. peronni, A. duboisii,* and *H. major* (Fig. 14). Sighting rates of sea snakes peaked in 2014 and subsequently reduced in 2015 and 2016. Numbers of species sighted also peaked in 2014 with six species and subsequently reduced to four identifiable species in 2015 and two species in 2016 (Fig. 14).

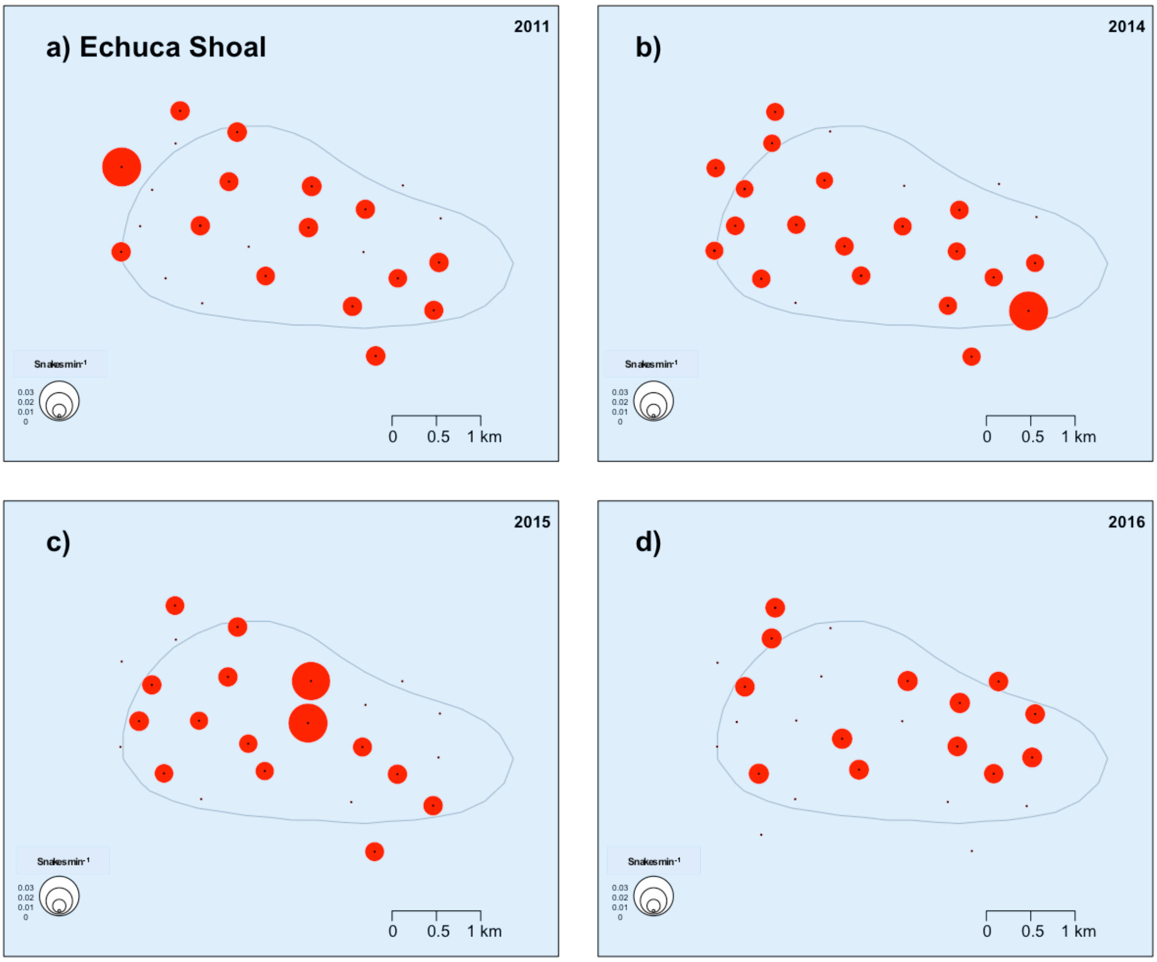


Figure 13. Spatial distribution of sea snake sightings on BRUVs at Echuca Shoal with temporal patterns over four repeated sampling surveys in (a) 2011, (b) 2014, (c) 2015 and (d) 2016. Black points on maps show locations of BRUVs drops. Size of red circles represent sighting rate of sea snakes at each location.

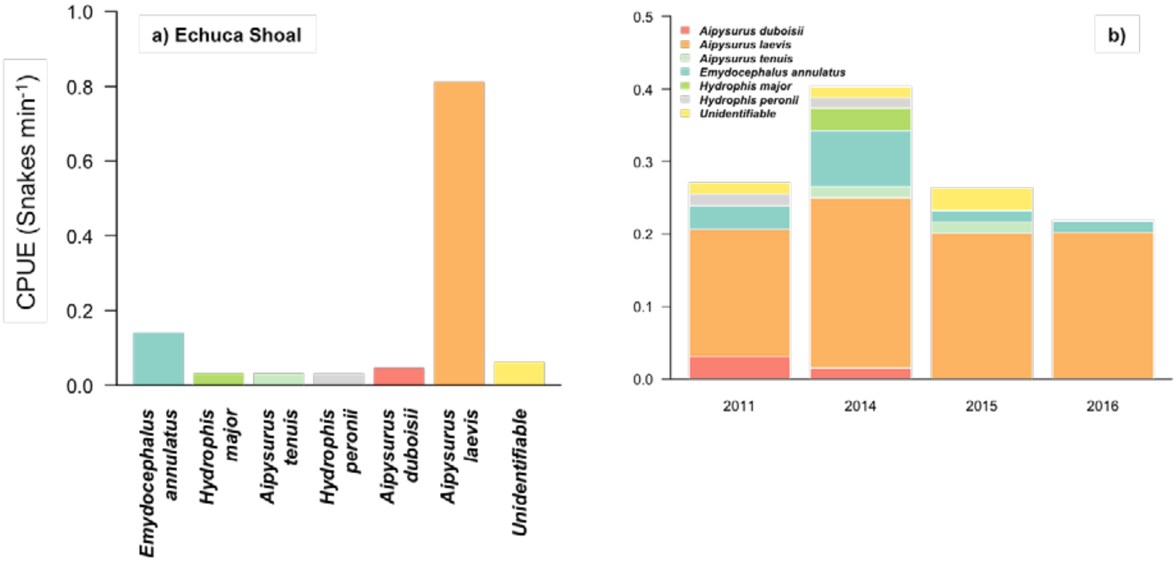


Figure 14. (a) Species assemblage and sighting rate of sea snakes at Echuca Shoal and (b) temporal trend in abundance and sighting rates of sea snakes across four repeated sampling trips.

### 2.2.5 Heywood Shoal

Five sampling rounds were conducted at Heywood Shoal in 2004, 2011, 2014, 2015 and 2016 (Fig. 15), with *A. laevis* being the most dominant species sighted on video footage during all five years of sampling (Fig. 16). Other species sighted at Heywood Shoal included *E. annulatus, A. tenuis, H. peronni, A. duboisii, H. major* and *H. ocellatus* (Fig. 16). Sighting rates of sea snakes remained relatively stable across all three years however, numbers of species sighted reduced from six identifiable species in 2004, 2011 and 2014 to four identifiable species in 2016 (Fig. 16).

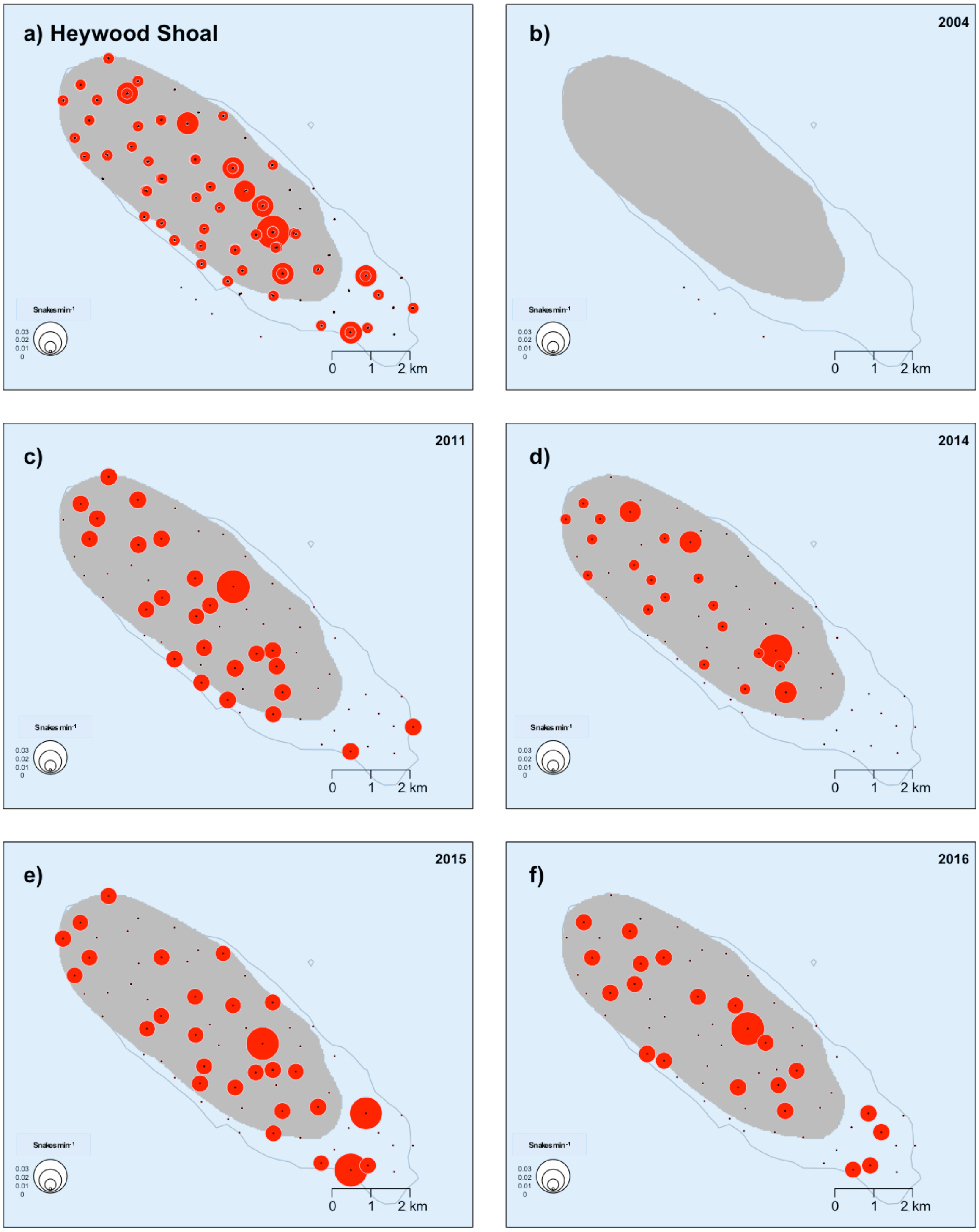


Figure 15. Spatial distribution of sea snake sightings on BRUVs at (a) Heywood Shoal and temporal patterns over five repeated sampling surveys in (b) 2004, (c) 2011, (d) 2014, (e) 2015 and (f) 2016. Black points on maps show locations of BRUVs drops. Size of red circles represent sighting rate of sea snakes at each location.

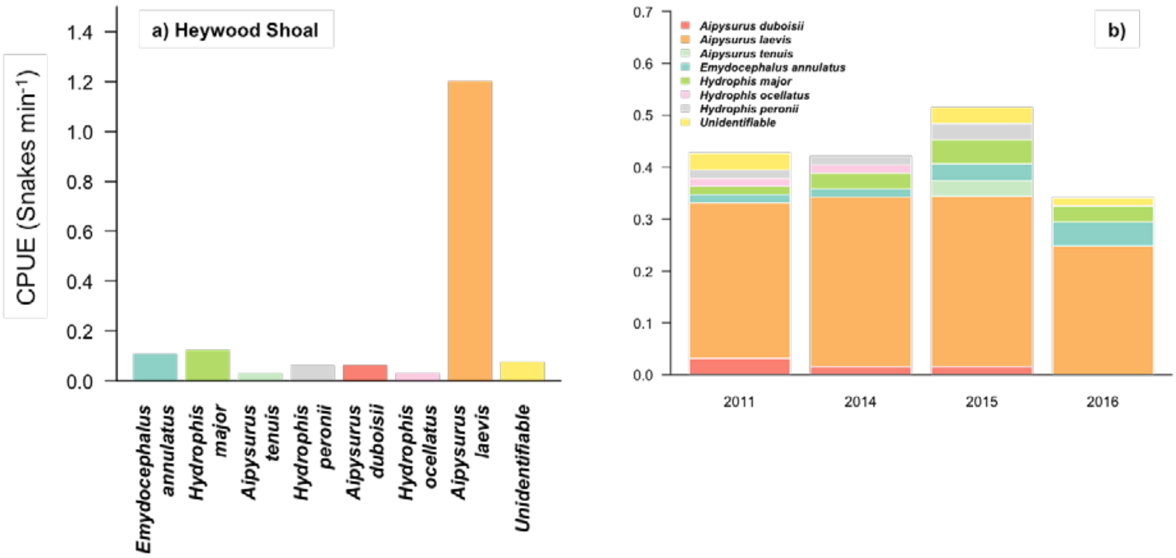


Figure 16. (a) Species assemblage and sighting rate of sea snakes at Heywood Shoal and (b) temporal trend in abundance and sighting rates of sea snakes across five repeated sampling trips.

### 2.2.6 Vulcan Shoal

Three sampling rounds were conducted at Vulcan Shoal in 2011, 2013 and 2017 (Fig. 17), with *A. laevis* being the most dominant species sighted on video footage during all three years of sampling. Other species sighted at Vulcan Shoal included *E. annulatus, A. tenuis, H. major* and *H. ocellatus* (Fig. 18). Sighting rates of sea snakes remained relatively stable across all three years however, numbers of species sighted reduced from four identifiable species in 2011 and 2013 to three identifiable species in 2017 (Fig. 18).

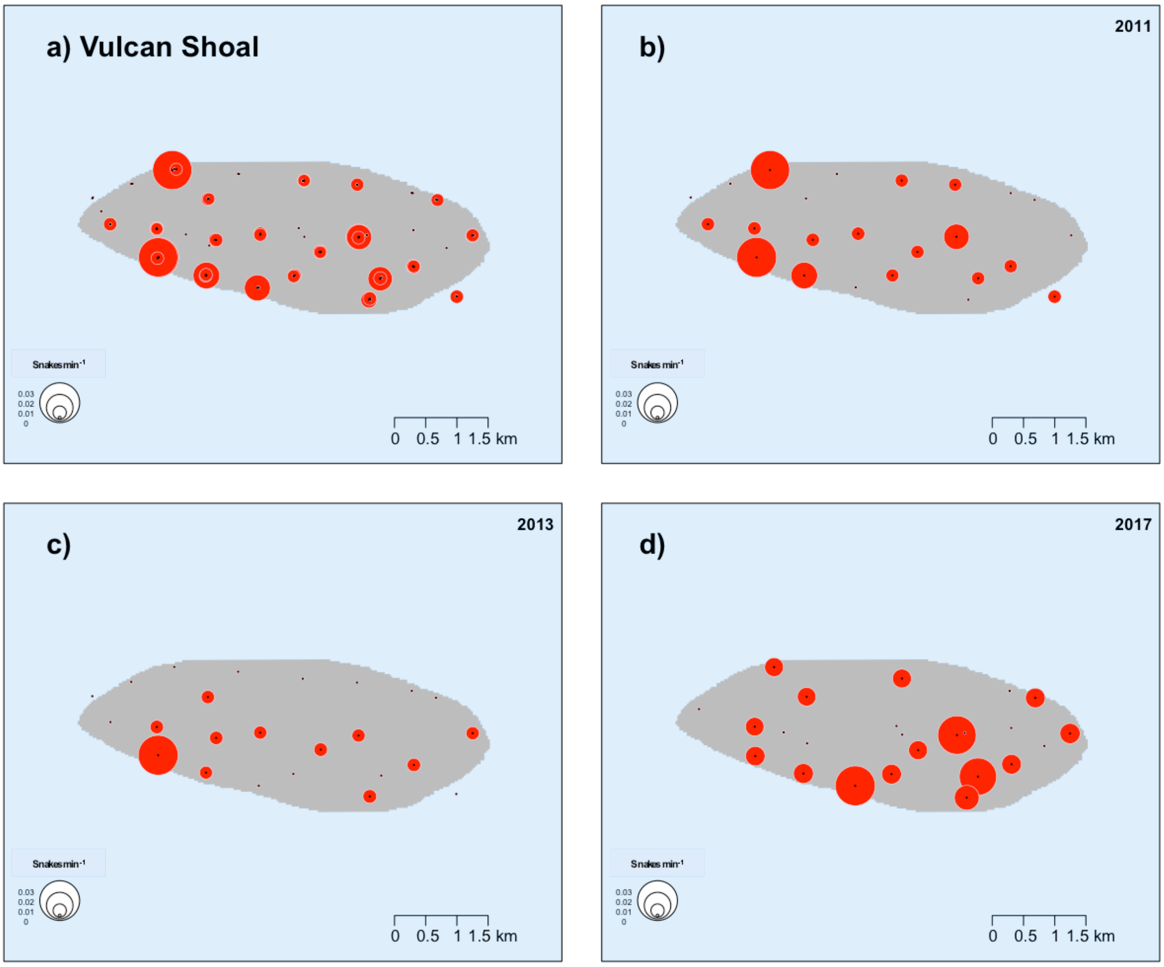


Figure 17. Spatial distribution of sea snake sightings on BRUVs at (a) Vulcan Shoal and temporal patterns over three repeated sampling surveys in (b) 2011, (c) 2013 and (d) 2017. Black points on maps show locations of BRUVs drops. Size of red circles represent sighting rate of sea snakes at each location.

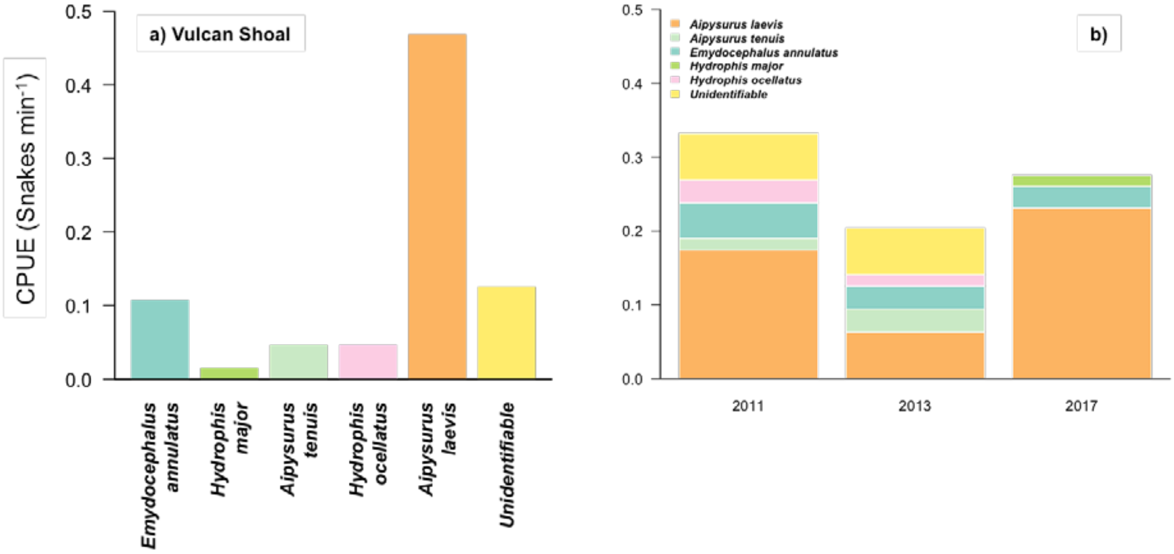


Figure 18. (a) Species assemblage and sighting rate of sea snakes at Vulcan Shoal and (b) temporal trend in abundance and sighting rates of sea snakes across three repeated sampling trips.

# 3. CONCLUSION

Repeated BRUVs deployments at selected reef and mid-shoal systems have identified a few locations where sea snakes are sighted consistently, however there is a trend of decreasing species richness at most sites over a period of seven years. *Aipysurus laevis* were consistently sighted at all sites and over repeated sampling periods, and were the most abundant species at each site. In addition to *A. laevis*, *Emydocephalus annulatus* and *Hydrophis major* were also sighted at all sampling sites. The lack of sightings of the three priority species (*A. apraefrontalis, A. foliosquama* and *A. fuscus*) highlighted the limited utility of BRUVs sampling for these species. Increased sampling using BRUVs and other techniques are required in these areas to ascertain how widely this pattern extends to other adjacent systems, and if the decreasing trend continues over time. Similarly, further analyses of long-term environmental and biological data (i.e. sea surface temperature, prey and predator density) at these sites are required to assess if there has been a significant change at these locations that can explain the decreasing sea snake abundance and richness patterns. The next step for this analysis will analyse trends in predator (e.g. sharks, grouper) and prey (e.g. eel, damselfish) using BRUVs at sites where repeated sampling was undertaken.

The sampling sites for BRUVs where sea snakes were abundant reflected locations on the SDMs that indicated high habitat suitability for all species of sea snake. However, since none of the priority species were sighted on BRUVs, SDMs for those species requires further field validation. Other survey techniques (i.e. research trawls, targeted SCUBA and snorkel surveys) are required to validate the SDM outputs. SDMs have identified coastal locations around Broome and the Kimberley region as locations with suitable for populations of priority species. Similarly, sites around Barrow Island and within the Montebello marine park have been identified as significant new sites for *A. apraefrontalis* and *A. foliosquama*. These sites may have more stable environmental conditions that allow the persistence of new populations of conservation priority species and need to be explored further. Field validation is the next phase of the current project that will focus on coastal sites between Exmouth Gulf and Kimberley coast identified by the current SDMs.

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