Ecogeographic and anthropogenic drivers of dolphin distribution: informing future spatial conservation planning in a marine protected area

Cecilia Passadore, Luciana Möller, Fernando Diaz-Aguirre & Guido J. Parra
The Bottlenose dolphins (Genus *Tursiops*)

Two species are widely accepted

Common bottlenose (*T. truncatus*):
Coastal and offshore temperate and tropical waters worldwide.

Indo-Pacific (*T. aduncus*):
Coastal and inshore India, west to east Australia, South China, the Red Sea, and eastern Africa.

Recent studies have suggested the inclusion of another species

Burrunanan or southern Australian (*T. australis*):
Coastal and inshore Victoria, Tasmania, South Australia, southern Western Australia.
Southern Australian bottlenose dolphins (*T. cf. australis*)

- Six genetically-distinct populations identified
- Each population should be managed as a separate entity

**Coffin Bay** is the smallest area with a genetically differentiated population of *T. australis*

- **Esperance/ St. Francis Island**
- **Spencer gulf**
- **Gulf St. Vincent**
- **Port Phillip Bay**: 80-100 inds.
- **Gippsland Lakes and Tasmania**: ~50-150 inds.

- **Coffin Bay** is within **Thorny Passage Marine Park (TPMP)**:
  - South Australia’s network of MPAs created in 2009
  - Manage and ensure conservation of ecosystems and species:
    - **Aim to protect top predators (e.g. dolphins)**
  - **Multiple-use MPA**

Coffin Bay is located in South Australia.
• Coffin Bay management zones:
  • 94% Multiple-use (allows human activities: oyster aquaculture, recreational fishing, wildlife tourism)
  • 6% Sanctuary (high conservation value, prohibits motorized water sports and fishing, allows low-impact recreation activities)
NO information was available on dolphins’ ecology/distribution

Dolphins were not included in management plan/zoning arrangements of TPMP

Human activities occurring in this multiple-use MPA (e.g. *aquaculture* and *vessels*) could be affecting dolphins’ distribution patterns and impacting population*

Urgent need to understand dolphins ecology, **distribution patterns (and its drivers)** and threats to inform future decision-making and the zoning of multiple-use MPAs in SA (2022 review)

*(Markowitz et al. 2004; Ribeiro et al. 2007; Bejder et al., 2006; Lemon et al. 2006; Pearson et al. 2012; Pirotta et al., 2015)*
Investigate the spatio-temporal distribution of dolphins in relation to ecogeographical and anthropogenic variables in Coffin Bay to inform management
1. Study the presence of dolphins in relation to environmental and anthropogenic variables

2. Identify areas of high probability of dolphin occurrence

3. Evaluate the relevance of the current sanctuary zones to protect areas of high probability of dolphin occurrence
Methods - Data collection

- Boat-based surveys
  - September 2013 – October 2015
  - Zig-zag equally spaced transects
  - Inner area (85 km²) (x 39)
  - Outer area (154 km²) (x 10)

- Collected *in situ* data on:
  - Dolphins location
  - Vessels location
  - SST, salinity, turbidity, pH, depth

- Spatial data from DEW and PIRSA:
  - Sanctuary zones
  - Oyster farms
  - Coastline
  - Benthic habitat type
**Methods - Data analysis**

- Ensemble modelling approach (package ‘Biomod2’ in R)

- Combined results from 5 species distribution models (SDMs):
  - GAMs, GBMs, CTA, RF and MaxEnt
  - 10 random data-splitting runs (75 training/25 evaluation)
  - Variable importance (randomization procedure, 10 permutations)
  - Model accuracy evaluated AUC

- Ensemble model:
  - SDMs runs with AUC > 0.5
  - SDMs weighted contribution (AUC)
  - Map predicted probability of dolphin occurrence (non surveyed cells)

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Figure 2. Schematic representation of the modelling procedure in BIOMOD.
Spatial layers of response and explanatory variables:

- ArcMap (ESRI)
- 500 x 500 m grid cell resolution

Data-sets:

- Coffin Bay (overall period)
- Inner area:
  - Overall period
  - Seasons: Summer, Autumn, Winter, Spring

Response variable:

- Presence = cell with at least one dolphin record
- Pseudo-absence = cell with survey effort higher than mean per area and no dolphin presence
Explanatory variables:

In all models:
- Land distance
- Depth
- Farm distance
- Sanctuary distance

In seasonal models:
- pH
- Turbidity
- Salinity
- SST
- Vessel ER

- Collinearity explored for each dataset
- Variables excluded using stepwise procedure ('usdm' in R):
  > ‘vifcor’ (correlation coefficient, threshold = 0.7)
  > ‘vifstep’ (VIF, threshold = 3)
## Results – Entire study area

Variable importance (0 – 1):

<table>
<thead>
<tr>
<th></th>
<th>Habitat</th>
<th>Land distance</th>
<th>Sanctuary zone distance</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAM</td>
<td>0.038</td>
<td>0.159</td>
<td>0.719</td>
<td>0.404</td>
</tr>
<tr>
<td>GBM</td>
<td>0.005</td>
<td>0.061</td>
<td>0.827</td>
<td>0.368</td>
</tr>
<tr>
<td>CTA</td>
<td>0.002</td>
<td>0.037</td>
<td>0.912</td>
<td>0.376</td>
</tr>
<tr>
<td>RF</td>
<td>0.017</td>
<td>0.151</td>
<td>0.691</td>
<td>0.381</td>
</tr>
<tr>
<td>MaxEnt</td>
<td>0.043</td>
<td>0.123</td>
<td>0.557</td>
<td>0.390</td>
</tr>
<tr>
<td>Mean of means</td>
<td>0.021</td>
<td>0.106</td>
<td>0.741</td>
<td>0.384</td>
</tr>
</tbody>
</table>

Ensemble model AUC = 0.90

Sanctuary zone distance

Up to 5,000 m distance from SZ (characterizes inner area)
Dolphins inhabiting the inner area of Coffin Bay have:

- Low emigration rates
- Strong site fidelity
- Most individuals are year-round residents
- Small representative ranges (<33.5 km²)

The inner area represents an important habitat for SABD

Shallow, sheltered, inverse estuary, highly productive
Can sustain high densities of fish and top predators (i.e. dolphins)

(Passadore et al. 2017, 2018)
### Variable importance:

<table>
<thead>
<tr>
<th></th>
<th>Habitat</th>
<th>Land distance</th>
<th>Farm distance</th>
<th>Sanctuary zone distance</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAM</td>
<td>0.073</td>
<td>0.162</td>
<td>0.167</td>
<td>0.075</td>
<td>0.756</td>
</tr>
<tr>
<td>GBM</td>
<td>0.007</td>
<td>0.116</td>
<td>0.092</td>
<td>0.049</td>
<td>0.772</td>
</tr>
<tr>
<td>CTA</td>
<td>0.011</td>
<td>0.042</td>
<td>0.042</td>
<td>0.017</td>
<td>0.953</td>
</tr>
<tr>
<td>RF</td>
<td>0.017</td>
<td>0.208</td>
<td>0.140</td>
<td>0.107</td>
<td>0.642</td>
</tr>
<tr>
<td>MaxEnt</td>
<td>0.073</td>
<td>0.240</td>
<td>0.175</td>
<td>0.126</td>
<td>0.610</td>
</tr>
<tr>
<td>Mean of means</td>
<td>0.036</td>
<td>0.154</td>
<td>0.123</td>
<td>0.075</td>
<td>0.747</td>
</tr>
</tbody>
</table>

Ensemble model AUC = 0.88
Water depth was the most important variable in most seasonal SDMs.
Results – Inner area

- Depth’s multi-modal response curves likely reflect communities (Diaz-Aguirre 2017) and their preferences towards different embayments and their characteristic.

Water depth

Dolphins occurrence (predicted)

Communities (association patterns)

(Diaz-Aguirre 2017)
Sanctuary zones vs. areas of high probability of occurrence:

<table>
<thead>
<tr>
<th>Sanctuary zone</th>
<th>Area (km²)</th>
<th>No. grids</th>
<th>Occurrence probability (Mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kellidie</td>
<td>4.5</td>
<td>18</td>
<td>0.27 ± 0.27</td>
</tr>
<tr>
<td>Little Mount Dutton</td>
<td>3.1</td>
<td>5</td>
<td>0.07 ± 0.01</td>
</tr>
<tr>
<td>Mount Dutton</td>
<td>3.1</td>
<td>17</td>
<td>0.52 ± 0.35</td>
</tr>
<tr>
<td>Port Douglas</td>
<td>4.8</td>
<td>18</td>
<td>0.42 ± 0.23</td>
</tr>
<tr>
<td>Outside</td>
<td>107.5</td>
<td>437</td>
<td>0.39 ± 0.29</td>
</tr>
</tbody>
</table>

Dolphin’s important areas
Areas of highest probability of dolphin presence located in 3 embayments

Areas reflect the interaction among ecological and social factors
Marine mammals are ‘species of ecological value’ in TPMP’s management plan, but no specific management arrangements protects SABD.

Findings should encourage the integration of SABD into the monitoring program and zoning arrangements of TPMP.

Areas of high dolphin presence should be considered as priority areas for dolphin conservation and for the implementation of vessel traffic, aquaculture and fishing regulations.
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Dolphins in Coffin Bay (video):
1. Estimate abundance, survival and emigration patterns of dolphins
2. Estimate individuals' site fidelity and representative ranges
3. Investigate the spatio-temporal distribution of dolphins in relation to ecogeographical and anthropogenic variables
4. Assess the social structure of dolphin population
5. Evaluate male and female association patterns and kinship

COFFIN BAY’S DOLPHINS PROJECT – AIMS

to inform management
Species distribution (and drivers)
Spatial conservation planning
Dolphins
preys and predators
abiotic and biotic factors
Human activities (e.g. boating, fishing and aquaculture)
Dolphin behavior
distribution patterns

BACKGROUND
Highlights the high conservation value of TPMP for the species, specifically hosting a genetically distinctive pop.

Long-term monitoring is needed to assess trends in CB's dolphin population and identify potential threats. The need to be managed as an entity suggests that T. australis should be recognized as a species of high conservation value for TPMP, where there is no species-specific management measures.

CB, particularly inner area, offers favourable year-round habitat conditions for abundant resident dolphin pop. High prey availability and low predation risk contribute to the conservation value of TPMP.
Species distribution modelling integrates species, environmental and anthropogenic data to identify important habitats and priority areas for management of dolphins within Coffin Bay.

Predicted dolphins' distribution and important areas (Phillips et al., 2006; Phillips and Dudík, 2008; Elith et al., 2011)

1- dolphins’ locations
2- environmental variables
   - SST
   - Depth
   - Bentic habitat
3- anthropogenic activities
   - Farms location
   - Boat traffic

Generate predictive model with Maxent, GLM & GAM
<table>
<thead>
<tr>
<th>Classification</th>
<th>Explanatory variables</th>
<th>Type: Values</th>
<th>Data source</th>
<th>Considered for models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthropogenic</td>
<td>Distance to sanctuary zone</td>
<td>Numeric, continuous: 0 – 21,188 m</td>
<td>NatureMaps (^a)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Distance to farms</td>
<td>Numeric, continuous: 0 – 15,558 m</td>
<td>PIRSA (^b)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Distance to land</td>
<td>Numeric, continuous: 0 – 6,756 m</td>
<td>NatureMaps (^a)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Vessels encounter rate</td>
<td>Numeric, continuous: 0 – 700</td>
<td>In situ</td>
<td>No</td>
</tr>
<tr>
<td>Ecogeographic</td>
<td>Benthic habitat type</td>
<td>Categorical, categories: seagrass beds, unconsolidated bare substrate, low profile coral reefs, macroalgae, invertebrate community, cobble and medium profile coral reefs</td>
<td>NatureMaps (^a)</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Water depth</td>
<td>Numeric, continuous: 0 – 36 m</td>
<td>In situ</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Salinity (surface)</td>
<td>Numeric, continuous: 30 – 47 PSU</td>
<td>In situ</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Sea surface temperature</td>
<td>Numeric, continuous: 11.5 – 25.9 °C</td>
<td>In situ</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Water visibility</td>
<td>Numeric, continuous: 0 – 16.5 m</td>
<td>In situ</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>Numeric, continuous: 7.7 – 9.0</td>
<td>In situ</td>
<td>No</td>
</tr>
</tbody>
</table>
Species distribution modelling integrates species, environmental and anthropogenic data to identify important habitats and priority areas for management of dolphins within Coffin Bay.

**Predicted dolphins’ distribution and important areas**

1. Dolphins’ locations

2. Environmental variables
   - SST
   - Depth
   - Bentic habitat

3. Anthropogenic activities
   - Boat traffic
   - Farms location

Generate predictive model with Maxent, GLM & GAM

(Phillips et al., 2006; Phillips and Dudík, 2008; Elith et al., 2011)