Spatio-temporal patterns in underwater sound within an urban estuarine river

Sarah Marley, Christine Erbe, Chandra Salgado Kent, Miles Parsons and Iain Parnum
Underwater Soundscapes

- Topographic Structures
- Environmental Conditions
- Species Compositions
- Human Activities

Abiotic

Biotic

Anthropogenic

Marine Soundscape
Underwater Soundscapes

- Anthropogenic noise in ocean is increasing
  - Alters the acoustic environment
  - Acts as a chronic, environmental stressor

- Individual responses can include:
  - Tolerance
  - Changes in Behaviour
  - Avoidance Reactions
  - Masking
  - Hearing Impairment
  - Physiological Effects
  - Mortality
Underwater Soundscapes

- Species occurrence and behaviour may be influenced by changing marine soundscapes
  - Especially true of coastal areas due to high overlap with human activities
  - Particularly acoustically-specialised species such as whales and dolphins (cetaceans)
Growing awareness of acoustic habitats and influence of anthropogenic noise.

May adversely affect many species – particularly those which are acoustically specialised.

Need baseline information to characterise dolphin acoustic habitats.

Also need to understand how dolphins respond to anthropogenic activities and associated noise in these habitats.
Aims

1) Identify prominent anthropogenic sound sources
2) Describe spatio-temporal patterns in dolphin soundscape
3) Investigate dolphin responses to human activities/noise

- Swan River
- Estuarine system
- Urban
  - > 1.4 million people
  - > 55,000 rec boats
- Resident dolphin community
Combination of acoustic and visual monitoring.

- Autonomous underwater acoustic recorders
- Low-frequency recorders (fs 22 kHz)
- High-frequency recorders (fs 96 kHz)
- Typically recorded 10 min of every 15 min
- Deployed at 5 sites
Combination of acoustic and visual monitoring.

- Land-based theodolite tracking
- Allows collection of fine-scale movement data for dolphins and vessels
- Used at 2 acoustic sites with help from > 60 undergraduate volunteers
Methods
Analysis

Soundscape Description

• Weekly spectrograms
• PSD percentile plots
• Octave-band levels
• Broadband noise levels
Analysis

Soundscape Description

- Weekly spectrograms
- PSD percentile plots
- Octave-band levels
- Broadband noise levels

Spatial and Temporal Patterns

- Generalised Estimating Equations (GEEs)
Analysis

Soundscape Description
- Weekly spectrograms
- PSD percentile plots
- Octave-band levels
- Broadband noise levels

Spatial and Temporal Patterns
- Generalised Estimating Equations (GEEs)

Dolphin Behaviour
- Generalised Additive Models (GAMs)
- Markov Chains
Results

Swan River Soundscape

Range of sound sources:

- **Abiotic**: Rain, waves, tidal movements
- **Biotic**: Snapping shrimp, fish, dolphins
- **Anthropogenic**: Vessel traffic, bridge/road traffic, pile-driving, machinery, on-shore construction
Results

Swan River Soundscape

Proportion of Acoustic Files (%)

Rain | Waves | Dolphins | Fish | Shrimp | Boats | Machinery

52% of recordings with vessel traffic
“rush hour” vessel traffic early AM/late PM
vessel traffic busiest on weekends vs weekdays
vessel traffic higher during holidays

Centre for Marine Science and Technology (CMST) | @sarahmarley86
Results

Swan River Soundscape

Frequency (Hz) 10^4

10^3

10^2

10^1

3/12 4/12 5/12 6/12 7/12 8/12 2013

Snapping Shrimp

Anthropogenic Noise

db re 1 µPa^2/Hz 120

110

100

90

80

70

60

50

40

101

102

103

104

120
Results

Swan River Soundscape

[Stylized graphs and charts showing frequency and time relationships with sound intensity levels.]
Results

Swan River Soundscape

Distinct spatial and temporal patterns within sites
Swan River Soundscape

Distinct spatial and temporal patterns between sites

Results
Results

Swan River Soundscape

Some sites are biologically noisy

Other sites are anthropogenically noisy
Results

Swan River Soundscape

Long-term patterns:
- Data from one site collected yearly from 2007 - 2015
- Some inter-year variation
- No overall increase / decrease in noise levels
- Long-term acoustic stability?
Results

Dolphin Responses

- Fremantle Inner Harbour ‘noisiest’ site anthropogenically
  - Average 16 vessels per hour
  - Maximum 56 vessels per hour

- Dolphin Occurrence
  - Presence/absence; number of sightings; time spent in area
  - Dolphins continued using area despite it being a busy, noisy environment

- Key foraging site, so perhaps not surprising
- But just because you don’t leave the area, doesn’t mean you aren’t disturbed...
Results

Dolphin Responses

- Movement speeds
  - High vessel densities = \(\uparrow\) average movement speeds
  - But only for some activity states (resting and socialising)

- Activity states
  - Behavioural budgets changed at varying vessel densities
  - High vessel densities = \(\uparrow\) travelling
    \(\downarrow\) resting or socialising
Results

Dolphin Responses

- Whistle Characteristics
  - Increased broadband noise = All nine characteristics varied
  - However, whistles also varied naturally according to activity state, group size, and calf presence
  - Strongest acoustic response was to low-frequency noise (1 kHz OBL)
Conclusions

- Swan River comprised of multiple acoustic habitats, each with its own characteristic soundscape and temporal patterns.

- Anthropogenically noisiest site was Fremantle Inner Harbour, which is also a key dolphin foraging site.
  - Dolphins maintain occupancy at Fremantle, despite high vessel densities.
  - But subtle behavioural and acoustical responses still exist.

- Need to consider:
  - Spatial and temporal patterns of underwater soundscapes.
  - Responses of coastal dolphins to busy, noisy environments.
Thank you!

- **Acoustic Fieldwork:** Many people for assistance in deploying and recovering some frankly very disgusting loggers from the sea bed, but particularly Dave Minchin, Mal Perry, and Sylvia Parsons.

- **Visual Fieldwork:** Over 60 undergraduate and work experience students, and Eric Kniest for assisting with theodolite set-up.

- **Assistance with acoustic data review:** Mariana Barbosa, Mat Bentley

- **Logistical Support:** Fremantle City Council, Fremantle Port Authority, Swan River Trust, and Department of Parks and Wildlife.

- **Funders:** Holsworth Wildlife Research Endowment (Equity Trustees Charitable Foundation & the Ecological Society of Australia); Australian Acoustical Society (AAS); Fisheries Research and Development Corporation (FRDC); the Australian Government.

- **Travel:** ASA Acoustical Oceanography Technical Committee, ASA Early Career Travel Subsidy
Effects of vessel traffic and underwater noise on the movement, behaviour and vocalisations of bottlenose dolphins in a highly urbanised estuary. *Scientific Reports.*

Underwater recordings of the whistles of bottlenose dolphins in the Fremantle Inner Harbour. *Scientific Data.*

A Tale of Two Soundscapes: Comparing the acoustic characteristics of urban vs pristine coastal dolphin habitats in Western Australia. *Acoustics Australia.*

Spatial and temporal variation in the acoustic habitat of bottlenose dolphins within a highly urbanised estuary. *Frontiers in Marine Science.*

Occupancy of bottlenose dolphins in relation to vessel traffic, dredging and environmental variables within a highly-urbanised estuary. *Hydrobiologia.*

Underwater sound in an urban estuarine river: Sound sources, soundscape contribution, and temporal variability. *Acoustics Australia.*