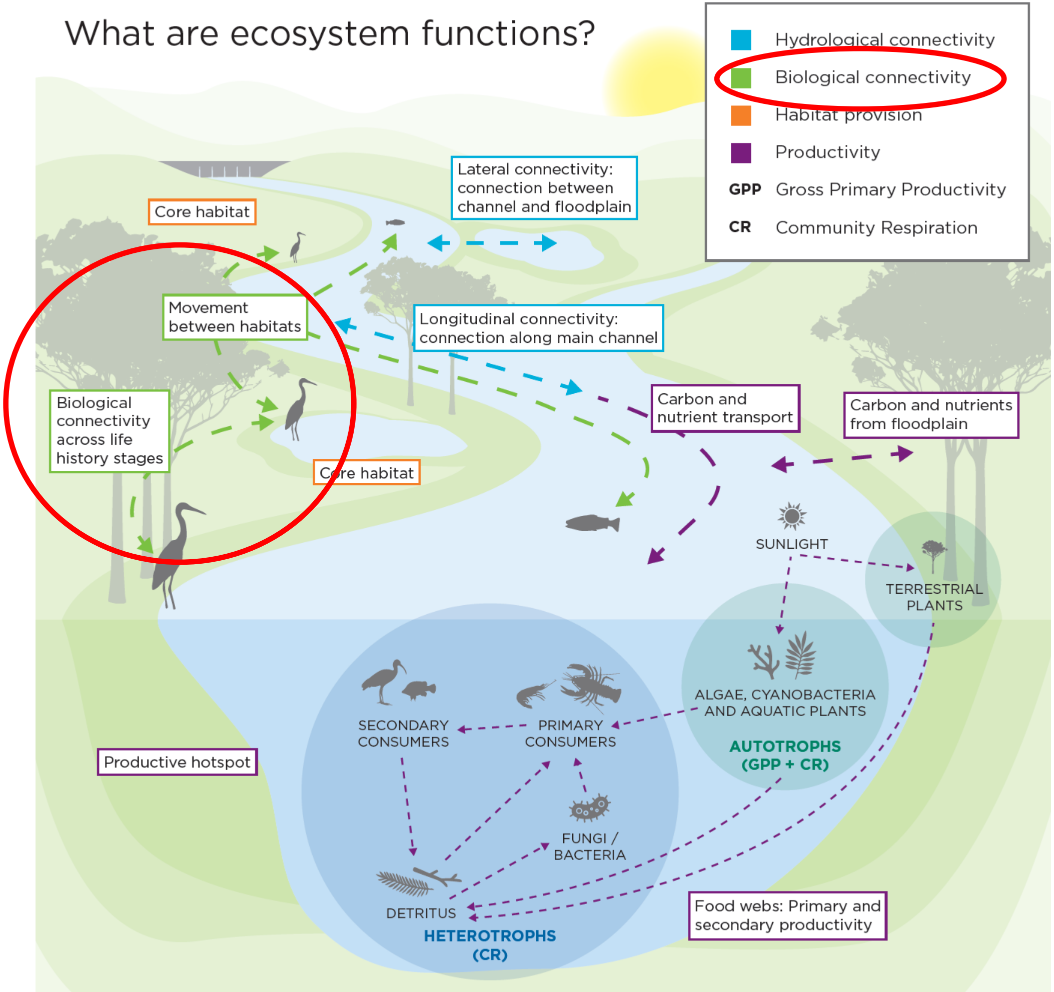
Modelling waterbird connectivity in the MDB

Sam Nicol, Luke Lloyd-Jones, Heather McGinness

Australia's National Science Agency

What are ecosystem functions?



Connectivity

Connectivity is *the degree to which the landscape facilitates or impedes movement of organisms*

Species have different movement requirements at different stages of their life histories. Species need to move:

- Locally (e.g. foraging, territoriality, breeding)
- Long-distance (e.g. dispersal, nomadism, migration)

The ability of the landscape to facilitate these movements depends on many factors, including:

- Temporal factors (wind, weather, climate and seasonal effects)
- Landscape factors (land use, topography, vegetation)
- Water factors

Synchrony is the ability to match management actions to life history requirements to facilitate connectivity.

- Achieving synchrony requires us to understand connectivity.
- Here we demonstrate how to do this for a waterbird group in the MDB

Why is Waterbird Connectivity Important?

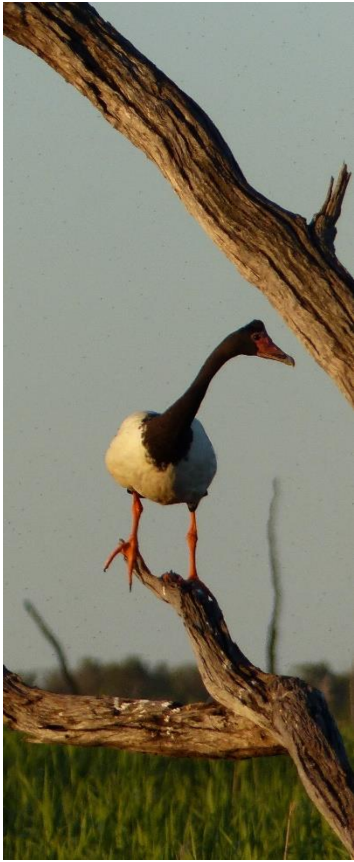
Waterbirds are a highly mobile group

- Many conduct long-distance movements of 100’s – 1000’s km within hours, days or weeks

They have a basin-scale impact on wetland ecosystem functions

  - Food web roles: Carnivores, omnivores, insectivores and herbivores – and in turn consumed
  - Movement of propagules (e.g. seeds and eggs)
  - Redistribution of nutrients and energy
  - Pest control
  - Contributing to biodiversity in ecosystems

- Charismatic and popular species that are integral to the character of wetlands



Why is Waterbird Connectivity Important?

- Rates of wetland habitat loss are increasing
- Waterbird populations have declined
- Australia has obligations to protect waterbirds and their habitats
  - International: CMS, Ramsar
  - National: Basin wide EWS

CMS Ramsar

River flows and connectivity	Vegetation	Waterbirds	Fish
Improve connections along rivers and between rivers and their floodplains	Maintain the extent and improve the condition	Maintain current species diversity, improve breeding success and numbers	Maintain current species diversity, extend distributions, improve breeding success and numbers
Maintained base flows: • at least 60% of natural levels **Improved overall flow:** • 10% more into the Barwon–Darling[1] • 30% more into the River Murray[2] • 30–40% more to the Murray mouth (and it open to the sea 90% of the time) **Maintained connectivity in areas where it is relatively unaffected:** • between rivers and floodplains in the Paroo, Moonie, Nebine, Warrego and Ovens **Improved connectivity with**	**Maintenance of the current extent of:** • about 360,000 hectares of river red gum; 409,000 ha of black box; 310,000 ha of coolibah forest and woodlands; and existing large communities of lignum • non-woody communities near or in wetlands, streams and on low-lying floodplains **Maintain the current condition of lowland floodplain forests and woodlands of:**	**Maintained current species diversity of:** • all current Basin waterbirds • current migratory shorebirds at the Coorong **Increased abundance:** • 20–25% increase in waterbirds by 2024 **Improved breeding:** • up to 50% more breeding events for colonial nesting waterbird species • a 30–40% increase in nests and broods for other waterbirds	**Improved distribution:** • of key short and long-lived fish species across the Basin **Improved breeding success for:** • short-lived species (every 1–2 years) • long-lived species in at least 8/10 years at 80% of key sites • mulloway in at least 5/10 years **Improved populations of:** • short-lived species (numbers at pre-2007 levels) • long-lived species (with a spread of age classes

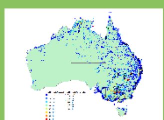
Waterbird connectivity modelling

Stage 1
Conceptualisation + method selection

Identification of priority species / groups

- Straw-necked Ibis, Royal spoonbill, Australasian Bittern

Collation of movement data



Collation of environmental covariates data

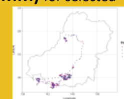
Review and selection of methods for modelling connectivity

Stage 2
Modelling how far birds fly

Classification of movement states

Hidden Markov Modelling (HMM) for selected species using satellite tracking data

- Four primary states identified



Modelling drivers of distances travelled

GAM model: distance travelled ~ covariates using satellite tracking data.

Covariates include:

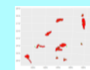
- distance measures to rivers, lakes, wetlands, urban areas and woody vegetation;
- annual evaporation, rain, temp;
- ASRIS PAWC
- WOfS
- land use;
- ANAE;
- MRVBF
- Movement state
- Near real time wind velocity
- proxy measures for local and landscape inundation
- Weather variables – near real time rain and pressure

Stage 3
Quantifying connectivity

Least cost path generation

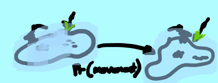
based on *habitat suitability.*
Conductance = habitat suitability

Compute connectivity between *breeding sites*



Modelling and mapping connectivity

Probability of movement = simulations of frequency of arrival along least cost paths



Stage 1

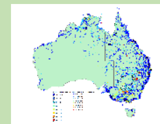
Conceptualisation + method selection

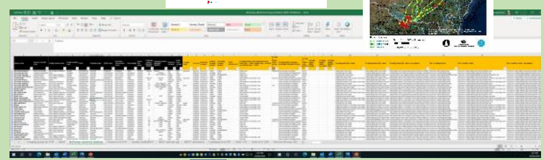
- Group / species selection: Representative of important movement groups and habitat requirements
  - ➢ Initial focus: Straw-necked Ibis
- Knowledge synthesis - literature review, expert knowledge, database development

Identification of priority groups / species

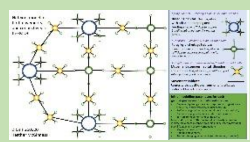
Collation, cleaning, synthesis and mapping of species / group movement, presence and breeding data

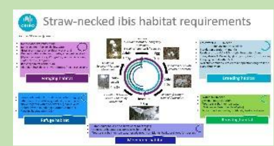
- ALA
- MDBA
- CEWO
- CSIRO





Identification, synthesis, conceptual modelling of species / group attributes, requirements and env. covariates





Review and selection of modelling methods

Why Straw-necked Ibis?

- Known dependencies on hydrological variables to support habitat or movement
- Broad-scale distribution and movements across MDB
- Movements at multiple spatial and temporal scales
- Management and policy significance
- Characteristics common to multiple other species
- Availability of high-quality spatio-temporal movement data across the MDB
    - Most other species lacked sufficient quality spatio-temporal movement data

Representativeness

- Straw-necked ibis (SNI) are part of the family of large colonial nesting waterbirds that is the most commonly targeted by managers and policy makers for environmental water support
  - Many of Australia's internationally listed Ramsar sites or nationally listed wetlands on the Directory of Important Wetlands in Australia (DIWA) are based on the breeding sites of this family where they can aggregate in 10,000s to 100,000s
  - The SNI is arguably the most intensively managed species within this family, because of its dependence on environmental water for completion of large colonial breeding events
- SNI breeding colonies managed with environmental water often include other nesting species such as glossy ibis, spoonbills, bitterns, herons, egrets, and cormorants
- SNI have similar food, habitat and connectivity needs to other large colonial-breeding and wading waterbirds:
  - water and water-dependent vegetation for nesting, foraging, refuge, roosting and movement
  - aquatic food sources including frogs, fish, crustaceans, and invertebrates when breeding

Other species that SNI connectivity modelling results maybe reasonably generalised to until new data become available include: Glossy Ibis, Australian White Ibis, Royal Spoonbill, Yellow-billed Spoonbill, Australasian Bittern, Nankeen Night Heron, Little Egret, Intermediate Egret, Great Egret.

Dataset

- 5 years of tracking data in Murray-Darling basin, Australia
  - Hourly fixes 07:00-19:00
  - 48 individual ibis
  - ~250k datapoints
- 32 predictor variables matched to location:
  - Water
    - Inundation (wet/dry; extent)
  - Land Use
    - NDVI and Land Use Classifications
  - Weather
    - Precipitation
    - Wind speed and direction
    - Temperature and pressure
  - Season

… etc

Dr. Heather McGinness with a captured straw-necked ibis. Note backpack transmitter. Image: CSIRO

CSIRO

Stage 2

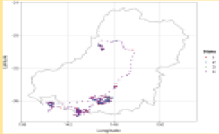
Modelling how far birds fly

- Classification of movement states

- Modelling drivers of distances travelled

Classification of movement states

Hidden Markov Modelling (HMM) for selected species using satellite tracking data



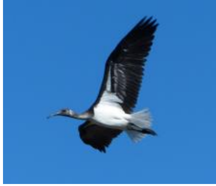
- Within individuals and across all individuals combined (by species)
- Four primary states

Modelling drivers of distances travelled

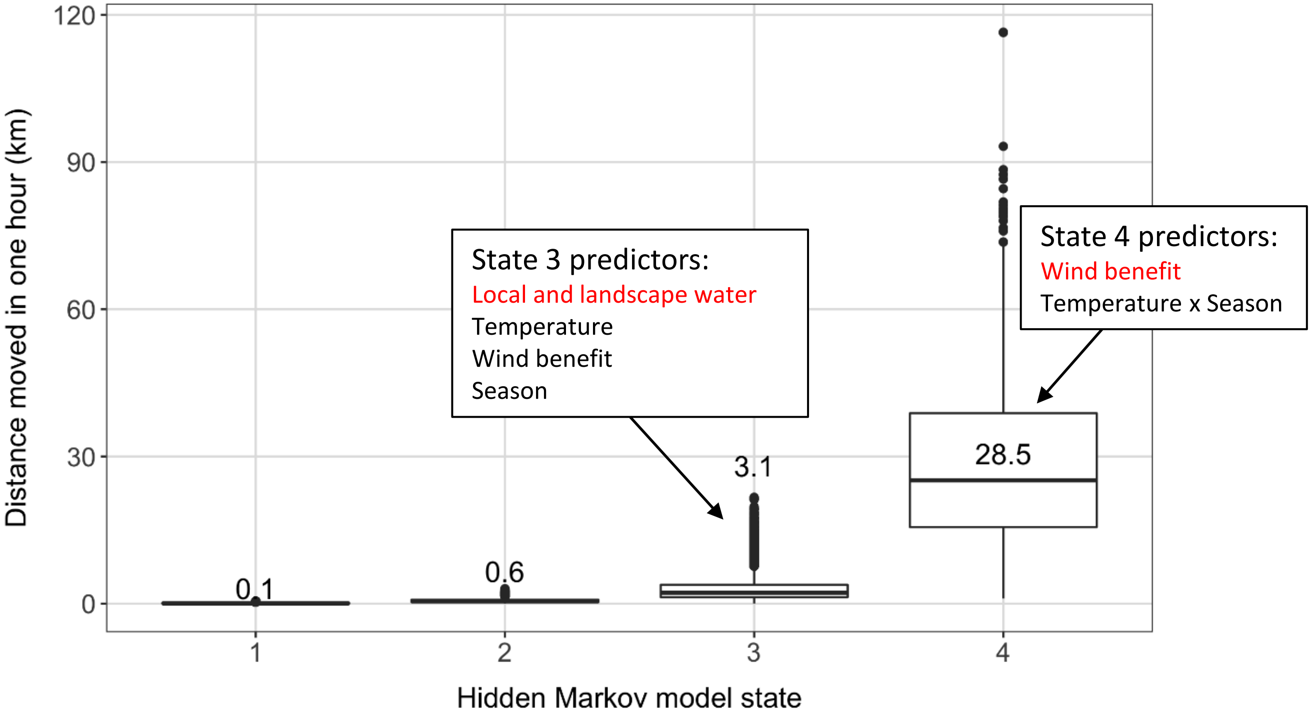
GAM model of distance travelled ~ environmental covariates, using satellite tracking data. Prediction intervals and repeat sampling / simulations within / across movement behaviour states

-*Initial covariates*: distance measures to rivers, lakes, wetlands, urban areas and woody vegetation; annual evaporation, rain, temp; ASRIS PAWC; WOfS; land use; ANAE; MRVBF; wind, pressure, distance to water

What drives movement distances?



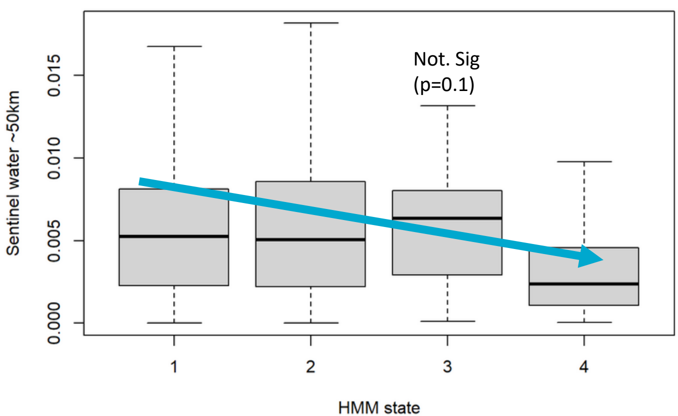
- GAM model to predict distance travelled based on environmental covariates.

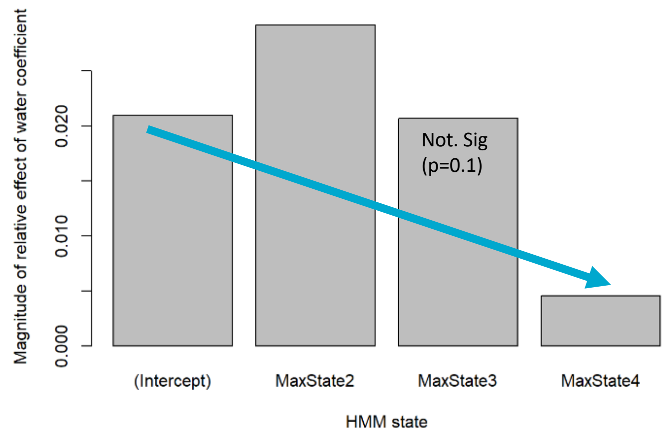


What is the role of water?

Interpreting the HMM states

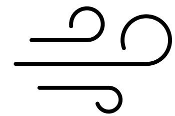
Local water has a greater influence on lower HMM states – short-distance movements

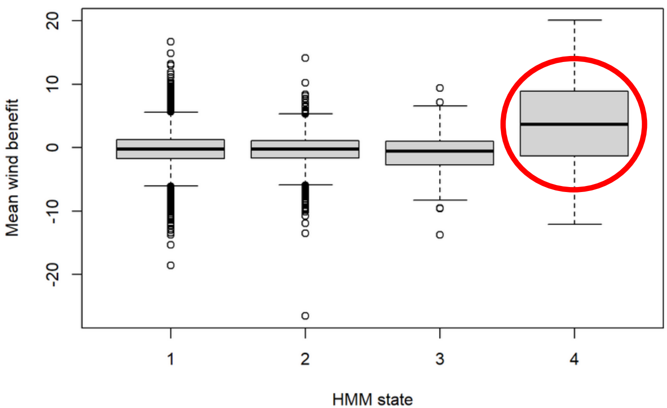


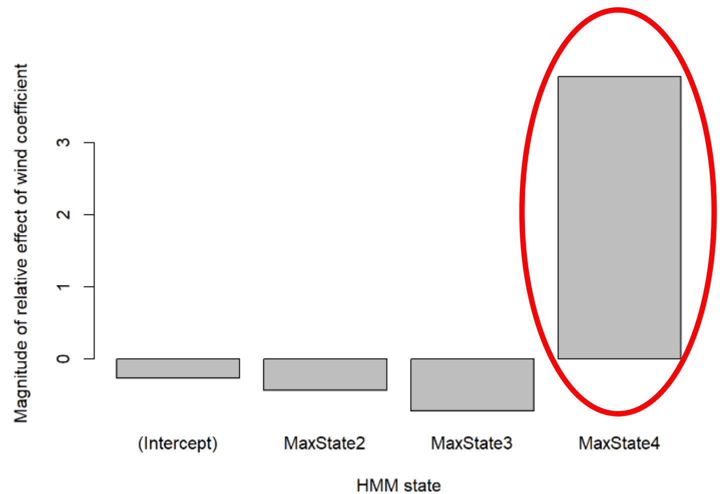


What is the role of water?
Interpreting the HMM states

Wind has a greater influence on the highest HMM state – long distance movements

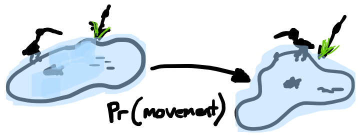






Stage 3

Quantifying connectivity



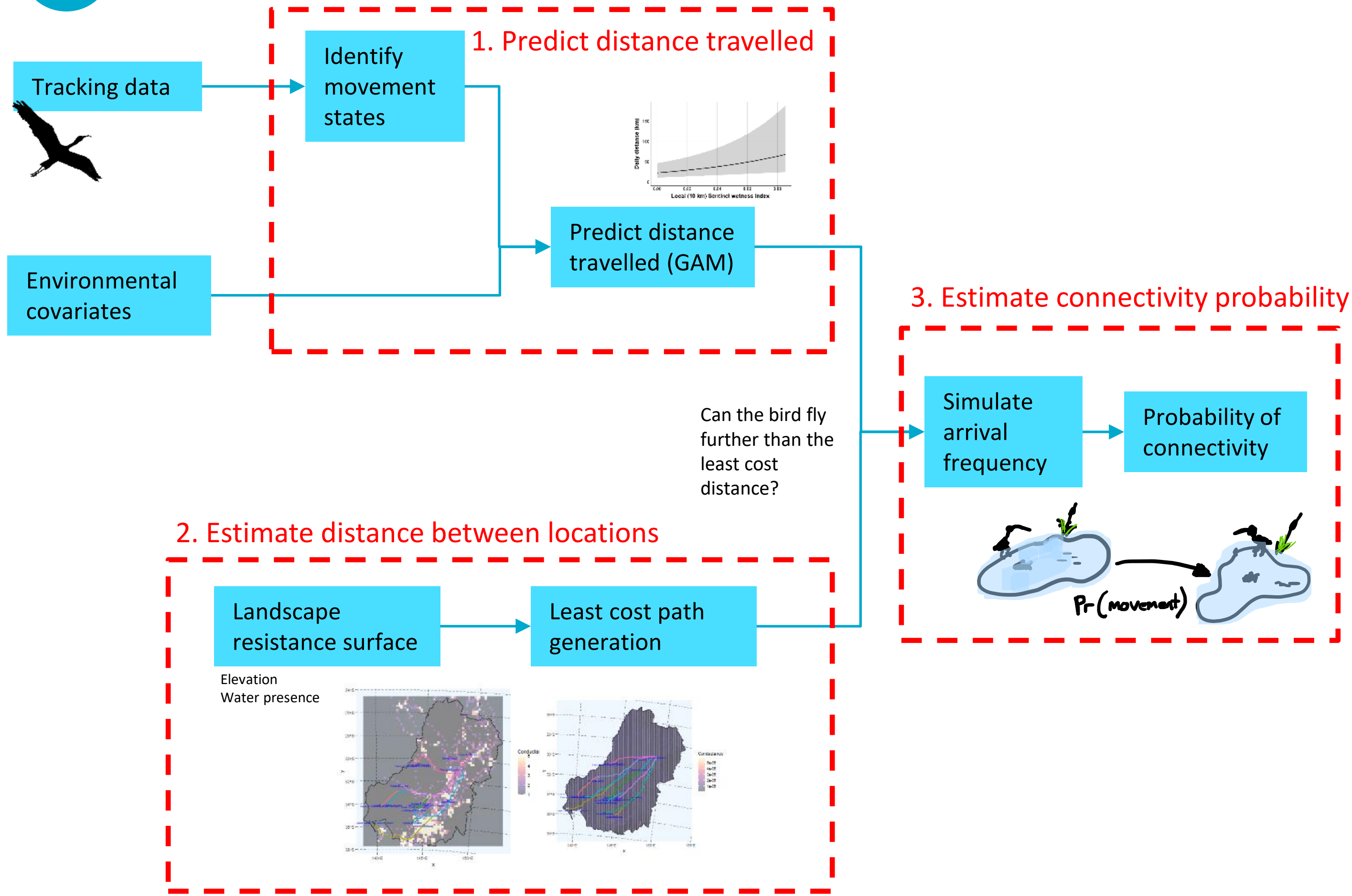
Modelling and mapping structural connectivity

Least cost path generation based on *habitat suitability* - Spatial conductance surface grid: Conductance = habitat suitability (score)

Modelling and mapping actual connectivity

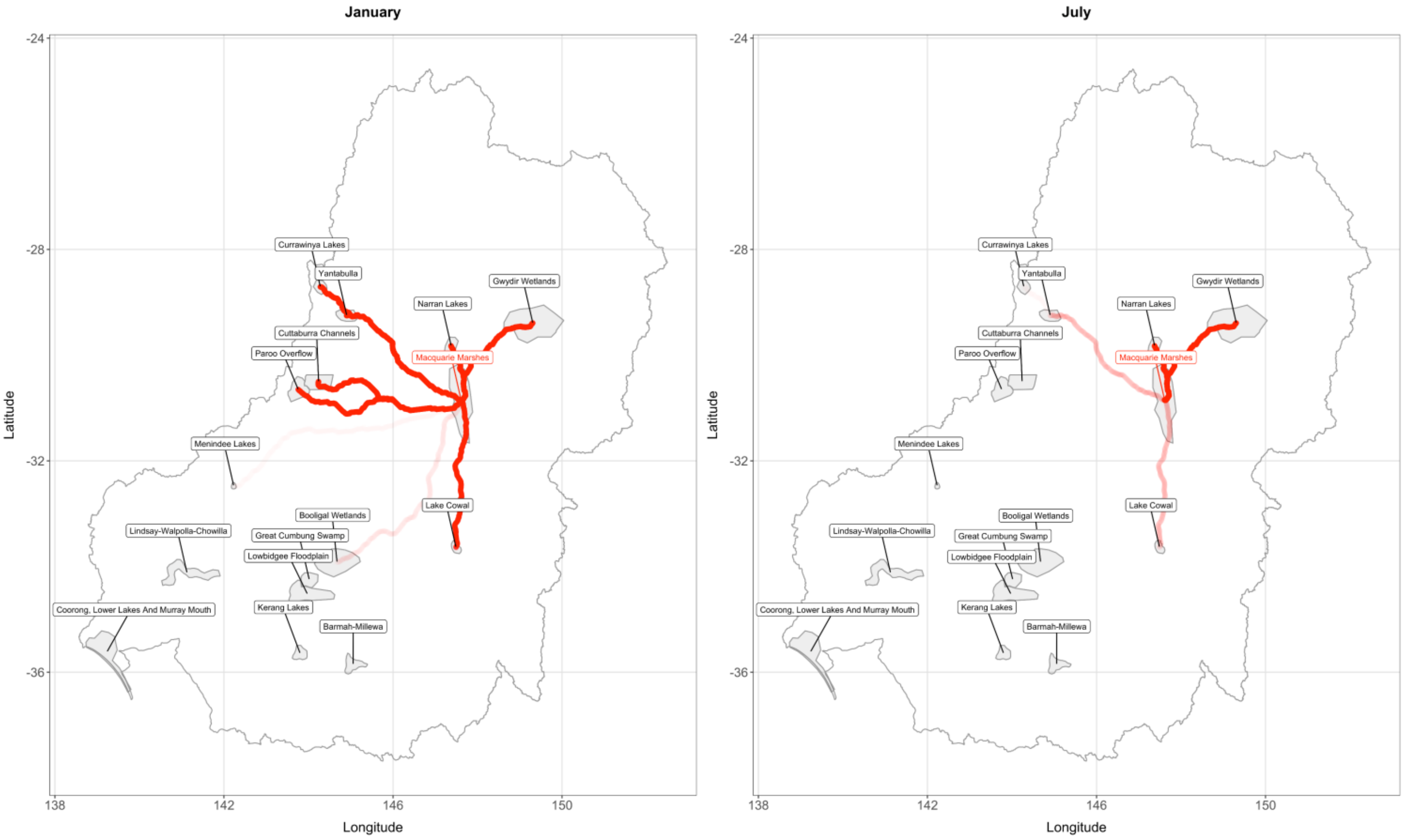
Probability of movement / simulations of frequency of arrival along least cost paths

Waterbird connectivity modelling

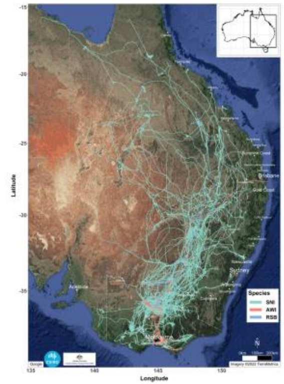


Connectivity modelling: average monthly connectivity

5-day simulated arrival probability from Macquarie Marshes under average conditions



Using the results:
From connectivity modelling to forecasts



- Basin-scale breeding site connectivity
    - Understanding monitored bird responses

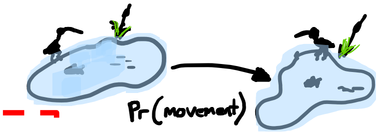
      E.g. Why did responses not occur as expected?
    - Annual / seasonal decisions and predictions

      E.g. What is likely to happen this year?
- Forecasts supporting local short-term decision-making
    - If we can predict where birds will be, then we can support movement by providing water in those places

Can we forecast most likely bird positions from our models?

From connectivity modelling to forecasts

Inputs: Month, wind direction, location



Probability that bird flies in a particular direction

(tracking data)

Probability of encountering environmental conditions
- water availability
- wind speed and direction
- temperature

(historical water, weather data)

Simulate for N birds

Probability that bird travels a specific distance

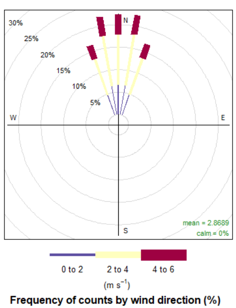
(GAM statistical model)

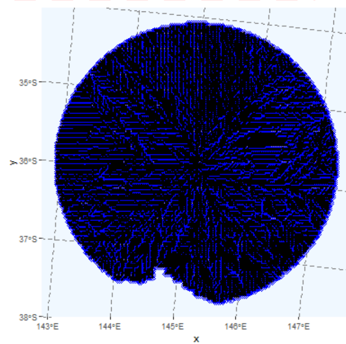
Most likely arrival location

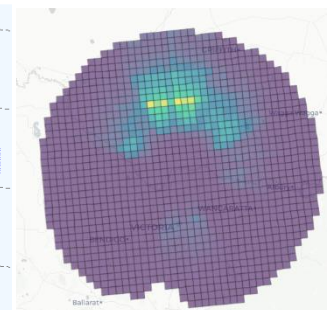
(least cost path analysis)

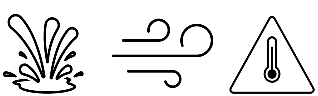
Probability that bird reaches each location

(frequency of simulations arriving at each location)





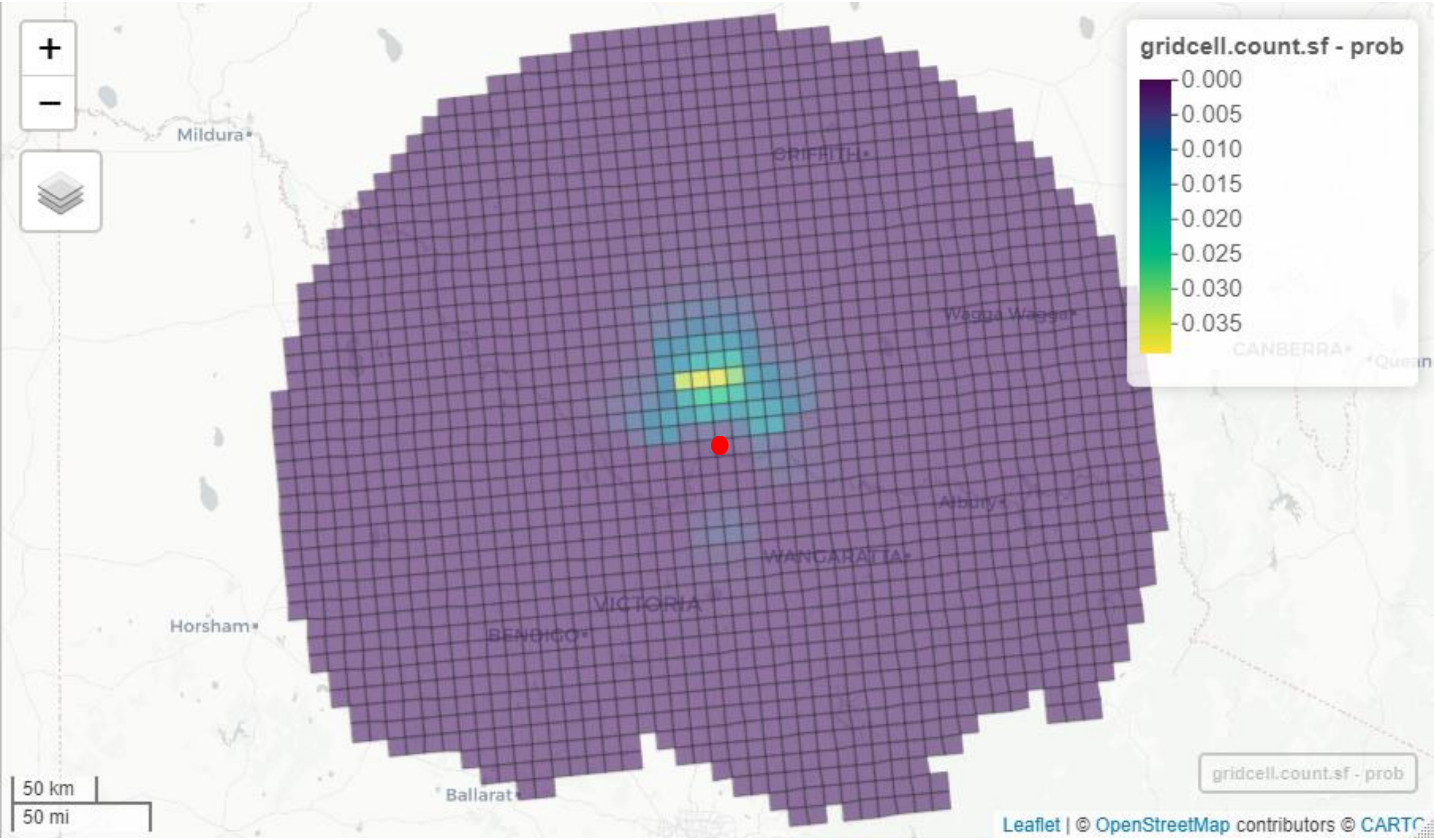




Forecasting bird movement

DAY 1

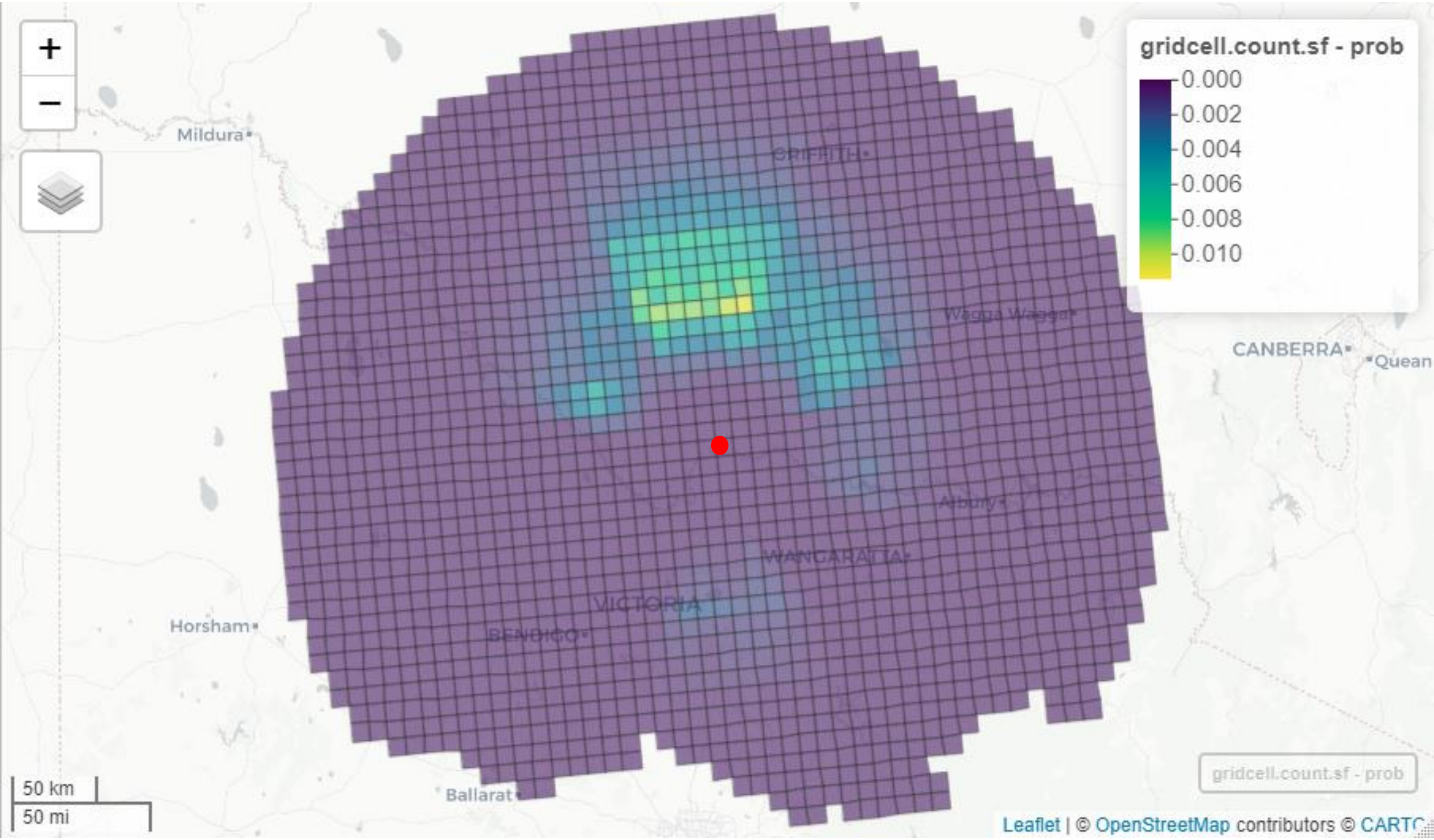
Input conditions: Water, wind, temperature
Month: September; Wind: S; Origin: Barmah-Millewa forest



*note water is sampled from nearest measuring location (and included in the least cost path)

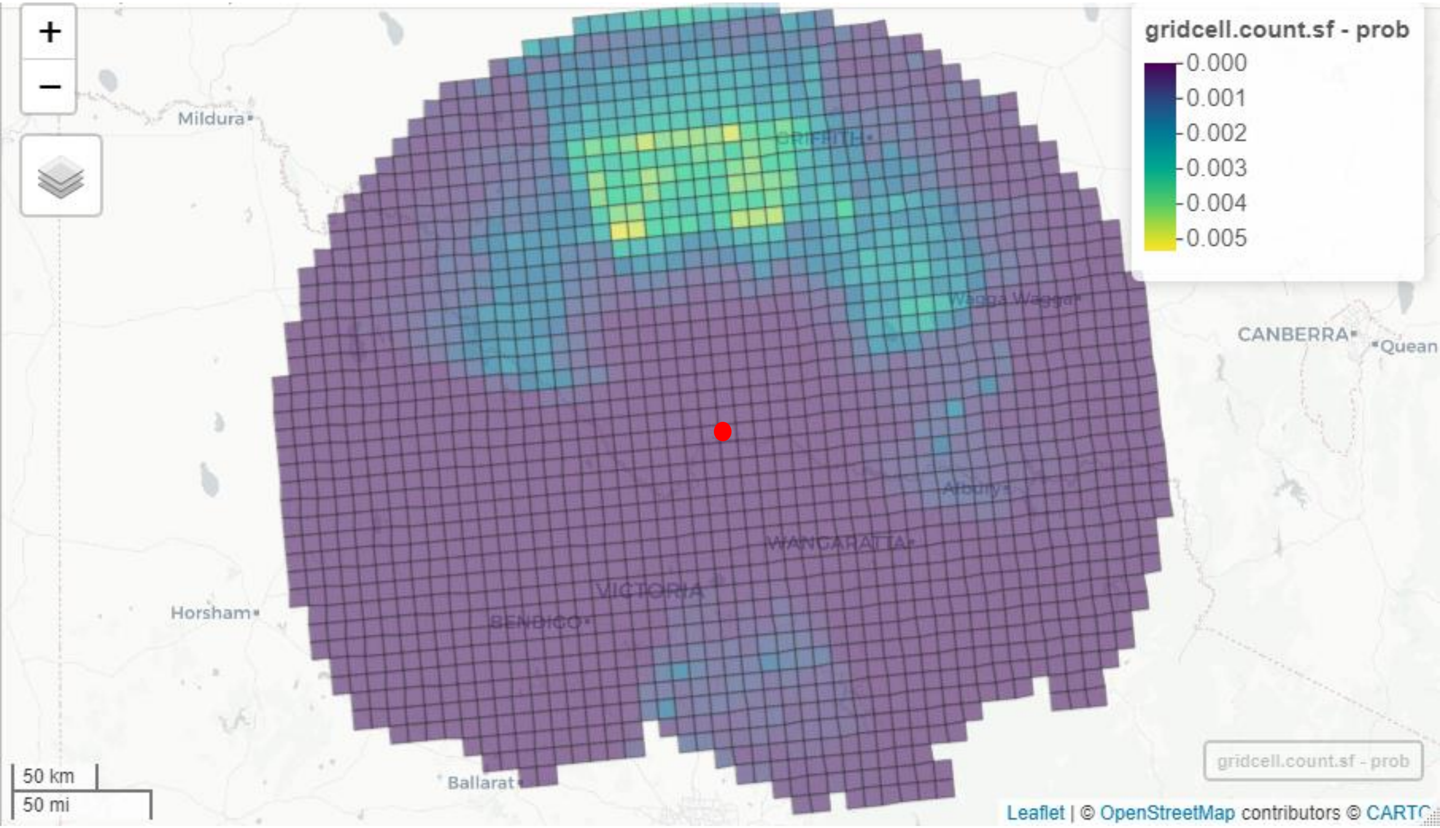
Forecasting bird movement

DAY 2



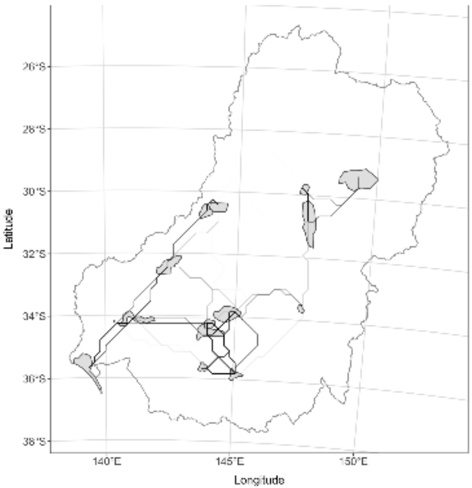
Forecasting bird movement

DAY 3



Connectivity modelling: Management relevance

- Explaining observed outcomes; e.g. why did/didn't birds arrive at breeding locations as expected, or breed at these locations in the numbers expected?
- Predicting expected connectivity conditions at seasonal scale; e.g. are wetlands likely to be connected given an expected scenario?
- Predicted wetland connectivity could inform planning and delivery of water for the environment; e.g. if a wetland is unlikely to be well-connected according to predictions:
  - whether environmental water should be provided to support stopovers or foraging
  - whether environmental water should be used elsewhere

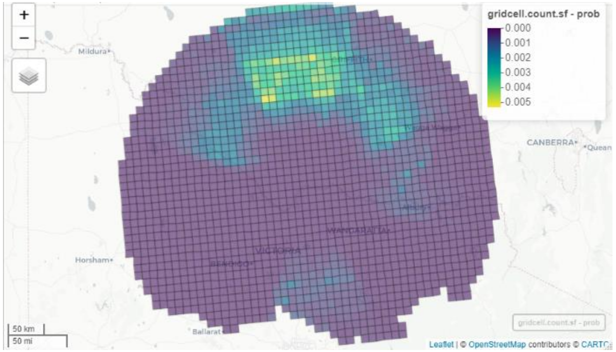


Probability of connectivity could be used to help inform Basin annual environmental watering priorities for waterbirds by helping to identify where environmental water would be most useful for supporting movement between key wetlands.

Forecasting Movements: Management relevance

- Developing reliable forecasts of waterbird location has the potential to align management actions to a timescale that matches bird movements; e.g. enabling water managers to release water to support ibis during stopovers.
- Building on the forecasting models presented here could help to ensure that environmental water is delivered to the places and times when it can be maximally effective for supporting movement.

Caveats:
○ Ideally requires a knowledge of movement cues, i.e., it is most useful if we know when and why a significant number of birds will leave the origin.
○ Assumes that birds fly consistently in the HMM state 4 (i.e., long-distance flight) and do not take extended overnight stopovers



This is the first attempt to forecast the position of Straw-necked Ibis in the Basin given certain conditions – and provides a useful step towards facilitating a real-time management system to support ibis movement.

Conclusions: Waterbird connectivity modelling

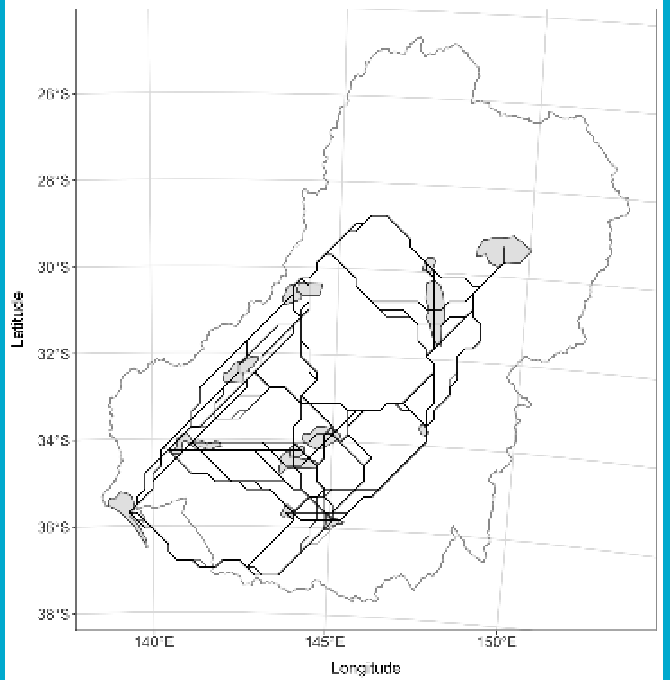
Our model captures the influence of near real-time local conditions on waterbird decision-making, movements and connectivity

It can be used to:

- Explain why waterbirds take the trajectories that they do
- Forecast where waterbirds are likely to be given wind and water conditions, to help water managers provide good conditions at the right time and place
- Explain why waterbirds may not have responded to managed e-watering or flood events as expected, e.g.
  - Why did waterbirds not arrive? Or why are there lower numbers than expected?
- Experiment with how water and land use are predicted to change waterbird connectivity or movements at the basin scale

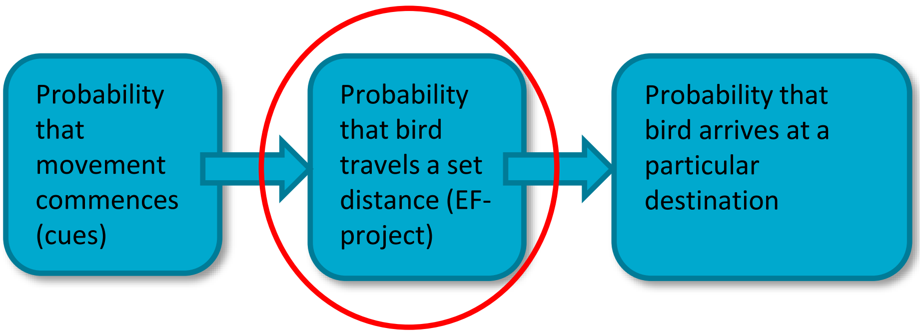
Further research

- Extend the modelling to **other species/groups** with fewer available data
- Learning how **connectivity changes with habitat** (integrating habitat projection models)
- Allowing for **movement state switching** in models
- How can **connectivity be maintained or restored** for different movement groups/species?



Further research

- Development of a complete predictive model of waterbird movement including movement cues



- Management application research: what management options would be optimal if bird positions could be forecast on a given timescale? E.g.
  - How much advance notice would be required to provide water at a location, and what would that mean for waterbird movements and habitat use?
  - What other landscape management activities could be facilitated at a timescale (and cost) that is meaningful for waterbird movement?

Thank you

CSIRO Land and Water
Dr Sam Nicol
Senior Research Scientist

Sam.Nicol@csiro.au

CSIRO Data61
Dr Luke Lloyd-Jones
Senior Research Scientist

Luke.Lloyd-Jones@data61.csiro.au

CSIRO Land and Water
Dr Heather McGinness
Senior Research Scientist

Heather.McGinness@csiro.au

Potential Use Cases

Use case 1: Inform the establishment of long-term EEO(s) for ecosystem functions (MDBA)

1. Inform the establishment of long term expected environmental outcomes (EEO) for ecosystem functions
2. Metrics/indicators to enable monitoring and evaluation
3. Define interim measures of success

Ecosystem function: Waterbird connectivity

1. Waterbird connectivity EEO: Waterbird connectivity is supported between important sites at required times of year, according to the prevailing climatic and resource availability scenario (e.g. wet year vs dry year)
2. Metrics/indicators:
    1. Probability of movement scores between important sites in the basin (under varying scenarios)
    2. Tracked movements between important sites in the basin under different conditions
3. Interim measures of success: Conditions conducive to connectivity: integrating weather, inundation, and landscape variables

Potential Use Cases

Use case 2: Inform basin-wide medium to long term e-watering strategies (CEWO)

1. Application of response-relationships developed

2. Guidance pathways that evaluate resource availability scenarios

Informing Basin-wide medium to long term e-watering strategies for waterbird connectivity

1. Response relationships developed between tracked waterbird movements, weather, water and landscape variables
   - applied to produce models and visualisations of connectivity under varying scenarios
2. Connectivity scores under varying scenarios to guide and evaluate prioritisation of e-water depending on connectivity scenarios
   - *E.g. If connectivity is low:*

- Option 1) Artificially create connectivity – partly dependent on season and resource availability e.g. full dams, lots of holdover, depending on delivery constraints;
- Option 2) Decide to hold off until conditions are better and season is appropriate (weather, wet vs dry year, cues).

Knowledge needs

ENVIRONMENTAL CONDITIONS

- Climate Patterns
- Short-term Weather
- Rainfall
- Temperature
- Wind
- Pressure
- Hydrology
  - Location, timing, volume, extent, duration, depth, velocity
- Water Quality
- Primary productivity
- Vegetation condition
- Vegetation type
- Structure
- Landuse
- Sediment / soil
- Topography
- Geomorphology

Long-term

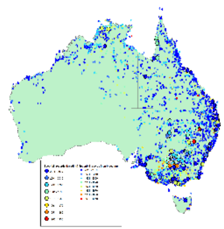
+

Short-term

WATERBIRD RESPONSES

Movement

Presence



Breeding

Movement preferences

- Distances
- Timing
- Routes

+

Habitat preferences

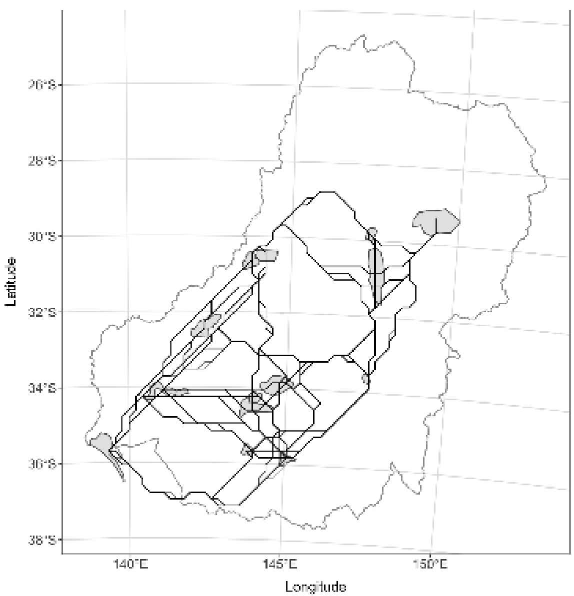
- Breeding
- Foraging
- Roosting
- Refuge

CONNECTIVITY

Connectivity modelling: scenario comparison

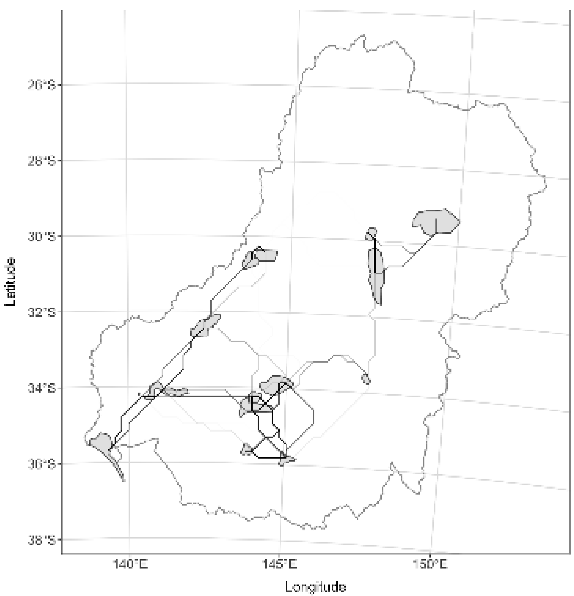
5-day simulations of arrival frequency, State 4 (long distance movement)

Good conditions, high connectivity



Good wind benefit, favourable month

Poor conditions, poor connectivity

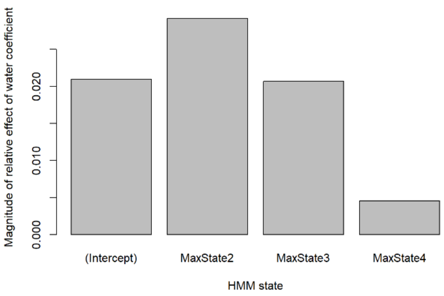


Poor wind benefit, unfavourable month

Distance modelling: Management relevance

Insights:

- For short- to mid-distance travel (e.g. daily travel between roosting/nesting sites and foraging sites):
  - Birds are more likely to travel further if the difference in surface water availability between the origin and destination sites was greater
- For longer-distance movements:
  - Wind support is important, and wind information can be used to predict routes and distances

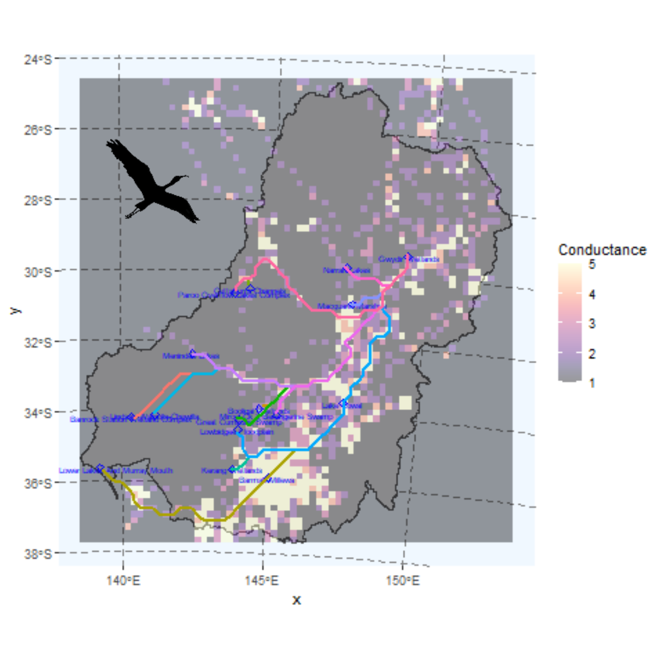


- When and where can we provide environmental water in locations close to roosts and nests, along likely routes to facilitate movements?
- If we can predict the distance and route moved, can water managers get water to where foraging or stopovers are most likely to occur, at the right time?

Modelling waterbird connectivity

MDB Ecosystem Function Project: *Investing in ecosystem functions knowledge to improve adaptive management of water for the environment in the Murray-Darling Basin*

Sam Nicol, Luke Lloyd-Jones, Heather McGinness
November 2022



MDB Ecosystem Function Project Objectives

To describe and demonstrate at the Basin-scale an understanding of:

1. Ecosystem Functions in the Murray-Darling Basin, for the purpose of their protection and restoration
2. Management of water for Ecosystem Function outcomes to support a healthy, working basin
3. Evaluation of Ecosystem Function outcomes and the contribution of management

‘Ecosystem functions’ are: *Processes that arise from the interaction of biota with the physical environment and with each other, and affect the integrity and health of an ecosystem*

Scoping statement

To achieve these objectives the Basin EF Project will focus on **Basin scale connectivity** as a management aim and a key driver for ecosystem function in the Basin

Generalising the results

- Choosing a species with high-quality data enabled us to develop and test state-of-the-art models, however there remains a need to obtain quality data for and adapt these models to other waterbird species of management concern.
- The species for which these results can be reasonably generalised include large colonial-nesting wading species that:
    - Are distributed and move throughout the MDB including long-distance flights during nomadic or migratory movements
    - Nest with or adjacent to Straw-necked Ibis in the same important wetlands – especially ephemeral breeding wetlands
    - Have similar habitat, food and connectivity requirements to Straw-necked Ibis – including water and water-dependent vegetation for nesting, foraging, refuge, roosting or stopover habitat, damp sediment, mud and shallow water environments, and aquatic food sources including frogs, fish, crustaceans, and invertebrates when breeding
- Species with these characteristics include: Glossy Ibis, Australian White Ibis, Royal Spoonbill, Yellow-billed Spoonbill, Australasian Bittern, Nankeen Night Heron, Little Egret, Intermediate Egret, Great Egret.

MDB EF Project Research Outcomes & Impacts

Outcomes

- Improved capacity to understand ecosystem function
- Improved science and tools for ecosystem function to inform decision making for planning and management, as demonstrated through use-case(s)
- Improved ability to communicate to the Australian public the importance of ecosystem function and management

Impacts

- To advance science-policy tools for water management
- To have improved outcomes for water management in the Murray-Darling Basin

MDB EF Project Overarching Use Cases

Use case 1: Inform the establishment of long-term EEO(s) for ecosystem functions (MDBA)

- Inform the establishment of long term expected environmental outcomes (EEO) for ecosystem functions
- Metrics/indicators to enable monitoring and evaluation
- Define interim measures of success

Use case 2: Inform basin-wide medium to long term e-watering strategies (CEWO)

- Application of response-relationships developed
- Guidance pathways that evaluate resource availability scenarios

Alignment to Basin Plan and BWS Ecosystem Functions

Basin Plan – Chapter 8 (EWP), Schedules 7 (Targets), and 9 (Criteria)

Overall environmental objectives (s8.04, s8.06)

a) protect and restore water-dependent ecosystems of the Murray-Darling Basin

b) protect and restore ecosystem functions of water-dependent ecosystems

c) ensure water-dependent ecosystems are resilient to climate change and other risks and threats

Criterion 1: The ecosystem function supports the creation and ***maintenance of vital habitats and populations***

Criterion 2: The ecosystem function supports the ***transportation*** *and dilution of nutrients, organic matter and sediment*

Criterion 3: The ecosystem function provides ***connections along a watercourse*** *(longitudinal connections)*

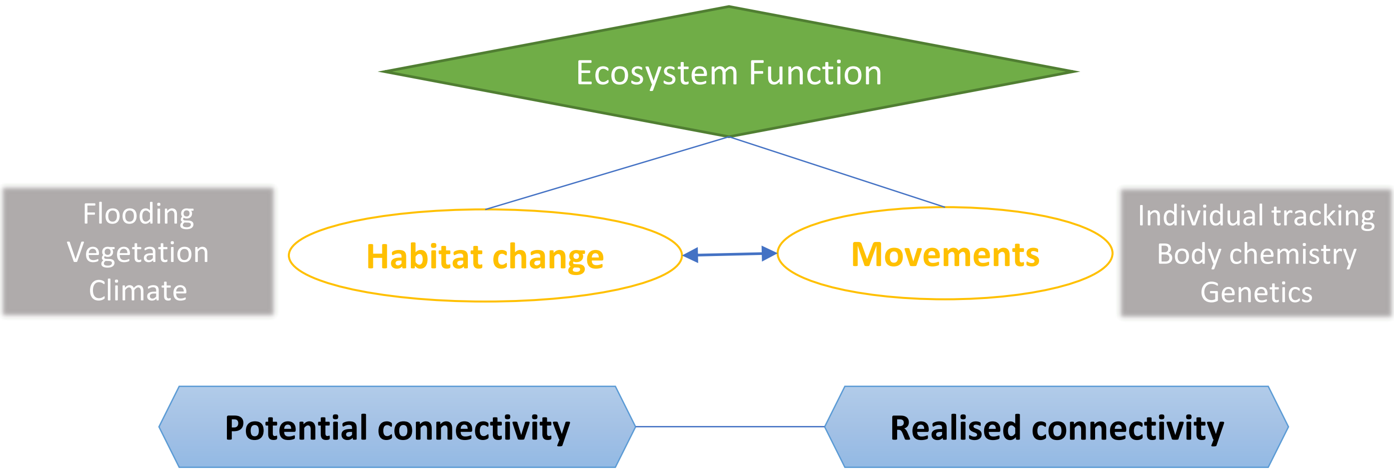
Criterion 4: The ecosystem function provides ***connections across floodplains, adjacent wetlands and billabongs*** ***(lateral connections)***

Background concepts

‘integrity and health of an ecosystem’

↑

*‘**processes** that arise from **the interaction of <u>biota</u> with the physical environment and with each other**’*

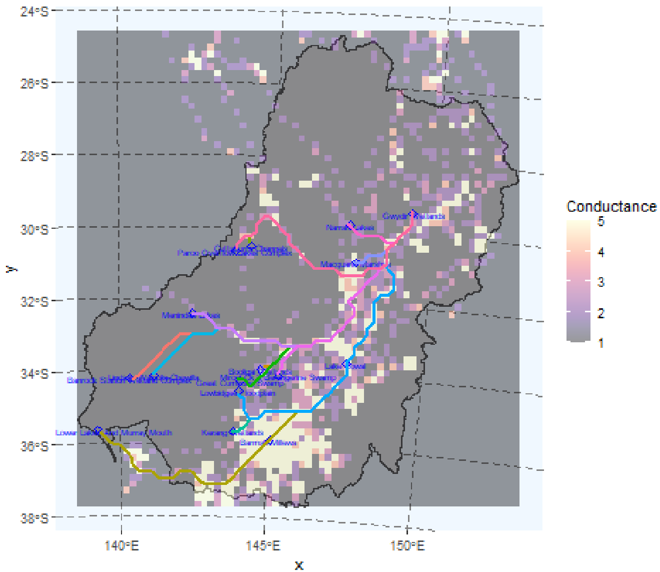


Potential connectivity considers both changes in the availability of suitable habitat and the potential for movement between those areas of suitable habitat

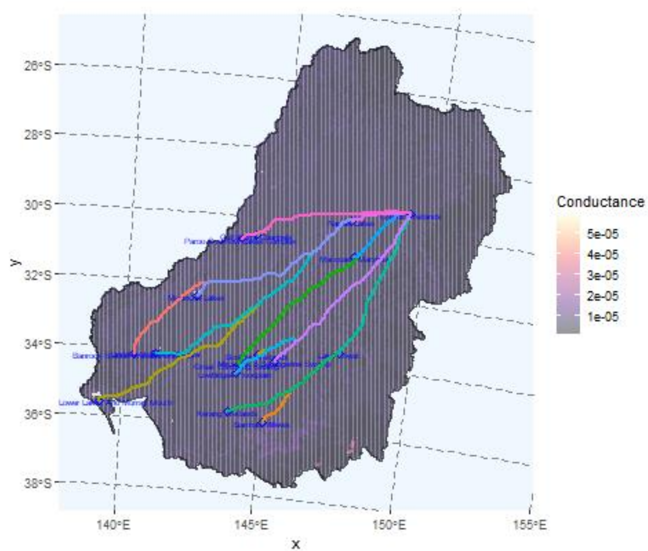
Realised, functional or actual connectivity – the actual movement of biota between different areas of habitat, as informed by evidence / data (tracking observed movements, body chemistry, genetics).

Least cost path results

Based on observed density of tracked birds (HMM states 3 & 4)



Based on predictive habitat modelling (WOFS, MRVBF, Dynamic Land Cover)

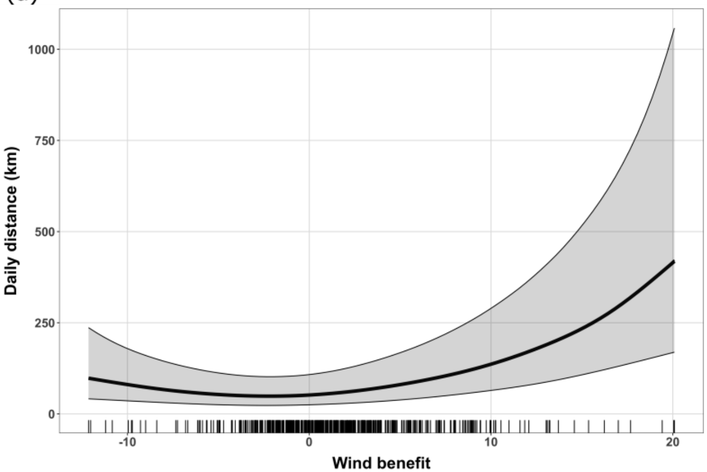


Differences likely attributable to strong influences of local impacts (wind, local water, other weather variables)

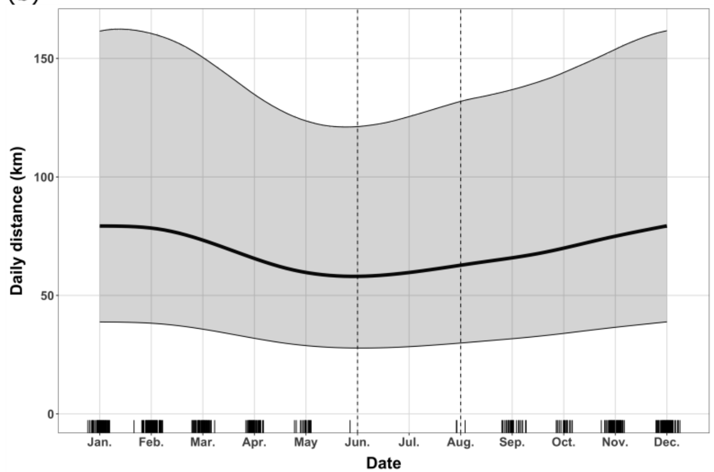
What drives movement distances?

HMM State 4 (long-distance movement) predictors

(a)



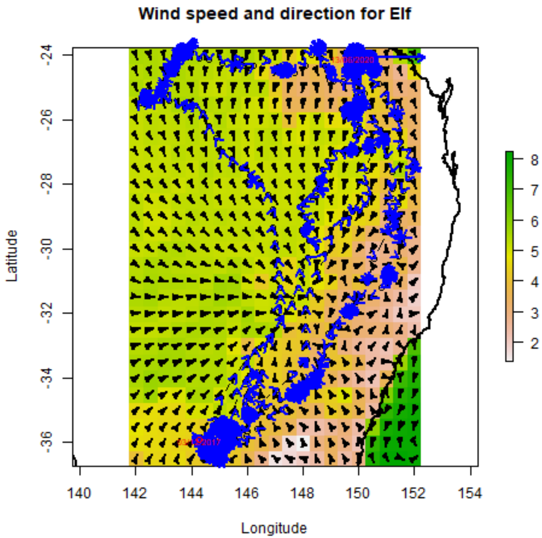
(b)

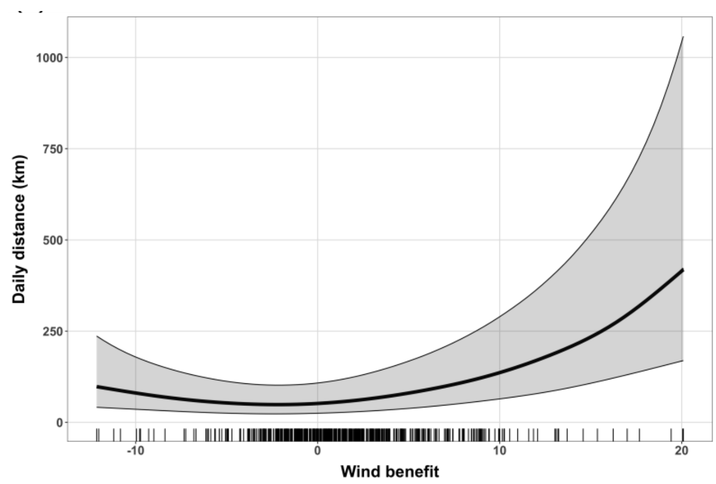


Stronger wind benefit= greater distance travelled

Some relationship with season– slightly greater distances travelled in spring and summer

Influence of wind on ibis movements





They don’t follow the mean wind direction…

… but they do respond to local wind events