# Proceedings of the Mathematics in Industry Study Group, Perth, 2026

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**Abstract**

The 2026 edition of the Australian MISG (Mathematics-in-Industry Study Group) was held on the campus of the University of Western Australia, Perth, in February, 2026. The MISG is a special interest meeting of ANZIAM, the Australia and New Zealand Industrial and Applied Mathematics division of the Australian Mathematical Society. Three problems were considered; the impact of humans on penguins on Penguin Island, the effect of controlled burns of native forest upon vegetation regrowth and the dynamics of a vertical wind turbine generator. In this document are the equation free summaries of these problems.

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# 1 Preface

The 2026 edition of the Australian MISG (Mathematics-in-Industry Study Group) was held on the campus of the University of Western Australia, Perth, in February, 2026.

The MISG is a special interest meeting of ANZIAM, the Australia and New Zealand Industrial and Applied Mathematics division of the Australian Mathematical Society. The MISG meetings take place annually and provide a forum where projects proposed by industry can be worked on intensively, by high profile scientists in the fields of Applied Mathematics, Statistics and Engineering, from Australia, New Zealand and around the world.

Three problems were considered; the impact of humans on penguins on Penguin Island, the modelling of the controlled burns of native forest for tree regrowth and the dynamics of a vertical wind turbine generator.

This special Section of the Proceedings of ANZIAM contains the refereed papers from the 2026 Mathematics in Industry Study Group. The writing of these papers was coordinated by the project moderators in consultation with the coauthors and company representatives. The manuscripts were submitted to the editors and refereed by two expert referees.

On the advice of the referees, manuscripts were accepted for publication, subject to the recommended revisions, and formally approved by the editorial committee.

## 1.1 Industry Partners

We gratefully acknowledge our industry partners: • The Department of Biodiversity, Conservation and Attractions (DBCA); • Oceans Institute, University of Western Australia; • Active Axis Wind Turbines, SIFTE Pty Ltd;

## 1.2 MISG2026 Organising Committee

- Professor Enrico Valdenoci (Co-Director)
- Professor Serena Dipierro (Co-Director)
- Dr. Neville Fowkes
- Dr. Brendon Florio
- Dr. Wafaa Mansoor
- Professor Graeme Hocking

# 2 Active Axis Wind Turbines

**Moderators:** Brendan Florio, Matthias Fresacher, Jonathan Whale.

**Industry Representative:** Kim Schlunke (SIFTE Pty Ltd)

**Group members:** Zoran Bozic, Hugo Fellows-Smith, Patrick Grant, Devin Kilminster, Mark Lukas, Colin Please, Rene Rossi, Jamie Simpson.

**Industry: Energy**

## 2.1 Introduction

Wind Power is an important source of renewable energy in the Australian power landscape. The typical wind farm is visualised as a field of tall white towers with three giant spinning blades. These are called Horizontal Axis Wind Turbines (HAWTs), as their axis of rotation lies horizontally. These turbines present huge engineering challenges in that the large horizontal wind pressure forces need to be mitigated by a heavy foundation. A typical 30 tonne wind turbine steel tower requires a 600 tonne concrete foundation, comprising approximately a quarter of its cost. Proposed offshore floating HAWTs require a significant and carefully engineered buoyant and stable base. The conventional Vertical Axis Wind Turbines (VAWTs), typically comprised of multiple independently rotating vertical axis blades mounted on the common rotating platform, are also able to harness wind energy, though in practise they are less efficient; At any given time, some blades are generating power, while others are dominated by drag.

The study group was presented with the design of a novel wind turbine by SIFTE Pty Ltd. This design is thought to improve on the efficiency of traditional HAWTs, due to its "higher swept area", and is also thought to mitigate the need for a large foundation. The system is comprised of a single blade grounded at one end by a pivot. Any vertical-axis torque at this pivot is used to turn the generator shaft to produce power. The pivot also allows the

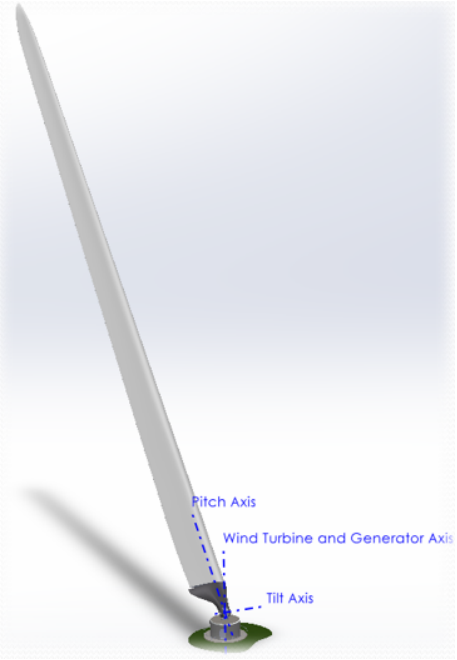



Figure 1: A visual description of the Active Axis Wind Turbine. The blade is grounded at one end, while lift forces provide both centripetal acceleration and vertical lift.

blade to "lift off" from the horizontal, changing the tilt angle (the angle of the blade relative to the ground). At typical tilt angles, the lift force generated by the blade contributes to both keeping the blade airborne and provide it with centripetal acceleration. The blade itself can be pitched on its own axis to change the angle of attack and thus the lift forces generated. See figure 1 for a visual description. A major advantage of this design is the assumption that reaction forces at the pivot are thought to be minimal due to lift forces bearing weight, resulting in a significant reduction in the required foundation. We will explore the validity of this assumption. This novel design is named the Active Axis Wind Turbine (AAWT).

While there are potential advantages in efficiency and structural costs, due to the many degrees of freedom, the design presents a challenge of how to control the blade for stability and throughput. By dynamically changing the blade pitch, many unique trajectories of the wing tip can be created under many different wind conditions. This gives the turbine the flexibility to adapt to a wide range of conditions.

Some vector mathematics had been completed showing viable equilibrium local blade-tip trajectories. SIFTE had the following questions for the attending mathematicians aimed at verifying the feasibility of the proposed novel AAWT concept:

- Can a continuous and complete trajectory be drawn for a full rotation under given wind conditions?
- How should the blade be controlled to optimise energy extraction?

The following sections summarise our methods to answer these questions.

## 2.2 Mathematical modelling

There is very little direct literature about this novel wind turbine design. There is extensive literature on helicopter blade dynamics which includes considering ideas such as rigid blades and simple descriptions of aeronautical forces such as lift and drag, but this concentrates on blades moving nearly in a disk rather than the 3D motions of interest here. Useful ideas were also found in literature about high-altitude kites which have fixed-radius flight paths and are driven by lift forces, similar to our novel wind turbine.

While vector calculations had been performed in quasi-equilibrium conditions by SIFTE, it was clear that a fully dynamic model capturing transient behaviour would be required to describe this control problem. The blade experiences three major forces: Lift, drag and gravity. Each part of the blade travels at a different speed and thus lift forces can vary significantly. The mechanical model is thus derived by calculating the forces at each individual

blade segment and integrating over them. For simplicity, we assume the blade is a completely rigid body.

Due to the nature of the pivot and the fixed length blade, the blade tip must always lie on the surface of a sphere. We chose to express the model in spherical coordinates to reduce the dimensionality of the problem. After detailed vector algebra, we were able to describe the trajectory of the blade tip as a system of two ordinary differential equations describing the change in its azimuthal (due to centripetal motion) and polar (due to lift and gravity) angles over time. Some group members also addressed the problem from a Lagrangian perspective and arrived at the same model. If we were to relax the assumption of a rigid blade body, the Lagrangian approach would be useful for vibration analysis.

The AAWT system can be thought of as a compound spherical pendulum with aerodynamic forcing of the blade by lift and drag forces, since, without these forces, its motion is the same as that of a spherical pendulum under the same initial conditions. To make this connection clearer, it can be imagined that the AAWT pivot is at the top of a tall tower.

There are two parameters considered as control variables: the pitch angle of the blade, and the torque extracted or applied to the system, corresponding to power generation and consumption, respectively. Total power generation (torque extraction) over a reasonable time frame is the quantity to be optimised, and, to achieve this, there may be short periods in which it is optimal or necessary to apply torque. For example, viable paths in a downwind arc may need small inputs of power. Furthermore, in no-wind conditions a small amount of input torque could keep the blade airborne, thereby reducing start-up ramping time and costs.

## 2.3 Equation-free analysis

Developing the model from scratch took a good portion of the week, but there was sufficient time for preliminary analysis. Post-MISG work is currently

underway to complete a more detailed analysis.

A preliminary nondimensional analysis has been done to show that the system depends on just three nondimensional quantities related to the blade tip speed relative to the wind, the drag relative to the lift, and the angle of attack.

During the week, we were able to find example solutions for the trajectory of the blade, both numerically and analytically. The simplest scenario to model is the system in a "maintenance" trajectory during no-wind conditions where power is consumed rather than generated. Due to symmetry in this case, we would assume that the blade tip traces a circular path of constant tilt angle (constant height), with a constant angular velocity for a given pitch angle. Indeed, such stable solutions are found and an example trajectory is shown in Figure 2. The governing equations were nondimensionalised with the aim to find perturbation solutions in "small-wind" conditions.

Interestingly, we found that for some parameter values, the circular solution is non-unique. If the (scaled) pitch angle is below a certain known value, then there will be a unique circular solution for any applied torque. However, for (scaled) pitch angles above this critical value, there is a range of torque values for which the blade may settle on a low-height stable circular path or a high-height stable circular path depending on the initial conditions, and, for torque values above this range, only the high-height circular path is possible.

One of the argued benefits of this novel "active axis" design is the assumption that it has insignificant reaction forces at the base, so structural foundations present a trivial engineering challenge. Our model challenges this assumption, and shows that reaction forces are not insignificant at the pivot point, though they are much smaller in magnitude than in traditional HAWTs. In summary, while these reaction forces do necessitate careful consideration of non-trivial foundation size, the novel AAWT design in question still has advantages over HAWTs.

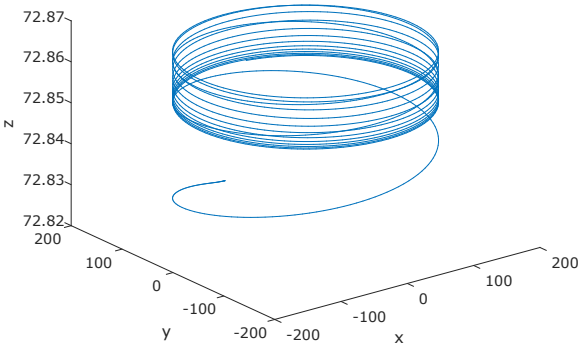



Figure 2: The trajectory of a wing tip in a no-wind maintenance cycle. The trajectory settles on a stable circular path of constant height.

## 2.4 Conclusion

The mathematical model of an AAWT needed to be built from fundamental concepts, which took time to do carefully. We were unable to address all the goals, particularly in regards to the optimal control of the blade. However, the model we developed is a keystone requirement to address such questions since it provides a method for predicting the total power produced by the blade for given control settings, which can be incorporated into optimisation methods in follow-up work. Our mathematical model has already answered some preliminary questions, such as the magnitude of the reaction forces at the base and details of stable maintenance trajectories in no-wind conditions. Furthermore, our model has strengthened proof-of-concept arguments and informed the design of the next prototype.

# 3 Bushfires and the Landscape Mosaic

**Moderators:** Melanie Roberts, Shannon Algar

**Industry Representatives:** Ben Miller, Russell Miller, Department of Biodiversity, Conservation and Attractions (DBCA))

**Group Participants:** Shannon Algar, Zachary den Boer, Pierluigi Cesana, Nev Fowkes, Tony Gibb, Melanie Roberts, Andrew Sullivan, Jessi Xian

**Industry: Environment**

## 3.1 Problem Statement

The Department of Biodiversity, Conservation and Attractions (DBCA) manages prescribed burns across fire-prone landscapes. In the south-west of Australia, the area under management operates under two fuel-age targets driven by hazard reduction policy. Near settlements, hazard separation requires that at least 60% of the landscape has fuel age less than 6 years. Across the broader landscape, a target of 45% of the landscape with fuel age less than 6 years is maintained. DBCA seeks quantitative guidance on how the frequency (return interval) of prescribed fire influences long-term vegetation persistence.

Of particular concern in these regions are *Banksia* species, treated as a sentinel ("canary in the coal mine") species for ecosystem risk. Unlike resprouting plants, many *Banksia* are obligate seeders: adult plants are killed by fire and populations persist only if sufficient seeds are released, dispersed, and successfully establish before the next fire. Seeds are stored in woody cones and are typically released in response to fire or smoke. After germination, seedlings require multiple years to mature and produce their own seed bank. If fires occur too frequently, plants burn before reproduction; if too infrequently, fuel loads accumulate, which risks more intense fires. Prescribed burns are an inherently patchy process, with the extent of burning through a landscape

increasing with increased fuel load (and hence time since last burn). This risks more widespread burns, and thus a larger proportion of the landscape would be simultaneously lacking mature trees to establish a new seed bank. Identifying burn regimes that balance hazard reduction with ecological persistence is critical for effective management.

## 3.2 Methods

The study group adopted three approaches to explore the inter-relationship between fire frequency (as prescribed burns) and the characteristics of *Banksia* propagation (maturity, seed dispersal, and survival curves) on survival outcomes. These studies collectively explored

- How fire return interval influenced long-term persistence of different plant functional groups
- How species fire-response traits shape competitive outcomes
- How parameter variability affects species viability

### 3.2.1 Lotka-Volterra Population Level Model

A population level Lotka-Volterra framework was used to understand how different plant groups (sprouters and seeders) responded to repeated fire.

This approach employed the Lotka-Volterra differential equations to model sprouters and seeders (e.g. *Banksia*) as competitive species. In the absence of fire, the populations increase according to a logistic growth function, which models a population limited by an environmental carrying capacity. Prescribed burns are applied as a Dirac delta forcing representing a sharp decline in population (with a given survival fraction) due to the burn. Dirac delta functions are also used to model a population increase from seeding maturation, which couples both germination and early growth into one process.

### 3.2.2 Lotka-Volterra Model on a Spatial Network

The Lotka-Volterra population model was extended to incorporate spatial heterogeneity in the landscape using a network-based framework. In this approach, the landscape is represented by a square lattice, where each lattice site corresponds to a contiguous patch, analogous to a chessboard. Each patch corresponds to a node in a graph and edges encode adjacency relations between neighbouring patches. In this formulation, an edge connects two nodes if the corresponding patches share a common boundary. On each node, we define a local Lotka-Volterra-type dynamical system, allowing population dynamics to evolve both locally and through interactions with neighbouring patches. To represent variability in real landscapes, randomness is introduced at multiple levels: we consider realisations of random lattices, which induce corresponding random graph structures, as well as random initial conditions for the state variables. Additionally, seed dispersal is explicitly incorporated into the model. Seeds are generated within individual patches but can spread to adjacent patches via the graph connectivity, allowing both information and stochastic effects to propagate across the network. This mechanism produces spatial heterogeneity and patchiness in plant occupancy. Phase diagrams were constructed for different random realisations of the landscape, illustrating how relevant model parameters influence persistence, spread, and the emergence of complex population patterns over time.

### 3.2.3 Cellular Model

A cell-based model was developed to capture spatial processes and fine-scale demographic dynamics across a heterogeneous landscape. The landscape is represented as a square grid of cells. In each cell, plant life stages (seeds, seedlings, and mature plants) evolve according to simple, rule-based transitions. In years without fire, plants age, some die through background mortality, mature individuals produce seeds, and fuel load accumulates. Seeds disperse locally following an exponentially decaying kernel, allowing spatial patterns to emerge from local reproduction and short-range movement.

In fire years, each cell burns with a probability that increases with time since its last burn. If a cell burns, all living plants in that cell die. Seeds are released from their pods, a subset of which germinate, and the resulting seedlings are then thinned to cell carrying capacity. If a cell does not burn, it follows the same ageing, mortality, and seed-production rules as in a no-fire year.

Stochasticity is incorporated throughout the model, including random draws for burn events, seed survival, plant mortality, seed production, and individual maturation age. This allows the framework to explore how spatial processes—such as clumping, dispersal, and local fire history—shape both short-term dynamics and long-term persistence under repeated burning. Data shared by DBCA was used to identify the fire-interval and age dependent typical traits including maturation, dispersal, and burn probability.

## 3.3 Results

Collectively, these studies demonstrated that the ratio of maturation to fire interval is key for *Banksia* persistence. These simulations found that fire intervals less than typical maturation resulted in species loss, as insufficient seeds would exist in the landscape to repopulate after a fire.

The multi-species population models further demonstrated that fire reshapes the competitive balance between seeders (e.g. *Banksia*) and sprouters, suppressing seeder populations even when co-existing.

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## Acknowledgements

We thank the industry representatives Ben Miller and Russell Miller from DBCA, and the contributions of all participants at the MISG.

# 4 Little Penguins survival under climate change

**Moderators:** Soudabeh Shemehsavar, Ed Cripps, Wafaa Mansoor

**Industry Representative:** Belinda Cannell (Oceans Institute, University of Western Australia, Perth, Australia)

**Group Participants:** Connor Stewart-Green, Soudabeh Shemehsavar, Wafaa Mansoor, Graeme Hocking, Bruce Yu, Daniel Claassen, Ed Cripps, Ha Nguyen, Marcus Dyson, Antony Mizzi, Neville Fowkes

**Industry: Environment**

## 4.1 Introduction

Little Penguins are found along the west coast of Australia in the Perth-Mandurah coastal region. Data related to the penguins and the local environment has been collected since the 1980s. The data includes 18 quantities: Year, number of artificial nesting boxes, total eggs laid, total chicks hatched, total fledged, Fremantle sea Level (FSL), mean sea-surface temperature, standard deviation in sea temperature, anomaly from long-term average in sea-surface temperature, rainfall, number of pairs of penguins, number of chicks per pair, number of nesting boxes checked, percentage hatched, percentage fledged, Indian Ocean Dipole (IOD), fish catch per unit effort (CPUE).

The group was charged with examining these data and considering the likely impacts of climate change and also to consider changes as a result of particular events within the timeline of the data, such as the opening of the Dawesville Cut in 1994 and the particularly severe marine heatwave in 2011 [1].

The data were examined by taking the annual or monthly average values of most quantities. Figure 3 shows a comparison of daily sea-surface temperatures with annual average sea-surface temperatures. Although these data are

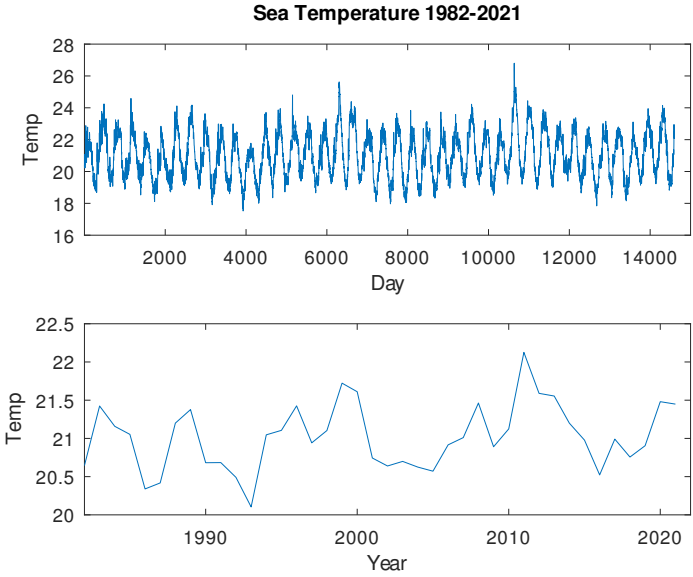



Figure 3: Sea Temperature near Garden Island, 1981-2021. Daily average (top panel), yearly average (Bottom panel)

smoothed by this averaging, the temperature signal for each year is still evident. In addition to the annual analysis, the data was analysed over the crucial months of the breeding season from April through to September.

One use of the analysis is to inform the development of a simple population model. The purpose of the model is not to predict population numbers, but to examine the impact of each parameter on the behaviour of the penguin population. It can also be used to consider the impact of population growth in the region [2] and climate change [3].

The combination of these two parallel approaches of statistical analysis and mathematical modelling provides not only a clearer picture of the impact of each environmental and human parameter, but also provides a mechanism to analyse future changes in these inputs.

## 4.2 Statistical Analysis

### 4.2.1 Exploratory Analysis and Correlation Structure

The large amount of data took some time to consider. Some visualisation of the data was initially performed. Figure 4 shows a histogram of eggs produced with eggs hatched and number of chicks successfully fledged. The variations across the 33 years can be seen clearly. The Dawesville Cut was opened in 1994 and there is some signal there, while the marine heat wave in 2011 is very evident as a drop in population. Breeding success was high in 2005-2007, but clearly was significantly impacted after 2011 before rebuilding a little up to 2016, after which it began to drop away again.

Analysis was performed to determine correlations between all data with the goal of reducing the number of parameters to assess. For example, sea-surface temperature, sea-surface temperature anomaly and Fremantle sea level were all very strongly correlated. Similarly, total breeding was highly correlated with total chicks, and chicks per pair with percentage fledged. These relationships suggest it is unnecessary to include all of each in analysis of their impact on successful breeding of the penguins.

These strong correlations were considered when selecting predictors for the regression models to reduce redundancy and avoid multi-collinearity effects.

A generalised linear model (GLM) was fitted across various parameters. Surface-sea temperature was found to be marginally significant in breeding success, while rainfall and percentage hatched were not significant predictors. Figure 5 shows some linear fits to the data of percentage fledging success (c.f. eggs hatched) with fish catch (CPUE), Fremantle surface level, sea-surface temperature and rainfall. There are some trends but the data is rather scattered. They suggest negative effects of fish catch, sea-surface temperature, Fremantle Sea Level and rainfall on total breeding. Further work is needed to identify possible causes for these trends.

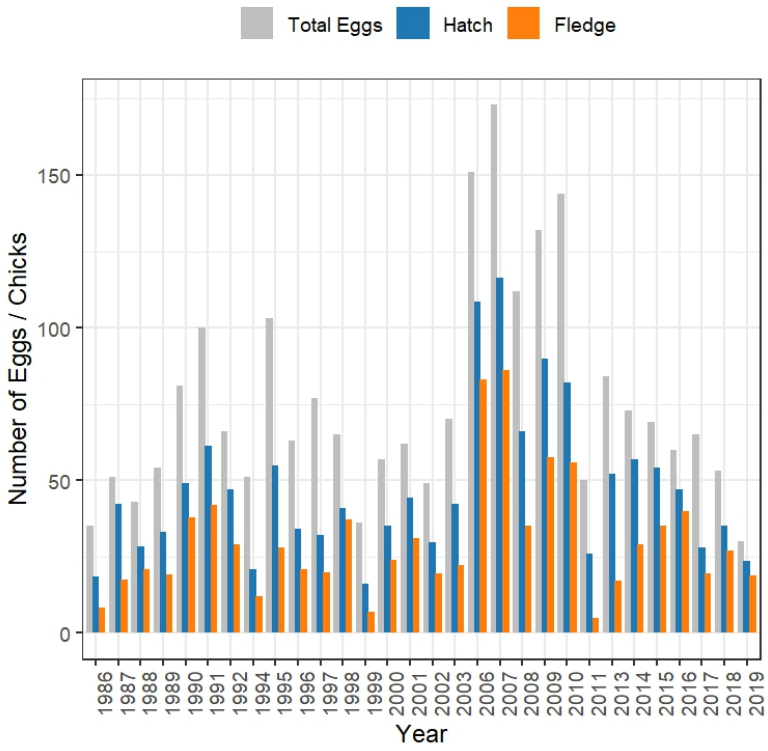



Figure 4: Visualisation of the number of eggs produced, the number hatched and the number successfully fledged. These are all indicators of the breeding success for each year and can be compared with the other conditions to determine important correlations.

## 4.3 Population model

The interactions observed in the data analysis highlight the importance of each factor on changes in the penguin population given the various environmental and anthropogenic factors. Using these factors a model can be built that represents the impact of each of the parameters. For example, we can model the potential consequences of climate change on the penguin population

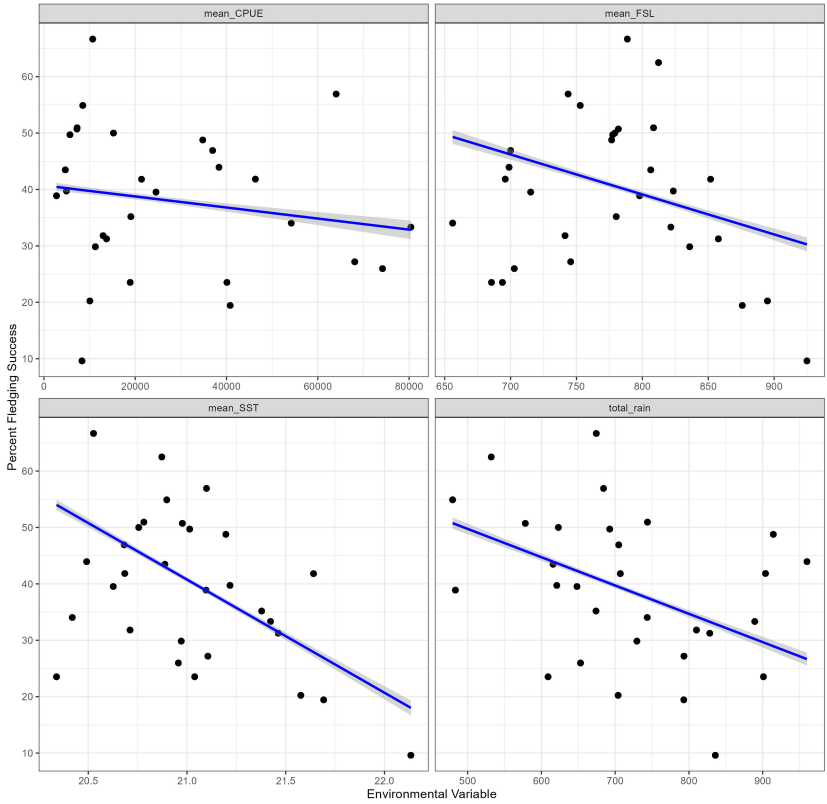



Figure 5: Fledging success related to mean Catch per unit effort (fishing), Fremantle surface level, Sea-surface temperature and rainfall. There are trends visible, but there is a lot of scatter in the results.

by including changing climatic conditions. The impacts of anthropogenic (man-induced) changes can also be examined by considering the impact of tourism, boating and infrastructure development on the nesting grounds.

A simple version of such a model was developed with two different time steps; one with 4 steps per year (quarterly) and one with a single time step per year. Figure 6 shows the output of the model with a one year time step

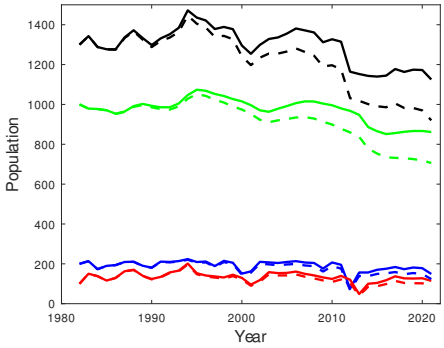



Figure 6: Example of a simple simulation of population. The blue line is fledging numbers (0-1 year old), red is juvenile population (1-2 years old) and green is adult (greater than 5 years). The black lines are total population. The solid lines are simulated with no impact of human population, while the dashed line shows the population with the inclusion of a negative term proportional to the population of the nearby city of Rockingham.

and a starting population of about 1300 penguins, including juveniles. For this example, 1000 adult penguins, 200 fledges and 100 juveniles (one year old) were chosen as the starting population. This model only incorporates sea-surface temperature as the driving variable, but other quantities can be included as the data are analysed further. The solid lines indicate populations given a simple model of the impact of sea-surface temperature. A drop in births due to the 2011 marine heat wave can be seen in the model results (Figure 6). The population of juveniles (1-2 years old) lags a year behind the birth/fledged values. Anthropogenic effects [2] were included in this example by using a term proportional to the growth of the population of the city of Rockingham. The impact is assumed to be negatively correlated with an increase in human activity. It could include collisions with boats or jet skis and a loss of habitat. In the model results (Figure 6) the impact of this is shown as a dashed line and produces a steady “extra" decline in the population even with a very small rate constant.

## 4.4 Concluding Remarks

The group considered the problem using two approaches; a statistical analysis of the data and a simple mathematical model informed by the outcome of the data analysis. Some correlations among various factors were obtained, allowing a reduction in the set of data to be analysed and indicating the impact of different factors. A model was developed to incorporate some of these factors and visualise their impact. This approach shows promise to consider the potential impacts of climate change, human expansion and loss of habitat.

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