**Title:** The impact of disease on within individual variations in social thermoregulatory behaviours in the eastern water dragon

Nannizziopsis == Chrysosporium anamorph

**Abstract (250 words):**

**Main (2000 words):**

**Background**:

Thermal regulation in ectotherm and why is it important; Variability (within and between individual) in reptile behaviours and thermal regulation:

Body temperature is one of the most important physiological variables in ectotherms, as it directly impacts on the behaviour and the performance of the animals (Michael J 2002). For most ectotherms, there is a narrow range of body temperature where their performance can be maximized (Michael J 2002). The maintenance of the body temperature within this optimal range is therefore important and is directly relevant to the fitness and the survival of the ectotherms, thus many ectotherms have developed thermoregulation techniques both physiologically and behaviourally (Herczeg, Gábor 2006; Michael J 2002). However, thermoregulation usually at a cost, and the optimal body temperature is not always achievable due to environmental constraints, the physiological conditions of individuals or the availability of the resources, which varies from case to case (Herczeg, Gábor 2006; Michael J 2002; Jameel J. Khan 2010). For many ectothermic reptiles, even within the same species, their body temperature can vary between populations, between individuals, and within individual over time (Frank Seebacher 2005; Jameel J. Khan 2010). The most effective heat source for most reptiles is the solar radiation, where their skin is the first receiving end of the heat (Charles 1949). The skins of the many reptile species also contain thermoreceptors, which are deterministic to how the reptiles will perceive and react to ambient temperatures (Glenn 2006).

Thermal regulatory disease in reptiles and function of the *Nannizziopsis* fungus:

The fungi under the genus *Nannizziopsis* are the causative agent of the commonly known yellow fungus disease (YFD) (Paré 2016). In reptiles, YFD may lead to deep granulomatous dermatomycosis and become lethal to infected individuals, where the skin of these individuals become necrotic and their internal organs become inflamed (Paré 2016). Even if not being directly killed by YFD, infected individuals rarely recover, and usually end up in a state of dehydration, starvation, or secondary infections (Nicola R. Peterson 2020). While there is currently no evidence of *Nannizziopsis* *sp.* directly causing thermoregulatory issues in reptiles, *Nannizziopsis* *sp.* was found to be growing optimally under certain temperature, and individuals with weakened immune system are more susceptible YFD due to their inability to regulate their body temperature (Lionel Schiliger 2023; Nicola R. Peterson 2020). We speculate that YFD will lead to a positive feedback loop in infected individuals due to the damage it may cause on their skins.

Transmission of the fungus and social behaviours of the dragon:

The YFD was mostly found in captive environment, however, there have been an increase in reports of wild infected individuals in the recent decades, with the earliest record in Australia dating back only to 2013 (Nicola R. Peterson 2020). The exact mode of transmission and pathogenesis of *Nannizziopsis* *sp.* are poorly understood, but the transmission rate is likely to be host density dependent (Matthew C. Fisher 2012; J. Tacey 2023). Some *Nannizziopsis* *sp.* have been found to be non-host specific, giving them a higher chance to persist in the environment by jumping between host species (Savannah Gentry 2023).

The eastern water dragon *Intellagama lesueurii* can be found across Queensland, Australia. The population in Brisbane, Queensland in particular was the first to be identified as YFD infected in the wild and was found to have more than 30% of the individuals being infected through repeated surveys (J. Tacey 2023; Nicola R. Peterson 2020). *I. lesueurii* are particularly at risk, as the most severely infected individuals were found to be more likely to socialize with others, speeding up the transmission of the pathogen (J. Tacey 2023), this would likely be exacerbated when their basking sites were limited resources where individuals were more likely to aggregate as seen in other dragon species (Jameel J. Khan 2010). The social behaviours of *I. lesueurii* quantified as conspecifics have also been found to be sex dependent, but both sexes tended to social associate more when the population density was high, which might create more opportunities for the transmission of YFD (Kasha Strickland 2019). While lethal pathogen may not be spread across the entire population easily under standard scenario as infected individuals do not persist long in the population, the increased socialization of YFD infected *I. lesueurii* may not follow this rule, and may actually drive population into local extinction (Matthew C. Fisher 2012)

Behavioural response of the dragon (e.g. behavioural induced fever); Why high variability can be an indication of reduced fitness:

Some reptiles have been found to display behavioural induced fever to up-regulate their body temperature and fight off fungal infections, this can be achieved by utilising the micro-environment available around them, such as basking more under sunlight, as *Nannizziopsis* *sp.* will struggle to grow when the temperature is above 37 C° (Ciera M. McCoy 2017; Gordon Burns 1996; Paré, Jean A 2020). It is currently unclear whether *I. lesueurii* will respond in such way to YFD, however, we do know that *I. lesueurii* could adjust their social behaviours throughout their life history based on their environment and physiological conditions both among and within individuals within the same population (Kasha Strickland 2019). Nevertheless, the potential response of *I. lesueurii* to YFD may be ineffective, as there may be risk of UV from basking causing subcutaneous tissue damages due to the lack of skin covering, which may feed into a positive feedback loop to promote the growth of the fungus (E Adkins 2003). The potential need for long-term basking for diseased dragon individuals due to their poor skin conditions may also come as a trade-off to their feeding, reproduction, and predation avoidance, which may reduce their fitness elsewhere (Frank Seebacher 2005). It worth noting that many factors have been identified to be correlated to body temperature variability in *I. lesueurii*, such as sex and location (ambient temperature and resource availability) (Riana Zanarivero Gardiner 2014), so determining whether YFD is one of the major causes of their body temperature variability is difficulty due to potential interaction of YFD with these known terms both physiologically and behaviourally, and this will be the focus of my research project.

This research project will address the body temperature of the *I. lesueurii* among and within individuals in a population collected at Roma Street Parkland, Brisbane. In particular, we will look at how YFD would interact with other physiological and environmental variables to contribute to the mean and variability in the body temperature. The within individual variability in body temperature will be our major focus, as it has not been studied on this species in relations to YFD before.

**Methods:**

Data collection:

In this study, the eastern water dragons around Queensland, Australia were monitored for their body temperature, behaviour and *Nannizziopsis* disease status for xxxxxxx years. The disease status was determined by visual examination of the skin lesions and through qPCR sequencing of the skin swabs. Other physiological information such as sex, length and weight were also recorded for each observation. All data were geographically located, and the number of dragons that were within the home range of each recorded individual was then calculated as “conspecific”. Only individuals with more than 20 observations across the years are used in the following analysis.

Data clean up and processes:

Data is cleaned up by xxxxxx in R, disease statuses are classified as diseased (symptomatic or asymptomatic) and healthy. Individuals could have their disease status changed over time, and these individuals were noted. Diseased and Healthy individuals are also made into subset and will be analysed separately to compare their mean differences.

General linear models (with/without Bayesian inferences) were used on xxxxxx:

Population mean effect of disease:

We hypothesized that *Nannizziopsis* *sp.* infected *I. lesueurii* will have a higher variability in their body temperature than healthy individuals due to (). Assuming every variable would interact with disease status.

Body temp ~ Disease +Sex + Location + Weight to Length ratio + Conspecific + Number of sighting per individual + Disease\*Sex + Disease \*Location + Disease \*Weight to Length ratio + Disease\*Conspecific + Disease \* Number of sighting per individual + (1|Individual name) + residual

1. Should Include hypothesis on how each variable would impact on body temp? or Just saying why the term is included as already outlined in the background part is enough? NO, just explain what they are.
2. Do I need to justify why the disease would interact with each. Explain this!

Within individual variability:

The hypothesis is that diseased individuals do not maintain their body temperature as consistently as healthy individuals (because they increase it [induce fever] or it drops [can’t access bask sites because of poor condition; avoid conspecifics]):

Body temp ~ Sex + Location + Weight + Conspecific + Number of sighting per individual + (1|Individual name) + (1|Sighting:Individual name)

Hypothesis:

We hypothesized that *Nannizziopsis* *sp.* infected *I. lesueurii* will have a higher variability in their body temperature than healthy individuals due to (). Diseased individuals will xxxxx and were likely to have more diseased individuals in their home range, and more total individuals in their home range (). The response on the thermoregulatory ability would also correlate to the relative weight of the individual to its length, where healthy individuals would have a higher weight to length ratio on average as their feeding behaviour is less impacted by the disease (xxxx). Location that the individuals inhabit may also directly correlated to their thermoregulations, as most of the time their body temperature will be close to the average ambient temperature, and the gap of mismatch between the average ambient temperature to the optimal performance temperature of the dragon will be correlated to their energy expenditure and ability to thermoregulate (xxxxx).

**Schedule (MAKE Ganett Chart):**

Project reading and understanding of data. Start: 24/07/2023 End: 24/08/2023

Data clean up and wrangling. Start: 02/08/2023 End: 30/08/2023

Writing research proposal. Start: 09/08/2023 End: 25/08/2023

Statistical analysis and modelling. Start: 09/08/2023 End: 27/09/2023

Weekly meeting and progress check-up: Start: 24/07/2023 End: 27/10/2023

Writing reports. Start: 20/09/2023 End: 27/10/2023

Writing for seminar. Start: 27/10/2023. End: 08/11/23

**Proposed outcomes and deliverables:**

MAKE SOME TABLES/DIAGRAMS!!!!

We expect to have answered both the hypotheses listed in the method part by the due date of the written report. As the research project is exploratory, we also expect to discover unexpected outcome and form new hypothesis, which we may directly address in our report or leave them for further research. All data given will be tidied up, and every code used will be reproducible and made available on GitHub. The report will contain visual elements such as tables, graphs, and details of the model outputs to facilitate the discussion. The report will be made with journal publishable standard in mind.

**References:**

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