



The applicability of Optimum Foraging Theory to *Pygoscelis* spp.

memory and effort allocation at the sub-mesoscale

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Introduction

Optimum Forage Theory (OFT):

- Memory – Use previous forage success to inform next location
- Effort allocation – directed, transiting behavior between patches of tortuous foraging effort (Area Restricted Search)

Testing OFT expectations on small temporal and spatial scales:

- Forage Trips
- Day to day
- ~10-25 km

Species:

- Adélie
- Gentoo

Location:

Palmer Station,

Anvers Island GPS Tagged Gentoo penguin (*Pygoscelis papua*)

2 years of Tag data:

- Double tagged - GPS & Depth Recorders

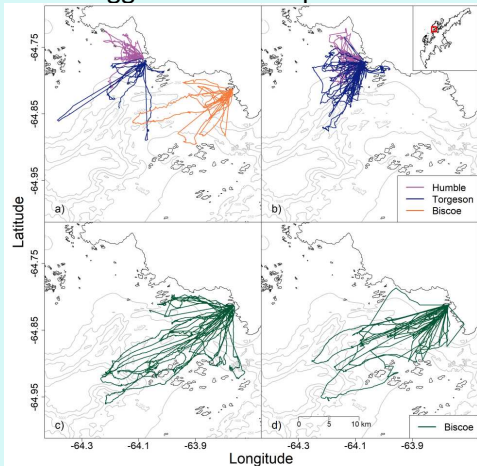


Fig. 1 GPS tracks of tags with >1 trip recorded a) 2019-2020 Adélie, b) 2020-2021 Adélie, c) 2019-2020 Gentoo, d) 2020-2021 Gentoo

Cimino, M. A., Lynch, H. J., Saba, V. S., & Oliver, M. J. (2016). Projected asymmetric response of Adélie penguins to Antarctic climate change. *Scientific Reports*, 6, 1-9. <https://doi.org/10.1038/srep26785>; Jensen ID, Patterson TA, Costa DP, Doherty PD, Godley BJ, Grecian WJ, Guinet C, Hoemmer X, Kienle SS, Robinson PW, Votier SC, Whiting S, Wit MJ, Hindell MA, Harcourt RG, McMahon CR (2020). "A continuous-time state-space model for rapid quality-control of Argos locations from animal-borne tags." *Movement Ecology*, 8, 31. doi: 10.1186/s40462-020-00217-7; <https://doi.org/10.1186/s40462-020-00217-7>; Orsini, G.H., Pearson, N.E., 1979. On the theory of central place foraging. In: Horn, D.J., Mitchell, R.D., Stairs, G.R. (Eds.), *Analysis of Ecological Systems*. The Ohio State University Press, Columbus, pp. 154-177; Riaz, J., Bestley, S., Wotherspoon, S., & Emmerson, L. (2021). Horizontal - vertical movement relationships - Adélie penguins forage continuously throughout provisioning trips. *Movement Ecology*, 9(43), 1-15. <https://doi.org/10.1186/s40462-021-00280-8>

Methods

Memory – Forage Success vs Trip Similarity

- Forage Success – Vertical Measure
 - Identify forage dives (Cimino et al. 2016)
- Forage Freq. = # forage dives/trip length
- Cumulative Attempted Catch (CAC) = total # of wiggles recorded on tags
 - Indicative of prey capture attempts
- Trip Similarity - Fréchet Distance (Fig. 2)
 - Measures similarity of 2 sequential trips

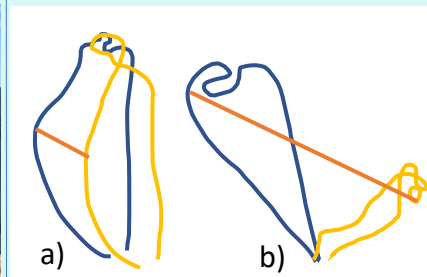


Fig. 2. a) example of small Fréchet distance, b) example of large Fréchet distance. (Detailed explanation in Supplement)

Expectation: Forage Success ↑, Fréchet ↓

Effort Allocation

- Fit Movement Persistence to tracks (Fig 3)
- γ = Autocorrelation in speed and direction
 - Low γ = tortuous non-directed (foraging)
 - High γ = faster more directed (searching)
- Section by low and high γ
- Measure effort in sections (Forage freq. and CAC)

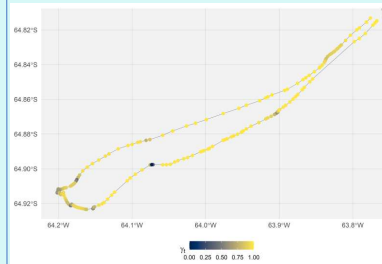


Fig. 3. Gentoo track fitted with movement persistence model. Darker colors indicate lower movement persistence, brighter colors indicate higher movement persistence

Expectation: More foraging in tortuous sections

Results

Memory: No sig. relationship b/w Forage Success and Fréchet Distance

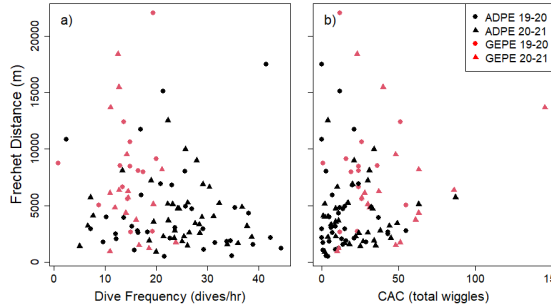


Fig. 4. Fréchet distance vs. 2 forage success metrics. Color and shape indicate species and year: red - Gentoo, black - Adélie, 2019-2020 - circle, 2020-2019 - triangle. a) Fréchet Distance vs. Dive Frequency, b) Fréchet Distance vs. Cumulative Attempted Catch. Additionally, no significance was found when split by spp.

Effort Allocation: Less/equal foraging in tortuous sections

- Majority of time spent in directed sections

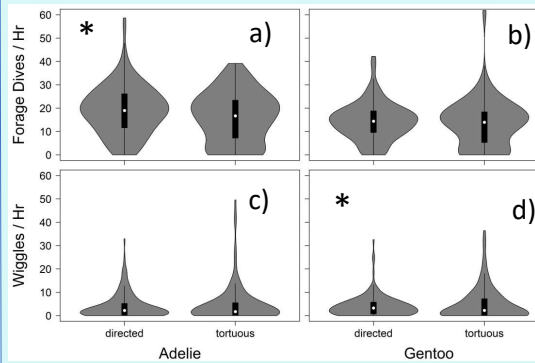


Fig. 5. Violin plots of forage dive frequency and cumulative attempted catch in directed sections (high γ) and tortuous sections (low γ) of forage trips. Width of the violin indicates distribution with the white dot indicating median and inner black box indicating IQR. Directed effort significantly higher in Adélie dive frequency and CAC, and gentoo CAC: a) Adélie Dive Freq, b) Gentoo Dive Freq, c) Adélie CAC, d) Gentoo CAC

Environment: Weak pos. relationship b/w Fréchet Distance and daily difference in wind speed

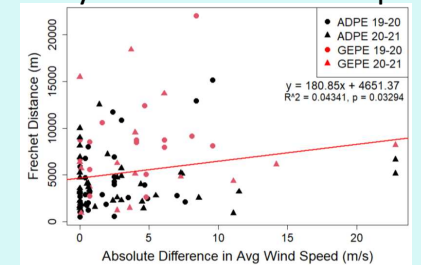


Fig. 6. Scatter plot of Fréchet distance against the absolute difference in average daily wind speed from the 2 days the forage trips took place. Weak positive relationship was found

Conclusions

- Be wary of assuming foraging effort from horizontal behavior
- Two OFT tenets not followed in this system
- Areas of low movement persistence could be resting/predator avoidance behavior
- Weak significant relationship between absolute daily change in wind speed and trip similarity
- Penguins may forage continuously in random "transects" out and back
- Hit krill balls opportunistically
- Change direction of "transect" when large wind shifts prey distribution
- Factors that could be affecting adherence to OFT:
 - Prey behavior
 - Locomotion strategy (flight vs. swim)
 - Distance to foraging region
 - Environmental variability

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