Background: One of the crucial scientific challenges of this century is characterizing the vulnerability of ecosystems to global climate change. Warming temperatures and sea ice reductions are predicted to have large impacts on the timing and abundance of food resources of apex predators, particularly in polar regions[1]. Changes in food web structure and seasonality may directly decrease survival and fecundity by preventing individuals from acquiring sufficient food. In addition, seasonal changes in ice extent and weather may have indirect effects by increasing thermoregulatory costs in large endotherms. While bioenergetics models have been used to quantify energetic requirements, no model has included feedback lops between physiological processes or linked energy deficiencies to reproductive consequences. Therefore, my research is comprised of two aims: 1) to <u>Model the seasonal fluctuations in the energy budgets of adult, female Weddell seals (*Leptonychotes weddellii*)</u> by developing an agent-based model. Weddell seals are an ideal species to model because their high site fidelity, low predation and human interference levels, and predictable spatial distributions have allowed for several investigations on population reproductive rates and seasonal body composition changes[2] that will permit validation of my model; and 2) to <u>Examine how changes in environmental parameters influence survival and reproductive success</u> by running model simulations with perturbed conditions. Together, these two aims will elucidate how extrinsic conditions may impact individual fitness and identify dynamic shifts in energy allocation or behavior under environmental stressors.

Methods: During the first year of my graduate research, I developed an agent-based, ecophysiological model that simulates the energy balance of free-ranging adult Weddell seals (Fig. 1). Energy intake depends both on foraging effort and stochastic prey availability at each timestep, whereas energy output is calculated using[3]:

(Activity+Maintenance+Reproduction+Thermoregulation+Molt)/(Efficiency).

Currently, the model is implemented in *R* and consists of the following parameters: *Activity* is energy required for swimming and diving; *Maintenance* costs are those associated with basal metabolic rate, as adjusted for time-specific lean and total body mass; *Reproduction* adds the costs of gestation and lactation; *Molt* is the cost of hair synthesis; *Thermoregulation* represents the added cost of endothermy in relation to ambient air and water temperatures derived from the National Center for Atmospheric Research and NOAA Optimum Interpolated Sea Surface Temperatures, respectively[4]; and lastly, the model accounts for energy losses due to indigestible or unmetabolizable energy (*Efficiency*). At the beginning of the simulation, each animal's mass and body composition are those of a healthy animal[2]. The animals choose their behavior based on time-specific energy demands and the energetic losses/gains of each activity. For instance, during the molt, the animals fluctuate between hauling out to molt (perfusing the skin to promote hair regrowth) and foraging based on their current lipid stores and the weather conditions. At the end of each time step, excess energy (i.e. energy input from prey that exceeds energy requirements) is deposited as lipid or lean mass. Conversely, if the energy obtained from prey cannot satisfy requirements, the animal catabolizes tissues and loses mass. Mortality occurs when 1/3 of the initial lean body mass has been catabolized[3].

In order to explicitly link animal condition to reproductive success, so that the fitness consequences of different environmental scenarios can be tested, I will collaborate with colleagues at UAA and the University of Saskatchewan to create logistic equations of pregnancy/pupping success as a function of body condition[5]. The energetics model will use the logistic curves to determine the probability that each simulated seal will reproduce given their time-specific body condition. Following development and validation with empirical time-activity budget data, I will run model simulations to study the response of individuals to: (1) baseline conditions; (2) reduced prey availability; and (3) increased air temperature and wind strength (Fig. 1). The conditions will be altered from baseline levels to reflect climate scenario predictions for the end of the 21st century under a moderate greenhouse gas scenario[6].

Expected Results: I hypothesize that the energy requirements for reproductive females will be highest during lactation and more than 1.5 times the requirements of a non-breeder[7], but stochasticity in time-activity budgets and foraging efficiencies will result in large fluctuations (Aim 1). A decrease in food abundance will likely affect survival rates during critical life history stages by forcing a shift to low-energy prey items and longer duration foraging trips (Fig. 1, Aim 2). Further, variability in weather will likely result in altered time-activity budgets and an intermediate number of mortalities (Aim 2). Ecophysiological modeling will help to elucidate the behavioral strategies that may help mammals maximize the probability of survival and reproduction under future climate scenarios. Ongoing NSF funding to Dr. Burns (ANT-1246463) will provide logistical support for my fieldwork.

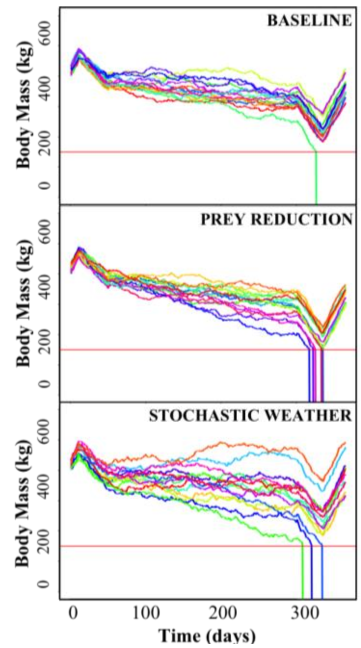

Figure 1. Results for 25 seals simulated for one year. The horizontal red line represents minimum mass for survival.

Intellectual Merit: Once fully developed, the agent-based model will provide a multidisciplinary, mechanistic tool to examine the physiological (body composition changes) and behavior responses of an apex predator to predicted climate and prey scenarios. In addition, due to the flexibility of the model, it will be straightforward to apply the modelling approach developed here to other species with similar life history characteristics, and I anticipate doing so through collaborations with other Association for Polar Early Career Scientists members. Highlighting the temporal sensitivities of Weddell seals and other polar species to predicted anthropogenic changes will be a valuable contribution to the study of global change biology, and it can be used to direct the focus of the research community by underlining the importance of planning for conservation of natural resources. This information is crucial for understanding how top-down ecosystem effects might change in response to climate change.

Broader Impacts: I will disseminate my findings in presentations at scientific conferences and open-access journals to ensure accessibility to researchers and STEM educators. During each summer, I will supervise one undergraduate student through the University of Alaska Anchorage NSF Research Experience for Undergraduates program, and this experience will allow me to foster the next generation of global change biologists. In addition, I will use my background in education to develop and present a mathematical modeling lesson to native Alaskan students through the K-12 outreach program I created. This direct linkage between mathematics and biology provides students with the motivation and interest to become more involved in STEM. Lastly, I will collaborate with a Polar Teachers and Researchers Exploring and Collaborating (PolarTREC) teacher in preparing interpretation exhibits and constructing participatory activities for students.

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[1] Vaughan et al. *Clim. Change* (2003). [2] Hastings and Testa. *Jour. Anim. Ecol.* (1998). [3] Winship et al. *Mar. Ecol. Prog. Ser.* (2002). [4] Kemp et al. *Methods in Ecol. And Evol.* (2012). [5] Albon et al. *Jour. Anim. Ecol.* (1983). [6] Meehl et al. *Bull. Am. Meteorol. Soc.* (2007). [7] Hadley et al. *J. Anim. Ecol.* (2007).