THE KERGUELEN PLATEAU: MARINE ECOSYSTEM + FISHERIES
Proceedings of the Second Symposium
heardisland.antarctica.gov.au/research/kerguelen-plateau-symposium

Extended abstract

Modelling southern elephant seals in East Antarctica using an individual-based model with a dynamic energy budget

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Higher-trophic level marine predators can be used to observe effects of changes in ecosystem dynamics and physical environments (e.g. Constable et al., 2014). Modelling tools provide an important means to understand and predict the dynamics of Southern Ocean predator populations, including for the Kerguelen Plateau. We have developed an individual-based model (IBM) (Grimm et al., 2005; Railsback and Grimm, 2011) incorporated with a dynamic energy budget (DEB) (Kooijman, 2010; Sousa et al., 2010), know as a DEB-IBM (Figure 1) for southern elephant seals (*Mirounga leonina*) to test hypotheses regarding observed population changes. The DEB-IBM combines the deterministic approach of DEB theory and the stochasticity of IBMs to investigate population-level effects while taking into account energetic use and traits of individuals. The model integrates the southern elephant seals' complex life-history traits and breeding behaviour, as well as detailed energetic requirements and uses. Model parameters are estimated using dynamic energy budget theory and census data (Goedegebuure et al., 2018) from southern elephant seals from Macquarie Island.

The DEB-IBM was developed so that it (i) realistically simulated energy use and life histories, as well as breeding traits without any of these properties being directly prescribed or influenced by chosen parameters, i.e. these properties emerged from the model, (ii) projected a stable population over time, and (iii) had realistic population dynamics and structure, also based on emergent (not directly forced) life-history features (Goedegebuure et al., 2018). Female southern elephant seals generally produce one pup at a time. They breed between September and November and are impregnated while suckling their pup (Carrick et al., 1962). Their pregnancies last for approximately 217 days, while suckling of their pup lasts for around 23 days (Laws, 1984). The mothers fast for 30 days while they are on land for breeding and return to sea for 60–70 days to replenish energy stores prior to the annual moult (Carrick et al., 1962; Hindell and Burton, 1988; McConnell et al., 2002. This complex breeding behaviour and energetic detail has been captured in the DEB-IBM (Figure 2).

The model has been developed to investigate possible responses of southern elephant seals to likely changes in their environment, such as movement of major fronts or changes in prey populations, which may affect their energy consumption/demand. Macquarie Island has undergone decline in the southern elephant seal population (–1.45% p/a) (McMahon et al, 2005; van den Hoff et al., 2014; Hindell et al., 2016, 2017). The reasons for this decline are unclear. Four scenarios were implemented in the model to test hypotheses behind the possible drivers of this observed decline. We implemented (i) climate variability, (ii) reduction of yearling survival, (iii) reduction in the fecundity of mothers, and (iv) density dependence (gradual decline in food availability) (Goedegebuure, 2018).

Each of the four scenarios demonstrated parameter regimes where the population declined. With implementation of some of the scenarios, the modelled population collapsed, leading to local extinction; with others the population stabilised after the initial decline. Importantly, for specific parameter choices the simulated population decline was similar in magnitude and rate of the observed decline at Macquarie Island. The preliminary analyses suggest that each of the scenarios have the capacity to reproduce the observed population decline in southern

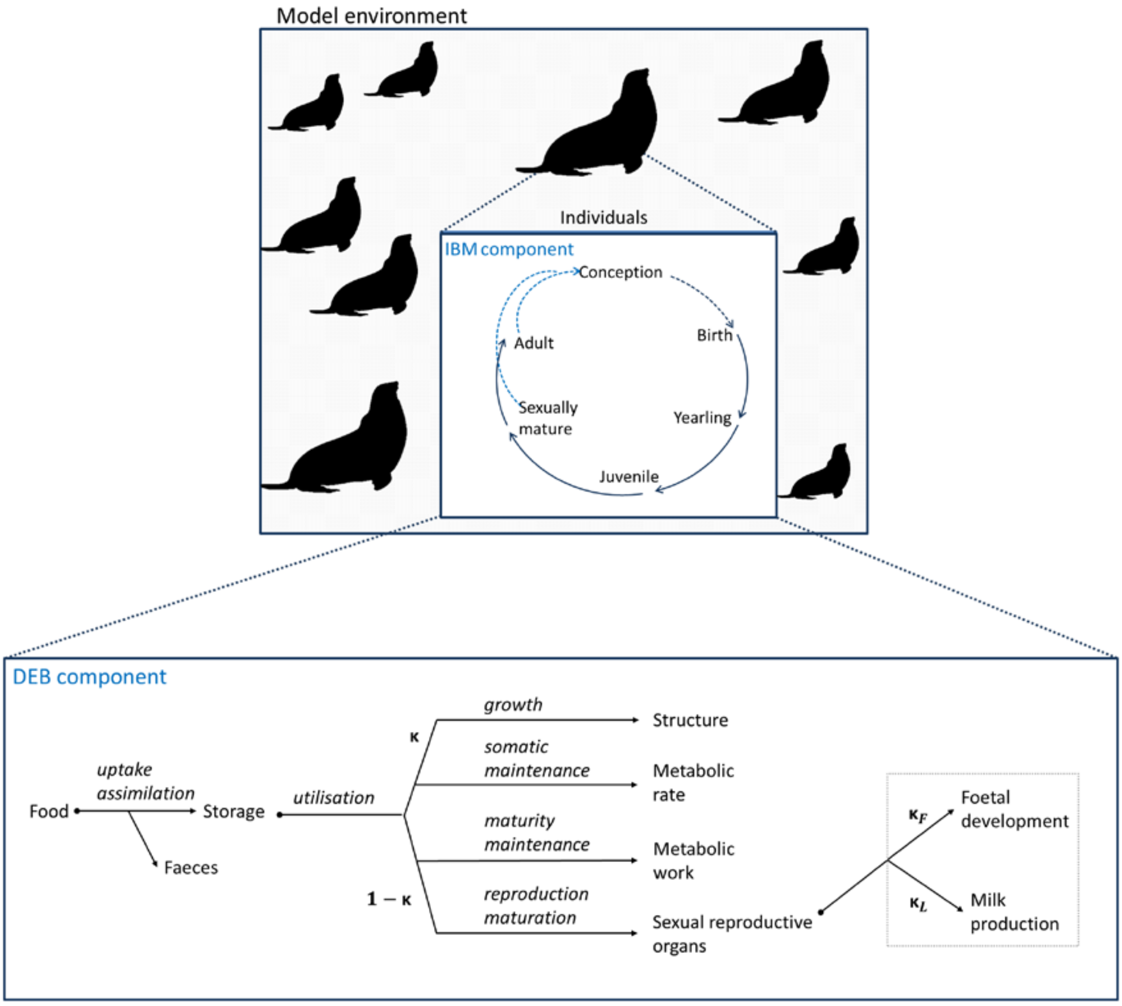

Figure 1: The DEB-IBM environment contains individuals of different age and stage classes. Each individual steps through their life stages and behaviour through the stochasticity of the individual-based modelling (IBM) components, based on feeding and energy use determined by the dynamic energy budget (DEB) components. Where food is ingested, energy is extracted and added to the reserves (storage), and utilised for; growth; somatic maintenance; maturity maintenance, and reproduction maturation. Absolute priority is given to energy allocation for growth and somatic maintenance (κ). Any 'left over' energy (1 – κ) is utilised for maturation (embryos and juveniles) or reproduction and maturity maintenance (adults) (kappa rule, Kooijman, 2010).

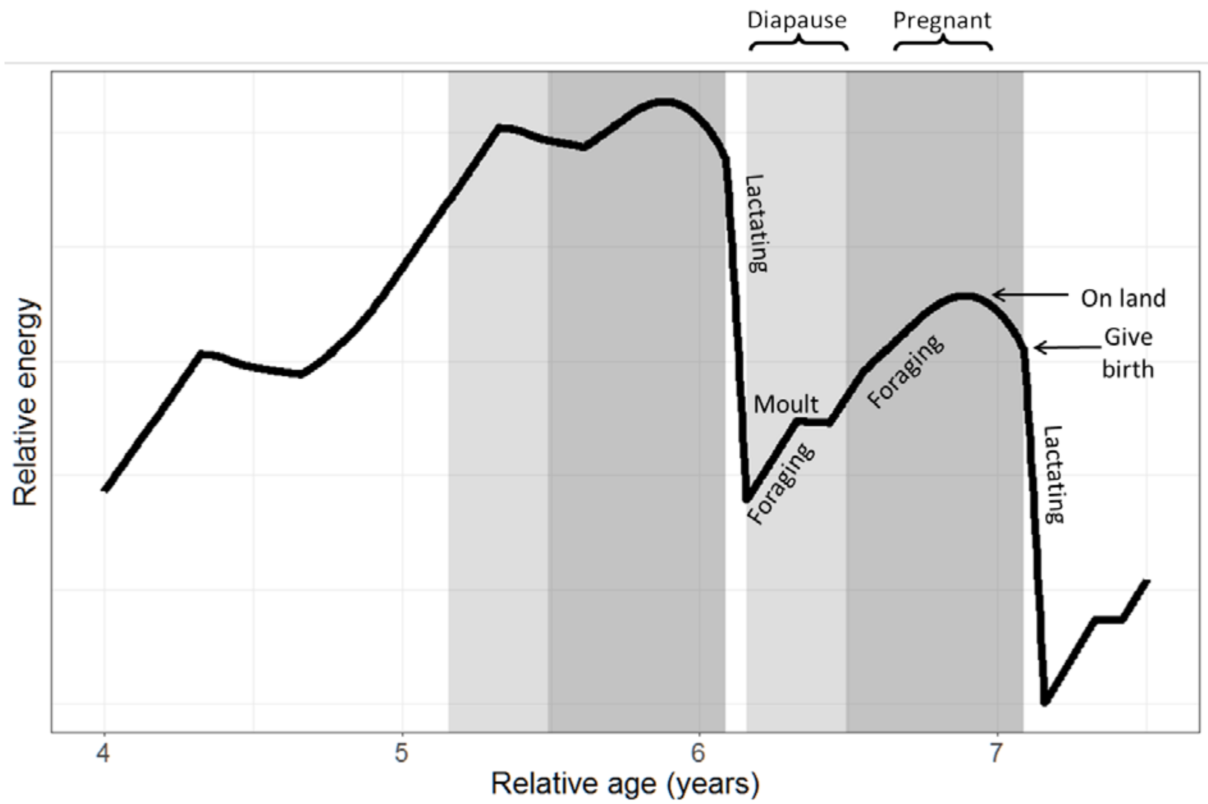

Figure 2: Model results for relative energy storage and use by an individual mother over two consecutive pregnancies. Relative age is included to show the timeframe before, during and after pregnancies. Energy stores are depleted during fasting periods while the individual is on land (moulting and lactating), and are replenished during foraging trips (pre- and post-moulting periods). The reproductive energy storage fluctuates with behaviour and pregnancy requirements (as labelled). Grey background panels indicate stages of pregnancy: light grey indicates the period from conception to implantation (120-day diapause); and dark grey indicates post-implantation (i.e. foetal development) period.

elephant seals at Macquarie Island, and may thus be a possible driver of that decline. Further analyses and comparison with the observations are required before we can make further conclusions regarding the likelihood of these scenarios causing the observed population decline. While we present here a model that was parameterised for southern elephant seals on Macquarie Island, it is relatively simple to implement this model for other sub-populations of southern elephant seals – including those on the Kerguelen Plateau. The model could also be adapted to represent other colony-breeding predator species such as penguins. Models such as this can be used to answer ecological questions on how populations are affected by intrinsic and extrinsic changes.

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