Variations in behavior and condition of a Southern cean top predator in relation to *in situ* oceanographic conditions

M. Biuw [†], L. Boehme , C. Guinet[‡], M. Hindell[§], D. Costa[¶], J.-B. Charrassin , F. Roquet , F. Bailleul[‡], M. Meredith , S. Thorpe , Y. Tremblay[¶], B. McDonald[¶], Y.-H. Park , S. R. Rintoul^{††}, N. Bindoff^{‡‡}, M. Goebel^{§§}, D. Crocker[¶], P. Lovell , J. Nicholson^{¶¶}, F. Monks , and M. A. Fedak

*Natural Environment Research Council Sea Mammal Research Unit, Gatty Marine Laboratory, University of St. Andrews, St. Andrews, Fife KY16 8LB, United Kingdom; [†]Centre d'Etudes Biologiques de Chizé, Centre National de la Recherche Scientifique, Villiers-en-Bois, F-79360 Beauvoir sur Niort, France; [§]Antarctic Wildlife Research Unit, School of Zoology, University of Tasmania, P.O. Box 252-05, Hobart, TAS 7001, Australia; [¶]Center for Ocean Health, Institute of Marine Sciences, Long Marine Laboratory, University of California, 100 Shaffer Road, Santa Cruz, CA 95060; Laboratoire d'Océanographie Physique Muséum National d'Histoire Naturelle, 43 Rue Cuvier, 75231 Paris Cedex 05, France; **British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom; ^{††}Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine and Atmospheric Research and Antarctic Climate and Ecosystems Cooperative Research Centre, G.P.O. Box 1538, Hobart, TAS 7001, Australia; ^{‡‡}Antarctic Cooperative Research Centre, University of Tasmania, P.O. Box 252-80, Hobart, TAS 7001, Australia; ^{§§}Antarctic Ecosystem Research Division, National Oceanic and Atmospheric Administration, 8604 La Jolla Shores Drive, La Jolla, CA 92038; and ^{¶¶}Valeport Ltd., St. Peter's Quay, Totnes, Devon TQ9 5EW, United Kingdom

Edited by Mary E. Power, University of California, Berkeley, CA, and accepted by the Editorial Board June 18, 2007 (received for review February 8, 2007)

Responses by marine top predators to environmental variability have previously been almost impossible to observe directly. By using animal-mounted instruments simultaneously recording movements, diving behavior, and *n s tu* oceanographic properties, we studied the behavioral and physiological responses of southern elephant seals to spatial environmental variability throughout their circumpolar range. Improved body condition of seals in the Atlantic sector was associated with Circumpolar Deep Water upwelling regions within the Antarctic Circumpolar Current, whereas High-Salinity Shelf Waters or temperature/salinity gradients under winter pack ice were important in the Indian and Pacific sectors. Energetic consequences of these variations could help explain recently observed population trends, showing the usefulness of this approach in examining the sensitivity of top predators to global and regional-scale climate variability.

body condition | ocean observation | oceanography | elephant seals

he Southern Ocean (SO) is one of the most productive of the world's oceans, mainly a result of short, intensive spring phytoplankton blooms (1). Because of restrictions on landocean-atmosphere interactions by the Antarctic ice cap, nutrient supply via rivers and dust is generally small or absent. Input of sedimentary nutrients is limited to coastal shelves, whereas pelagic waters over deep basins can be enriched via nutrient release from melting sea ice (2), advection of nutrient-rich water masses from upstream shelf regions (3), or upwelling from distant sediment sources (4). The spatial and temporal distribution of nutrients is therefore highly influenced by interactions between bottom topography, water mass properties, ocean currents, and sea-ice dynamics. Significant phytoplankton blooms occur mostly on continental or island shelves, in the wake of the retreating sea ice or along frontal systems within the Antarctic Circumpolar Current (ACC) (5). Understanding the responses of higher trophic levels to such spatial and temporal variability is fundamental to the effective management of living resources in the SO, and for predicting how animals may respond to climate change and the consequent changes in ocean circulation, ice dynamics, and biogeochemistry.

It is often difficult or impossible to observe directly how marine predators interact with their environment and the prey within it. It is especially challenging to obtain information on diet and the distribution of potential prey for long-ranging migrating species. Stomach contents and fecal remains are rarely available, and sufficiently detailed surveys of prey distribution are often lacking. Most studies of foraging ecology of marine predators

have instead attempted to correlate habitat use or movement patterns to environmental characteristics (6–8). Such studies do not adequately examine prey choice or food web interactions, but can characterize critical habitats for conservation and management purposes. Relating movement and behavioral data from animal tracking to specific local environmental features is also challenging. For instance, data on ocean surface properties may not be good indicators of environmental conditions relevant to deep-diving species, and subsurface data are often not available at relevant spatial and temporal scales. It is not surprising that some studies have found strong correlations between behavioral patterns and environmental characteristics (8, 9), whereas other results have been more ambiguous (10).

To understand the effects of environmental variability on foraging success and, ultimately, reproductive performance requires not only direct measurements of reproductive output coupled with studies of movement patterns while at sea, but also some method of identifying where and when animals actually improve their body condition. Appropriate feeding indices are often difficult to obtain, and most studies instead use proxies such as changes in movement patterns and time spent within discrete areas. Although these patterns may indicate high search effort, they do not necessarily relate to foraging success or, even more importantly, changes in animal condition.

Southern elephant seals (*Mirounga leonina*) represent a unique opportunity for studying links between environmental variability, individual physiology, behavior, and population dynamics across a range of scales in space and time. They are

Author contributions: M.B., L.B., C.G., M.H., D. Costa, L.-B.C., F.R., M.M., S.T., Y.-H.P., S.R.R., N.B., M.G., D. Crocker, and M.A.F. designed research; M.B., C.G., J.-B.C., F.R., F.B., Y.T., B.M., M.G., and M.A.F. performed research; M.B. and L.B. analyzed data; M.B., L.B., and M.A.F. wrote the paper; P.L., J.N., F.M., and M.A.F. developed hardware and analytical tools; and S.T. was a key researcher on the United Kingdom component of Southern Elephant Seals as Oceanographic Samplers and provided extensive input into manuscript preparation.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission. M.E.P. is a guest editor invited by the Editorial Board.

Abbreviations: SO, Southern Ocean; CTD-SRDL, conductivity-temperature-depth satellite relay data logger; ACC, Antarctic Circumpolar Current; SACCF, Southern ACC Front; SAF, Subantarctic Front; PF, Polar Front; AAIW, Antarctic Intermediate Water; , potential temperature; S, salinity.

[†]To whom correspondence should be sent at the present address: Norwegian Polar Institute, Plarmiljøsenteret, 9296 Tromsø, Norway. E-mail: martin.biuw@npolar.no.

This article contains supporting information online at www.pnas.org/cgi/content/full/0701121104/DC1.

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