

Bayesian Data-Model Synthesis for Biological Conservation and Management in Antarctica

The Problem—Management of Antarctic Living Resources

- Antarctica is a vast, inhospitable continent with large regions that remain essentially unexplored
- Current population abundance estimates are subject to under-reporting and sampling bias: estimates are typically confined to regions close to scientific research stations
- Antarctica is changing in response to commercial fishing, a growing tourist industry, and the effects of climate change
- Management decisions on fishing catch allocations, tourism, and designation of specially protected areas depend on the “best available” estimates of population abundance and dynamics

Expected result: A data-to-knowledge pipeline that harnesses the power of remote sensing for effective resource management in the Antarctic

Our Solution—Data Assimilation for Population Modeling

- A focus on the Adélie penguin: circum-Antarctic distribution and recognized as a key indicator of ecosystem health and status
- Development of a physically-based algorithm to convert satellite remote sensing data to Adélie penguin colony location and spatial extent on a continent-wide basis
- An ecologically-based Dynamic Bayesian Network (DBN) model assimilates remote sensing imagery from various sources with other sources of information such as field counts and predictions from state-space models of population change
- A browser-based geospatial application custom designed to address the needs and concerns of the Antarctic research and management communities

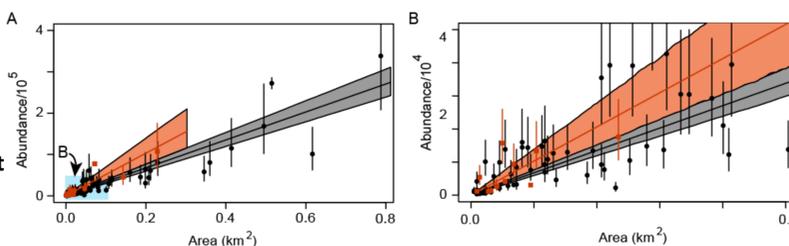
Objective 1: Automated retrieval of Adélie penguin distribution & abundance



- Physically-based algorithm developed to retrieve Adélie penguin colony location and spatial extent
- 249 Landsat ETM+ scenes from around the entire continent of Antarctica were processed
- 248 colonies retrieved with sizes ranging from 900 m² to 616,500 m²
- Low algorithm errors of omission (2-4%) and commission (1%) in comparison to recent studies

- There is a relatively constant “packing density” of nests per unit area within penguin colonies
- A strong correlation was found between Adélie penguin population (measured by other studies) and colony area retrieved from Landsat data
- A Poisson regression was used to model colony abundance as a function of guano stain area

$$Abundance_i \sim Pois(\lambda_i) \left. \begin{array}{l} \log(\lambda_i) = b_0 + \log(Area_i) \end{array} \right\} e^{b_0} = \text{“effective density”}$$



Colony abundance vs. guano stain area. (A) Colony abundance (and 95th percentile confidence intervals) as a function of the area identified as guano in the Landsat-7 survey (black circles = continental Antarctica, orange squares = Antarctic Peninsula), with best-fitting Poisson regression model (and associated 95th percentile prediction envelop; gray-shaded envelop = continental Antarctica, orange-shaded envelop = Antarctic Peninsula). (B) Zoomed in portion shown as blue box in Panel A.



- Several new penguin colonies were identified in the Landsat ETM+ retrieval (unmatched yellow pushpins in this example from the Danger Islands). These are very likely to be comprised overwhelmingly of Adélie penguins.
- Brash Island (far left and near left in hi-res DigitalGlobe imagery [Copyright DigitalGlobe (2014)]) has a population estimated at 166,078 breeding pairs based on the Poisson regression model illustrated above. If verified this would be the 5th largest Adélie colony in Antarctica.
- Phase-2 plans include multi-decadal retrieval using Landsat TM, ETM+ & OMI, plus ground validation to further reduce algorithm errors

Demonstrated Objective-1 success, results submitted for peer-reviewed publication

Partnerships/Process Improvements

Oceanites, Inc.

- This 501(c)(3) scientific and educational organization leads the Antarctic Site Inventory, which is focused on mapping and monitoring the abundance of penguins and other biota for use by Antarctic stakeholders
- Oceanites’ cost-sharing resources include ship time on commercial cruise ships and privately chartered yachts to access breeding colonies for ground validation, plus public outreach via its education program

International Association of Antarctica Tour Operators

- IAATO is a trade organization for Antarctic tour operators with needs for understanding the distribution and abundance of wildlife
- IAATO works with Treaty Parties to develop Site Guidelines for Visitors and participates in the Antarctic Treaty Consultative Meetings
- In Phase-2, we will develop an application that will actively solicit input of data (photos, counts, and other observations) from IAATO and member companies to enable crowd-sourced input of information to resolve ambiguities in the interpretation of satellite imagery

Antarctic and Southern Ocean Coalition

- A coalition of > 30 NGOs involved in Antarctic environmental protection
- ASOC is an active participant in the Antarctic Treaty Consultative Meetings, with the goal of lobbying for ecosystem-based management in the Antarctic, including the establishment of Marine Protected Areas

Antarctic Treaty System’s Committee for Environmental Protection (CEP)

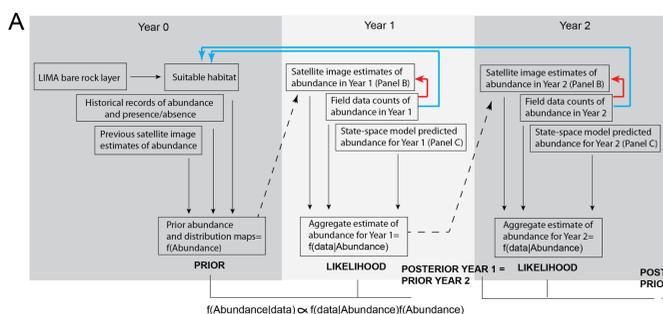
- The CEP is the key advisory body on environmental protection within the ATS
- Proposals for Antarctic Specially Managed Areas (ASMAs) and Antarctic Specially Protected Areas (ASPAs) originate here, as do Site Guidelines for Visitors, and discussion of the environmental impacts of new stations
- Management Plans for ASPAs and ASMAs, as well as Comprehensive Environmental Evaluations (CEEs), currently rely on outdated and/or un sourced data on penguin distributions; our application will have an immediate positive impact on discussions by providing current and transparent estimates of the distribution and abundance of penguins

Commission for the Conservation of Antarctic Marine Living Resources

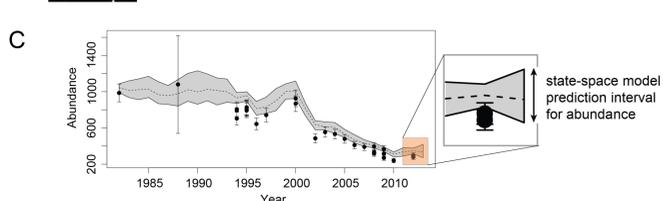
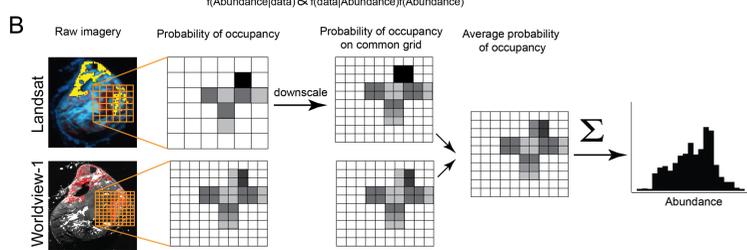
- CCAMLR practices ecosystem-based management to ensure harvesting of krill and other marine resources is sustainable
- The working groups on Ecosystem Monitoring and Management and Statistics, Assessment and Modeling (WG-EMM, WG-SAM) report to the CCAMLR Scientific Committee and advise the SC
- Our decision support software will provide CCAMLR members the ability to plan Marine Protected Areas (MPAs) and compare proposed delineations

Results will help “formulate, adopt and revise conservation measures on the basis of the best scientific evidence available” (CCAMLR Article IX)

Objective 2: Develop an ecologically-motivated Dynamic Bayesian Network (DBN) model that combines satellite and ground based observations in a decision support tool



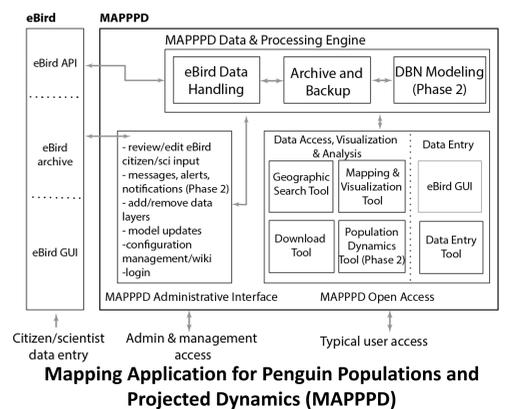
(A) Schematic of data inputs and outputs for Dynamic Bayesian Network model. Field data will be used to tune the satellite imagery analysis algorithms (red arrow), and the models of suitable habitat (blue arrows). (B) Workflow for interpretation and aggregation of satellite imagery to produce a probability distribution representing estimated abundance. (C) State-space model and construction of a prediction interval for abundance.



Objective 3: Unrestricted, browser-based data products of Adélie penguin breeding distribution and abundance

- **Functional design** document written for MAPPDP, which acts as a portal for data assimilation and Adélie population prediction
- **Prototype development** planned as part of the NSF-funded National Socio-Environmental Synthesis Center (SESYNC) Summer Computational Institute
- **Phase-1 implementation:** extensive use of new media for interactive, web-based geospatial visualization of Adélie penguin distribution and abundance, Phase-2 interface for DBN modeling
- **Crowd sourcing:** Citizen-scientist observations (photos, text) entered via an eBird interface, Phase-2 digital object identifier (doi) generation for field survey datasets (aerial photography, autonomous camera, field census) submitted by investigators and non-governmental organizations
- **Resource Management tool:** Assimilation of a wide variety of data types; rapid interactive tools for iterative population estimation and hypothesis formulation; scalable in space from a single colony to the entire continent, in Phase-2 scalable over 4-decades of Landsat TM/ETM/OMI and hi-res Digital Globe observations

Functional design complete, applied for design/build charrette hosted by SESYNC July 7-11, 2014



For more information:

- LaRue, M.A., H.J. Lynch, P. Lyver, K. Barton, D.G. Ainley, A.M. Pollard, G. Ballard. 2014. Establishing a method to estimate Adélie penguin populations using remotely-sensed imagery. *Polar Biology* 37: 507-517.
- Lynch, H.J., and M.A. LaRue. First global survey of Adélie penguin populations. In Press.
- Lynch, H.J., and M.R. Schwaller. Multi-sensor cross validation of Adélie penguin detection and abundance estimation. In Review.
- Schwaller, M.R., C.J. Southwell, and L.M. Emmerson. 2013. Continental-scale mapping of Adélie penguin colonies from Landsat imagery. *Remote Sensing of Environment* 139: 353-364.