Project proposal: Foundation Model Adaptation for Biodiversity of Hawaii

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Background

The National Ecological Observatory Network (NEON) collects an unprecedented variety of ecological data through field sampling and remote sensing. A crucial component of this work involves collecting, counting, and identifying biological specimens that act as environmental indicator species or play ecologically significant roles.

Among these, beetles, particularly ground beetles (Carabidae), are one of the most diverse insect groups. They serve as pollinators, decomposers, and sensitive indicators of environmental change. NEON's work on Carabidae involves sampling specimens from across the continental United States, Puerto Rico, and Alaska, followed by manual identification — a time-intensive process that can take over a year. The resulting data informs biodiversity studies and conservation efforts.

Hawaii, with its unique ecosystems and high proportion of endemic species, presents additional challenges to biodiversity monitoring. Current methods are hampered by limited taxonomic expertise, the high costs and slow pace of manual species identification, and difficulty capturing cryptic or rare species. These gaps highlight the need for innovative, scalable solutions.

Multi-modal foundation models like BioCLIP [1] and CLIBD [2] show promise for assisting with these tasks by leveraging image, text, and DNA data. However, these models have not been specifically adapted or evaluated for Hawaii's unique ecosystems and biodiversity.

Liu et al. [3] demonstrate that multi-modal foundation models can be effectively fine-tuned using various strategies, including (1) prompt-based methods, (2) adapter-based approaches, and (3) techniques leveraging external knowledge.

These methods provide a robust framework for tailoring foundation models to specific ecological and biodiversity challenges, making them highly relevant for addressing Hawaii's monitoring needs.

Problem Overview

Effective biodiversity monitoring and species identification in Hawaii face several challenges:

1. Limited taxonomic expertise to identify the wide range of endemic and introduced species
2. High cost and time requirements for manual species identification
3. Difficulty capturing and identifying cryptic or rare species
4. Lack of comprehensive baseline data on species distributions and abundances

Research Question

Can multi-modal foundation models, such as BioCLIP and CLIBD, be fine-tuned using image, text, and DNA data to improve the efficiency and accuracy of species identification and ecological assessment for Hawaiian Carabid beetles?

Project Goals

- Develop more robust and specialized models by incorporating Hawaii data in low source settings
- Fine-tune the foundational efficiently with less computation and storage requirements
- Assist local conservation efforts through improved monitoring capabilities
- Collect data for new multi-modal modalities (images, DNA, habitat info) during fieldwork

Methodology

Data collection

1. Existing Resources:

- Specimen images and data from the Bishop Museum, NEON, and other collections
- DNA barcoding databases (e.g., BOLD, GenBank)
- Citizen science observations from platforms like iNaturalist
- Species checklists and taxonomic databases for Hawaii

2. Fieldwork Approach:

- We will look at certain beetle taxa that are found in Hawaii (Carabids)
- Our project is going to work closely with the Beetle project
- Data collection will primarily involve imaging beetles in the NEON lab, as the Carabids are not active during our visit. We will utilize NEON's existing beetle samples and imaging equipment to capture high-resolution images for analysis

- We will incorporate DNA data if available, but due to limited on-site expertise, we will not conduct DNA sampling ourselves. Instead, we will rely on existing DNA barcoding data from NEON, if it is available, as well as external sources like the Barcode of Life Datasystem (BOLD)

Technical approach

- We will utilize DNA barcodes for each specimen, if available, to help with understanding biodiversity
- We will build on foundational models such as BioCLIP [1] and CLIBD[2] that are designed for species identification and classification. BioCLIP leverages image and text data, incorporating taxonomic information to enhance biodiversity analysis, while CLIBD integrates DNA sequences with visual and text data for genomics-informed classification.
- To adapt the foundational models to the unique biodiversity of Hawaiian Carabid beetles, we will employ few-shot learning and efficient fine-tuning techniques.
- Zero-Shot Evaluations:
    - As a first step, we will do a zero-shot evaluation of the existing foundational model to establish a baseline for the Carabid Beetles.
- Few-Shot Learning:
    - Similar to BioCLIP, we will follow SimpleShot [5] and use a nearest-centroid classifier for few-shot learning.
    - Linear Probing: We can also fine-tune only the final layers of the foundational models, keeping most of the model parameters frozen. This would limit the generalizability of the foundational model.
- Efficient Fine-tuning:
    - PEFT: We will apply PEFT [4] techniques to efficiently fine-tune low-source data on foundation models [1,2]
- DNA Encoding:
    - Upon the availability of DNA barcodes or sequences for the Carabid beetles, we plan to utilize BarcodeBERT[6] or DNABert [7] respectively as a pre-trained encoder.

Relevance

This project will aim to demonstrate how cutting-edge AI tools can address critical ecological challenges. The integration of advanced AI models with fieldwork provides a unique opportunity to bridge the gap between theory and practice, showcasing the potential of interdisciplinary approaches to biodiversity research.

Hawaii's biodiversity — characterized by a high number of endemic species and significant threats from habitat loss and invasive species — offers a compelling context for this work. Adapting foundation models to these unique ecosystems enables innovative solutions to overcome traditional barriers like resource constraints and taxonomic expertise gaps.

This proposal highlights the broader potential of using AI to generate actionable insights in conservation science. By addressing urgent biodiversity monitoring needs, the project exemplifies the transformative impact of combining ecological knowledge with technological innovation. It underscores the importance of developing scalable tools that can advance both scientific understanding and practical conservation efforts.

References:

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