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pangeo-fish: A Python package for studying fish movement using biologging and earth science data

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Summary

Geo-referenced data plays an important role in understanding and conserving natural resources, particularly when investigating biological phenomena such as fish migration and habitat uses. Biologging, the practice of attaching small devices (called *tags*) to animals for recording behavior, physiology, and environmental data, proves to be invaluable in this field.

As fish can not be tracked directly using tracking devices such as GPS receivers, geolocation models have emerged to estimate fish positions by correlating individual series of physical measurements — e.g. temperature and pressure records — with geophysical reference fields — oceanic temperature and bathymetry — derived from satellite observations and hydrodynamical model outputs.

Beside the difficulty of working with vast earth science datasets (due to their size and diversity), there is no open source implementation for biologged fish tracking. Yet, these fish geolocation models are critical for better understanding fish behavior and are nowadays seen as a powerful tool by policy makers to improve fish management and conservation.

To address this challenge, we developed a Python package, named **pangeo-fish**, for fish tracking estimation. It is based on the Pangeo ecosystem, which offers a unique interoperable, scalable, open source environment for interactive data analysis in the field of big data marine and geoscience.

Statement of need

Biologging consists in attaching onto (or sometimes inserting into) an animal an electronic device that will record in its memory physical and/or geochemical parameters as a function of time so that scientists can reconstruct the activity of the animal, the characteristics of the environment it travels in and the interactions between the two.

These tools can provide a wealth of information on the behaviors and movements of free-swimming marine animals, such as diving and activity patterns, energy use and interaction with environment.

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Figure 1: Promotion of the FISH-INTEL tagging campaign.

However, unlike terrestrial animals or marine mammals, whose positions can be directly estimated using ARGOS or GPS technologies, tracking fish underwater is challenging. To address this issue, various tagging experiments have been conducted on a variety of fish species (Carla et al., 2021; Mucientes et al., 2021), and methods have been proposed for approximating the fish locations, referred to as geolocation models (de Pontual et al., 2023; Woillez et al., 2016).

For studying fish movements, the two widely used electronic tagging technologies are acoustic telemetry and Data Storage Tags (DST, or archival tags). Acoustic telemetry involves a tag that emits an acoustic signal containing a unique ID and possibly sensor data. This signal can be detected by an acoustic receiver when the tagged animal is within range, and the detection data is retrieved from the receiver. As such, acoustic tags do not need to be recovered, but there is no guarantee that the tagged fish will swim around the receivers network.

In contrast, archival tags store sensor measurements at set intervals in their memory. To access the logged data, these tags must either be recovered (which mostly depends on fishers and the local population living along the coast) or transmit their information via satellite. In the former case, tagging campaigns usually promote and possibly reward tag or fish captures (see for instance, the advertisement from the FISH-INTEL campaign on Figure 1). The data from archival tags can offer detailed insights into vertical movement patterns (Heerah et al., 2017) or environmental preferences (Carla et al., 2021; Righton et al., 2010), and can be used to reconstruct migration paths through geolocation modeling.

Figure 2: Example of an acoustic tag (on the left) and a DST (on the right). See the centimeter scale for size reference.

Figure 2 shows an example of an acoustic tag as well as a DST.

The estimation of fish positions depends on the likelihood of the observed data from the DTS's logs, such as temperature at specific depths, alongside the reference geoscience data such as satellite observations and ocean dynamic models. Some approaches can enhance the accuracy of the model's predictions by using additional information, such as telemetric detection data from the acoustic tags mentioned above (Goossens et al., 2023). The use of oceanic models with high spatial and temporal resolutions can significantly improve the accuracy of reconstructed fish tracks. However, higher resolutions involves more data, that requires significant computing power and storage capacity. The Pangeo community handles these challenges, by fostering an ecosystem of interoperable, scalable, open source tools for interactive data analysis in the field of big data marine and geoscience. Therefore, the Pangeo ecosystem represents a powerful mean through which biologists can analyze more easily their biologging data and improve fish geolocation modelling. Not only their results would eventually guide policy makers to manage fish stock in a more sustainable way, they could also be used to forecast potential movement changes due to the ongoing climate change.

Unfortunately, the research community lacks of adaptable, scale and open source implementations of geolocation models. **pangeo-fish** is a Python package that fills this gap.

As its name suggest, the software has been designed to be used within the Pangeo ecosystem on several aspects, therefore accounting for both the users' needs (user-friendly API and meaningful result visualization) and the computational challenges. In particular, **pangeo-fish** has a robust data model based on Xarray and scales computation with Dask.

Data loading processes are furthermore streamlined by libraries like `intake`, `kerchunk` or `fsspec`, and the previously mentioned `xarray` data model enables interactive visualization of the results thanks to tools such as the `hvplot` library and the JupyterLab environment.

Similarly, `pangeo-fish`'s I/O operations are automatically distributed with the combination of Dask and Zarr. The Pangeo software stack provides researchers with the necessary tools to access reference data and perform intensive computations in a scalable and interactive manner. `pangeo-fish` gives ecologists a user-friendly tool for inferring fish locations from archival tag data, hence filling the gap between their expertise and the Pangeo's environment capabilities.

Geolocation Model

pangeo-fish implements a method well established in the fish trajectory reconstruction literature Goossens et al. (2023). It consists of a Hidden Markov Model (HMM).

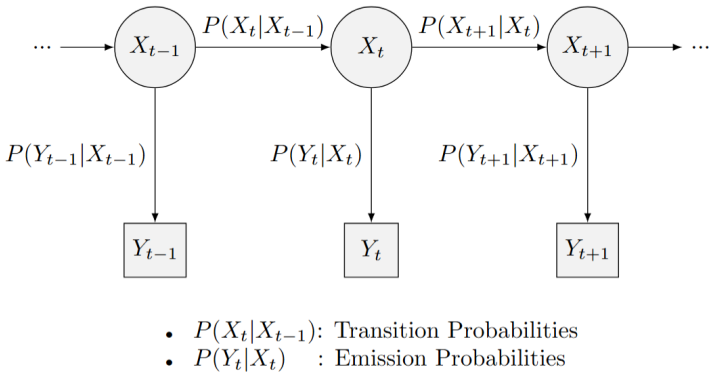

Figure 3: Illustration of the Hidden Markov Model. The hidden states Xt describe the fish's positions, and the emission probabilities $P(Y_t|X_t)$ correspond to the likelihood of observing the fish at time t.

As illustrated in Figure 3, the latent (or *hidden*) states X_t of the HMM infer the (daily or hourly) fish's positions, and the observation process relates the sensor records with the oceanic data. The transition matrix between the hidden states is modelled by a Brownian motion parametrized by σ. As such, fitting the geolocation model for a tag's records aims to determine the value of σ that maximizes the likelihood of the state sequence (i.e., the fish's trajectory) given the observations. The optimal likelihood value reflects the level of residual inconsistency between the tag observed (recorded) and reference data.

Conclusion

pangeo-fish is a Python package that implements a geolocation model, based on a Hidden Markov Model, for estimating fish positions from archival tag and oceanic data. Designed to work with the Pangeo ecosystem, it aims to support the ecologists with their research, by handling backend processes — such as data loading or parallel computation — while exposing a user-friendly interface to manage their archival tag data and run the geolocation model.

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