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Tails of the Deep

A photo-ID catalog for sperm whales of the Northeast Pacific from 1991-2024

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> …I celebrate a tail.
>
> … The more I consider this mighty tail, the more do I deplore my inability to express it. At times there are gestures in it, which, though they would well grace the hand of man, remain wholly inexplicable.
>
> *Herman Melville, Moby Dick*

Summary

The sperm whale (*Physeter macrocephalus*), the largest toothed whale, is a globally distributed, deep-diving marine mammal known for pronounced sexual dimorphism and complex social structure. In the northeastern Pacific, key aspects of their ecology—including movement patterns, stock structure, the connection between high-latitude males and breeding groups, and regional site fidelity—remain poorly understood. This study aims to improve understanding of the geographic and temporal movements of individual whales and contribute to an ongoing assessment of demographically independent populations (stocks) in the eastern North Pacific.

Using the non-invasive method of photo-identification (photo-ID), we compiled a catalog of 90 individual sperm whales from 19 research cruises conducted between 1991 and 2024. These data, archived in the Southwest Fisheries Science Center (SWFSC) catalog, support efforts to map distribution, identify movement patterns, and behavior and will be made publicly available as a NOAA Fisheries Technical Memorandum.

Comparative analyses included matching the SWFSC catalog with other photo-ID catalogs from Hal Whitehead's Dalhousie University lab (photographs from the eastern tropical Pacific), Jan Straley's SEASWAP[1] project (photographs from southeast Alaska), and John Calambokidis/Cascadia Research Collective (photographs from the northeast Pacific). Images were also uploaded to Happywhale and Flukebook for machine learning-assisted matching.

Three matches showed movement patterns of distance and duration described in the Technical Memorandum (Appendix I) consistent with female groups studied in the ETP (Whitehead 2008). No matches were found for mature males from the Gulf of Alaska to other regions. One male, tracked by both SWFSC and Cascadia Research Collective (CRC), was recorded foraging near the Channel Islands over 16 years. Preliminary satellite tagging data from CRC revealed that this whale traveled ~5,000 km toward the Galápagos Islands before returning to the Channel Islands in 2012—the first documented instance of this migratory route by a male sperm whale.

Background and Introduction

The sperm whale, the largest of the toothed whales, is a globally distributed, deep-diving marine mammal known for its pronounced sexual dimorphism and complex social structure.

[1] Southeast Alaska Sperm Whale Avoidance Project

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Distinguished by its massive, square-shaped head, which houses the world's largest brain, the sperm whale uses echolocation to navigate and hunt, they have been known to dive as deep as 2,000m and remain submerged for over an hour (Lockyer 1977, Clarke 1980, Papastavrou *et al.* 1989, Watkins *et al.* 2002 cited in Whitehead 2006). Sperm whales exhibit extreme sexual dimorphism: females can reach up to 11m and 15t while adult males can reach 16m and 45t (Rice 1989). Sperm whales are known to live up to 60-70 years (Rice 1989).

Population Trends

Sperm whales are found throughout the world's oceans in deep (>200m) ice-free waters (Rice 1989, Whitehead 2003). They are a highly social species characterized by stark differences between male and female life histories. The foundation of female social structure consists of long-term units of approximately 11 females and their dependent young, some of whom may be close relatives (Mesnick *et al*. 2003, Whitehead 2003, Whitehead *et al*. 2012,). In the Pacific, units may travel with one or more other units forming temporary large "groups" (Whitehead *et al*. 1991; Whitehead and Kahn 1992). Males leave their natal units between four and 21 years of age and form 'bachelor' groups. As they age, they disperse from these groups and the largest males tend to be solitary (Best, 1979). Females and their dependent young typically occur at latitudes less than 40°, in both hemispheres, except in the North Pacific where they are found at latitudes up to 50°N. Males move to higher latitudes, returning to lower latitudes to mate; however, movement patterns of the mature males remain unclear including when, how often, and where mature male sperm whales migrate during these periods (Whitehead 2003, Whitehead et al. 2008).

Hunted commercially from the 1700's to 1988, a recent study estimates that the global population declined nearly 60% from approximately 1,950,000 individuals to current estimated levels of 845,000 (Whitehead, 2022). Today, sperm whales are protected under the U.S. Endangered Species Act (ESA) and Marine Mammal Protection Act (MMPA). They are listed as "endangered" under the ESA, "depleted" under the MMPA, as "vulnerable" by the International Union of Conservation of Nature (IUCN).

There are multiple regional estimates of abundance for sperm whales in the northeast Pacific. In the U.S. Exclusive Economic Zone (EEZ) off California, Oregon, and Washington, the most recent estimate is 2,606 (CV = 0.135) (Becker *et al.* 2020). For Alaskan waters, Rone *et al.* (2017) estimated 345 (CV = 0.43) sperm whales, and Carretta *et al*. (2023) estimated 5,707 (CV=0.23) for Hawaiian waters. In the Eastern Tropical Pacific, the abundance of sperm whales has been estimated as 22,700 individuals (95% CI=14,800 - 34,600) (Wade and Gerrodette 1993).

Population studies by Moore and Barlow (2017) based on abundance estimates in the California Current from 1991-2014 are inconclusive as to whether the population has increased or decreased. For the Hawaiian Islands Whitehead and Shin (2022) estimated the population in the Hawaiian Islands to be increasing at a rate of 0.1%. In contrast, population trends in the ETP decreasing at an estimated rate of -4.9% and in the Gulf of Mexico at an estimated -.4.2% (Whitehead and Shin 2022). Entanglements with fishing gear, pollution, plastic debris, and ship strikes are among the known pressures on sperm whales, and anthropogenic mortality and injury

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is likely underestimated due to the pelagic nature of this population. The potential biological removal (PBR) level for this stock is 4 animals per year (Carretta et al 2024). Climate change may cause changes in prey availability and distribution due to ocean warming trends.

Stock Structure

Sperm whales found in the California Current are genetically distinct from those of Hawaii and the Eastern Tropical Pacific based on analysis of single-nucleotide polymorphisms, microsatellites, and mitochondrial DNA (Mesnick *et al.*, 2011). Attempts to further refine genetic stock structure in the North Pacific are hampered by several factors, including the complex social and sexual structure, the relationship of high latitude males to breeding groups, low mitochondrial genetic diversity, small sample sizes in some strata, and their highly nomadic behavior. It is hypothesized that the whales of the Eastern Tropical Pacific constitute a single stock (Carretta *et al.*, 2024); however, across decadal time scales, sperm whales can exhibit significant shifts in their geographical distribution (Cantor *et al.*, 2017).

For the purposes of managing sperm whales in U.S. waters under the MMPA, NOAA Fisheries delineates sperm whales in the northeast Pacific into three stocks: 1) California, Oregon and Washington waters, 2) the waters around the Hawaiian Islands, and 3) Alaska waters (Carretta *et al.* 2024). An evaluation is underway to assess whether these stocks meet the criteria for "demographically independent populations" (DIPs) under the Marine Mammal Protection Act (MMPA) (NMFS 2016).

Sperm whales in the northeastern Pacific remain understudied—particularly with respect to their movement patterns, stock structure, the connection between high-latitude males and breeding groups, and regional site fidelity. Understanding genetic differentiation and movement patterns—such as through photo-ID comparisons—is critical to this determination.

Movements

Research on the movements of sperm whales of the North Pacific is complicated by the difficulty of obtaining data across their broad and continuous distribution. Both males and females are known to travel great distances in the Pacific Ocean basin with males covering longer distances than females (Kasuya and Miyashita 1988, Mizroch and Rice 2013, Straley 2014, Wild *et al.* 2024). Discovery mark data show whales covering distances of up to 5,000 km from Southern California along the west coast of the U.S., and as far north as the western Gulf of Alaska (Mizroch and Rice, 2013). Satellite data from 29 whales tagged in southeast Alaska documents five whales traveling south along the west coast of North America as far as southern California and Baja Mexico, and one whale as far as into the Gulf of California (Wild *et al.*, 2024). A 15-year photo-ID study of sperm whales (gathering 11,255 photographs) in the Eastern Tropical Pacific showed groups of females and immatures making regular movements between the Galàpagos Islands to Panama, Ecuador and Peru, and eight individuals moving from the Galàpagos to the Gulf of California, and one case from Panama to the Gulf of California (Whitehead *et al.* 2008).

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Using Photo-ID to study Sperm Whales

Scientists use a variety of tools to study sperm whales including visual sightings, satellite tags, bioacoustics, genetic sampling, drones, and photo-ID, a non-invasive capture-recapture technique involving photographing a unique feature of an individual–in the case of sperm whales this is the training edge of the whale's tail caught as it is diving–and storing them in a catalog to match with future photographs–or recaptures–of the same individual. A successful photograph must be taken of the ventral side (underside) of the fluke, just before the whale dives.

PHOTO-ID CAPTURE, SPERM WHALE FLUKE SHOWING TRAILING EDGE.
SOURCE NOAA: SPERM WHALES (PHYSETER MACROCEPHALUS) PHOTOGRAPHED IN THE GULF OF MEXICO. CREDIT: NOAA FISHERIES (PERMIT #779-1633) (FISHERIES 2024)

Photo-ID is used by cetacean scientists to identify, catalog, and study marine mammals and is used to track individual whales over space and time and to study their behavior, distribution, and abundance (Arnbom 1987, Dufault et al. 1995). Photo-ID allows researchers to:

- Estimate population sizes, and distribution and track changes over time.
- Understand migration routes and movement patterns.
- Reveal how individuals interact with each other, including who associates with whom and the stability of social groups.
- Provide information on calving intervals, life spans, and other key life history parameters.

Over the years, photo-ID has evolved, first with the advent of digital cameras, and, next, with the advent of artificial intelligence. Flukebook[2] and Happywhale[3] are two publicly available platforms commonly used to capture and store photo-ID that utilize artificial intelligence. These programs use algorithms developed with the assistance of artificial intelligence to facilitate the process of comparing whale identification photos: algorithms find potential matches which are then visually reviewed by researchers. These platforms allow researchers and citizen scientists to upload photographic data sets, facilitating the comparison of data across catalogs and even citizen science data. Happywhale has developed a catalog of humpback whales (*Megaptera novaeangliae*) that has captured what are believed to encompass most living individuals (27,956 unique individuals) in the North Pacific Ocean, combining 39 separate catalogs, supplemented with community science data. Happywhale's image recognition algorithm can identify recaptures with an estimated 97-99% accuracy (Cheeseman et al. 2023).

[2] Flukebook: https://www.flukebook.org/
[3] Happywhale: https://happywhale.com/home

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Project goals

The specific goals of this project were to:

- Develop a sperm whale photo-ID catalog utilizing the SWFSC research data.
- Import the catalog to Flukebook and Happywhale, identify matches with other catalogs or entries.
- Analyze results for information that can add to the understanding of the population structure, temporal distribution, and movements of sperm whales in the North Pacific.
- Contribute to a distinctive independent population (DIP) analysis NOAA is conducting, combining these data with others to refine the understanding of sperm whale population structure and movements.

Broader Research questions

- Combined with the additional existing data and analysis, what can we learn with respect to:
    - How many stocks of sperm whales are there in the eastern N Pacific: are the currently defined (HI, CA/OR/WA and AK) stocks valid?
    - Where do Alaska males go when they migrate to mate with females?
- What new data are needed to address these questions?
- How can artificial intelligence platforms be used to collaborate with other sperm whale researchers? What outcomes would that make possible, and would the matching process be accelerated?
- Can this information be used to design conservation strategies? For example, how can it be applied to the design of Marine Protected Areas and Marine Mammal Corridors? What other strategies can be used to protect this species from anthropogenic pressures?
- What additional research is needed?

The primary audience for this work is NOAA scientists and managers, and in addition, marine mammal researchers, conservation professionals, fisheries managers, and policymakers. After peer review this catalog will be published by NOAA and made publicly available on the SWFSC Publication Portal and NOAA Institutional Repository. The catalog can be used in future stock assessments, abundance estimates and distribution studies in combination with other data – such as acoustic recordings, genetic, and tagging data.

Methodology: Developing the Catalog

NOAA maintains photo-ID catalogs of sperm whales in the North Atlantic and the Gulf of California. NOAA's Southwest Fisheries Science Center (SWFSC) has a repository of 100 individual sperm whales documented with photo-ID dating back to 1991, which have been reviewed and partially compiled through 2008. The remaining photographs from surveys from 2009 to 2024 had not been analyzed or catalogued.

Photographs of sperm whales were collected from cruises conducted in the northeast Pacific by the SWFSC, from research vessels operated by CRC, and opportunistically by citizen scientists. The SWFSC has been conducting shipboard visual line-transect cetacean abundance surveys

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since 1986 (Kinzey, Olson, Gerrodette 2000; Jackson *et al.* 2003). The collection of photographs from the SWFSC cruises are the basis of this catalog.

During SWFSC visual line transect surveys, date, time, latitude and longitude, species, group size, and behavior were recorded for all cetacean sightings, including sperm whales (Figure 1). Visual detections of discrete groups of cetaceans were called "sightings", and each group was given a unique sighting number for that cruise. Some of the sperm whales sighted on the line transects were single individuals and some were groups comprised of sub-adult males or of females and their dependent young. Photographs of sperm whales were obtained opportunistically during the surveys as time permitted – the primary research objective was collecting sighting data; so, photographs were not obtained from every sighting, and not all individuals of a group were likely photographed. Thirty-five mm SLR film cameras using both black and white negative and color slide films were used through 2003; after 2003 digital SLR cameras were used almost exclusively. Black and white negative and color slide films were scanned into digital format for analysis.

To be included in the catalog, photographs had to be sufficiently high resolution to show the unique shape of the trailing edge with enough clarity to differentiate it from other individuals. Researchers reviewing photographs selected good quality photographs based on focus, resolution, angle, and visibility of the fluke's trailing edge. Photographs that were excessively grainy, angled, or obscured by water or other objects, were excluded unless a distinctive and highly identifiable feature was visible that could permit a positive identification in the future (photographs were not scored for distinctiveness). The highest quality photo of each individual from each sighting was selected to represent the individual and given a unique number in the catalog. Photographs of unique whales were compared by eye within and between years to identify any re-captures. Photographs lacking location data and/or dates were excluded.

Photographs and their accompanying metadata (date, latitude, longitude) from the ID catalog were imported to Flukebook. Previously, 47 of the 90 identification photographs in this catalog had been imported to Happywhale. We imported the additional ID photos identified in the study. The photographs were analyzed using the algorithms of Flukebook and Happywhale to identify potential matches and the photos and associated metadata deposited on the sites to facilitate future matches.

Catalog Organization

Individual whales are assigned unique ID numbers – NEP for northeastern Pacific, followed by a three-digit number (e.g. NEP_001). Photographs of each whale were labeled with the individual's number on the lower left corner. Whale identification numbers are not consistently sequential due to the timing of the photographs being incorporated into the catalog.

Once the full SWFSC catalog was compiled, we worked with other research organizations in the region that were known to have collected sperm whale photo-ID. One was Hal Whitehead's (Dalhousie University) extensive research catalog of sperm whales to the south (from the Eastern Tropical Pacific including the Gulf of California to Ecuador and the Galàpagos Islands) which are in Flukebook. Second was Jan Straley's (University of Alaska) catalog of adult males in

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southeast Alaska (SEASWAP). A third was the CRC, which conducts cetacean research on the U.S. West Coast and Hawaii. The SWFSC collaborates with all three of these research teams.

Results

Photographs were collected from 19 SWFSC research cruises from 1991 to 2024 (Appendix I). The cruises were conducted off the coasts of Alaska, the U.S. West Coast and Canada, the Hawaiian Islands, the Eastern Tropical Pacific (ETP), and within the Gulf of California.

The photo-identified whales were located throughout the northeastern Pacific (Appendix I, Figure 2), including 9 from the Gulf of Alaska, 26 from the U.S. West Coast, 26 from Mexican waters including the Gulf of California, and 30 from the tropical north Pacific. During the SWFSC cruises in the Eastern Tropical Pacific, the survey transect lines extended into the very northern portion of the Southern Hemisphere. For completeness, photographs collected from those survey lines off Ecuador and northern Peru were included. There were three intra-annual matches within the catalog, and five inter-annual matches found. Full results are described in the attached Technical Memorandum (Appendix I).

The current draft of the Technical Memorandum containing the catalog is shown in Appendix I. **This draft is for reference only and not intended for publication, citation or reproduction.** A copy of the final report will be published on the website of the SWFSC and NOAA. The draft technical memorandum will not be published on e-scholarship.

Discussion

The SWFSC photo-ID catalog was combined with photo-ID from collaborating scientists. The combined photo-ID catalogs of the northeast Pacific yielded 250 photo-IDs. In an estimated population of 26,000, the 250 photos do not constitute a large sample size, and it is expected that few or no matches would be found. Additional data from CRC from the Hawaiian Islands and the West Coast of the US is expected to increase the sample size.

The matches found showed movements within ranges and time frames that comport with distances and time frames summarized in the long-term study of the ETP female sperm whale groups in the ETP (Whitehead et al. 2008). The four whales observed in the Gulf of California and three years later in the ETP, as reported by Jaquet et al. (2003) are consistent with the movements observed in the same study but are not typical of most of the groups observed in that region who tended to remain in the ETP between the Galàpagos Islands, Ecuador and Peru. One mature male was documented by photo-ID 15 times in the Channel Islands and this would constitute the first known instance of a mature male consistently foraging in this location and traveling toward the ETP.

Possibilities and limitations of photo-ID

Photo-ID one of the most established methods for identifying individual cetaceans and other wildlife, and while it evolves due to digital photography and artificial intelligence, photo-ID remains uniquely valuable for behavioral studies. Sometimes it is the only method to track

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movements of animals, especially over long distances and extended time frames, as many as decades. Because sperm whales live over 70 years, and are known to travel thousands of miles, photo-ID is well suited to this species. It can be used to identify social interactions and individual behaviors, especially of an intelligent marine mammal that has shown that it does not conform to a generalized set of rules. Combined with other techniques – e.g. bioacoustics, satellite tagging, and genetic data – photo-ID can yield information that are needed to better understand the social structure and behavior. In this case more will be learned by combining observation and genetic sampling data to some of the photo-ID, if recorded. This will start to paint a bigger picture of these whales' behavior and social structure. Photo-ID presented in this study was used to identify an individual who then was tagged with a satellite tracker to produce data on a single whale's use of the habitat over 16 years.

Conversely, photo-ID is limited for this species by several factors. Sperm whales spend much of their time in the open ocean, and submerged, making them difficult and costly to find. Photographic evidence does not always conform to the requirements of photo-ID. Sperm whales do not always show their flukes when diving, and photo-ID is also not always successful at capturing the whale with the correct angle, within a decent distance, and camera focus to create a photo of high enough quality to qualify for photo-ID.

Flukebook and Happywhale AI-enabled computer vision platforms were found to be useful in finding matches. However, manual review is necessary in all cases. The additional value of having photo-ID from multiple sources across an ocean basin exist in the same platform can yield immense value for sperm whale research, for example, matches between the northeast Pacific and the ETP were found in this study between two catalogs. However, because not all the catalogs are in each platform matches could be left undiscovered.

Conclusion

There is much to learn about sperm whale social structure, movement, and behavior. Once published, this photo-ID catalog will establish a reference point for future research of sperm whales in the northeast Pacific. There is opportunity to enrich the knowledge base by combining photo-ID with genetic, bioacoustic, and tagging data to further contextualize the findings, and provide more insights into the behavior and social structure of sperms whales in the northeast Pacific, particularly with respect to the spatial and temporal movements of mature males and their relationships to female groups. Collaboration with other research organizations in the Pacific basin is essential for the understanding of this wide-ranging, social, and intelligent species.

Beyond this study, investing in sperm whale research is vital for the conservation of this iconic species, which, as an apex predator, plays an important role in maintaining healthy ocean ecosystems. As key players in the marine food web, sperm whales help regulate prey populations and contribute to ocean nutrient cycling. These whales offer opportunities for whale watchers and the ecotourism industry as well as existence value as demonstrated by their status as protected species globally. Scientific research is still underway to understand the unique biology of this deep-diving species, and new technologies will enable more discoveries in years to come.

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Despite the international moratorium on commercial whaling, sperm whales are vulnerable to threats such as ship strikes, entanglement in fishing gear, ingested plastic pollution, and underwater noise from ships, seismic exploration, and naval exercises. Additionally, climate change is altering their habitats and food availability in ways we are only beginning to understand and that are difficult to predict. Research provides the data necessary to track population trends, understand behaviors and migration routes, and implement effective protection policies. Continued investment in scientific studies and monitoring must support efforts to design evidence-based protection policies for sperm whales, supporting the recovery of this extraordinary species.

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