Progress Update: Department of the Navy – US Pacific Fleet Environmental Readiness Division

# Project

Advancing monitoring capacity in Hawaii through non-invasive triaxial accelerometry tags to evaluate fine-scale responses of marine mammals to disturbance

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September 5, 2025

# REPORT DOCUMENTATION PAGE

*Form Approved*
**OMB No. 0704-0188**



| 1. REPORT DATE *(DD-MM-YYYY)* | 2. REPORT TYPE | 3. DATES COVERED *(From - To)* |
|---|---|---|
| 05-09-2025 | Progress Update | 2022-2025 |

**4. TITLE AND SUBTITLE**
ADVANCING MONITORING CAPACITY IN HAWAII THROUGH NON-INVASIVE TRIAXIAL ACCELEROMETRY TAGS TO EVALUATE FINE-SCALE RESPONSES OF MARINE MAMMALS TO DISTURBANCE

**5a. CONTRACT NUMBER**
N62470-20-D0016

**5b. GRANT NUMBER**
W9126G-22-2-0033

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
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Aude Pacini
William Gough

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
University of Hawaii at Manoa Marine Mammal Research Program Hawaii Institute of Marine Biology 46-007 Lilipuna Rd Kaneohe, HI 96744

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Commander, U.S.Pacific Fleet, 250 Makalapa Dr. Pearl Harbor, HI

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**12. DISTRIBUTION AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
This project advanced marine mammal monitoring capacity in Hawai'i through the deployment and analysis of non-invasive triaxial accelerometry biologging tags to quantify fine-scale behavioral and energetic responses of protected species to potential anthropogenic disturbance. Conducted from 2022–2025 under a cooperative agreement co-funded by the National Marine Fisheries Service and the Office of Naval Research, the work addressed critical information needs associated with Navy activities within the Hawaii Range Complex, which overlaps habitat for more than 30 protected marine mammal species. A total of 95 tag deployments were completed on humpback whales (*Megaptera novaeangliae*), short-finned pilot whales (*Globicephala macrorhynchus*), false killer whales (*Pseudorca crassidens*), and a Hawaiian monk seal (*Neomonachus schauinslandi*), generating foundational datasets that include first-ever accelerometry deployments on free-ranging false killer whales and novel documentation of humpback whale reproductive behavior. Analytical efforts produced peer-reviewed publications and transferable energetic frameworks that provide baseline parameters directly applicable to Population Consequences of Disturbance modeling. In parallel, the project emphasized local capacity building through hands-on training, workshops, and mentorship, and established durable data infrastructure to ensure long-term stewardship of Navy-funded datasets. Collectively, these efforts deliver actionable science while strengthening regional expertise essential for long-term marine mammal monitoring and management.

**15. SUBJECT TERMS**
Monitoring, marine mammals, toothed whales, satellite tagging, Customized Animal Telemetry tags (CATS), biologging devices, passive acoustic monitoring, Hawaii Range Complex

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON<br>Department of the Navy |
|---|---|---|---|---|---|
| a. REPORT<br>Unclassified | b. ABSTRACT<br>Unclassified | c. THIS PAGE<br>Unclassified | UU | 7 | 19b. TELEPONE NUMBER (*Include area code)*<br>808-471-6391 |

**Abstract:**

This project advanced marine mammal monitoring capacity in Hawai'i through the deployment and analysis of non-invasive triaxial accelerometry biologging tags to quantify fine-scale behavioral and energetic responses of protected species to potential anthropogenic disturbance. Conducted from 2022–2025 under a cooperative agreement co-funded by the National Marine Fisheries Service and the Office of Naval Research, the work addressed critical information needs associated with Navy activities within the Hawaii Range Complex, which overlaps habitat for more than 30 protected marine mammal species. A total of 95 tag deployments were collected for humpback whales (*Megaptera novaeangliae*), short-finned pilot whales (*Globicephala macrorhynchus*), false killer whales (*Pseudorca crassidens*), and a Hawaiian monk seal (*Neomonachus schauinslandi*), generating foundational datasets that include first-ever accelerometry deployments on free-ranging false killer whales and novel documentation of humpback whale reproductive behavior. Analytical efforts produced peer-reviewed publications and transferable energetic frameworks that provide baseline parameters directly applicable to Population Consequences of Disturbance modeling. In parallel, the project emphasized local capacity building through hands-on training, workshops, and mentorship, and established durable data infrastructure to ensure long-term stewardship of Navy-funded datasets. Collectively, these efforts deliver actionable science while strengthening regional expertise essential for long-term marine mammal monitoring and management.

**Background:**

The Navy has expressed interest in obtaining information from marine mammals in the Hawaiian Island region to explore the potential consequences of Navy training on the long-term health of these species, particularly those that are listed under the Endangered Species Act (ESA). The Navy's Hawaii Range Complex overlaps with the habitat of >30 species of protectedwhales, dolphins and one phocid species, the endangered Hawaiian monk seal (*Neomonachus schauinslandi*). It is, therefore, crucial to ensure a strong and locally-based science team to monitor the potential impacts of anthropogenic activities on these species.

The Navy's marine mammal monitoring efforts in the Western Pacific region have focused mainly on the use of satellite telemetry, photo-identification, and passive acoustic monitoring to provide broad-scale response metrics to military acoustic exposure. However, these methods do not currently offer the resolution needed to measure immediate short-term responses and effects on exposed animals. Fortunately, non-invasive archival tags now have the capacity to integrate several synchronized data streams (including high-resolution triaxial accelerometry, video and acoustic data) in odontocete, mysticete, and pinniped species. These tags provide anopportunity to measure fine-scale baseline data (Bejder et al., 2019) as well as short-term behavioral and physiological response metrics associated with a stressor (Mikkelsen et al. 2019; Elmegard et al., 2021**;** Czapanskiy et al., 2021). These baseline and acute response data areimportant to quantify effects of disturbance and to inform predictive models such as the Population Consequences of Disturbance framework (PCoD) (Booth et al. 2020; Pirotta et al., 2021).

Using the mysticetes tag-analysis toolkit developed by Stanford University, tag deployments on a range of mysticete and odontocete cetacean species have begun to yield crucial results

at the interface of ecology, behavior, biomechanics, kinematics and physiology (e.g., Cade et al., 2016**;** Goldbogen et al., 2017; Goldbogen et al., 2019a,b**;** Gough et al., 2019; Czapanskiy et al., 2021). This toolkit was made available as an open resource in 2020 with a formal week-long training led by Dr. David Cade and Dr. Gough. This toolkit can be found on Github (https://github.com/cadede/CATS-Methods-Materials)

With tag development evolving rapidly, it is important to continue the foundational work to generate an analysis platform that can be expanded to new tags, species and regions. Because of its current effort and existing capacity, the Marine Mammal Research Program (MMRP) can ground truth, expedite, and disseminate the tools that will be derived from this project to other researchers working on Navy's priorities and marine mammal conservation.

In light of this background, funding was provided to employ Dr. Will Gough as a post-doctoral researcher through a Cooperative Agreement titled: "*Advancing monitoring capacity in Hawaii through non-invasive triaxial accelerometry tags to evaluate fine-scale responses of marine mammals to disturbance*". This effort is co-funded by National Marine Fisheries Service and the Office of Naval Research. Below is a review of progress on this project.

**Primary Goals and Progress on this Project:**

For the period of funding (September 6th, 2022 – September 5th, 2025), the Marine Mammal Research Program (MMRP) employed a postdoctoral researcher (William Gough, PhD) to advance monitoring capacity in Hawai'i through the collection, analysis, and application of non-invasive triaxial accelerometry data. Over the course of the award, Dr. Gough worked toward the successful completion of four interconnected Award Goals focused on data collection, behavioral and energetic analysis, local capacity building, and the development of durable data infrastructure. Collectively, these efforts have resulted in foundational datasets, novel analytical frameworks, peer-reviewed scientific outputs, trained personnel, and long-term infrastructure that support Navy and NOAA priorities related to the monitoring and management of marine mammals. Details of each Award Goal and the progress made are outlined below:

1) ***Award Goal 1*** **- Data Collection on Species of Interest** - To collect baseline behavioral and physiological data on species that are currently of interest to the Navy and NOAA through the deployment of non-invasive tri-axial accelerometer tags around the main Hawaiian Islands.
2) ***Award Goal 2*** **- Behavioral Data Analysis** - To use the collected accelerometry datasets to explore fine-scale behavioral signatures (e.g., locomotion, respiration, diving, vocalization) as well as their variability in response to anthropogenic stimuli.
3) ***Award Goal 3*** **- Local Capacity Building** - To generate training materials and build local capacity in Hawaii, ensuring that local researchers at the MMRP (Marine Mammal Research Program) and interested members of NOAA PIFSC, the Navy, and other community groups have the ability to work independently with accelerometry data in the field and in the lab.
4) ***Award Goal 4*** **- Building Data Infrastructure** - To build critical infrastructure and data-handling protocols at the MMRP lab, allowing for safe storage and easy data access for lab members and collaborators.

***Award Goal 1:*** Under this award, Dr. Gough acted as primary tag support for five field expeditions, and secondary tag support for five additional expeditions. These efforts are outlined

in the table below (Table 1). The goal of each expedition was to collect behavioral and movement data from species of interest using Customized Animal Tracking Solutions (CATS) biologging tags. These field expeditions also served Award Goal 3 (Local Capacity Building) in training graduate students and interns in tag preparation, deployment and data analyses. This resulted in a total of **95 tag deployments** on species including humpback whales (*Megaptera novaeangliae*; HBW), false killer whales (*Pseudorca crassidens*; FKW), and short-finned pilot whales (*Globicephala macrorhynchus*; SFPW), and Hawaiian monk seals (*Neomonachus schauinslandi*).

As primary tag support, Dr. Gough was responsible for the maintenance and preparation of biologging devices prior to field expeditions, small-boat operations for deployment and recovery of biologging devices, and processing of recovered data for subsequent analyses. As secondary tag support, Dr. Gough assisted trained graduate students (e.g., Augusta Hollers, Jens Currie) to successfully perform all primary tag support activities, providing on-site or remote assistance as necessary.

The majority of tag data was collected from humpback whales (**n=83**) during the period of funding. This included calves (n=19), yearlings (n=3), mothers (n=24), male escorts (n=16), males engaging in reproductive competitive groups (n=4), and foraging adults (n=17). These deployments included the first known tag-based visual documentation of reproductive behavior for this species. These deployments are being analyzed by MMRP graduate student August Hollers as part of an LMR-funded project that commenced in Spring 2025 with further funds being contributed from an ONR-award commencing in October 2025. This research is outlined below in further detail (Award Goal 3).

Field efforts also led to the first triaxial accelerometry tag deployments on free-ranging false killer whales (**n=5**). One of these deployments included video and data from a "prey-sharing" cooperative foraging encounter, allowing novel insight into this unique behavior. These deployments are being used by MMRP graduate student Jens Currie as part of his dissertation work. This research is outlined below in further detail (Award Goal 3).

Dr. Gough also helped the team collect a ~50 hour deployment on a short-finned pilot whale and gave the team an opportunity to track a tagged animal as well as work out logistics to successfully recover a biologging tag >50 nautical miles from shore. This deployment was a successful test of a prototype CATS tag that can be deployed on deep- diving animals (up to 2000 m) and included headlights that can be used to illuminate behaviors at depth. In subsequent deployments, these headlights captured presumed foraging events (corroborated by time-synced acoustic foraging "buzzes") for the first time. These deployments (**n=6**) have been analyzed by Dr. Gough, resulting in a published manuscript (Gough et al., 2025 – described in further detail below [Award Goal 2]).

Under this award, Dr. Gough also assisted NOAA PIFSC and MMRP graduate student Kirby Parnell as secondary tag support with the preparation of CATS tags, resulting in a successful Hawaiian monk seal deployment (**n=1**).

During the period of funding, Dr. Gough used external funding (through ONR grant no. N000142212721) to act as tag support for a field effort (field expenses were externally funded)

in Baja California Sur (Feb-March 2025), with the goal of training a previously mentored MMRP intern (Cameron Nemeth) to learn how to set up, deploy, and successfully retrieve biologging tags in the field, providing him with the skillsets to start a PhD at the MMRP in 2026. While this effort was not funded by FLEET, it resulted in progress towards Award Goal 1 and Award Goal 3 of the current agreement.

*Table 1: Outline of each field effort pertaining to this funding period.*

| **Effort Period** | **Effort Location** | **Role in Effort** | **Total Number of Deployments** |
|---|---|---|---|
| 2022 – November | Lanai | Primary tag support | 1 SFPW |
| 2023 – February | Maui | Primary tag support | 8 HBW, 1 FKW |
| 2023 – November | Lanai | Primary tag support | 3 SFPW, 1 FKW |
| 2024 – January | Oahu | Secondary tag support | 1 HMS |
| 2024 – February | Big Island (Hawaii) | Primary tag support | 27 HBW |
| 2024 – April | Lanai | Primary tag support | 2 SFPW |
| 2024 – July/August | Southeast Alaska | Secondary tag support | 17 HBW |
| 2024 – October | Lanai | Secondary tag support | 2 FKW |
| 2025 – February | Maui | Secondary tag support | 31 HBW |
| 2025 – April | Lanai | Secondary tag support | 1 FKW |
| | | | **83 HBW, 6 SFPW, 5 FKW, 1 HMS** |

***Award Goal 2:*** Under this award, Dr. Gough progressed on a number of projects resulting in published (**n=3**), in review (**n=1**), and in-prep manuscripts (**n=8**) (outlined in Table 2). Many of these projects have directly or indirectly relied on insights obtained from tag data collected under this award.

The primary first-authored manuscript that Dr. Gough produced during the period of funding utilized short-finned pilot whale tag deployments collected in service of Award Goal 1. This manuscript focused on the daily dive behavior and bioenergetics of short-finned pilot whales in Hawaii, and has been accepted for publication in the *Journal of Experimental Biology*, with public release expected shortly. This project represented the first use of a new analytical framework to estimate energetic expenditure (and energetic intake, based on stomach content and prey data availability) using a combination of biologging tags (short-duration CATS and longer-duration satellite) and UAS-photogrammetry, as well as the first holistic energetic budget for the population of short-finned pilot whales residing within Hawaiian waters. This budget is being reported using "per-second" and "per-day" energetic cost/intake metrics that can be directly applied to management frameworks (e.g., Population Consequences of Disturbance; PCoD) as baseline values for a healthy/undisturbed population. As a result of this project, the same analytical framework is being used by MMRP graduate students Augusta Hollers for humpback

whales in Hawaii and by Jens Currie for the Main Hawaiian Islands false killer whales, with future publications planned for both (Award Goal 3). This framework is also being extended to a methods comparison across ~17 species of cetaceans ranging in size from the harbor porpoise (Phocoena phocoena) up to the blue whale (Balaenoptera musculus), and will inform a validation paper comparing the energetic results from this framework against controlled estimates (e.g., respirometry) of daily energetic expenditure, with the goal of determining the aerobic efficiency factor (i.e., the conversion of metabolic to mechanical work within the body) for cetaceans. Dr. Gough summarized the findings from his short-finned pilot whale publication (and the relevant methods on estimation of energetic expenditure from accelerometry data) in a segment of a review manuscript being developed by MMRP members and frequent collaborators (Dr. Ashley Blawas and Dr. Andreas Fahlman). This review will place the newly developed analytical framework in context with other literatures sources and provide clear directions for future research into the metabolic rates of marine mammal species of interest to the Navy and NOAA. These metrics are critically important when informing and populating Population Consequences of Disturbance models.

Dr. Gough has also completed the first full manuscript draft related to their analysis of humpback whale thermoregulation. This manuscript is aimed at quantifying the heat loss potential of humpback whales of various body sizes in both Hawaii and Alaska. These analyses utilized morphometrics from ~6000 whales (using UAS-photogrammetry methods) collected by MMRP lab members and collaborators between 2018 and 2025, as well as anatomical measures of appendage (i.e., pectoral flippers and tail flukes) blubber thickness obtained by members of the Health and Stranding Laboratory (University of Hawai'i at Manoa). This project is the first to formulate a holistic model of heat loss for the species across age classes and geographic regions that incorporates the heat loss potential of the appendages, rather than just the body. Thermoregulation is a significant concern for animals living in the marine environment. Mitigating heat loss has also been proposed as one reason why humpback whales (and other cetaceans) migrate to the tropics to give birth and wean their calves. Modeling the heat loss of humpback mothers and calves in warm and cold-water scenarios provides additional insight into their energetic expenditure and metabolic scope, as well as inform how this population may react to future changes in ocean conditions. These metrics will feed into an upcoming LMR/ONR-funded project ("Evaluating Population Consequences of Disturbance (PCoD) to Support Navy Compliance Permits").

Working together with Alaska Whale Foundation, Dr. Gough has continued his involvement with a series of papers that employ the large biologging dataset that we have for humpback whales foraging in southeastern Alaska - one of the primary foraging grounds for the humpback whales that breed and overwinter in Hawaii. The first of these papers, "Solitary humpback whales manufacture bubble-nets as tools to increase prey intake", was recently published in Royal Society Open Science. Understanding the foraging and energetic intake of these whales on their foraging grounds can provide insight into their health and reproductive potential on the breeding grounds of Hawaii – and hence of relevance and importance for modeling Population Consequences of Disturbance on marine mammals

In addition to journal publications, Dr. Gough was a co-author on **six conference abstracts** at the 25th Biennial Conference on the Biology of Marine Mammals in Perth, Australia (November 2024). This included a primary-authored oral presentation related to his short-finned pilot whale

bioenergetics work.

*Table 2: Publications written / co-authored by Dr. Gough during the period of funding.*

| Citation (Authors and Title) | Status | Publication Date | Journal | Dr. Gough's Contribution |
|---|---|---|---|---|
| Szabo, A., Bejder, L., Warick, H., van Aswegen, M., Friedlaender, A.S., Goldbogen, J., Kendall-Bar, J.M., Leunissen, E.M., Angot, M., **Gough, W.T.** \| Solitary humpback whales manufacture bubble-nets as tools to increase prey intake. | Published | 2024 - August | Royal Society Open Science | Data Creation, Experimental Design, Experimental Analysis |
| Nemeth, C., **Gough, W.T.**, Segre, P.S., Fish, F.E., Szabo, A., Fassmann, W.N., Thomson, S.L., van Aswegen, M., Burrows, J.A., Chenoweth, E.M., Di Clemente, J., Friedlaender, A.S., Goldbogen, J.A., Simon, M., Straley, J.M., Videsen, S.K.A., Visser, F., Weir, C.R. and Bejder, L. \| The key to bubble-net feeding: how humpback whale morphology functionally differs from other baleen whales. | Published | 2025 - August | Journal of Experimental Biology | Conceptualization, Data Creation, Experimental Design |
| **Gough, W.T.**, Madrigal, B., Hollers, A., Currie, J.J., Baird, R.W., West, K., Fahlman, A., Fish, F.E., Evans, L., van Aswegen, M., Stirling, B., Pacini, A., Olson, G.L., Stack, S.H., Blawas, A.M., Walker, W.A. and Bejder, L. \| Daily energetic expenditure and energy consumption of short-finned pilot whales. | Accepted for Publication | 2025 - September | Journal of Experimental Biology | Conceptualization, Data Creation, Experimental Design, Experimental Analysis, Manuscript Writing |
| Madrigal, B.C., **Gough, W.T.**, Currie, J.J., Bejder, L., Hollers, A., Baird, R.W., Mooney, T.A. and Pacini, A.F. \| Acoustic behavior of endangered Hawaiian false killer whales. | In Review | 2025 (*presumed*) | Royal Society Open Science | Data Creation, Experimental Analysis |
| Currie, J.J., Stirling, B., Olson, G., van Aswegen, M., Evans, L., Stack, S.H., Kobayashi, N., Ueda, K., Higa, S., **Gough, W.T.**, Vivier, F., McPherson, L., Fertitta, K. and Bejder, L. \| Body condition differs among social clusters and across years in endangered false killer whales in Hawai'i. | Manuscript In Prep | 2026 (*presumed*) | Endangered Species Research | Data Creation |
| Szabo, A., **Gough, W.T.**, van Aswegen, M., Bloch, D., Kosma, M.M., Sharpe, F., Eckert, L.E. and Bejder, L. \| Division of labor with role specialization among group bubble-net foraging humpback whales. | Manuscript In Prep | 2026 (*presumed*) | PLOS One | Data Creation |
| Nemeth, C., **Gough, W.T.**, van Aswegen, M., Hollers, A., Evans, L., Szabo, A. and Bejder, L. \| Energetic scaling of propulsive costs across body sizes in humpback whales. | Manuscript In Prep | 2026 (*presumed*) | Marine Ecology Progress Series | Conceptualization, Data Creation, Experimental Design |
| Hollers, A., **Gough, W.T.**, van Aswegen, M., Szabo, A., Evans, L., Currie, J., Blawas, A., Fahlman, A., Goldbogen, J. and Bejder, L. \| Energetic benefits of resting behavior in humpback whale mother-calf pairs revealed by biologging and UAS-photogrammetry. | Manuscript In Prep | 2026 (*presumed*) | Conservation Physiology | Data Creation, Experimental Design |
| **Gough, W.T.**, van Aswegen, M., Evans, L., Szabo, A., Currie, J., Fahlman, A., Christiansen, F., Hollers, A., Fish, F.E., West, K., Phipps, J., Hofmann, N. and Bejder, L. \| Hot Wings: Quantifying the impact of large appendages on the heat loss potential and migratory decision-making of humpback whales. | Manuscript In Prep | 2026 (*presumed*) | Functional Ecology | Conceptualization, Data Creation, Experimental Design, Experimental Analysis, Manuscript Writing |
| Blawas, A., **Gough, W.T.**, Allen, A., van Aswegen, M., Christiansen, F., Bejder, L. and Fahlman, A. \| Estimating cetacean at-sea energetics: a review of an expanding methodological landscape. | Manuscript In Prep | 2026 (*presumed*) | Biological Reviews (*presumed*) | Manuscript Writing |
| **Gough, W.T.**, *co-authors TBD* \| Validating the aerobic efficiency factor for cetaceans using accelerometry and physiological metrics in captive bottlenose dolphins (*Tursiops truncatus*). | Analyses in Progress | 2026 (*presumed*) | *Undecided* | Conceptualization, Data Creation, Experimental Design, Experimental Analysis, Manuscript Writing |

| | | | | |
|---|---|---|---|---|
| **Gough, W.T.**, *co-authors TBD* \| Estimating energetic expenditure of cetaceans species using a multi-method comparative approach. | Analyses in Progress | 2027 (*presumed*) | *Undecided* | Conceptualization, Data Creation, Experimental Design, Experimental Analysis, Manuscript Writing |

***Award Goal 3:*** Under this award, Dr. Gough has trained and mentored a host of collaborators and students (high school through PhD graduate candidates) on methods related to collection, processing, and analysis of accelerometry data from CATS and other biologging tags. At the graduate level, this has included **seven PhD students from the MMRP lab, one PhD student from the UH Shark lab, and one PhD student from the University of Alaska Fairbanks**. The affiliations of these students are outlined in Table 3.

**Augusta Hollers** is an MMRP PhD student studying the behavior and energetics of humpback whales in Hawaii and Alaska, with special focus on mother-calf pairs. Dr. Gough trained her to work with all aspects of the CATS tag workflow, from deployment and recovery to data analysis and interpretation. During the period of funding, Dr. Gough also helped Augusta transition the newly collected humpback tag deployments – as well as the lab's backlog of CATS data (collected between 2020-2022) – into processed and calibrated data packets known as PRH (pitch-roll-heading) files. Augusta's work with this data has resulted in one manuscript in preparation (co-authored by Dr. Gough) focused on the energetic implications of resting behavior for mothers and calves in Hawaiian waters. A follow-up manuscript will investigate calf suckling frequency and the energetic implications of maternal body size.

**Jens Currie** is the chief scientist at Pacific Whale Foundation and an MMRP PhD studying false killer whale movement and foraging behavior. **Brijonnay Madrigal** is an MMRP PhD student that focused her research on acoustic behavior of false killer whales and short-finned pilot whales. The data (accelerometer, camera, audio) collected from these two species during the period of funding has been invaluable to their research goals. Jens has worked with Dr. Gough to estimate daily energetic expenditure from false killer whales, using the analytical framework the Dr. Gough developed for his short-finned pilot whale manuscript. Brijonnay, meanwhile, assisted Dr. Gough on the acoustic portion of that same short-finned pilot whale manuscript, and incorporated similar dive-scale behavioral metrics into her own manuscript (in review with *Royal Society Open Science*) focused on the acoustic behavior of false killer whales.

**Martin van Aswegen** is a former MMRP PhD student using UAS (unoccupied aerial system) morphometrics to quantify the body condition and related energetics of humpback whales throughout the year. **Lewis Evans** is an MMRP PhD student using UAS to quantify body condition and energetic metrics for humpback males on the breeding ground. **Liah McPherson** is an incoming MMRP PhD student (and former MMRP Masters student) using UAS and CATs tags to quantify body condition and energetic metrics for gray whales (Eschrichtius robustus) in Alaska. Dr. Gough has provided Martin, Lewis, and Liah with support as well as energetic insights gleaned from accelerometry tag data.

During the period of funding, Dr. Gough has also acted as a committee member for former UH undergraduate **Jessie Hoffman**, a Nancy Foster scholar (Hawaiian Islands Humpback Whale National Marine Sanctuary) and current PhD student at University of Alaska Fairbanks interested in the energetic implications of entanglement for humpback whales in Hawaiian waters. Dr. Gough has helped Jessie formulate a chapter that uses CATS accelerometry data from entangled humpback whales to estimate the added drag of gear and subsequent energetic

burden of prolonged entanglement. Jessie successfully completed her comprehensive exams in 2025.

In addition to graduate students, Dr. Gough has worked closely with a UH undergraduate student, **Cameron Nemeth**, on multiple projects related to the biomechanics of humpback whale swimming. These have resulted in peer-reviewed manuscripts focused on 1) the turning performance of humpback whales bubble-net feeding in Alaska and 2) the hydrodynamics and thrust production of humpback whales across a range of body sizes. The former manuscript was published in the Journal of Experimental Biology in August 2025 and was presented as a speed talk at the 25th Biennial Conference on the Biology of Marine Mammals. The latter manuscript is in preparation and is planned for submission to the *Marine Ecology Progress Series* in the next ~1-2 months. Dr. Gough has also trained Cameron to work with CATS tags, both in the field (e.g., setup, deployment, recovery) and the lab (e.g., data processing, analysis, interpretation), in preparation for joining the MMRP lab (Fall 2026) as a PhD student.

In addition to Cameron, Dr. Gough acted as research mentor for two undergraduates, **Sami Salaz** and **Trevor Thompson**, that were working at the MMRP as summer interns. Dr. Gough advised Sami as she performed a literature review searching for accelerometry tag-based publications and collecting metadata on the numbers and types of tags used in each. Trevor performed a preliminary analysis collecting simple kinematics for bubble-netting humpback whales in Alaska.

Beyond cetaceans, Dr. Gough has assisted with accelerometry data pertaining to pinnipeds and sharks. **Kirby Parnell** is an MMRP PhD student (dissertation defended in 2025) that focused her research on the foraging acoustics and diving behavior of Hawaiian monk seals. During the period of funding, Dr. Gough helped Kirby to successfully collect a single CATS tag deployment from a monk seal and analyze the resulting dive data to align with acoustic signatures. **Paige Wernli** is a UH PhD student in the Shark lab interested in the foraging behavior and locomotion of tiger sharks (*Galeocerdo cuvier*). During the period of funding, Dr. Gough trained Paige to process and analyze her accelerometry data.

Apart from these graduate and undergraduate students, Dr. Gough spent time building capacity within the wider Hawaiian research community for the use of accelerometry data. This included engagement in training and professional development with a number of parties, including local Hawaiian high school students (through the Summer Marine Mammal Intensive Learning Experience [SMMILE] program set up by MMRP PhD students Brijonnay Madrigal and Kirby Parnell), non-profit organizations such as the Pacific Whale Foundation and Cascadia Research Collective, and staff from federal organizations such as the NOAA Pacific Island Fisheries Science Center, Hawaiian Islands Humpback Whale National Marine Sanctuary, and PACFLEET. These training sessions have taken the form of small group classes (<12 students) or one-on-one topics in the lab and the field. Topics in the classroom have been tailored to the age-range and expertise of the group, primarily focused on simple data types and use of tags. One-on-one training sessions in the lab have been more in-depth, with topics ranging from tag calibration and preparation to data processing methods and analysis. In the field, Dr. Gough has provided his knowledge of tag deployment and recovery as well as use of relevant equipment.

In addition to these training avenues, **Dr. Gough developed and ran a workshop (March /**

**April 2024)** similar to the CATS tag data processing workshop run by Dr. David Cade and himself at Stanford University in 2020. The format for this workshop was changed slightly, with more time provided between sessions (one meeting every other Tuesday across eight weeks) to allow for more complete uptake of information and supplemental one-on-one meetings. This workshop was targeted towards those in the Hawaiian research community who are currently working with accelerometer data or interested in working with those data in the future. The majority of participants (**~8-10 in total**) were MMRP graduate students, with two members joining from PACFLEET. Dr. Gough covered the entire process of preparing and calibrating a biologging device, deploying it in the field, recovering and retrieving animal-borne data, and processing the data into a package that would be ready for further analysis.

The code necessary to perform these processing steps can be found in the CATS-Methods-Materials Github repository (https://github.com/cadede/CATS-Methods-Materials). Field protocols and guidance for how to work with this code can be found in the attached wiki (https://github.com/cadede/CATS-Methods-Materials/wiki). Dr. Gough's website (https://www.wgough.com/cats-tag-information) gives additional information, including links to recordings of the 2020 workshop and a link to the previously published article describing the CATS processing methods (https://link.springer.com/article/10.1186/s40317-021-00256-w).

During the period of funding, Dr. Gough has successfully trained a cohort of students (Augusta Hollers, Jens Currie, Cameron Nemeth) that can work independently with biologging data and train additional personnel within the Hawaiian research community, solidifying the capacity that he has built over the full contract period.

In addition to his capacity building efforts, Dr. Gough engaged with the wider public through multiple avenues. These included a guest lecture at Hawaii Pacific University on Alaskan bubble-net feeding humpback whales, an interview with Hawaii Public Radio on tool use in humpback whales, and a podcast episode exploring his career in research. He also traveled to Maui and participated in a Q&A session as part of a fundraiser for Pacific Whale Foundation at the Maui Ocean Center. This event constituted the single-night premiere of "Call of the Dolphins", a large-screen format documentary that included a segment on MMRP's tagging efforts on short-finned pilot whales off the coast of Lanai.

Table 3: Students mentored by Dr. Gough during the period of funding.

| | | | |
|---|---|---|---|
| Augusta Hollers | Graduate Student – PhD | University of Hawaii at Manoa – MMRP | Behavioral energetics of humpback whales – focus |
| Jens Currie | Graduate Student – PhD | University of Hawaii at Manoa – MMRP | Energetics of MHI false |
| Brijonnay Madrigal | Graduate Student – PhD | University of Hawaii at Manoa – MMRP | Behavioral acoustics of MHI false killer whales and |
| Kirby Parnell | Graduate Student – PhD | University of Hawaii at Manoa – MMRP | Behavioral acoustics of |
| Martin van Aswegen | Graduate Student – PhD | University of Hawaii at Manoa – MMRP | Morphometrics and energetics of humpback |
| Lewis Evans | Graduate Student – PhD | University of Hawaii at Manoa – MMRP | Morphometrics and energetics of humpback |
| | | | |
| Paige Wernli | Graduate Student – PhD | University of Hawaii at Manoa – Shark Lab | Foraging behavior of tiger |
| Jessie Hoffman | Graduate Student – PhD | University of Alaska Fairbanks | Energetic impacts of entanglement in humpback |

| | | | |
|---|---|---|---|
| Cameron Nemeth | Undergraduate / Graduate Student – PhD | University of Hawaii at Manoa – MMRP | Biomechanics and energetics of humpback whale swimming |
| Samantha Salaz | Undergraduate | California Polytechnic State University | Aggregation of CATS / Dtag deployment literature |
| Trevor Thompson | Undergraduate | University of Hawaii at Manoa | Behavioral classification of bubble-netting in humpback whales |

***Award Goal 4:*** During the period of funding, Dr. Gough established a section of the lab devoted to tag setup, calibration, diagnostics, and data processing. This area includes two desktop computers with a full suite of relevant software and a dedicated staging area for field expeditions. He also enhanced the physical and cloud-based data storage capacities at the MMRP by implementing both 1) a local **Synology network-attached server** with enough storage space (~120 TB) for the entire MMRP lab and 2) a **cloud-synced backup** through UH's KoaCloud system. The server and the KoaCloud backup can be accessed from anywhere in the world, allowing for faster data storage and transfer between lab members and collaborators, including those in the field or away on related travel. The KoaCloud backup also provides an additional level of security and resilience in the case of a catastrophic event (e.g., fire, flood) at the MMRP that incapacitates the Synology server.

As these storage solutions came on-line, Dr. Gough assisted multiple MMRP lab members to upload their data backups to the physical MMRP-based Synology server. They also updated the storage limit for the MMRP KoaCloud account to accommodate current and future data storage and backup needs.

**Achievements:**

During the period of funding, Dr. Gough made substantial contributions toward all four Award Goals, resulting in substantial advances in data collection, analytical outputs, workforce development, and infrastructure.

Field efforts resulted in the successful collection of biologging data from multiple cetacean species of interest to the Navy and NOAA, including humpback whales, false killer whales, short-finned pilot whales, and Hawaiian monk seals. (**Award Goal 1**)

***Award Goal 1 - Data Collection on Species of Interest***

- **10 field expeditions supported** (5 as primary tag support, 5 as secondary support)
- **95 total biologging tag deployments**, including:
  - **83 humpback whales**
  - **6 short-finned pilot whales**
  - **5 false killer whales**
  - **1 Hawaiian monk seal**
- First triaxial accelerometry deployments on free-ranging false killer whales
- First tag-based video documentation of humpback whale reproductive behavior

Analytical efforts culminated in a first-authored accepted publication in the *Journal of Experimental Biology* on the daily energetic expenditure and energy consumption of short-finned pilot whales, alongside numerous additional peer-reviewed publications, manuscripts in review, and manuscripts in preparation that leverage data collected during this award. Collectively, these outputs provide critically needed baseline energetic and behavioral metrics that are directly

applicable to Population Consequences of Disturbance (PCoD) modeling and other management frameworks relevant to Navy and NOAA operations. (**Award Goal 2**)

***Award Goal 2 - Behavioral Data Analysis***

- **3 peer-reviewed journal articles published** (1 first author, 2 co-authored)
- **1 manuscript currently in review**
- **8 manuscript in preparation** (3 led by Dr. Gough, 4 led by MMRP students, 1 led by MMRP collaborator)
- **6 conference abstracts** presented at an international scientific meeting
- Development and application of a novel accelerometry-based energetic framework now being used across multiple cetacean species and research programs

Over the course of the award, Dr. Gough trained and mentored a diverse cohort of undergraduate students, graduate students, and external collaborators, many of whom are now able to independently deploy tags, process accelerometry data, conduct advanced analyses, and train additional personnel. These efforts have already resulted in multiple student-led publications, successful field seasons conducted with minimal oversight, and long-term continuity in biologging expertise within the MMRP and the broader Hawaiian research community. (**Award Goal 3**)

**Award Goal 3 – Local Capacity Building**

- **9 graduate students trained** (PhD level across UH Manoa, UH Shark Lab, and University of Alaska Fairbanks)
- **3 undergraduate students and interns mentored**
- **Multiple external partners trained**, including NOAA PIFSC, Hawaiian Islands Humpback Whale National Marine Sanctuary, PACFLEET, Pacific Whale Foundation, Cascadia Research Collective, and local high school programs
- **Multi-week biologging data-processing workshop developed (~8-10 participants)**
- Established a self-sustaining cohort of researchers capable of independently deploying tags, processing data, and training others

Finally, the postdoctoral researcher established durable data-handling and storage infrastructure at the MMRP, including the implementation of a high-capacity Synology NAS server, secure permission structures, and a cloud-based backup system. These systems ensure the long-term integrity, accessibility, and security of Navy-funded data, even under challenging environmental or logistical conditions. (**Award Goal 4**)

**Award Goal 4 - Building Data Infrastructure**

- Implementation of a **~120 TB Synology NAS server** for secure, centralized data storage
- Deployment of a **cloud-based backup system (UH KoaCloud)** for redundancy and remote access
- Standardized data-handling and access protocols supporting long-term stewardship of Navy-funded datasets

Together, these achievements represent a significant and lasting advancement in monitoring capacity, analytical capability, and workforce development in Hawai'i, while producing actionable scientific outputs that directly support Navy and NOAA management priorities.

**Next Steps:**

This constitutes the final annual report of the 3-year award, but the awardees have requested a no-cost extension to finalize the work performed by Dr. Gough towards completion of each Award Goal. To that end, in the next reporting period he will continue his training efforts with MMRP students, collaborators, and members of the local research community. This will include editing and providing feedback to Cameron Nemeth as he completes a draft of his second manuscript and prepares it for submission (related to the kinematics and cost of transport for humpback whale mothers and calves). It will also include helping Augusta Hollers to interpret and finalize analyses and text for her first PhD chapter. In addition to training, he will finalize his manuscript related to the heat loss potential of humpback whales in Hawaii and Southeast Alaska, with a revised target submission date of October 2025 (*Journal of Experimental Biology* or similar). These manuscripts will all serve to further our understanding of energy usage and behavioral baselines for a species of interest to the Navy (humpback whales), in preparation for a broader modeling exercise on disturbance (in the "Population Consequences of Disturbance" framework or similar).

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