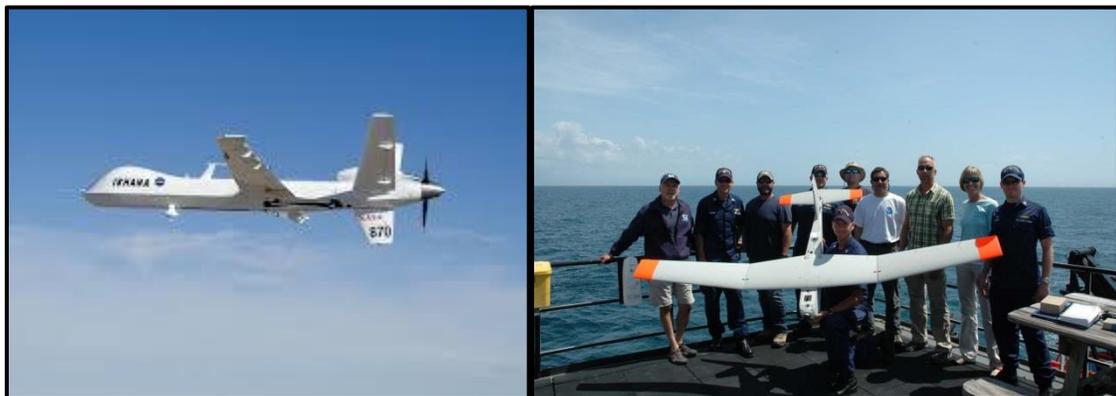
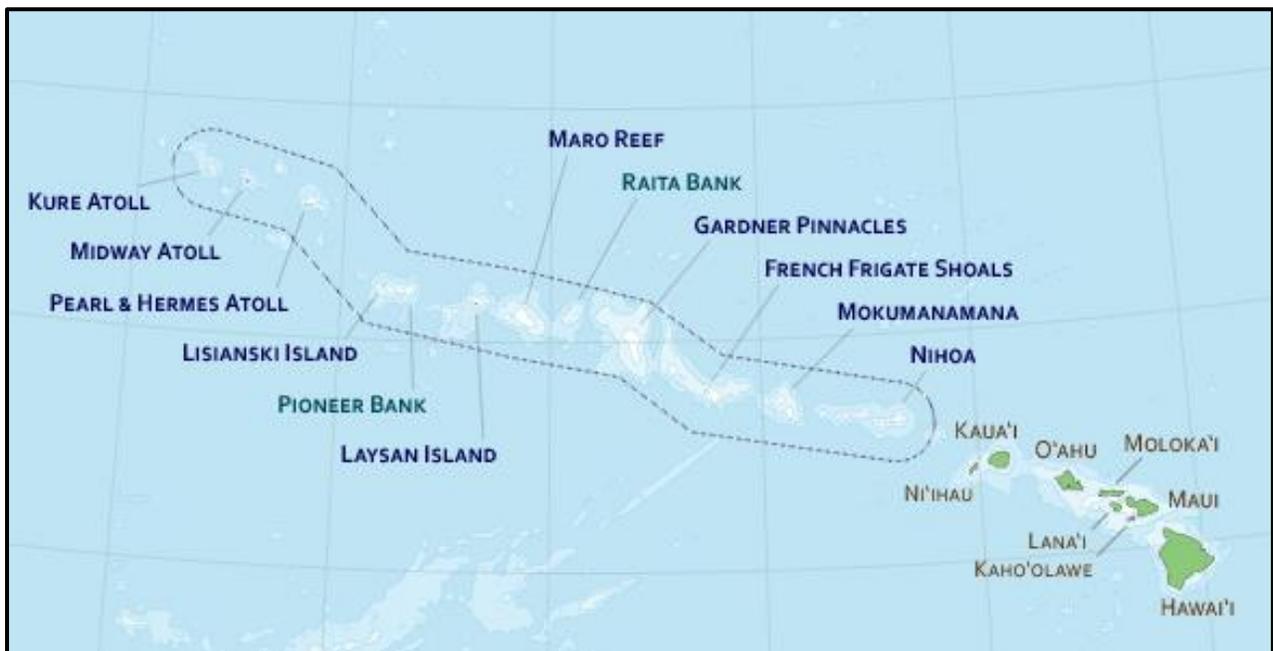


# Tern, Tern, Tern: Using Unmanned Aircraft Systems (UAS) in the Papahānaumokuākea Marine National Monument

## Project Description

June 2014



**Unmanned Aircraft Systems (UAS)** have the potential to efficiently and safely bridge critical information gaps in data sparse and remote locations of the global environment and advance the understanding of key processes in Earth systems. Optimizing the capabilities that UAS offer will advance NOAA's mission goals through improved understanding of oceanic and atmospheric exchanges, hurricanes, wildfires, marine ecosystems, polar regions, hazards, and other environmental and ecological processes, ultimately leading to improved climate and weather predictions and management of marine resources. NOAA is partnering with other civilian agencies, industry and the academic community to develop UAS operations, systems and platforms that can be safely deployed, both nationally and globally, to fill observational data gaps with increased efficiency and decreased risk to personnel.

**Executive Summary:** This project will evaluate the effectiveness of remote observations in the Northwest Hawaiian Islands collected by Unmanned Aircraft Systems (UAS) to meet validated NOAA observing requirements for National Ocean Service and National Marine Fisheries Service responsibilities in the area. Two representative UAS, the NOAA Puma and the NASA Ikhana, will operate over isolated areas of the Papahānaumokuākea Marine National Monument to monitor maritime activity, marine debris, endangered species, marine resources, and habitat.

Puma, a hand-launched aircraft with a nine-foot wing span that flies at an altitude below 500 feet, will deploy from the NOAA Ship Hi'ialakai during 16-23 June 2014. Ikhana, a medium altitude long endurance aircraft with a 66 foot wingspan that flies at altitude below 40,000 feet, will operate out of the Pacific Missile Range Facility at Barking Sands on Kauai for five weeks during latter June and July 2014 as part of a multi-agency collaboration. Both aircraft will observe the islands of Nihoa and Mokumanamana and the French Frigate Shoals, as well as analogous locations near the main Hawaiian Islands. Visible, infrared, radar and vessel identification sensors will provide real-time and post-mission data to support multiple marine monitoring objectives. The results will be compared between platforms and with ground truth, prior observations, and satellite data to determine effectiveness.

While there are technical lessons to be learned, primarily with the NASA Ikhana configuration and deployed operations, both aircraft and their sensors are relatively mature, allowing the project to focus on evaluating their ability to satisfy operational needs. The results of this experiment will inform decisions for future operational use of UAS. The project will identify operational considerations for specific application to marine monitoring, including coordination across multiple organizations, multi-platform observations, and integrating observations into effective management of vital marine resources.

- Come-as-you-are aircraft and sensors (relatively mature)
- Evaluate against validated NOAA observation requirements
- Understand marine monitoring needs and constraints
- Inform future operational applications of unmanned aircraft

RECAP

**Objective:** This project supports the responsibility of the NOAA UAS Program to evaluate the feasibility of UAS technologies using a requirements-based systems approach. Marine, polar and high impact monitoring are three key mission areas which could be significantly improved by UAS performance capabilities for remote sensing, endurance, range, flight altitude, low noise, ease of transport, or rapid response deployment. This project is specifically focused on marine monitoring in remote areas using low and medium altitude UAS due to the cost and risk of such remote operations with manned ships and aircraft. The technology readiness of UAS observations for civilian applications is steadily maturing but requires further technology assessment in the context of NOAA mission observing needs.



The project evaluation of medium altitude UAS makes sense now because of the recent leap forward in the maturity of non-military government use, represented by the US Customs and Border Patrol fleet of Predator B aircraft, and the deployed availability of the NASA Ikhana variant of the Predator B. Marine monitoring in remote areas reflects the broader strategic opportunity for unmanned aircraft, as limited resources and global changes challenge our ability to manage valuable marine resources. The Puma element of this project is a significant milestone building on recent experience in NOAA Puma deployments to less remote National Marine Sanctuaries off the U.S. mainland coasts. Puma will support the evaluation of Ikhana sensors and contribute to an analysis of a multi-platform observing strategy.



Regional focus on Papahānaumokuākea offers a lower-risk environment to evaluate concepts that can extend to even more remote and hazardous regions such as the Aleutian island chain and the North Atlantic. Multiple validated requirements in the monument are conducive to remote observation. While unmanned systems cannot completely satisfy those requirements that involve direct human intervention, they can be used in such cases to augment and render more effective valuable and limited ship time.

<ul style="list-style-type: none"> <li>• Balance UAS portfolio with medium altitude long endurance unmanned aircraft</li> <li>• Address validated and established marine monitoring mission areas</li> <li>• Leverage other US agency investments in aircraft and sensors</li> </ul>	<b>RECAP</b>
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**Papahānaumokuākea Marine National Monument:** The Papahānaumokuākea Marine National Monument in the Northwestern Hawaiian Islands (NWHI) comprises one of the largest protected areas in the world. The Monument, a vast, remote, and largely uninhabited marine region, encompasses an area of approximately 139,793 square miles (362,061 square kilometers) of Pacific Ocean in the northwestern extent of the Hawaiian Archipelago. Covering a distance of more than 1,200 miles, the 100-mile wide Monument is dotted with small islands, islets, and atolls and a complex array of marine and terrestrial ecosystems. This region and its natural and historic resources hold great cultural and religious significance to Native Hawaiians. It is also home to a variety of post-Western-contact historic resources, such as those associated with the Battle of Midway. As such, the Monument has been identified as a national priority for permanent protection as a Monument for its unique and significant confluence of conservation, ecological, historical, scientific, educational, and Native Hawaiian cultural qualities.

Monument Vision and Mission	
<b>Vision</b>	
To forever protect and perpetuate ecosystem health and diversity and Native Hawaiian cultural significance of Papahānaumokuākea.	
<b>Mission</b>	
Carry out seamless integrated management to ensure ecological integrity and achieve strong, long-term protection and perpetuation of NWHI ecosystems, Native Hawaiian culture, and heritage resources for current and future generations.	



A monument management plan outlines six priority management needs including: understanding and interpreting the Northwest Hawaiian Islands, conserving wildlife and habitats, reducing threats to Monument resources, managing human uses, coordinating conservation and management activities, and achieving effective Monument operations. Action plans consist of multiple strategies and activities to address one or more priority management needs and achieve a desired outcome.

<ul style="list-style-type: none"> <li>● Sensitive marine resource of global significance</li> <li>● Limited knowledge of unauthorized access to sensitive sea areas</li> <li>● Marine debris accumulates at a rate of more than 50 tons per year</li> <li>● Field camps reduced to seasonal use after 30 years of year-round residency</li> <li>● Endangered species of seals, turtles, cetaceans and birds</li> <li>● Defending against invasive species and restoring lost species</li> <li>● Dynamic coastal habitat includes changing shorelines and ephemeral islands</li> </ul>	<b>AMPLIFY</b>
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**Puma:** The Puma AE (All Environment) is a small unmanned aircraft system designed for land based and maritime operations. Capable of landing in the water or on land, the Puma AE delivers 3.5+ hours of flight endurance. It carries both an electro-optical and infrared camera on a lightweight mechanical gimbaled payload. The precision navigation system with secondary Global Positioning System (GPS) capability provides precise positional accuracy and reliability. A ground control station allows the operator to control the aircraft manually or program it for GPS-based autonomous navigation.



*PUMA being launched during 2012 demonstration in Hawaii.*

Two Puma systems, each consisting of three airframes and one ground control station, were purchased by the NOAA UAS Program in 2012. Since then, the Puma systems have been supported by the NOAA Aircraft Operations Center for National Marine Sanctuary and other marine demonstrations. Transition planning from research demonstration to full operational use by NOAA personnel is currently under development.

Current airspace management restrictions limit flights to remain within one mile so that an operator can maintain line of sight to comply with current FAA guidance for small UAS. A deep-stall landing profile accommodates small landing zones. Recovery is often accomplished by water landing and small boat retrieval. Improved sensors and a shipboard recovery capability are in development.

- Hand-launched ship-compatible operations
- Operated and maintained by NOAA personnel
- High-resolution electro-optical and infrared video

AMPLIFY

# Puma Operations 16-23 June 2014

Aboard the NOAA Ship Hiialakai

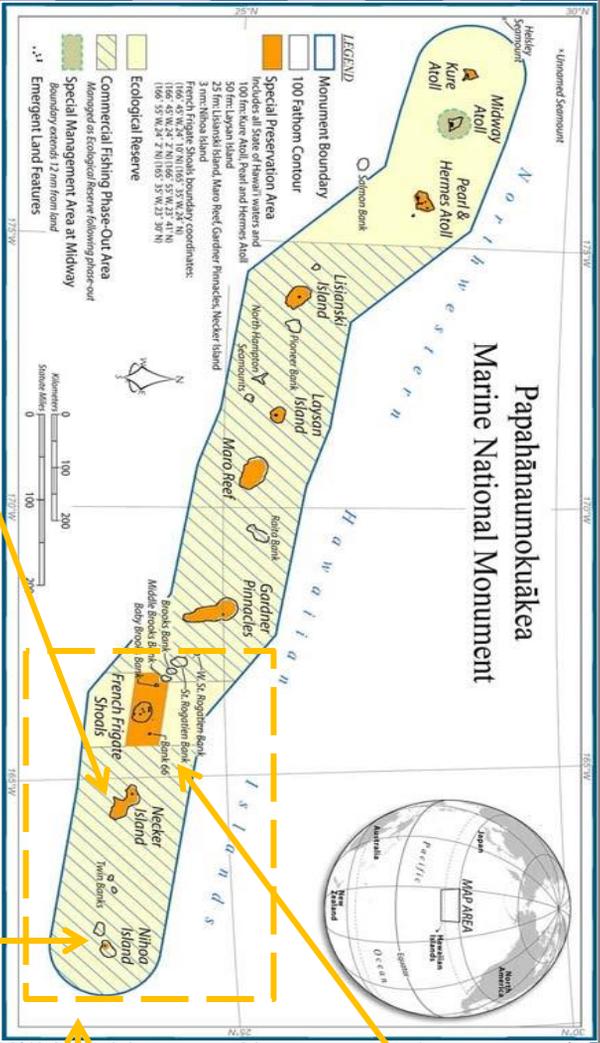
June 2014 NWHI

**Puma AE (LASE) Sensor**

**Visible Imagery**

**Near Infrared**

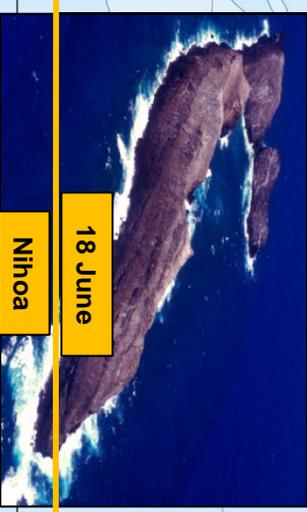
**Streaming Video**



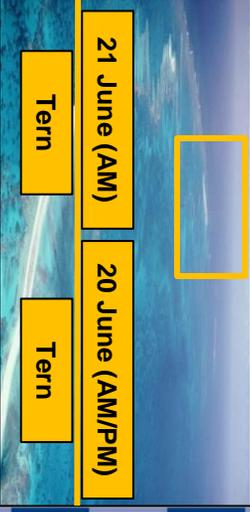
**19 June - Arrive Necker Island**  
**Conduct daytime ship based Puma operations**  
*(Multiple 1-2 hour day sorties)*  
**Imagery collection for monk seals, birds, vegetation and coastal mapping**



**18 June - Arrive Nihoa Island**  
**Conduct daytime ship based Puma operations**  
*(Multiple 1-2 hour day sorties)*  
**Imagery collection for monk seals, birds, vegetation and coastal mapping**

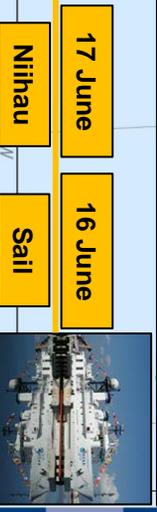


**20-21 June - Tern Island (FFS)**  
**Conduct daytime ship/shore based Puma operations**  
*(Multiple 1-2 hour day sorties)*  
**Imagery collection for monk seals, sea turtles, birds, vegetation and coastal mapping**



**17 June - Arrive Nihoa Island**  
*(Not depicted / outside of the monument)*  
**Conduct daytime ship based Puma operations**  
*(Multiple 1-2 hour day sorties)*  
**Imagery collection for monk seals, birds, vegetation and coastal mapping**

**16 June - Depart Oahu on NOAA Ship Hiialakai**  
*(Not depicted / outside of the monument)*



**Ikhana:** NASA operates an MQ-9 Predator B unmanned aircraft system to support Earth science missions and advanced aeronautical technology development. The aircraft, named Ikhana, also acts as a test bed to develop capabilities and technologies to improve the utility of unmanned aircraft systems. Ikhana is a Native American Choctaw word meaning intelligent, conscious or aware. The name is descriptive of the research goals NASA has established for the aircraft and its related systems.



The MQ-9 aircraft, designed for long endurance high altitude flight, has been modified and instrumented for use in multiple civil research roles. A variety of Earth science *in situ* and remote sensing instruments can be installed to collect data during flights lasting more than 20 hours. Data gathered by sensors on Ikhana within the Earth's atmosphere complement measurements of the same phenomena taken from space and those taken on the Earth's surface.

NASA's MQ-9 Ikhana / Predator B has a wingspan of 66 feet and is 36 feet long. More than 400 pounds of payload can be carried internally and over 2,000 pounds in external pods. In 2013, Ikhana received a major avionics upgrade, to ensure the performance capabilities are state-of-the-art and the UAS is more maintainable and sustainable. The Ikhana project also acquired a new 140-by-30-inch generic science pod with a payload capacity of more than 500 pounds. The pod's internal arrangement is reconfigurable to accommodate a variety of science sensors and instruments.

For this project, Ikhana will be equipped with a suite of maritime surveillance sensors used by the US Customs and Border Patrol, including the SeaView radar, the MTS-B electro-optical and infrared sensor and the Automatic Identification System. The sensors are primarily designed to rapidly detect, track and identify maritime vessels in a range of weather conditions. They will also provide high-resolution video and still-imagery of marine resources. The SeaView radar will demonstrate its best performance at flight altitudes below 29,000 feet.

<ul style="list-style-type: none"> <li>● Deployed operation out of the Pacific Missile Range Facility</li> <li>● Mission Monitoring Shelter with real-time sensor data on Ford Island</li> <li>● One 6-8 hour flight with up to 90 minutes on station at Nihoa (155 miles)</li> <li>● One 10-hour flight with up to 3 hours at French Frigate Shoals (400 miles)</li> <li>● Maritime radar cued to imaging sensors and Automatic Identification System (AIS)</li> <li>● High-resolution electro-optical and infrared video and still-frame imagery</li> </ul>	<b>AMPLIFY</b>
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# Dedicated NOAA Science Flight (8 hrs) 16 July 2014



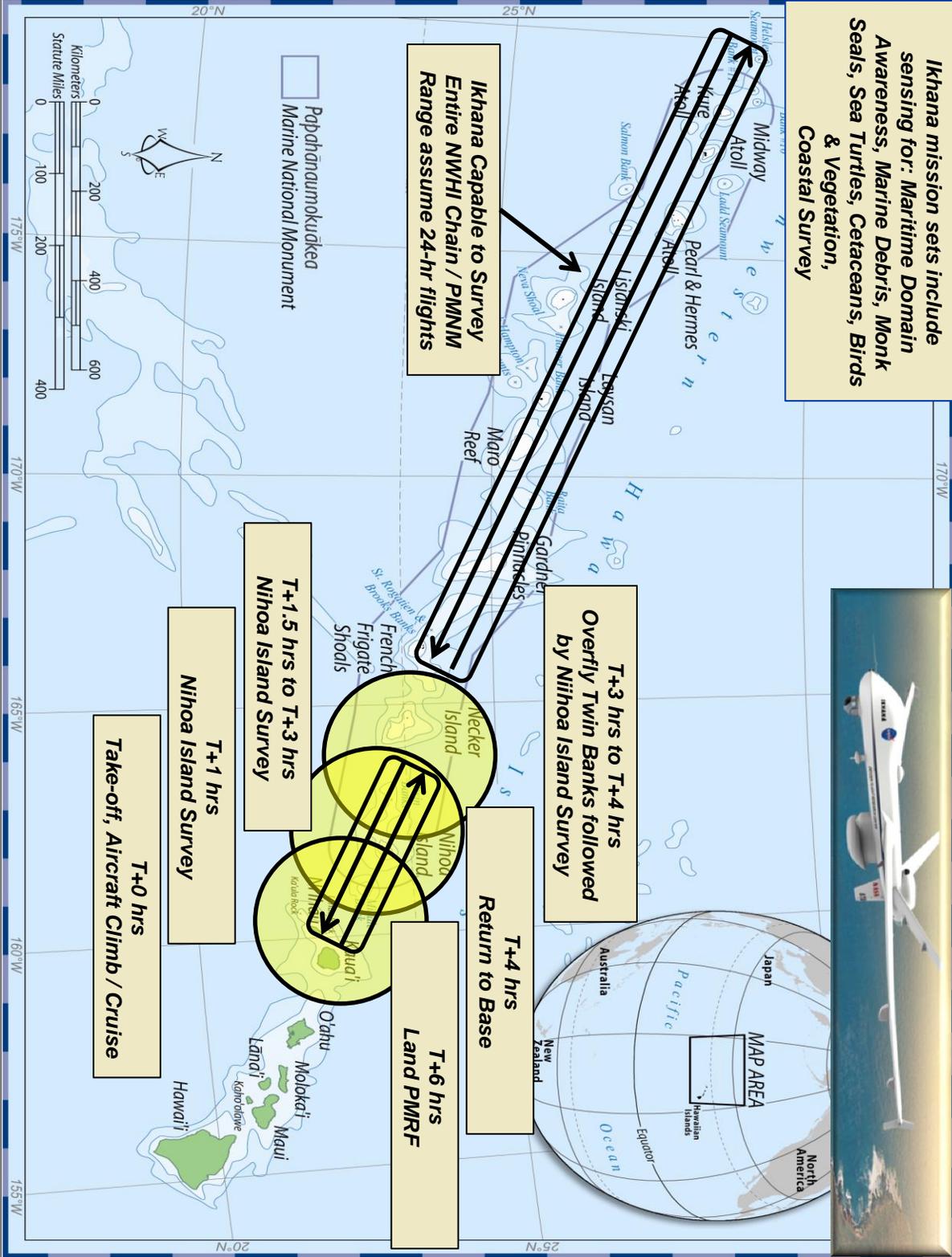
**Ikhana mission sets include sensing for: Maritime Domain Awareness, Marine Debris, Monk Seals, Sea Turtles, Cetaceans, Birds & Vegetation, Coastal Survey**

**July 2014 NWHI**  
**Ikhana Predator B (MALE)**  
**Sensor**

**SeaVue Maritime Radar**  
**AIS Receiver**

**Visible (MTS-B Skyball)**

**Infrared (MTS-B Skyball)**



**Ikhana Capable to Survey Entire NWHI Chain / PMNM**  
**Range assume 24-hr flights**

**T+3 hrs to T+4 hrs**  
**Overfly Twin Banks followed by Nihoa Island Survey**

**T+4 hrs**  
**Return to Base**

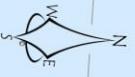
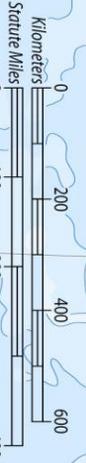
**T+6 hrs**  
**Land PMRF**

**T+1.5 hrs to T+3 hrs**  
**Nihoa Island Survey**

**T+1 hrs**  
**Nihoa Island Survey**

**T+0 hrs**  
**Take-off, Aircraft Climb / Cruise**

**Papahānaumokuākea Marine National Monument**



175°W 170°W 165°W 160°W 155°W

# Dedicated NOAA Science Flight (10 hrs) 18 July 2014



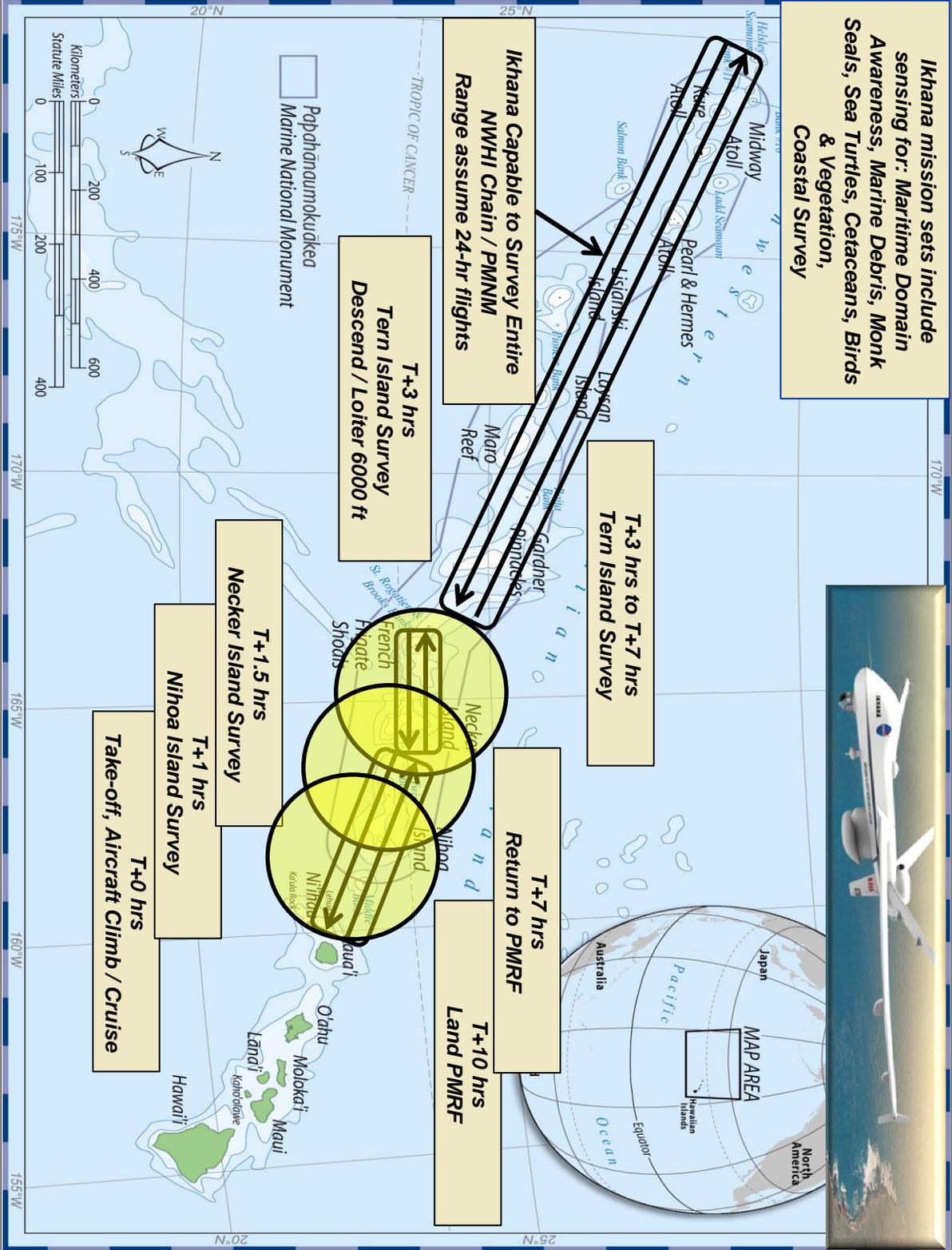
**Ikhana mission sets include sensing for: Maritime Domain Awareness, Marine Debris, Monk Seals, Sea Turtles, Cetaceans, Birds & Vegetation, Coastal Survey**

**July 2014 NWHI**  
**Ikhana Predator B (MALE)**  
**Sensor**

**SeaVue Maritime Radar**  
**AIS Receiver**

**Visible (MTS-B Skyball)**

**Infrared (MTS-B Skyball)**



**Marine Domain Awareness:** Human activity in the Papahānaumokuākea Marine National Monument is limited in order to protect sensitive ecosystems. With an area of approximately 139,793 square miles (362,061 square kilometers) in the middle of the Pacific Ocean, enforcement is difficult. Each year, about 200 large vessels report plans to transit the monument. At least 40 vessels per year appear to violate sensitive areas around the islands and shoals based on these reported plans, US Coast Guard aircraft patrols, and reports by permittees on vessels and in field camps.



Since 2004, most ocean going vessels have been required by international convention to broadcast Automatic Identification System (AIS) information. An analysis of recorded AIS transmissions from 2008 to 2013 indicates a large volume of unreported traffic in the monument. Additional vessels may not be transmitting as required.

The Ikhana sensor suite is designed specifically for maritime domain awareness. As Ikhana operates around the main islands and over the monument, it will detect vessels using AIS and radar. Primary focus of the project will be ship detection using NOAA marine vessels as surrogates for prohibited traffic violators. Permitted and reported traffic will be available for reference. Ships of opportunity will be observed closely by radar, visual and infrared sensors to determine classification, activity and identity. This process is referred to as “rigging.” During the long flight out to French Frigate Shoals, mission plans allow for a few significant excursions to “rig” vessels that are not close to the planned route.

Identifying prohibited traffic using UAS observations could someday support management decisions regarding risk, permitting and reporting processes, and further enforcement measures. Recognizing illegal activity, such as fishing in protected waters, is even more valuable. Identifying specific vessels by AIS, name and hailing port, or other unique features may be sufficient to issue warnings and citations.

**Marine Debris:** The NOAA marine debris project in the NWHI started with a pilot study in 1996 by the protected species division to evaluate the extent and impact of marine debris in the NWHI. A larger scale project was started in 2001 to remove historical marine debris from the NWHI, involving 30 to 120 days at sea per year through 2005. Since 2005 the NWHI marine debris project has focused on new debris accumulating in the NWHI. Debris is identified by freedive,



tow board and swim surveys. A study concluded that 52 metric tons of derelict fishing gear accumulates each year in the NWHI alone. About 70 percent of debris is trawl or seine nets and less than one percent is longline gear, which is the primary rig used by fisheries in Hawaii. Most debris is recovered in less than 10 feet of water. There has been a decline in ship time dedicated to marine debris removal in the years since 2009.

The areas of most concern include Pearl and Hermes Atoll and Mauro Reef, both of which are beyond the range of planned Ikhana missions for this project but not for subsequent Ikhana mission that might be conducted at a later date. Although less debris accumulates in the French Frigate Shoals, Ikhana missions to this area during this project will still be useful for determining the effectiveness of aerial surveys with Ikhana sensors. Remote observations could help identify concentrations within the reef so dive surveys can operate more efficiently.

The Hi'ialakai will identify and locate marine debris in the French Frigate Shoals using small boats and the Puma UAS. Puma imagery will be evaluated to determine effectiveness. Ikhana will image areas of French Frigate Shoals where debris was found by the Hi'ialakai. Ikhana imagery will also be evaluated to determine effectiveness. Open sea between islands will be imaged and evaluated to identify free-floating debris, if possible. We also hope to image analog sites in the main Hawaiian Islands.

**Hawaiian Island Monk Seals:** Hawaiian Island Monk seals are the only tropical seal on the planet. Surveys of monk seals in the NWHI consist of beach counts dating back to the 1950s. High resolution surveys began in the 1980s and provide the most complete detail of a specific population anywhere in the world. Ideally, every seal is tagged and tracked for life - from a two-month-old pup to a 20-year-old adult. Individuals are primarily identified by flipper tags, but bleach tags, satellite tags and scars and other distinctive natural features are also used. "Critter cams" provide detailed insight into individual behaviors over periods of many days.



The Monk Seal program will be impacted by reduced access to field camps, and needs to find ways to operate more efficiently. Aerial surveys may help, but effective species management will still require physical presence for activities like rescue from debris entanglement or veterinary intervention. Uncertainty in population assessments lies in the percentage of time individuals spend on the beach versus foraging for food according to sub-population or personality. Ni'ihau is the most important sub-group located in the main islands and will be used as an analog to the animals in the monument. The Robinson family has recently allowed more access to the island and the population has been found to be larger than expected. There is interest in observing seals during the night, but this will not be possible during this project.

Puma will image beaches on various islands using different sensors at different ranges and viewing geometries. Ikhana will also image beaches on various islands using different sensors at different ranges and viewing geometries. Real-time and post-mission population counts will be made and compared to historical data. A manual count will be made on beaches in the French Frigate Shoals for ground truth.

**Green Sea Turtles:** The majority of green sea turtles in the National Monument nest in the French Frigate Shoals. The most valuable population data is an actual count of active nesting sites and hatchlings. Daytime observations are less useful because of false nesting, old versus new nests, overlapping nests, etc. Nests are typically pits one meter across and 40 cm deep. Peak nesting at French Frigate Shoals occurs at high tide under the June full moon. The ideal observation scenario would be multiple passes every night for two weeks in August, at the end of the nesting season, to monitor nocturnal emergence that typically occurs over a few hours starting at dusk.



Puma and Ikhana will image adults on the islands in French Frigate shoals using different sensors from different altitudes and viewing angles. Manual beach counts will be conducted by personnel from the Hi'iialakai. Turtles may be imaged on Ni'ihau as an analog to turtles in the National Monument. Turtles may also be imaged and identified in the water. Night observations and imaging of hatchlings will not be possible during this project, and daylight observations may be of little value beyond determining the ability to identify and count adult turtles.

**Cetaceans:** The waters of Papahānaumokuākea are home to more than 20 cetacean species, six of them are federally recognized as endangered. Important areas throughout the main Hawaiian Islands constitute the Hawaiian Islands Humpback Whale National Marine Sanctuary. Populations in both areas are monitored to satisfy legislative requirements, to support research and education, and to inform management of fisheries and other maritime activities that impact endangered species.



Cetaceans are monitored primarily through periodic ship-based visual and acoustic line-transect surveys. Other methods include airborne line-transect surveys, fixed acoustic surveys, satellite tags, and using photo-ID databases. Line-transect surveys involve statistically estimating populations from the number and location of animals detected along a straight-line transect. Shipboard acoustic sensors can cue visual observations. Airborne surveys are generally used in the larger ranges of the Northern Pacific and not around the Hawaiian Islands. Surveys depend on the ability to differentiate species, although a small number of unspecified individuals are typically observed and counted separately. Fixed-site acoustic data can be used to estimate populations passing through a local area by the direction and amplitude of distinctive sounds. Satellite tags provide detailed movements for tagged individuals. Species-specific photo-ID databases can provide information about specific individuals identified by distinctive scars and body markings. Additional health and population information is determined by taking biopsy samples from individuals, performing necropsies of known fatalities, and even by sampling breath exhaled through blowholes. The military and the oil industry also monitor cetacean populations in their areas of operations. Military data is not generally available due to the sensitivity of the national security sensors used.

Humpback whales, one of the larger cetaceans in the area, will be in summer habitats in the Northern Pacific, far from the Hawaiian Islands during the project. Sperm whales and smaller, toothed whales, like false killer whales, as well as spinner dolphins will be present in low densities between the islands in the Monument. The U.S. Navy will be monitoring cetaceans in the context of military exercises during the time of this project, and efforts are under way to obtain real-time information to cue Ikhana sensors to image cetaceans around the main Hawaiian Islands.

Ikhana will attempt to image cetaceans with various sensors in known locations cued by U.S. Navy detections. Large cetaceans are known to generate distinctive radar returns, but it is not known if the Ikhana sensors will be able to practically detect them without specialized processing. Visual and infrared imagery will be collected in line-transect geometries between the islands of the Monument and evaluated real-time and post-mission to identify and count Cetacean species, hopefully using sample images collected in the main islands. However, it is possible that no Cetaceans will be observed during the project.

**Birds and Vegetation:** Six species of plants, including a fan palm, and four species of endemic birds, including remarkably isolated species such as the Nihoa finch, Nihoa millerbird, Laysan finch, and Laysan duck, one of the world's rarest ducks, are found only in the NWHI. In addition, more than 14 million seabirds nest on the tiny islets in the chain. Nihoa's seabird colony boasts one of the largest populations of Tristram's storm-petrel, Bulwer's petrel, and blue noddies in the Hawaiian Islands, and very possibly the world. 19 of Hawai'i's 22 seabird species are found in the French Frigate Shoals, giving it the highest species richness of breeding seabirds within the Monument.



Management activities include monitoring population trends, restoration of habitat, and elimination of invasive species. Sandbur (*Cenchrus echinatus*) is an aggressive invasive grass currently occurring at Kure and Midway Atolls, Pearl and Hermes Reef, Lisianski Island, and French Frigate Shoals. An intensive *Cenchrus* eradication effort at Laysan Island that took 12 years to complete has been a major contribution to the restoration of Laysan's seabird nesting habitat and has facilitated restoration of the island's native vegetation. The invasive gray bird locust (*Schistocerca nitens*) causes damage to native plant communities on Nihoa, including three endemic species listed as endangered. This grasshopper species has now also spread to Mokumanamana, French Frigate Shoals, and Lisianski Island.

Both Puma and Ikhana will image wildlife and vegetation on Nihoa, Mokumanamana and French Frigate Shoals with various imaging sensors from different altitudes and viewing geometries. Puma operations will approach from approximately 1000 ft above ground level and step down to a nominal viewing altitude of 200 ft, stopping higher if necessary to avoid disturbing birds. Launch and recovery will be conducted to minimize the risk of interacting with birds in flight or on the ground. Imagery will be reviewed to determine suitability for counting and differentiating by species, as well as other meaningful information, like nesting behaviors. Puma has a known capability to provide meaningful information about birds in coastal habitats. Ikhana capabilities will need to be determined. There is also interest in using Ikhana infrared imaging to determine soil moisture content to help manage the gray bird locust on Nihoa.

**Terrestrial Habitat:** The primary terrestrial habitat of interest is the beach and nearshore environment in the French Frigate Shoals. Terrain in the shoals is particularly dynamic. Beach areas change seasonally and after significant storms. Ephemeral islands come and go with the tide and as sands shift. Tern Island was modified by the military during World War II from crushed coral and steel retaining walls to form an airstrip and the metal is rusting away. Structures on the island were damaged by storms in 2012. Field crews can use information on site condition to plan encampments. Telephone-pole sized black plastic pipe has been left on the island to provide a barrier between seals, turtles and birds. There is a risk that erosion could introduce sections of the black pipe into the marine environment, where it poses a risk to coral reefs (as marine debris).



Aerial view approaching Tern Island

Ikhana and Puma will provide comprehensive nadir, or downward-looking, imagery from multiple altitudes of all land and intertidal areas of French Frigate Shoals, as well as shallow reef areas and the dredge channel along Tern Island. Overflight of Nihau and Mokumanamana Islands is limited in respect to cultural sensitivity and both platforms will only image coastline and cliff-side nesting sites. Culturally sensitive sites will be actively avoided. Imagery will be reviewed to determine how useful it is for evaluating changes in terrestrial habitat.



"Black pipe" on Tern Island

## Project Team

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