PACIFIC ISLANDS FISHERIES SCIENCE CENTER

Shark Predation on Hawaiian Monk Seals Workshop
Honolulu, Hawaii
January 8-9, 2008

Compiled and Edited by

Albert L. Harting

May 2010

Administrative Report H-10-02C
https://doi.org/10.25923/tats-nw81

About this report

Pacific Islands Fisheries Science Center Administrative Reports are issued to promptly disseminate scientific and technical information to marine resource managers, scientists, and the general public. Their contents cover a range of topics, including biological and economic research, stock assessment, trends in fisheries, and other subjects. Administrative Reports typically have not been reviewed outside the Center. As such, they are considered informal publications. The material presented in Administrative Reports may later be published in the formal scientific literature after more rigorous verification, editing, and peer review.

Other publications are free to cite Administrative Reports as they wish provided the informal nature of the contents is clearly indicated and proper credit is given to the author(s).

Administrative Reports may be cited as follows:

Harting, A. L. (Ed.) 2010. Shark predation on Hawaiian monk seals workshop, Honolulu, Hawaii, January 8-9, 2008. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-10-02C, 36 p. + Appendices.

For further information direct inquiries to

Chief, Scientific Information Services
Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
2570 Dole Street
Honolulu, Hawaii 96822-2396

Phone: 808-983-5386
Fax: 808-983-2902

Pacific Islands Fisheries Science Center
Administrative Report H-10-02C

Shark Predation on Hawaiian Monk Seals Workshop
Honolulu, Hawaii
January 8-9, 2008

Compiled and Edited by

Albert L. Harting
Harting Biological Consulting
8898 Sandy Creek Lane
Bozeman, Montana 59715

May 2010

PREFACE

This report has been sponsored by the Pacific Islands Fisheries Science Center and the Pacific Islands Regional Office of the National Marine Fisheries Service. It summarizes the proceedings of the Shark Predation on Hawaiian Monk Seals Workshop that was held January 8-9, 2008 in Honolulu, Hawaii. The workshop was convened primarily to address the ongoing problem of Galapagos sharks preying on preweaned Hawaiian monk seal pups at French Frigate Shoals in the Northwestern Hawaiian Islands.

Because this report was prepared by an independent investigator, its statements, findings, conclusions, and recommendations do not necessarily reflect the official views of the National Marine Fisheries Service, NOAA, U.S. Department of Commerce.

Frank A. Parrish
Marine Mammal Research Program
Protected Species Division
Frank.Parrish@noaa.gov
May 2010

(This page is intentionally left blank.)

EXECUTIVE SUMMARY

Overview

This report summarizes the proceedings of the workshop, *Shark Predation on Hawaiian Monk Seals*, sponsored by the Pacific Islands Fisheries Science Center (PIFSC) and the Pacific Islands Regional Office (PIRO) of the National Marine Fisheries Service (NMFS). The workshop was held January 8–9, 2008 in Honolulu, Hawaii.

The workshop was convened primarily to address the ongoing problem of Galapagos shark predation on preweaned Hawaiian monk seal pups at French Frigate Shoals (FFS) in the Northwestern Hawaiian Islands (NWHI). This predation was first observed on a large scale at Trig and Whaleskate Islands in 1997–1999 (map: Appendix A) and has persisted at varying degrees since that time. Various types of mitigation have been attempted, including harassment, translocation of weaned pups, and removal of predatory sharks. While these methods appear to have been partially successful in reducing predation, predation remains at unacceptable levels and is believed to constitute an impediment to recovery of this declining population. The workshop was therefore convened to examine the dynamics and history of Galapagos shark predation on monk seal pups, and to investigate the full range of mitigation options that might be applicable to the situation at FFS.

The workshop was chaired by Dr. John Reynolds, Chairman of the Marine Mammal Commission. Participants included representatives of key agencies with jurisdictions in the NWHI, shark ecologists, and researchers with expertise in recent innovations in the field of nonlethal shark deterrents (see Participant List, Appendix C). The workshop was structured around presentations conducted by PIFSC and visiting scientists, with abundant time devoted to moderated discussions. Abstracts were assembled from transcribed notes, as supplemented and reviewed by each presenter. The workshop culminated in a general evaluation of all mitigation alternatives proposed during the workshop.

Conclusions and Recommendations

Several dominant themes emerged from the presentations and discussions at the workshop. First, participants agreed that the problem of shark predation on preweaned and recently weaned pups at FFS constituted a significant obstacle to monk seal recovery at this atoll and some form of mitigation was appropriate. The difficulties inherent to developing and implementing timely and effective mitigation strategies within a multiagency context were acknowledged.

The three presentations on shark biology emphasized that very little is known about the local population (abundance and life history) of Galapagos sharks, both in the NWHI and at FFS in particular. Available data for this species in the NWHI are based on the few sharks tagged in prior studies or extrapolation of results from other areas that may not be fully applicable to the FFS population. It was agreed that additional research (tagging and other) was needed at FFS to estimate the abundance of Galapagos sharks engaged in pup predation to determine whether the predators were a quasi-distinct group of sharks or were part of the larger Galapagos shark population that ranged both inside and outside of the atoll, and to better characterize the shark movements and ecology at the atoll and their behavioral repertoire associated with pup predation. Shark researchers at the workshop agreed that the presence of Galapagos sharks in shallow water around pupping sites was not characteristic behavior for the species but could be a distinctive behavioral characteristic of the local (NWHI) population. Presentations on shark behavior and shark predation on pinnipeds in other areas demonstrated the unpredictability of the taxa in general and also showed their ability to learn and adjust their predatory behavior in accordance with changes in pinniped population numbers or distribution.

Presentations on nonlethal deterrents illustrated that several different types of devices hold promise, but either may not be ready for immediate deployment or would be logistically difficult to deploy in a remote open-water setting. Of the methods discussed at the workshop, permanent magnets and E+ metals appeared to be the most promising, but the optimal method for deploying these in the field was unclear. Potential methods discussed at the workshop included magnetic “barriers” placed in the water, attachment of E+ “mischmetal” directly on seal pups and other methods. Additional discussion, but no presentations, pertained to other deterrent types (visual, auditory, and electromagnetic deterrents) that might also be possible.

No workshop participants expressed disagreement with the concept that additional removal of sharks was the best option to immediately reduce the level of predation on monk seal pups. However, some attendees expressed reservations about the ability to successfully capture those individual sharks responsible for the predation. The shark researchers felt that although Galapagos sharks had clearly become exceedingly wary of traditional hook-and-line fishing near Trig Island, they could likely still be caught using a method similar to a short longline (25 hook drumline buoys of 50–100 m), set in shallow water elsewhere in the atoll. Justification for catching sharks away from Trig was based on the aforementioned observation that shallow-water patrolling was atypical behavior for the species, and it was therefore likely that any shark exhibiting that behavior was among the pool of predators. A representative of the Hawaii Department of Land and Natural Resources noted, however, that based on the limited success of shark removal attempts in prior years, a new proposal to conduct more removals would require additional scientific underpinnings to gain acceptance.

Outcomes from the Workshop (Post-workshop Developments)

Following the workshop, NMFS elected to defer removals pending results from experimental deployment of a suite of nonlethal deterrents (Appendix D). Deterrents deployed in 2008 and/or 2009 included visual deterrents (boat anchored offshore near

Trig Island; assorted visual stimuli in the water column; light source projected from shore or boat); auditory deterrents (boat noise broadcast by an underwater loudspeaker); magnetic deterrents (permanent magnets deployed in association with the visual stimuli); and electromagnetic deterrents (powered *Shark Shield* type device deployed at strategic access points near Trig Island). Devices were deployed in June through August. Results from the deterrent research will be presented in a separate report.

Also, consistent with recommendations made at the Workshop, the Hawai‘i Institute of Marine Biology (HIMB) initiated additional shark tagging studies at FFS in 2008 (Appendix E). In association with this research, NMFS deployed sonic tags on weaned pups at Trig Island. These joint tagging studies were designed to determine the spatial and temporal overlap of monk seal pups and Galapagos sharks at FFS.

(This page is intentionally left blank.)

CONTENTS

GOALS AND OBJECTIVES OF THE WORKSHOP

Goals

- Better understand the predation dynamic and facilitate monk seal recovery at French Frigate Shoals (FFS) by identifying those measures most likely to be effective in reducing predation impacts on monk seal pups;
- Address the conflict between agencies on the controversial nature of the shark removal program by exchanging opinions.

Objectives

- Disseminate/update information on shark predation trends at FFS with emphasis on seal population impacts and previous mitigation studies
- Provide an overarching perspective on ecological concepts and recent conservation thinking that apply to the shark predation problem at FFS
- Review aspects of shark ecology that influence predation dynamics
- Consider techniques others have used to mitigate shark predation that have been successfully applied or are currently under development
- Identify the most important shark studies and other ancillary research efforts that are needed
- Identify mitigation measures that are most likely to be feasible and effective for the FFS situation
- Discuss the issue of acceptable level of impacts to other resources

(This page is intentionally left blank.)

Welcome and Opening Remarks
(John Reynolds: Marine Mammal Commission, Moderator)

Galapagos shark predation on Hawaiian monk seal pups has been a challenging issue for NMFS and is one which has garnered the interest of the Marine Mammal Commission. One of the general principles that apply to these types of conservation issues is that the objective is to avoid just monitoring the situation—decisions, and change if necessary, must be made quickly. For example, we watched as the Baiji (a freshwater dolphin found only in the Yangtze River in China) went extinct, and its decline was well documented. We want to avoid waiting for an extreme crisis to occur at which time we may have almost no options, which is both expensive and painful. It is far better to make decisions prior to arriving at the crisis state.

SESSION I: BACKGROUND AND OVERVIEW OF SHARK PREDATION AT FRENCH FRIGATE SHOALS

Presentation 1: Overview of the Problem…Biological, Political, Social
(Bud Antonelis, Pacific Islands Fisheries Science Center)

Hawaiian monk seals (HMS) are primarily resident in the Northwestern Hawaiian Islands (NWHI), and those seals are declining in numbers. About 200 seals also occur in the main Hawaiian Islands (MHI) where they are increasing in numbers. The monk seal numbers are at their lowest levels in recorded history, and are declining at ~ 4% annually in recent years, with the current total population being about 1200 individuals. The population is expected to decline to < 1000 individuals sometime in the next few years. Juvenile mortality is the primary reason for the population decline, with starvation and predation being the two biggest problems. French Frigate Shoals (FFS) is largely responsible for the NWHI population decline, but beginning in 2000 other subpopulations began to also decline.

The conservation “conundrum” that characterizes this predation situation is that killing one native species to help another is not typically regarded as a sound conservation approach.

Although the legal mandates that apply to Hawaiian monk seal population management and recovery are not themselves inconsistent, the *interpretation* of those multiple mandates by multiple agencies can sometimes present difficulties. The primary mandates applicable to this situation are the Endangered Species Act, Marine Mammal Protection Act, and Maintain Biodiversity Fish and Wildlife Service Compatibility Determination.

Also, a number of social issues apply to the shark predation situation. We recognize that Native Hawaiian cultural history, knowledge, and traditional use of sharks must be properly considered in any mitigation strategy. Also, peoples’ perceptions of the appropriateness of shark removals may be affected by earlier cases of shark culling, most notably the history of shark removal by the State of Hawaii in MHI to improve human safety. That effort was very controversial and polarizing. Shark removals at FFS were initiated in 2000 after 3 years of unacceptably high rates of preweaned and recently weaned pup losses. The key factors leading to the FFS shark removal experiment that began in 2000 were:

- Galapagos sharks were primarily responsible for the observed preweaned pup losses
- This intense predation on preweaned pups was observed only at FFS
- Galapagos sharks are not threatened or endangered
- Direct observations suggested that a limited number (< 20 sharks) were likely involved
- A dramatic rise in pup mortality was documented in the late 1990s
- Ecosim modeling (preliminary results) indicated that the limited removal was unlikely to have pronounced ecosystem effects

The removal decision was predicated on an informal decision tree framework. That is, what were the best/worst possible consequences that would result from doing nothing, versus the best/worst possible consequences that would result from taking action (i.e., removing sharks). In that framework, in which there was a tradeoff in the interests of a critically imperiled species and a small number of a relatively abundant species, the course of action was unequivocal.

This workshop was convened in hopes of identifying alternative mitigation methods that are needed because current techniques are ineffective. Further, with the recent designation of the Papahānaumokuākea Marine National Monument, there is an additional management paradigm that discourages removal of native species within the coral reef ecosystem. Better coordination is also needed with the State. These considerations present new hurdles in designing and implementing a mitigation plan.

Presentation 2: Dealing with the Problem within a National Monument
(Randy Kosaki, Papahānaumokuākea Marine National Monument)

The NWHI make up three-fourths of the Hawaiian Archipelago and represent a unique ecosystem – many endemic fish species are present, as are a number of southern Japanese species not found in the MHI. Also, there are great numbers of apex predators (e.g., sharks and ulua). For comparison, the NWHI apex predators comprise 50% of the marine fauna, compared to 3% in MHI.

History of the Monument

In 1993, longline fishing was excluded for 50 nmi around the NWHI to reduce potential impacts to protected seabirds and seals. In 1998, the U.S. Coral Reef Task Force was formed to inventory coral reefs, and they found that most of the coral reef area in the United States lay within the NWHI. In 2000, President Clinton created the NWHI Coral Reef Ecosystem Reserve—the first step in designating a National Sanctuary (under the Sanctuary Act). From 2001 to 2006, the Sanctuary designation process was underway, but this was a slow process requiring lots of public input. Prior to the completion of that process, in June 2006 President Bush declared that the area instead be designated as a National Monument (under the 1906 Antiquities Act). Noteworthy is the fact that the conservation language is much stronger in the Sanctuary Act than in the Antiquities Act.

There are three management mandates for the Monument:

1. Comanaged by three agencies (NOAA, U.S. Fish and Wildlife Service, State of Hawaii Department of Land and Natural Resources (DLNR))
2. All activities are either expressly prohibited or permitted
3. Secretaries may not issue a permit unless the activity meets certain restrictive criteria: among these is that no permit will be issued unless the activity can have adequate safeguards for resources and the end value helps the Monument achieve its mission(s)

There is also a Monument Management Board that consists of several State and Federal Agencies, including the Office of Hawaiian Affairs (OHA). (Department of Land and Natural Resources-Division of Aquatic Resources/State of Hawaii Division of Forestry and Wildlife, OHA, United States Fish and Wildlife Service–Ecological Services/Refuges, NOAA Fisheries).

The permitting process has been simplified, so that each applicant receives one permit signed by the three comanaging agencies, rather than three separate permits from each agency. Permits using poisons, electrical charges or explosives are prohibited for the collection or harvest of a Monument resource. Permits currently take 90 days, with Feb 1 being the deadline for summer 2008. The permitting process is still evolving as it was established only in June 15, 2006, when the Papahānaumokuākea Marine National Monument was established.

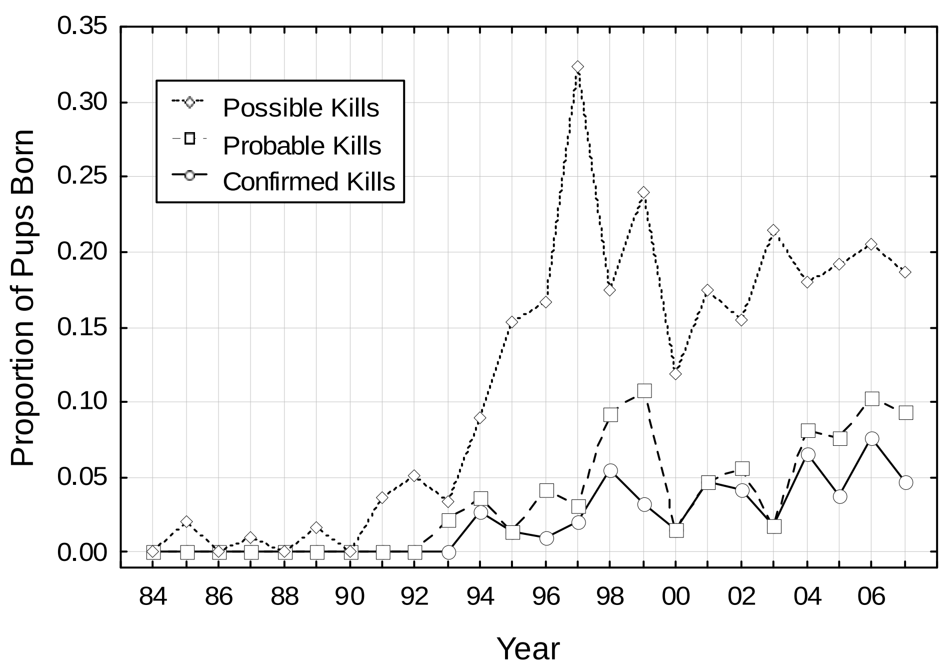
Presentation 3: Mitigation Efforts and Monitoring
(Bert Harting, Contractor to PIFSC)

Shark bites are observed on seals throughout the NWHI, and scars from shark bites are a common characteristic used to identify individual seals. However, the FFS situation is unique because the pre-weaning survival rate is lower than anywhere else (60–70% to end of pre-weaning stage on FFS vs. 85–95% at Midway Atoll (MID), Laysan Island (LAY), and Lisianski Island (LIS). Also, the incidence of observed bites on pups is much higher at FFS than elsewhere (LAY or LIS).

Summary of Known and Inferred Predation Mortalities at FFS

Our compilations of pup losses from shark predation require several categories to denote differences in how the mortality was determined to be a predation loss. "Confirmed" losses are those mortalities for which predation was actually observed (< 5/year). "Probable" losses include both confirmed predation losses (preceding category) plus any pups that had shark wounds and subsequently disappeared (1–10/year). Finally, "possible" losses include both of the preceding categories (confirmed and probable) plus pup disappearances inferred to be shark predation from specific defined criteria (presence of sharks, no other compromising factors, etc.). Although we are conservative in assigning an unexplained disappearance to shark predation, some of the inferred losses could also be based on some factor other than predation, such as starvation or male aggression. Inferred losses account for the preponderance of the total losses.

The proportion of FFS pups killed by sharks (all categories) has been about 15–20% of the annual cohort of each of the last few years (upper line in figure). The number of pups born has been declining because the number of breeding females is declining.



Monitoring and mitigation efforts at FFS have included intentional harassment of sharks, intensive monitoring of shark-seal interactions (with probable displacement as a result of human presence and activity), translocations of recently weaned pups, and shark removal. Observations in 1997–1999 indicated that 15–20 individual sharks were probably responsible for the predation losses (i.e., a small number of sharks). Intensive ground observations were initiated in 2000, and in 2001, a tower was set up on Trig Island to improve observations. The rate of shark observations dropped progressively from 2001 to 2003. By 2003, the sharks had become very wary and were rarely observed. Nonetheless, pup losses continued, indicating that sharks had shifted their predatory patterns to crepuscular periods. Concurrently, predation losses at sites other than Trig Island increased, suggesting that sharks were focusing on sites where there was less human activity. This spread to other sites across the atoll may have been a result of, at least in part, human harassment/presence at Trig.

Shark removal efforts occurred from 2000 through 2007, with variable success. In some years, no sharks were caught. A total of 12 sharks were removed: 2000—1 shark; 2001—5 sharks; 2002—2 sharks; 2003—2 sharks; 2004—0 sharks; 2005—2 sharks; 2006—0 sharks; 2007—0 sharks. Fishing methods included: hook/line (baited with fish, seal flesh, placenta) from shore and boat; handheld harpoon; harpoon gun, and drum method (2007 only; baited hooks hung from buoy). In 2007, a great deal of effort occurred (shorter window of fishing, but higher effort as a result of the greater number of hooks deployed simultaneously), but no Galapagos sharks were caught (bycatch included 3 tiger sharks, 3 grey reef sharks, and 1 white-tipped reef shark). Currently, we are not aware of any viable fishing method that is likely to catch Galapagos sharks with a low incidence of by-catch. Hook-and-line methods are now completely ineffective.

Pup translocation from Trig (the focal predation site) to other less risky sites has been practiced since 2001 (and in 1997 to mitigate for male aggression). The best recipient site is now Tern Island where human activity may discourage sharks. Most killed pups are preweaned (still nursing) and can therefore not be translocated. However, a substantial number of pups are injured/killed at/near weaning. The raw number of pups lost each year is now well below the high numbers observed in 1997–1999, and it is possible that the mitigation efforts (translocation in particular) may have contributed to the decline.

Presentation 4: Behavioral Studies (movement patterns) of Galapagos Sharks
(Carl Meyer, Hawai‘i Institute of Marine Biology)

Shark studies were conducted in both the NWHI and MHI, but the numbers tagged were small, so the scope of these studies is limited. Sharks were instrumented with acoustic (surgically implanted) and satellite tags, but most were acoustic tags. Acoustic tags require the placement of receivers to pick up the signal and store data. Satellite tags do not require receivers, but do require that the shark comes to the surface and project its fin out of the water; otherwise no signal can be picked up. Therefore, both methods have drawbacks.

Two shark tagging/tracking studies in the NWHI:

- Lowe et al. 2000–2003: Galapagos sharks and tiger sharks were tagged at FFS (10 receivers) and MID. Ten Galapagos sharks were tagged at MID/FFS, with 4 Galapagos sharks tagged next to Trig (one never heard from; another was culled at Trig 1 year later)

- Meyers 2005–2007: Shark/Ulua tagging study, mostly outside of the atolls. Forty Galapagos sharks were tagged, including 13 tagged at FFS (5 receivers). Only 1 was detected inside the atoll in 2 years (East Island). Tiger sharks were detected both outside and inside the atoll, including Trig Island

Galapagos sharks were difficult to catch within the FFS atoll. The 2002–2003 catch rate was 0.015 sharks per hook hour of fishing effort, as contrasted with 0.4 sharks per hour of fishing effort outside the atoll during the 2005–2007 study.

There are four primary management options to be considered:

- No action
- Exclude predator
- Remove selectively
- Reduce shark population

One big question that could drive the choice of options is whether Galapagos sharks are wide-ranging or site-attached. Based on results from 30 tagged tiger sharks, this species was very wide-ranging (thousands of kilometers) and routinely moved between atolls. In contrast, of the 60 tagged Galapagos sharks (40 were tracked for 2 years.), only 1 shark moved from Pearl and Hermes Reef (PHR) to FFS (1200 km). Based on these findings, it appears that unlike tiger sharks, Galapagos sharks are resident at one site.

Another key question is whether there are predictable patterns of movement in Galapagos sharks?

Some predator species (e.g., ulua) have very consistent and highly predictable diel, lunar and seasonal patterns of behavior at FFS. However, Galapagos shark movement patterns were nebulous, changing over time with no clear patterns. Consequently, it is more difficult to determine changes in their behavior because of human interactions. Three Galapagos sharks tagged in 2000–2003 did not overlap in time and had fewer hits over time. No hits were recorded at Gin Island or Round/Mullet; Trig was the hotspot. However, there is some evidence of use of core areas (e.g., near Tern Island), but such areas appear to be generally uncommon inside the FFS lagoon.

Absence of any particular diel or seasonal pattern may reflect adaptive behavior. If a predator is highly predictable, the prey will figure out when the predator is likely to appear. Random movements maximize the surprise factor. Further, if all predators behave the same, interspecific competition could result.
Preliminary conclusions from these two studies:

- Galapagos sharks were primarily resident at atolls
- Galapagos sharks were uncommon inside the FFS lagoon
- Galapagos shark behavior patterns varied among and within individuals
- There was evidence of core area use by some individuals

Suggested Studies:

- Conduct mark-recapture studies to assess Galapagos shark population size
- Deploy additional acoustic tags (on both sharks and seal pups) to determine when seals are in the water and characterize shark/seal movements within the atoll
- Increase the receiver coverage inside/outside barrier reef
- Colocate current profilers with receivers to evaluate current oceanography
- Conduct active tracking.

Presentation 5: Adaptive Management Experimental Approach
(Carl Walters, University of British Columbia)

Most agencies now claim to engage in adaptive management (predict, monitor, take corrective action). However, there are two types of adaptive management: "passive" and "active." Active adaptive management (AM) involves experimental probing of the system and is much rarer than passive AM.

The situation under consideration here is experimental adaptive management, with structural uncertainty about the system. There are actually few active adaptive management policies.

There are now around 30–40 different adaptive management studies that can be evaluated, and there is a failure rate of 90% of those. A notable example is the collapse of the Chesapeake Bay oyster fishery. In general, few people learn from experience – it did not require scientists to conclude that the fishery was falling apart.

Adaptive management is about learning to manage dynamic systems more effectively, not necessarily about "improving scientific understanding." Given high uncertainty about the impacts of applied policy, every policy choice is essentially an "experiment" — the only real issue is whether to admit this and proceed accordingly.

In passive adaptive management, we assume that a statistical estimate of performance is possible. In active adaptive management, the assessment is more complex. There are dual effects of system changes and our control, and we assume that the estimated change in performance resulted from policy.

There remains a need for active adaptive policies. Learning rates generally do depend on policy choice, since responses are generally regression relationships. However, not all "probing" policies are worth testing; candidates for testing are only those that have some potential for improving management performance. There is little reason to probe the system for something we would not want to happen. Again, the objective is not about responses, it is about improving management.

The basic approach for designing adaptive management policies:

- Begin by clearly identifying policy options
- Try to predict (model) the outcomes of each choice (although, we always fail to predict the actual outcomes)
- Honestly evaluate how uncertain those predictions are and whether the uncertainties can be resolved without actually trying each choice (define a "strategic range of alternative hypotheses about response to policy")
- Identify policy option(s) worthy of field-testing
- Develop experimental design and monitoring program for the field tests

Ecosim can be used to explore alternative explanations for system perturbations in the Northwestern Hawaiian Islands and FFS in particular. Initial Ecosim runs modeled trophic interactions but failed to include primary productivity in the model. Results indicated that around 1990 something happened in the ecosystem and fishing plus trophic interactions alone did not completely explain the monk seal decline. An improved prediction of the lobster decline is found by including the influence of primary productivity in the Ecosim model. Satellite chlorophyll data indicate a persistent 40–50% decline in primary production around 1990; this could "explain" the continued monk seal decline.

The experimental design choices for adaptive management experiments depend, in part, on the size and complexity of the system. Only BA (before-after) comparisons are available for large, unique systems. These types of comparisons inevitably fail due to uncertainty about the effect of treatment, time-treatment interactions (see below), and other factors. For spatially structured systems, "pilot experiments" can be used. For example, one can apply a "staircase experimental design" in which areas are sequentially treated to determine if the same effects are manifest in each area.

Dynamic systems are nasty and make it much more difficult to discern actual treatment effects. Time-treatment interactions must be understood: if a treated experimental unit shows some undesired response compared to control, should we assume the response was due to treatment? Proponents of the policy represented by the experimental treatment can simply argue that treated units respond differently to temporal forcing factors than do untreated units.

The proper design and implementation of adaptive management experiments is difficult. They are inherently expensive because of the need to control for complex time dynamic effects (invest high up front costs to enable lower monitoring costs as the experiment proceeds). These experiments are also risky because the realized responses may be the opposite of the expected. Finally, they require innovative monitoring approaches (e.g., cooperation with stakeholders, and use of advanced technologies with high initial capital cost).

Most adaptive management polices have failed due to one or several factors: self-serving science, risk averse decision makers, bad experimental design or inadequate monitoring programs.

SESSION II: ECOSYSTEM PERSPECTIVES

Presentation 6: Synopsis of Relevant Information from the Publication "Should Ecosystem Management Involve Active Control of Species Abundances?"
(Steven J.D. Martell, University of British Columbia)

This discussion addresses situations where there is a risk of extinction of one or more species caused by the cumulative effects of exploitation, or severe predation/competition with unnaturally more abundant species due to changes in the ecosystem. The central question is: Should management use active policies intended to control predation–competition? Or should it use passive policies, such as protection, to allow natural processes to occur?

The following are multiple arguments against active control:

1. Compensatory responses may occur in the controlled predator leading to the necessity for a sustained culling program. That is, once you start you must continue for life (e.g., shark productivity increases when others are culled)
2. Unexpected consequences: e.g., compensatory response in an exotic or prey species (the "vampire in the basement")
3. The action may trigger strong response from conservation groups who typically object to killing predators.

These considerations must be evaluated in light of the immediacy of extinction risk to the imperiled species.

Active control is often a politically sensitive issue. Among the more notable historical examples to control predators were the mounting of steel blades on Coast Guard vessels to slice basking sharks in half in the early 1900s (sharks were an inconvenience); mounting machine guns to reduce killer whale abundance (1950s); shooting killer whales (1951) w/ anti-aircraft guns (1951); a bounty on seals (ended 1970s); and seal cullings in the Puntlage River to benefit salmonids.

Initially, most of these efforts were initiated because the culled animals were an inconvenience to humans. Later efforts were motivated by the possible extinction of another species.

There are two main types of ecosystem control options:

1. Symptomatic actions: try to directly control predation risk and enhance the productivity of the prey species that is at risk. That is, deal with the immediate problem (culling of predators, hatcheries, rescue-rehab efforts, etc.)
2. Systemic actions: attempt to control the underlying factors that contributed to a high abundance of predators in the first place

Salmon-seal interactions in the Strait of Georgia provide one example of modeling to evaluate a candidate symptomatic control action. Coho salmon abundance declined significantly because of various ecosystem alterations. The working hypothesis for the response is that increased seal predation has led to decreased coho salmon abundance. Concerns preceding the action centered on whether reduced seal predation on hake might lead to increased hake predation on juvenile coho. Modeling predicted that the seal cull must be coupled with an increase on hake harvest in order to protect coho salmon. The key result of the symptomatic control modeling experiment was that reducing harbor seals (90% reduction) would increase juvenile salmon survival rates and allow continued fishing at present rates. However, the response is transient, requiring that the cull must be continued indefinitely.

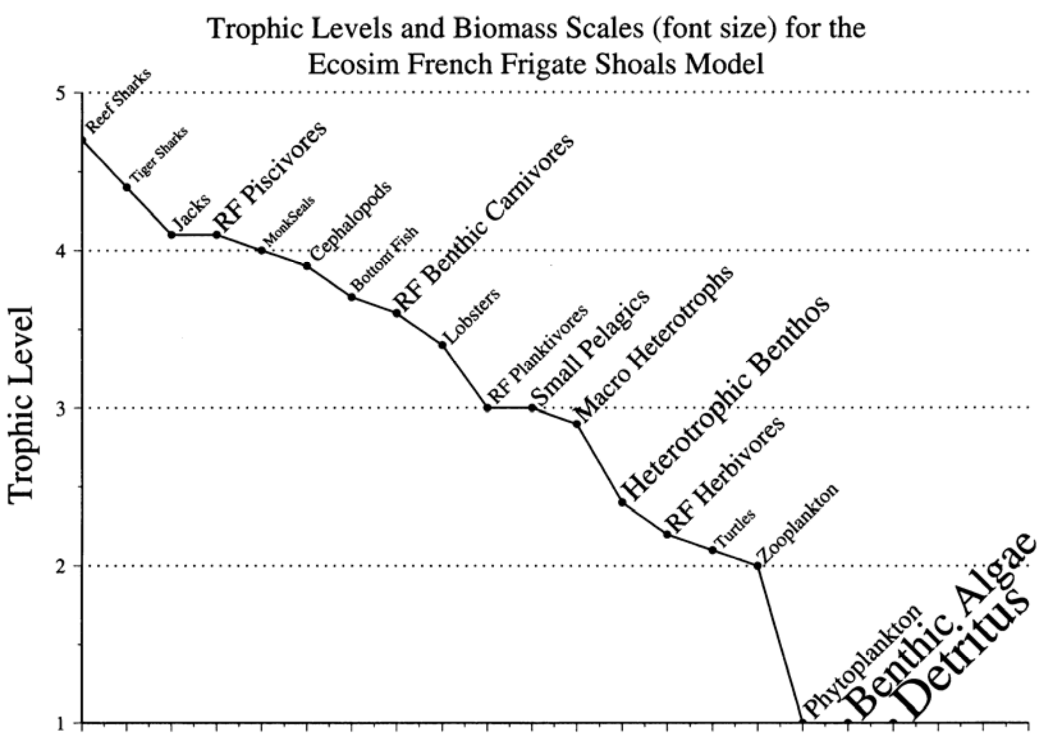
Another example pertains to large mammal interactions in northern boreal forests. The woodland caribou (listed as threatened) has declined as a result of ecosystem alteration associated with the loss of old-growth forest. The core hypothesis for the control action is that increased wolf predation on caribou was based on a positive numerical response in wolf abundance to increased production of moose. Systemic control would seek to protect old growth forest, while symptomatic control would cull wolves. One concern was that wolves would continue to prey on (low density) caribou populations if moose populations continued to support wolves. Key results and uncertainties from the modeling indicate that protecting the forest would lead to only minor increases in caribou densities, with a high probability of extinction. Alternatively, the response to wolf control was a short-term increase in caribou but long-term decline associated with continued forestry operations. Also, the response to moose control was similar to that of wolf-control; however, long-term caribou densities were nearly double. Finally, if both wolf and moose control was conducted, caribou densities tripled, thereby allowing for continued forestry operations.

These preceding case studies demonstrate the value of models for comparing/ranking policy options, identifying alternative hypotheses, and developing decision tables. Aggressive control policies are not risk averse and should be considered in formal risk analyses. When evaluating a control action, researchers should look for other signs of stress that indicate habitat problems (e.g., food limitation for caribou). Finally, we must recognize that inaction is itself an experimental policy choice that carries with it a reasonable probability of failure.

Presentation 7: Demonstration of Ecosim Model
(Jeff Polovina and Evan Howell, PIFSC)

The French Frigate Shoals modeling effort originally began by looking at diet information from the early 1980–1990s using the predecessor to Ecosim (ECOPATH), first published in 1984. Frank Parrish modified the model in the 2000s to look at a larger ecosystem perspective to estimate Hawaiian monk seal carrying capacity. Parrish subdivided various trophic components and also provided a finer breakdown of the apex predators to produce an FFS trophic ecosystem. Initially, it was believed that the HMS ate shallow water reef fish, so the model has been modified as new data became available.

Frank ground-truthed by estimating biomass independent of the model using dive transects and habitat information to estimate atoll population of reef fishes. New information from satellite tagging and CRITTERCAM work indicated that HMS were foraging outside of FFS in deeper waters well outside the atoll community. Additional info came from fatty acid and CRITTERCAM studies. Current diet analysis indicates that HMS feed 12% in the shallow reef fish community; mesophotic = 67%; subphotic community = 21%.



Parrish ran the model using the default vulnerabilities to try and answer preliminary questions. When removing Galapagos sharks, the model shows an increase in jacks, etc. as one reef apex predator is replaced by another. The best estimate is that the ecosystem responds with an increase in jacks as well as other prey items that are more sensitive to top down shark production.

The FFS model is the best ECOPATH model ever built as it is built on an enormous amount of data. The final model will be available to the public once it is published and peer reviewed. The HMS population will be used to proof the model, along with actual surveys of marine environment.

SESSION III: SHARK BEHAVIOR

Presentation 8: Traditional Knowledge and the Hawaiian Perspective (William Aila, local fisherman and member of the Hawaiian Monk Seal Recovery Team)

There is very little contemporary information on native Hawaiians and the HMS. There is a passage in "Ruling Chiefs" in which Kamehameha IV shot some monk seals on his way to Ni'ihau for reannexation. No explanation as to why the seals were harvested is provided. Records show that King Kamehameha shot and killed monk seals back in the day. Uncle Charlie Maxwell knows of some 'oli (chants) talking of the HMS in the form of 'aumakua – it is not unexpected that there would be a relationship between native Hawaiians and the HMS.

There are some records of ancestors talking about monk seals being their 'aumakua. But there is a missing piece of knowledge because sharks as a species have also been considered 'aumakua (Hawaiian guardian spirit in animal form). However, if a shark is the embodiment of an ancestor, it would be an individual and *not* an entire species. This information has not been passed down – something is missing. There are 30–40 documented cases of sharks being an aumakua.

The relationship with the monk seal is not well documented. There are, however, some old documents (many indigenous newspaper articles) that have not yet been translated. As this is done, perhaps it will shed some more light on monk seals. Although it is not a scientific process, something being processed in our na'au (gut) was the Hawaiian way of assimilating information.

Galapagos sharks and monk seals are similar in that they are opportunistic feeders, dealing with whatever limitations they face, whether that is being a juvenile HMS and not being able to dive as deep as adults, or being a juvenile Galapagos shark and feeding on monk seals because they are available. From a Hawaiian (indigenous) perspective, there are three primary rules: eat, avoid being eaten, and live long enough to create the next generation. These rules apply to all forms of life.

What is the contemporary relationship with the HMS and how does it drive the geo-political situations? There is a small group of Hawaiians that say leave the HMS alone and let nature run its course. Others say we are in charge of managing the mistakes that we have created and thus, perhaps, we do need to cull some sharks. Other nonlethal methods may also be considered by this group. The vast majority of the native Hawaiian community feels that it is their kuliana (responsibility) and need to take responsibility to help save the seals and be proactive. There are historical models for shark removal, e.g., a specific shark threatening a community would then be removed.

From a contemporary standpoint how would we compare predation on a juvenile HMS to predation on kids on boogie boards? In the past, there would be shark cullings. From a cultural standpoint there was some psychological benefit, but unknown scientific benefit.

From this standpoint, culling is an option that should be considered. However, culling 100 Galapagos sharks might not be acceptable. Twelve likely shark culprits are likely to be more acceptable. Some members of the public feel that if the land is going to be lost to sea level rise, why even bother culling sharks? We have a responsibility to solve this problem, however. If we take sharks, we have to make sure to use as much of the shark as possible–that is nonnegotiable.

If the last 2 years have been unsuccessful at culling sharks, then it is because something is wrong–whether it is because of the wrong people trying or the wrong personalities or the wrong mentalities, etc. That needs to be fixed.

The shark predation is a learned behavior so we must remove the sharks that are causing this problem. We need to consider which points of view are the most pervasive, and we have to be proactive and do something now.

Presentation 9: Galapagos Shark Geographical Distribution, Status, and Predator Characteristics

(R. Dean Grubbs, Florida State University Coastal and Marine Laboratory and IUCN Shark Specialist Group, formerly of HIMB)

Distribution and Conservation Status

The Galapagos shark, *Carcharhinus galapagensis*, is a widespread tropical species with discrete semi-isolated or isolated populations typically associated with oceanic islands. To date, a study of global phylogenetics has not been completed for this species though it is likely that discrete allopatric populations exist. Galapagos sharks are listed globally on the World Conservation Union (IUCN) Redlist as Near Threatened (IUCN, 2007). This is a precautionary listing because wide-ranging species with isolated populations are of particular conservation concern because of the potential for local extirpations and resulting loss of global genetic diversity. However, in all regional assessments by the IUCN Shark Specialist Group, Galapagos sharks have been listed as Data Deficient due to an overall lack of basic life history data, no information on abundance trends, and worldwide problems of misidentification and confusion with congeners.

Galapagos sharks are found throughout the Hawaiian Archipelago but are much more common in the Northwestern Hawaiian Islands than the main Hawaiian Islands. They most often occur on off-reef habitats with converging currents where water depths are 30 to 50 m but may occur at depths to 300 m (Wetherbee et al., 1996). There is some evidence that sexual segregation by depth occurs in the Hawaiian Islands. While no work on population genetics has been conducted, it is likely that a single semi-isolated or isolated population exists throughout the Hawaiian Archipelago. If true, the Hawaiian population of Galapagos sharks may be the largest (geographically and numerically) in the world.

Life History

The only published data concerning litter sizes, age and growth for Galapagos sharks come from sharks captured in the State of Hawaii shark control programs conducted from 1959 to 1976 (Wass, 1971; Wetherbee et al., 1996). Galapagos sharks are viviparous. Embryos are initially lecithotrophic feeding from a yolk-sac attached to the digestive tract. Once the yolk is used, the yolk sac interdigitates with the uterine wall forming a yolk-sac placenta through which matrotrophic nourishment in the form of histotroph is transmitted to the embryo. The mean litter size in Hawaii was 8.7 pups and ranged between 4 and 16 pups. The smaller litters may have excluded aborted embryos, however. Therefore, the actual mean litter size may be slightly higher than reported. Galapagos sharks are born at ~ 80 cm total length (TL). Gestation is unknown. Based on very few data, Wetherbee et al. (1996) and deCrosta et al. (1984) suggested a 12-month gestation period. A reexamination of these and unpublished data suggests a gestation period of 20 to 24 months may be just as likely. Galapagos sharks are related closest to dusky sharks (*C. obscurus*), a species with a known gestation of up to 24 months. Only 18% of mature female Galapagos sharks caught in the Hawaii shark control programs were pregnant, suggesting either the reproductive periodicity of this species is greater than 2 years or a proportion of pregnant females were not available to the capture gear (due to movement or lower catchability).

Galapagos shark males mature between 205 and 239 cm TL and reach at least 267 cm TL. Females mature between 215 and 245 cm TL and reach at least 300 cm TL. Age at maturity is unknown for Galapagos sharks. Vertebral aging was conducted by deCrosta (1984) using 45 samples; however, no mature animals were included in the analysis and some confusion between the birth band and age-band may have existed. Using these limited samples, age at maturity was estimated to be 10 years for males and females. Wetherbee et al. (1996) used this same growth model to estimate that maturity occurs at 6–8 years in males and 6.5–9 years in females. These are likely gross underestimates of age at maturity. The very closely related dusky shark matures at approximately 20–22 years of age. It is likely that the actual age at maturity of Galapagos sharks is roughly twice that reported by Wetherbee et al. (1996).

Diet

Data concerning the diet of Galapagos sharks are limited. Typical of most “ridge-backed” species in the genus *Carcharhinus*, Galapagos sharks possess serrated, triangular upper teeth for cutting and narrow lower teeth for grasping. This dentition allows these predators to feed on a wide range of prey taxa. Overall, the diet of Galapagos sharks in Hawaii is similar to that of sandbar sharks though there is some evidence that resource partitioning exists between these two shark species in terms of habitat. Galapagos sharks feed on a large variety of teleosts as well as cephalopods and crustaceans and among the largest Galapagos shark size classes, an ontogenetic shift in diet from teleost fishes to elasmobranch fishes occurs (Wetherbee et al., 1996). The available data suggest that Galapagos sharks feed on marine mammals infrequently. However, in limited bait comparisons, Galapagos shark catch rates were much higher when using marine mammals (Delphinidae) as bait than when using fish (Scombridae) as bait (Wass, 1971).

Summary

The biology of Galapagos sharks is poorly studied for any population. Studies of global phylogeny and population genetics are needed. Large gaps in life history knowledge greatly hinder population assessments and attempts to model population growth rates, resilience, and doubling times to date have been based on the likely erroneous estimates of life history parameters. For example, Smith et al. (1998) estimated the rebound productivity (r_{2M}) for Galapagos sharks to be 0.48 and the population doubling time to be 14.5 years compared to 0.20 and 29.9 years for dusky sharks, respectively. The rebound productivity and doubling time for sandbar sharks, which likely have faster rates of individual and population growth than Galapagos sharks, were estimated to be 0.28 and 25.1 years. A rigorous life history study should be a priority for this species. The Northwestern Hawaiian Islands may be an ideal place for such a study due to its large population of Galapagos sharks and the absence of any significant fisheries mortality. No directed fishery exists for coastal sharks in Hawaiian waters, and bycatch in bottomfish, handline, and longline fisheries is minimal. Catch rates of Galapagos sharks in the main Hawaiian Islands did not decline during the Hawaii shark control programs (Wetherbee et al. 1996) suggesting that sampling of sharks sufficient for completing a study of age, growth, and reproduction should have little impact on the population.

Presentation 10: White Shark Research in Australia
*(***Barry Bruce, CSIRO***)*

White sharks are protected in Australia, and therefore have a National Recovery Team and a recovery plan. Additionally, measures are in place intended to reduce bycatch, and there are efforts to promote ecotourism management, public safety, etc. Research provides much of the information needed to support these efforts. Researchers are especially interested in movement patterns and their relationship to shark control programs.

Tagging Program

Since 1990, 550 sharks have been tagged with a variety of tags, including simple marker tags, acoustic tags and satellite tags. Long-life acoustic tags require listening stations, and the tags last 2–5 years. Many acoustic tags have been deployed in a large bay in S. Australia (North Neptune Island, South Neptune Island, and Dangerous Reef) where seal colonies are present to see how sharks move in the vicinity of seals.

A key question is whether sharks are resident in certain areas. No, the average period of residency was 36 days (max. 90 days), but they returned to the same places on a seasonal basis. The seasonality depended on the individual – with no pattern for the species at-large. Shark #36 provided an extreme example of seasonal visits. This shark was present in Sept 2001 to Nov 2001 and then disappeared until Sept 1, 2002—1 day earlier than in the previous year and left again in November. Other individuals are present in summertime, spring, or winter (this pattern allows resource sharing).

White sharks displayed defined diel activity, such as greater activity during the middle of the day in bays where seals are abundant. Specificity in time of day occurs on N. Neptune Island in the bay where an Australian Sea Lion colony is located. Sharks resided in the bay during daytime. Outside the bay (< 1 km away), the sharks showed different patterns: some individuals were present during morning only, others in late-morning to midday. Sharks would surface for a very brief duration in the bay during the day.

The diel pattern where seals were not abundant was quite different, with no peak during the middle of day. The diel patterns completely depended on the individual, with no overall species pattern for seasonal or diel movements. At night, the sharks tended to go into deeper water (common pattern for most or all sharks). In spite of differing seasonal movement patterns for individual sharks, there were more sharks in the area during the late winter (August), perhaps because seal pups were most abundant at that time. There was a seasonal signal with an influx of larger female sharks in June–Sept, and arrival of newly weaned pups in July-Sept. There was annual variability in shark abundance with high and low years at the Neptune Islands. For example, 2003 was below average, but this pattern was a distributional issue (sharks were somewhere else), rather than something related to the seal colony.

Most of the white shark literature deals with their patterns near pinniped colonies. However, more white sharks spend time away from pinniped colonies than near them. White sharks feed more often on prey other than seals, as shown by satellite tagging. These data indicate extensive movements all along the southern Australia coast for thousands of kilometers (extending to the southern end of the Great Barrier Reef) and up the west coast of Australia (north of Perth) and even to New Zealand. These sharks have preferred areas where they spend a lot of time (hotspots), and many of those locales do not have seal colonies. In these areas, sharks feed on teleosts and other elasmobranchs. The tagging demonstrates how individuals alter their diel behavior (e.g., in terms of dive depth, surfacing intervals, and diel patterns) as they move from one hotspot to the other and switch between seals and fish. Their movements and their feeding preferences are not very predictable.

Ten white sharks (juveniles 2–2.5 m length) were tagged at a popular beach near Sydney in 2007. Tagging data indicated that they spent a great deal of time on popular surf breaks, in spite of a shark culling program. Individual sharks were very site-specific in their movements, and as summer approached, they all moved out of the area. One 2-m shark traveled to New Zealand.

On the NSW coast of Australia, 51 beaches are netted off with bottom sets (100–200 m long) to reduce the abundance of resident populations of sharks. Some nets are also set at the surface, or as drumline sets. Bycatch is a concern, and nets are only deployed from Sept to April to try to minimize the bycatch.

Beach netting was nominated as a “key threatening process” in 1993. There is continuing concern and controversy over the environmental impacts through bycatch of non-dangerous marine life. Impacts and species composition varies in ‘noncontrolled’ vs ‘controlled’ beaches. Variations in net/drumline configuration may alter the impacts.

The shark culling program uses nets and drumlines, which both impact protected species like seals (Australian fur seals), dugongs, sea turtles (loggerhead, green, leathery) and humpback whales. For example, 28 loggerheads per year are killed in Queensland. The program is controversial as it pits public safety vs. conservation of protected species. Each year since 1951, about 5–25 white sharks have been caught in New South Wales. During the early years, there was no recording of the bycatch. Twenty-nine of 51 netted beaches recorded white sharks in 1990–2007, with 2 beaches accounting for approximately 30% of the total captures (= “hotspot”).

In conclusion, one can ask whether there is any correlation between culling of sharks and the number of fatal attacks. However, only1 human mortality has occurred, so cause and effect is difficult to establish. There are also lots of beaches lacking meshes. Meshes serve to catch sharks about 2 m (2–3 m), and, therefore, larger sharks escape. Female white sharks mature at 5 m long and males mature at 3.5 m long. Two studies related to tiger shark predation are summarized below.

Tiger shark predation on green turtles at Rain Island in Queensland (Limpus et al. 2006): Tiger sharks scavenge on turtle carcasses, and less frequently on live turtles, with negative correlations between the number of nesting turtles and number of bitten turtles (i.e., a higher proportion were suffering shark attacks when the nesting population was low).

Tiger shark predation on dugongs and turtles in Shark Bay, Western Australia (Heithaus et al., 2007): Tiger sharks influence foraging strategies of both prey species. Large tiger shark abundance is strongly influenced by dugongs (counters the notion that they are purely opportunistic feeders). Turtles in poor body condition select profitable, high-risk microhabitats, whereas turtles in good condition selected safer less profitable habitats. When shark predation risk was low, turtles in good condition moved into more profitable habitats.

Presentation 11: Dietary Shifts Associated with Marine Mammal Predation in Sharks
(Greg Skomal, Massachusetts Shark Research Program)

Shifts in shark predatory behavior can be due to ontogenetic shifts (size, capacity, habitat, and distribution), change in prey abundance (environmental and fisheries impacts), change in density of shark population (intraspecific competition), ease of prey capture (energetic benefit) or learned behavior/conditioning. Evidence suggests that Galapagos sharks undergo an ontogenetic diet shift at about 200 cm, based on samples collected during the Hawaii shark culling program of the 1960s (Wetherbee et al., 1996).

The frequency of marine mammals in diets (stomach sampling) in shark species are: 35% in great white sharks; 20% in oceanic white tips; 13% in tigers; Portuguese (18%), down to 1% in sandbars. A single Galapagos shark sample (Wetherbee et al., 1996) indicated 2% marine mammals. In predatory sharks that are known to consume marine mammals (great white, tiger, six-gill, seven-gill, and bull sharks), a small proportion of stomachs contain marine mammals.

White sharks are the most studied of these shark species (e.g., Tricas and McCosker, 1984). These sharks feed on teleosts and then shift to pinnipeds and cetaceans as they get bigger. Subsampling along the vertebrae for stable isotope analysis can be used to determine if the shark has consumed marine mammals (Estrada et al., 2006) (vertebrae should be stored from all Galapagos shark specimens for this important analysis).

White shark studies in the Farallon Islands (four seal species) and in South Africa (Cape Fur Seal) have produced details of shark predation on seals (prey size, season, depth, predation success rates, etc.). For both sites, attack zones are entry/exit points of the pinnipeds. White sharks prey predominantly upon juvenile Northern elephant seals in the South Farallon Islands. Most attacks occur during autumn at 25–450 m from shore (5–50 m depth), all daylight hours, during high tide. There is a 64% predation success rate. At Seal Island, South Africa, white sharks prey on cape fur seals young-of-the-year. Most attacks occur during winter, 0–400 m offshore, 26–30 m depth, in low light and high tides, with a 48% success rate. It has been suggested in both areas that individual success increases with learning through accumulated experience. White sharks lurk at the bottom to ambush their prey.

In the South Farallon Islands, historical data (1970–1992) indicate a relative increase in predatory attacks on pinnipeds over time (Long et al., 1996). This pattern could be due to more prey, more sharks, or both. Ainley et al. (1981, 1985) reported an increase in elephant seal abundance from 1968 to 1981. It was suspected that as few as six sharks may be responsible. Four sharks were removed in 1982–1985. Subsequently, there were fewer attacks until the 1987–1993 plateau in seal abundance, accompanied by an increasing number of sharks (Ainley et al., 1981, 1985; Pyle et al., 1996). Both an increase in the number of sharks and increased learning may have lead to an increase in predation rates.

Predation on harbor seals by an uncertain shark species at Sable Island, Canada (Lucas and Stabo, 1996 and Bowen et., al. 2003) has affected seal productivity and led to a dramatic decline in harbor seal production. The harbor seal predation may be due to "collateral damage" as sharks primarily target grey seals, which have experienced a population increase (12%/year). These two seal species have overlap in both diet and habitat use.

White shark predation on pinnipeds (harbor and grey seals) in New England may follow a pattern reminiscent of the South Farallon Island situation. Both seal species have experienced recent population increases. White sharks are attracted to the area primarily to feed on whale carcasses, but recent evidence of predation on grey seals pups/juveniles (Chatham, MA) suggests that a new situation is emerging.

As with Galapagos sharks at FFS, evidence suggests that white sharks learned to feed on juvenile seals at both these sites (Farallon and Maine coast). The increase in predation rates may be due to more seals, more sharks or both. In the Farallons, it appears to be the former, as the seal population has tripled in the last 30 years, and the number of shark attacks increased accordingly. Similar patterns are being observed elsewhere, including in New England, where certain seal species are increasing rapidly, and shark attacks have become more frequent. This may merely indicate a return to a more natural state as seal populations recover.

Closing Comments for Day One
(John Reynolds, Moderator)

Referring to the seven objectives, we have completed the first three and established a common understanding for approaching our deliberations. Tomorrow, we will discuss mitigation techniques, and identify research directions (objectives 4–6).

Options discussed thus far in this workshop:

- No action
- Limited culling
- Widespread culling–doesn't seem supported
- Deterrents
- Long-term management–suite of options in addition to direct shark mitigation

In the coming sessions, we will consider research tasks and prioritize that research for the future. We will also ask: What are the salient unknown questions for monk seals in this predation scenario? What are pups doing when most vulnerable?

DAY TWO: January 9, 2008

SESSION IV: SHARK DETERRENTS

Presentation 12: ***Use of Chemical Agents and Permanent Magnetics to Deter Shark Predation***
(Eric Stroud, Shark Defense)

This presentation deals with two types of deterrent devices: permanent magnets and semiochemicals. Repellent behavior in response to permanent magnets has been observed in multiple species of elasmobranchs. These magnets require no power input (e.g., similar to a refrigerator magnet). They are ferromagnetic (magnet moments are in parallel) and retain their magnetism until reaching the Curie temperature, are exposed to a stronger field, or sustain damage. Dipole fields (south to north) cause repellent behavior in many elasmobranchs. The gauss (G) is the unit of measure for magnetic fields–the earth has a magnetic field of about 0.5 G.

Permanent Magnets

Many animals, including sharks and seals, are sensitive to magnetism, which they may use for navigation. Permanent magnets often have a powerful field (lots of Gs) but merely because the magnetic field decreases as the inverse cube of distance have only a much localized zone (few inches or feet).

There are three types of permanent magnets:

1. NIB (Neodymium-iron-boride)—these are the most powerful rare-earth metal (up to 10,000 G = 1T), but they have poor corrosion resistance. If the coating rusts out (likely in a marine environment), they do not function. Teflon coating is possible, but would be expensive.
2. Ceramic (barium-ferrite or C8) rare earth magnets—this type appears to be the best option for our application. These are larger and heavy, but are cheap and corrosion-resistant.
3. SmCo (Samarium-cobalt sinter) —powerful (up to 1,000 G +) and corrosion resistant, but very expensive.

Experiments on the effects of magnets on sharks have been initiated only recently (starting in Feb 2005). In a pool maze, sharks learned the maze in four trials when magnets were situated to indicate the wrong direction. When sharks were immobilized (by turning upside down), they bend away from magnets or wake up, indicating stress. Also, magnetic fields strongly influence swimming and feeding behaviors, as sharks have a strong aversion to the fields. Other tests have used magnets in feeding preference tests and in creating magnetic "fences." Several elasmobranch species have been studied, including sharks, skates and rays, all of which are repelled by permanent magnets.

Possible applications for the magnetic deterrents include putting magnets on longlines near the bait to repel sharks and limit shark bycatch. It is still uncertain whether this application works. Avoidance behavior of turtles to permanent magnets is a possibility, as turtles use magnetoreception. However, avoidance behaviors in turtles have apparently not been studied.

The physiology for the reaction is not fully understood but is under investigation. If an animal has magnetite in its head, this could be the mechanism for showing how the magnet works (magnetite based magnetoreception). Another possibility is induced electric current from the Faraday Effect.

Table 1--Summary of repellency using ceramic C8 magnets.

Animal	n	Type of Test(s)	Results
Southern Stingray	**37**	**Feeding Preference**	Obvious bait avoidance near ceramic magnets
Nurse Shark	**10**	**Feeding Preference, Tonic Immobility**	Obvious bait avoidance near ceramic magnets
Bonnethead	**4**	**Tonic Immobility**	Violent termination of TI
Lemon Shark (juvenile, subadult)	**20**	**Tonic immobility**	Bending, termination of TI
Tiger Shark (juvenile)	**1**	**Fence**	Appeared to avoid magnetic treatment
Clearnose Skate	**4**	**Tank Wall**	Distress and flapping

The deterrent effects of C8 magnets have been observed in multiple studies (Table 1). In feeding preference trials in the Florida Keys, stingray and nurse sharks (bottom feeders) preferred to feed away from the magnets. Bonnetheads were extremely sensitive to magnets: bringing magnets close to this species resulted in a violent response. Lemon sharks showed bending from magnets. Rare earth magnets also resulted in obvious bait avoidance. Blue sharks flinched and closed the nictitating membrane when presented with a magnet.

There are limitations to the observed responses. If an immobilized shark is held and subjected to repeated exposures, the response decreases. This appears to result from a magnet-sensory "shut-off" that is typically exhibited after four exposures. Some obligate ramjet ventilators do not respond to magnets when placed into tonic immobility (TI). It is not clear if this same pattern would be present in free-swimming sharks.

The deterrent effects of C8 magnets were tested in tiger sharks in the Bahamas. Sharks were placed into open pens 1 hour after capture. They approached a control opening more often than a magnetic opening, although later the sharks did cross both openings equally. These are very limited results which may have resulted from stress after the shark first went through the magnetic opening.

Reef fish and tuna will not be affected by a magnetic fence. Shark repellents are never 100% (sharks are inherently unpredictable), but these devices can reduce the interactions.

Semiochemicals and Gustatory Compounds

The semiochemicals of interest here are basically chemicals present in rotten shark tissue. These chemicals seem to repel sharks but not teleosts. Similar repellent behavior was observed with extracts derived from decayed shark tissue.

The basic approach is to extract decayed shark tissue with polar solvents. A shark carcass is allowed to rot about 4 days, so that various compounds are created. The extracts are screened and analyzed to determine what components are present that trigger a response by sharks but not by fish. The resulting chemical "soup" is highly specific–some fish are actually attracted to the chemicals.

Caribbean reef shark (*C. perezii)* was the subject for most field trials. The repellent (500 mL) was delivered by a remotely actuated pressurized syringe discharged near bait (fish head), and the size of the school (and teleost behavior) was recorded before and after the repellent was delivered.

Researchers are interested in chemically making the compounds instead of creating it from the shark. Tonic immobility can be used as a rapid screening tool to identify the best compounds for free-swimming tests. It is still unclear specifically which compounds cause the chemical repelling: these are being studied in more detail and seem to have potential. To date, research has found that aldehydes affect taste (gestation), whereas carboxylic acids and ketoacids affect olfaction. The aldehydes appear to be a powerful fish attractant too, which is good because then you can get fishermen to use them (for example, to help catch swordfish or other commercial fish). Tests were conducted using time-release jelly placed on squid bait that allowed the semiochemicals to slowly dissolve. This method is unsuitable at deep depths because pressure causes the jelly to pop out. Further work on time-release is underway. Fishermen may eventually be able to use these chemicals to increase catch and reduce shark bycatch.

In 2005, NMFS provided Shark Defense with a Galapagos shark carcass. Testing in the Bahamas indicated that the carcass repelled other species. For field application at FFS, drums and pumps would be required to dispense the chemical. The chemical would be carried away by the current, so this method is probably not practical for the monk seal situation at FFS. Use of chemicals requires compliance with regulatory laws and coordination/consultation with six different agencies.

Proposed Research

Because little is known about how magnets and chemicals affect Galapagos sharks, research is needed to investigate these deterrent methods. The main problem is catching sharks to serve as experimental subjects. Shark Defense proposed a study with captive Galapagos sharks to confirm the aversive responses to permanent magnets. Also, field tests could be conducted in which a temporary C8 perimeter fence was constructed around the area of highest vulnerability, with bottom monitors placed near fence openings (large enough to permit seals, sharks, and large predatory fish through).

Semiochemical tests were proposed using decayed carcasses from culled Galapagos sharks. For field tests, tissue blocks could be deployed at the primary entrance and exit corridors. Additional testing was proposed on captive Galapagos sharks to confirm aversive responses to decayed *C. galapagensis* tissue.

Presentation 13: ***Studies Using E+ Metals (lanthanides) to Deter Shark Feeding*** **(John Wang, PIFSC)**

Sensory cues are commonly used to *attract* animals to fishing gear (auditory, visual, electrical, and chemosensory). Beginning last year, studies were initiated on deterring sharks from feeding, for example, to deter them from longlines in order to reduce bycatch. Sharks and rays make up a large proportion of incidental catch in many fisheries (about 1/3 of HI longline bycatch).

Sharks and rays use electroreception to find prey, to find mates, and to navigate. The ampullae of Lorenzini detect the electric fields near the shark. This has been used for products like the "Shark Shield" which generates a large electric field and which divers can wear to reduce likelihood of shark attack.

Oxidation of certain metals (lanthanides—extremely electrical positive) in seawater can also repel sharks. Lanthanide metals are also known as 'rare earth' metals, although they are not actually very rare. Examples of these metals include Serium (used in lighter flints), demium (used in stereo speakers and other audio equipment), and neodymium. Compounds made from these metals are called mischmetal.

Fields tests to determine if Nd-PR mischmetal affected the feeding behavior of sharks were conducted on the North Shore of Oahu (Hawaii) in collaboration with a commercial shark watching operation. Tests using one lanthanide, E+ mischmetal, showed very promising results with a piece of metal about an inch long. Shark "choice experiments" (shark selecting from among multiple forage items) were conducted from a shark cage. Two poles were extended from the shark cage, with one pole having a control metal (lead) and the other pole having the E+ mischmetal. The bait was presented in pairwise tests (opelu bait). The sharks bit the treatment item first in 25% of the tests and the control item in 75% of the tests. These tests appear to verify that the E+ mischmetal was very effective in repelling Galapagos sharks from feeding.

Additional tests recorded the number of bites on the two poles by Galapagos and sandbar sharks. They found greater aversion to the electrical positive metal; however, the sharks did go to both poles. For Galapagos sharks, the number of bites on the control pole was three times greater than the number of bites on the treatment pole. (The difference was not significant for sandbars due to small sample size).

Additional tests are underway to study the effects of the E+ mischmetal on juvenile sandbar shark behavior in a tank. A tracking system provides data that can be used for motion path analysis (*LoliTrack* software) to see if the shark is consistently avoiding the metal. Results demonstrated a 60-cm diameter zone of avoidance around E+ metal bars placed on the bottom of the tank. Lead weights were used as controls. Future tests will evaluate the effects of other factors, like food deprivation, number of sharks in the tank, adding food scent in the water, salinity, temperature, etc., on the aversion response. More paired feeding assay trials are also planned, along with experiments to better understand the electrochemical properties of these metals E+. Additional field tests will examine the effect of the metals on CPUE.

Research Objectives, Questions, and Methods (developed during open discussion)

The final session of the workshop was devoted to a discussion of the key research needs and methodologies that must accompany any mitigation action. The workshop participants were in agreement that in order to design an effective long-term mitigation strategy, more data were needed on the core biology of both monk seal pups and Galapagos sharks. Specifically, the participants felt that sonic tagging of both monk seal pups and Galapagos sharks at FFS would help characterize the spatial and temporal movement patterns and behaviors of both species, and reveal where and when pups were most vulnerable to predation. Most of the research topics discussed herein were introduced during earlier sessions but are recapitulated and reorganized here for clarity.

1. Are there just a few sharks preying on seals?
   - If the predation involves a small group of individuals then limited cull could work.
   - Taking a pup is not a common event relative to what a shark would be doing throughout the year: a rare event means more time and effort to investigate.
   - The Shark Photo ID library from FFS might help determine how many sharks are involved.
2. Are other species besides Galapagos sharks involved? Are tiger sharks involved directly or possibly post-kill?
3. Where are the predation events happening? That is, what is the spatial scale and where is the danger zone?
   - A better understanding of the spatial scale will inform the mitigation response and will be useful to set up the ability to catch the sharks/barrier trials, etc.
   - Pup research: When/where are pups vulnerable? Time in the water; locations of the seals.
   - Age-specific seal behavior/feeding ecology of different seal size classes.
   - GIS technology may be appropriate for this research.
4. Shark tagging research:
   - Are other shark species (besides Galapagos) involved (e.g., tiger shark interactions kill or post-kill)? What is known about interactions of Galapagos sharks with other shark species? If other species are involved, does the size or condition of the pups taken by the two species differ?
   - Primary methods: acoustic and predator tags; photo ID of sharks.
   - Listening stations are required for acoustic transmitters.
   - Tag sharks both inside and outside of the atoll to determine the occupancy and interchange.
   - Pingers should be placed on the pups too: tags might be detected inside shark.
   - Sharks will normally expel a tag within 24–48 hrs of swallowing it. Treble hooks could be used to lodge the tag in the stomach (up to 10 years), but these hooks are now rarely used.
   - Define the repertoire of specific behaviors of sharks: also review historical observation notes on shark-seal interaction behavior to identify the repertoire of specific behaviors of sharks exhibited in past interactions

- Multispecies tagging opportunity: any bycatch from drumline shark captures could also be instrumented with sonic tags.
- Larger question: In order to distinguish between shark losses and starvation losses during off-season, NMFS would need to change the time of year of field work because the bulk of the juvenile losses occur during fall/winter when field camps are not traditionally deployed.

5. Assessment of mitigation actions: before-and-after effects of mitigation actions (culling or other action):
   - the objective is to learn; important to decide in advance on an appropriate metric to measure the success rate.
   - avoid doing multiple things at one site as their effects will be confounding.
   - consider Galapagos shark monitoring at a site without the decline or without predation as a comparison study (i.e., a non-FFS site)
6. Environmental effects on pup vulnerability: (e.g., temperature effects: do pups spend more time in the water in hot years?)
7. Galapagos shark biology:
   - Genetics and population structure of Galapagos sharks (MHI vs. NWHI; Is FFS a distinct population?; possibly a UH graduate project).
   - Need to have a minimum number of animals for useful information.
   - Longevity and maximum age of Galapagos shark (could just use one vertebrae sample).
   - Galapagos shark dietary studies (not known how often they eat mammals): Biochemical techniques to determine if the shark fed on marine mammals (using samples from the sharks, e.g., vertebrae), but pup predation is a rare event and might be hard to detect. However, a shark habituated to eating seals may still have a signature of marine mammals. Two dozen samples would be useful too. Still looking at stable isotopes for analysis.
8. Research on deterrent and removal methods:
   - Methods for attaching deterrents to seals and seal behavior: how much time do seals spend on the beach vs. in the water?
   - Review historical observation notes on shark-seal interaction behavior to inform new mitigation efforts. Focus on the repertoire of specific behaviors of sharks exhibited in past interactions.
   - Pup/Juvenile seal diving behavior that reduces predation: What leads to vulnerability of the pup, e.g., do they go into the water at night?
   - Can mother-nursing pup pairs be moved, and would that action reduce predation?
   - Track similar situations/developments elsewhere: review other relevant research (e.g., seal-shark interactions at Sable Island, Canada).
   - Kill methodology (how to dispatch Galapagos sharks).

General Comments on Research Objectives (Preceding List)

- The key questions must be clearly articulated: The two most frequently asked questions are “How many/how often do Galapagos sharks caught on the outside of the reef come inside the lagoon?” and “How many sharks are involved in the pup predation?" First question is relatively easy to answer by tagging many sharks outside the atoll and monitoring occurrence inside the atoll.

- The research agenda must be prioritized (see below), because it is certain that not all objectives will be funded. How expensive and logistically feasible is each item?
- Which components of the research agenda are short-term vs. long-term?
- Fishing for Galapagos sharks: 2007 fishing was at 15–25 ft. depth; historical removals in MHI found juvenile Galapagos in shallower water and bigger/older sharks in deeper water.
- Bycatch from bottomfishing in the NWHI: may include Galapagos sharks for life history studies; would need to compensate fisherman for retaining carcasses.

Prioritization of Research Topics

1. Pool of predators: small number of sharks vs. widespread in population
2. Deterrents–impacts on environment (seals, corals, other species)
3. Optimum method for shark removal
4. Spatial Issues: When/where pups most vulnerable (time in water, etc.)
5. Shark movements and shark species involved in pup predation (other than Galapagos sharks)

LITERATURE CITED

Adair, R. K., R. D. Astumian, and J. C. Weaver.
1998. Detection of weak electric fields by sharks, rays, and skates. Chaos **8**, 576.

Ainley, D. G., C. S. Strong, H. R. Huber, T. J. Lewis, and S. H. Morrell.
1981. Predation by sharks on pinnipeds at the Farallon Islands. U.S. Fish. Bull.78: 941–945.

Ainley, D. G., R. P. Henderson, H. R. Huber, R. J. Boekelheide, S. G. Allen, and T. L. McElroy.
1985. Dynamics of white shark/pinniped interactions in the Gulf of the Farallones. Mem. So. Calif. Acad. Sci. 9: 109–122.

Bowen, W. D., S. L. Ellis, S. J. Iverson, and D. J. Boness.
2003. Maternal and newborn life history traits during periods of contrasting population trends: implications for explaining the decline of harbor seals (*Phoca vitulina*) on Sable Island. J. Zool. 261(2):155-163.

DeCrosta, M. A.
1984. Age determination, growth, and energetics of three species of carcharhinid sharks in Hawaii. M.S. Thesis, Department of Oceanography, University of Hawaii, Honolulu, Hawaii, USA

Estrada, J.A. A. N. Rice, L. J. Natanson, G. B. Skomal.
2006. Use of isotopic analysis of vertebrae in reconstructing ontogenetic feeding ecology in white sharks. Ecology 87(4): 829-834

Heithaus, M. R., A. Frid, A. J. Wirsing, L. M. Dill, J. W. Fourqurean, D. Burkholder, J. Thompson, and L. Beider.
2007. State-dependent risk-taking by green sea turtles mediates top-down effects of tiger shark intimidation in a marine ecosystem. J. Anim. Ecol. 76(5):837-844

Limpus, C. J., D. J. Limpus, M. Munchow, and P. Barnes
2006. Queensland Turtle Conservation Project: Raine Island Turtle Study, 2004-2005. Editor: Michelle Jones, State of Queensland. Environmental Protection Agency, Freshwater and Marine Sciences Unit Environmental Sciences Division Conservation technical and data report 2005(4), pp. 25

Lucas, Z., and W. T. Stobo.
2000. Shark-inflicted mortality on a harbour seal (Phoca vitulina) population at Sable Island, Nova Scotia. J. Zool. 252, 405-414.

Pyle,P., S. D. Anderson, and D. G. Ainley.
1996. Trends in white shark Predation at the South Farallon Islands, 1968-1963. Great White Sharks, Biology of *Carcharodon carcharinas*. Academic Press, Inc. p. 375-379.

Smith, S. E., D. Au, and C. Show.
1998. Intrinsic rebound potentials of 26 species of Pacific sharks. Mar. Freshw. Res. 49(7):663-678.

Tricas, T C. and J. E. McCosker.
1984. Predatory behavior of the white shark (Carcharodon Carcharias), with notes on its biology, California Academy of Sciences. San Francisco. Proc. Calif. Acad. Sci.. 43(14):221-238.

Wass. R. C.
1971. A comparative study of the life history, distribution, and ecology of the sandbar shark and gray reef shark in Hawaii. PhD dissertation, University of Hawaii. pp 219.

Wetherbee, B. M., G. L. Crowe, and C. G. Lowe.
1996. Biology of the Galapagos shark, *Carcharhinus galapagensis*, in Hawaii. Environ. Biol. Fishes 45:299–310.

APPENDIX A: MAP OF NWHI

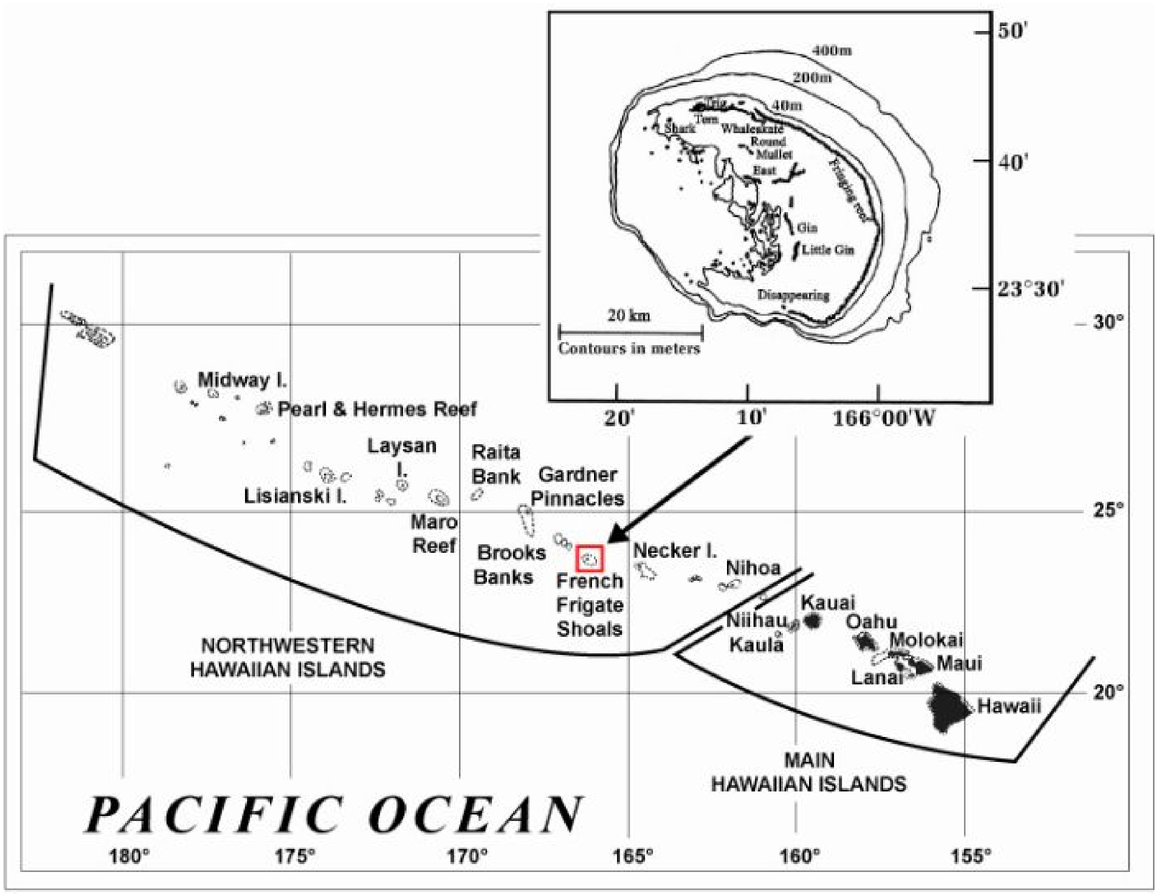


Figure 1.--Trig Island at French Frigate Shoals is the historic focal point for shark predation on monk seal pups. Predation has also been observed at Round Island, the Gins, and East Island.

(This page is intentionally left blank.)

APPENDIX B: 2008 SHARK PREDATION MITIGATION PLAN (DEVELOPED POST-WORKSHOP)

The *Shark Predation on Hawaiian Monk Seals Workshop* was successful in achieving its stated objectives. The information disseminated in the presentations by managers and shark experts, and augmented through the open discussion sessions, provided many valuable insights into the nature of the predation dynamic at FFS and identified a number of promising options for mitigating the high pup losses.

As a federal agency, the National Marine Fisheries Service has the primary authority for developing plans that promote the recovery of the Hawaiian monk seal. Those plans are developed in consultation with other federal and state agencies having jurisdiction in occupied monk seal habitat, and are aided by input from public stakeholders and formal or informal advisory groups. The information provided through the workshop was one source of data on which to rely as NMFS formulated a mitigation plan for shark predation in 2008 and beyond. Under the rules and regulations pursuant to the Federal Advisory Committee Act of 1972 (FACA; Public Law 92–463), consulting experts such as those participating in the Shark Predation Workshop, can provide information and input on which to evaluate management decisions, but the final decision for federal actions remains with the agency. Accordingly, the strategic plan for mitigating shark predation mortality at FFS in 2008 was developed through further consultation and interagency dialog subsequent to the workshop.

Based on the discussions held at the workshop, the majority of those present believed that the alternative most likely to be feasible and effective in reducing predation was the removal of Galapagos sharks from shallow waters inside the FFS atoll using revised fishing techniques. The shark researchers felt that although Galapagos sharks had clearly become exceedingly wary of traditional hook-and-line fishing near Trig Island, they could likely still be caught using a method similar to a short longline (25-hook drumline buoys of 50–100 m), set in shallow water elsewhere in the atoll. The justification for applying this approach differed from the logic put forth by NMFS prior to 2007, according to which the removals would be limited to sharks that displayed distinct predatory behaviors. In 2007, that restriction was relaxed to allow for drumline fishing in 15–25 ft depths, but that method failed to catch any Galapagos sharks. It is, therefore, uncertain whether additional gear, location or personnel adjustments would be successful in removing Galapagos sharks.

Shark researchers present at the meeting were in consensus that Galapagos sharks observed in shallow, near shore water were exhibiting behavior distinctly unlike that observed in the species in other locations. Therefore, any Galapagos sharks found in shallow water (whether near Trig or elsewhere in the atoll) were likely to be predators on monk seal pups and should be removed. The researchers acknowledged, however, that the tendency for Galapagos sharks to be found in shallow water could be a unique behavioral trait characteristic of this species in the NWHI, but thus far documented only at FFS.

Although at the conclusion of the workshop, there was general support for more aggressive shark removals (with concurrent shark tagging research to gather additional data on shark numbers, movements, and behavior), NMFS elected to forego shark removals in 2008 in favor of testing various nonlethal deterrents. The shark research agenda outlined at the workshop is also being pursued in collaboration with researchers at the Hawaiʻi Institute of Marine Biology (University of Hawaii).

The decision to defer shark removals in 2008 was predicated on both practical and biological considerations. First, in recent years, the permitting process for conducting shark removals at FFS has become increasingly contentious. This is due in part to the more public nature of the Monument permitting process and an increasing awareness by the public of this management action. Further, one aspect of the mitigation plan that has been criticized in the past is the limited attempt to pursue nonlethal mitigation methods. NMFS has, therefore, chosen to conduct experiments on nonlethal deterrents in 2008 and defer additional removals pending evaluation of the results from those experiments. The 2008 suspension of shark removals does not signify that this method is being permanently withdrawn from consideration, and removals may be proposed in future years if other methods prove unsuccessful.

The specific plan specified in the 2008 Monument permit application calls for a suite of deterrent devices to be deployed at Trig and possibly other sites at FFS (Gins or East Island). The proposed deterrent devices consist of four primary types:

1. Visual Deterrents: to include 3 subtypes
   a. Boat anchored in nearshore water
   b. Assorted visual stimuli (floats and other) deployed in association with the magnetic and electromagnetic deterrents
   c. Light source projected from shore or anchored boat
2. Auditory: underwater loudspeaker system to broadcast boat noise
3. Magnetic: permanent magnets deployed in water column at strategic access points
4. Electromagnetic: powered system that emits low-level electrical field

Several of these deterrent types were derived directly from discussions at the workshop, while others were developed in post-workshop discussions. Additional descriptions are provided in Appendix D, which is extracted from information provided in the 2008 Monument permit to conduct these deterrent activities. The work will be initiated in spring/early summer 2008. The full permit application may be viewed at: http://hawaiireef.noaa.gov/resource/permit_sum.html

APPENDIX C: INVITED PARTICIPANTS

Table 1.—Invited participants of Shark Predation on Hawaiian Monk Seal Workshop. (Names and affiliation of other participants are identified at first mention in the body of the document).

Name	Affiliation and/or Expertise
William Aila	Hawaiin Monk Seal Recovery Team, fisherman and representative for native Hawaiian cultural perspective
Bud Antonelis	NMFS (Pacific Islands Fisheries Science Center)
Bob Braun	Contractor veterinarian
Barry Bruce	Commonwealth Scientific and Industrial Research Organisation (Australia)
Aaron Dietrich	Contractor; former member of FFS shark team
Bill Gilmartin	HMS Recovery Team
Dean Grubbs	Shark researcher; Florida State University
Bert Harting	Harting Biological Consulting (contractor)
Kim Holland	Hawaiʻi Institute of Marine Biology
Dominique Horvath	U.S. Fish and Wildlife Service (Honolulu)
James Kitchell	University of Wisconsin
Randy Kosaki	Papahānaumokuākea Marine National Monument
Charles Littnan	NMFS (Pacific Islands Fisheries Science Center)
Steven Martell	University of British Columbia
Carl Meyer	Hawaiʻi Institute of Marine Biology
Dan Polhemus	Hawaii Department of Land and Natural Resources
Jeff Polovina	NMFS (Pacific Islands Fisheries Science Center)
John Reynolds (moderator)	Mote Marine Laboratory
Greg Skomal	Massachusetts Department of Fish and Game
Lance Smith	NMFS (Pacific Islands Regional Office)
Eric Stroud	Shark Defense/Oak Ridge Shark Laboratory
Carl Walters	University of British Columbia
John Wang	NMFS (Pacific Islands Fisheries Science Center)
Susan White	U.S. Fish and Wildlife Service (Honolulu)
Chris Yates	NMFS (Pacific Islands Regional Office)

(This page is intentionally left blank.)

APPENDIX D: SHARK DETERRENT DEVICES PROPOSED FOR DEPLOYMENT AT FRENCH FRIGATE SHOALS IN 2008 (EXCERPTED FROM 2008 PERMIT APPLICATION FOR ACTIVITIES WITHIN THE PAPAHĀNAUMOKUĀKEA MARINE NATIONAL MONUMENT)

The information provided herein supplements the information previously provided in the permit application submitted by the Pacific Islands Fisheries Science Center of the NMFS (G. Antonelis, principal investigator) to experiment with the use of nonlethal shark deterrents at French Frigate Shoals. This document provides additional information, as requested, on the potential environmental effects of the deterrent devices to be deployed at FFS.

As indicated in the permit, NMFS proposes to deploy 4 main classes of devices:

- Visual—to include 3 subtypes
  - Boat anchored in nearshore water
  - Assorted visual stimuli (floats and other) deployed in association with the magnetic and electromagnetic deterrents
  - Light source projected from shore or anchored boat (withdrawn: see below)
- Auditory—underwater loudspeaker system to broadcast boat noise
- Magnetic—permanent magnets deployed in water column at strategic access points
- Electromagnetic—powered system that emits low-level electrical field

The third type of visual stimuli listed above (light source projected from shore or anchored boat) was withdrawn from the permit application. However, this type of device may be considered for deployment later in the season or in future years pending additional research on the logistics and environmental effects of this type of stimulus. NMFS will submit a separate permit application at a later time should we seek to deploy a light deterrent in 2008.

Because this is the first year in which NMFS has proposed deploying deterrent devices, and because realistic field trials for some devices are lacking, careful monitoring of each deployment will be necessary. We anticipate that some devices will be modified, relocated or retired as the season progresses. The objective is to identify the suite of devices that proves most efficient and effective in eliminating shark predation on monk seal pups, while at the same time minimizing any environmental hazards or secondary effects on nontarget species. Because the magnetic and electromagnetic shark repellent technologies are relatively new, much of the available information comes from private firms that develop and market these technologies. While we acknowledge that these sources are less preferable than peer-reviewed research, we feel that the available evidence is compelling enough to warrant further exploration of these technologies, especially given that the primary alternative mitigation strategy is lethal removal of sharks.

Visual Stimuli

Anchored Boat

The hypothesis that a boat anchored offshore near Trig Island will serve as a passive deterrent is based on direct observation of sharks patrolling nearshore waters around the island in previous years. NMFS personnel found that patrolling sharks tended to leave the area as a boat approached and also tended to avoid the area near where boats were anchored. Further, the fact that in recent years most shark predation has occurred when no humans were present at the island suggests that sharks may have used visual cues to detect when humans were present and adjust their predatory behaviors accordingly. Based on these observations, NMFS believes that a decoy boat placed in the water may help to deter shark predation. Because boats are commonly used at FFS, this type of visual stimulus is an accepted part of the regular operations at FFS and does not introduce any novel environmental risks to the system. No fuel, batteries or other risk factors will be left on board the anchored boat. As with all of the deterrents, this deterrent type will be suspended if any unforeseen risk is detected.

Visual Stimuli Deployed with Magnetic and Electromagnetic Deterrents

These stimuli include various types of floats, streamers and buoys to be deployed in conjunction with the magnetic and electromagnetic deterrent devices. As described in the permit application, these will be placed on the surface or within the water column and will serve the dual purpose of providing an attachment point for the other devices, while at the same time serving as additional visual stimuli. These visual stimuli are intended to either deter sharks directly or warn them of the presence of other stimuli that deliver an unpleasant sensation. These devices will consist of standard, over-the-counter devices (such as fishing buoys, fishing floats, water “noodles” and similar objects) made from plastics or other inert materials. These materials should not degrade appreciably during the relatively brief time they are deployed. These devices will resemble objects already commonly found in the water or on the beaches at FFS and will not introduce any novel environmental risks to the system. The arrays will be deployed in such a fashion that no entanglement hazards will be created. That is, each segment of the line will be far enough away from the next adjoining segment that there will be no possibility of cross contact. As with all of the deterrents, this deterrent type will be modified or suspended if any unforeseen risk is detected.

Auditory Stimuli

This stimulus will consist of amplified boat noise to mimic the sound of a small boat approaching the island. As with the anchored boat, the objective is to displace predatory sharks by imparting the impression that humans are in the vicinity. The unit will be a Lubell LL916 transmitter, having a maximum output of 180 dB at 1k Hz, and frequency range of 200 Hz to 20 kHz. For our application, the projected output would not exceed

120 dB or the maximum output from a boat approaching at 38.6 km (24 miles) per hour and passing directly overhead.

The combination of inner ears and lateral lines found in sharks is collectively known as the acoustico-lateralis system. Field and laboratory experiments have demonstrated that sharks can hear sounds with frequencies ranging from about 10 Hz (cycles per second) to about 800 Hz, but are most responsive to sounds less than 375 Hz. Therefore, the Lubbell LL916 transmission will overlap the upper end of sharks frequency range (200 Hz–800 Hz), but will not transmit in the low frequency of sharks hearing range (10 Hz–200 Hz). The absence of transmissions in this range may be advantageous as some biologists speculate that low frequency sound may in fact attract sharks.

Boat noise is different in character from biological noise. Underwater it has two domains, or operating conditions: noncavitating and cavitating noise. The frequency and power of boat noise is directly related to the speed of the vessel. The faster the propeller rotation, the more cavitation is created. As tiny bubbles form and collapse, they produce a broad range of frequencies above prevailing ambient conditions at frequencies up to 20,000 Hz. Conversely, when the rotation of the propeller is reduced and a boat is traveling slowly, the turbulence is minimal, and both the frequency and power spectrum of the noise are significantly reduced. The dominant noise spectra are below 1000 Hz. As stated above the upper hearing threshold for sharks is 800 Hz.

Ambient noise generally ranges from 60 to 90 decibels, over a frequency range of 1 to 20,000 Hz, but levels can reach 130 dB during heavy rain or in industrial areas. The critical ratio compares the intensity of a signal at the moment it is just detectable (the masked threshold) to the intensity of the background noise. The size of the critical ratio has important significance, as high ambient levels could conceivably raise detection thresholds beyond the absolute acoustic energy emitted by many boats or our proposed sound transmissions. Therefore, while our sound transmissions may occasionally be masked at distance by ambient sounds, we believe they may still prove to be a deterrent in close proximity to the speaker within the shallow confines of the Trig lagoon.

Information on the auditory systems of pinnipeds and cetaceans and exposure risks from auditory stimuli are provided at the end of this report. Based on the auditory sensitivity information provided therein, the salient conclusions are:

- Pinnipeds: Our proposed sound output would be approximately 50% of that known to cause injury in pinnipeds.
- Cetaceans: The recommended pressure criterion for injury is 230 dB, approximately 50 dB above our maximum speaker output and 120 dB greater than our maximum desired output of 120 dB (a boat at high-speed overhead).

Magnetic Deterrents

Much of the seminal work on the use of magnetic deterrents on sharks has been conducted by Shark Defense (PO Box 2593 Oak Ridge, NJ 07438, (877) 571–2207 http://www.sharkdefense.com), founded in 2001 by Eric and Jean Stroud. The following information has been largely extracted from information provided by Shark Defense.

Elasmobranchs (sharks, rays, and skates) have a unique sensory adaptation that allows them to detect electric fields in the marine environment. This sensory ability is referred to as electroreception, and the sensory organ associated with electroreception is the Ampullae of Lorenzini. The ampullae are gel-filled pores homogenously distributed around the nose and mouth. The sensory system is designed to detect weak electric fields generated by mechanical muscle movement (e.g., swimming muscles or a beating heart). In the presence of an electric field, the electric potential at the surface of the animal will vary from the electric potential of the interior of the animal. This potential difference is then detected by the sensory cells that line the ampullae. Once the voltage differential is recognized, the sensory information is transmitted to the brain via afferent neurons (Adair et al., 1998).

Shark Defense has found that flux per unit area of certain permanent magnets, particularly Neodymium-Iron-Boride and Barium-Ferrite magnets, corresponds closely with the detection range of the Ampullae of Lorenzini. A permanent magnet with the correct specifications is hypothesized to overstimulate the Ampullae of Lorenzini, and may, therefore, be used as selective shark repellent. The fields generated by these permanent magnets decrease at the inverse cube of the distance from the magnet. Therefore, at distances of a few meters from the magnet, the field exerted is less than the earth's magnetic field.

For our application, the most important fact is that animals which lack an Ampullae of Lorenzini organ do not display aversive behavior in close proximity to the magnetic field, making this technology selective to sharks and rays (elasmobranchs). Thus, behavior of elasmobranchs which do not prey on monk seals (e.g., reef sharks, rays) may also be affected, causing them to avoid areas where stimuli are deployed. Bony fish (teleosts), marine mammals, and turtles do not contain these electroreceptors, thus the use of permanent magnets is a selective repellent technology that should have no effects on non-elasmobranch species within the Monument. However, as with all of the deterrents, this deterrent type will be modified or suspended if any unforeseen risk or reactions are detected.

Electromagnetic Deterrents

Two different devices are being considered for use as electromagnetic deterrents at FFS: MARINER and FREEDOM 7 units, both manufactured and marketed by Shark Shield (http://www.sharkshield.com). Each device uses "electronic wave-form" technology that was invented by the Natal Shark Board of South Africa (http://www.shark.co.za/). The following information on the mechanics and specificity of the Shark Shield device is extracted from the Shark Shield web site, and/or is based on direct communication with the company's representatives.

The physiological basis for this technology, like the magnetic deterrents described above, is the Ampullae of Lorenzini, the gel-filled sacs located in the shark's snout which are used to pick up the electrical signals emitted by the nerve impulses from living creatures. The Shark Shield produces a three-dimensional electronic wave form which creates an unpleasant sensation impacting the shark's Ampullae of Lorenzini. When the shark comes into proximity with the electronic wave form (around 8 m in diameter) it experiences nondamaging but uncontrollable muscular spasms causing it to flee the area. The field is projected from the unit by two electrodes, which create an elliptical field that surrounds the user. Both electrodes must be immersed in the water for the field to be created. The electrode configuration depends on the model of the Shark Shield unit. From testing, the closer the shark is to the Shark Shield field, the more spasms occur in the sharks' snouts. This becomes intolerable and the shark then veers away and usually doesn't return. Electromagnetic deterrents, like magnetic deterrents, do not select among elasmobranchs, so nontarget elasmobranch species such as reef sharks and rays may also alter their behavior.

A distinct advantage of the unique electronic wave form is that it deters sharks and does no lasting harm to the shark. Once the shark is out of the affected area, it no longer feels the effect of the electronic wave form.

On its Web site, the manufacturer describes results from laboratory and field tests of Shark Shield devices. According to the manufacturer, the devices pose no risk to humans and will not affect the behavior of non-Elasmobranch species:

> *Direct contact with, or very close proximity to the antenna, may cause twitching of the surface muscles of the skin, in time with the slow pulsing of the signal. The conductive field readily travels through seawater, it being a better conductor than the human body. Thus the field tends to surround the body rather than penetrate it. Scientific tests show that the type of signal generated by the Shark Shield is unable to pass through body tissues, unlike radio waves or microwaves that readily penetrate the body, and therefore it poses no health problems for users.*
>
> *… One of the distinct advantages of this unique electronic wave-form is that it only repels predator sharks and members of the Elasmobranch family including Rays and Skates. Elasmobranch animals all have Ampullae of Lorenzini.*

According to Paul Ludd, Shark Shield Sales Manager, "the wave form has absolutely no affect on marine life and this is why we use it in aquaculture, particularly the tuna industry around pens, the pearling industry, and on the cod-end of prawn trawler nets to prevent sharks attacking the net and loss of catch."

The Shark Shield units have an output of approximately 40 v. For comparison, an electro-shocking device used to nonlethally collect fish utilizes a DC current of 3–7 amps and 100–250 v in fresh water. At high conductivities (i.e., marine environments) salt water is less resistive than fish and the electroshocking current will flow around them. Another important parameter is the temperature. There is a 40% reduction in conductivity when the water temperature is reduced from 20˚C to 0˚C, therefore, colder water will increase the fishing efficiency. Thus, for our application, the lower voltage (80 v) and high conductivity of warm salt water support the manufacturer's claim of minimal impact on fish.

As with all other deterrent devices, the efficacy of these devices must be assessed by direct observation, and should any adverse effects to other species be detected, their use will be modified or suspended.

Supplement to Appendix D: Auditory Capabilities of Selected Marine Species

Pinnipeds

- Auditory bandwidth of pinnipeds in water (75 Hz–75 kHz).
- For Hawaiian monk seals, the frequency range of greatest auditory sensitivity is from 12 kHz to 28 kHz (Thomas et al., 1990).
- Nonpulses–temporary threshold shift (TTS) on harbor seal at 25 min exposure to 152 dB, California sea lion 174 dB, Northern elephant seal 172 dB. While the TTS of monk seals is likely just within the range of the 180 dB maximum output of our proposed speaker, our target output is 80–100 dB, would be much shorter in duration, (< 5 min., and as the animals are not captive they could easily move away from the sound source.
- Approx > 20 dB over TTS is required to induce permanent threshold shift (PTS), i.e., injury onset.
- For pinnipeds in water, the recommended pressure criterion for injury from exposure to nonpulsed sounds is the same value applies to pulses: unweighted values of 218 dB. **Therefore, our proposed sound output would be approximately 50% of that required to cause PTS in pinnipeds.**

Cetaceans

- For cetaceans, published TTS data are limited to the bottlenose dolphin and beluga (Schlundt et al., 2000). Temporary shift in masked hearing thresholds (MTTS) of bottlenose dolphins and white whales after exposure to intense tones. *Journal of Acoustical Society of America, 107, 3496–3508.*
- Schundt et al. (2000) reported TTS in five bottlenose dolphins and 2 beluga whales using nonpulsed sound at frequencies of 3 kHz, 10 kHz, and 20 kHz SPL (sound pressure levels) with TTS onset at 192–201 dB. This is above our maximum speaker output of 180 dB, our maximum desired output of 120 dB (a boat at high speed overhead) and our average target output (a boat at slow speed) of 80–100 dB.
- **For all cetaceans exposed to nonpulses, the recommended pressure criterion for injury is 230 dB, the same criterion as for single pulses. This is 50 dB above our maximum speaker output and 120 dB greater than our maximum desired output of 120 dB (a boat at high speed overhead).**

- The minimum distance of speaker deployment to any cetaceans is likely to be >1 mile at Trig with spinner dolphins occasionally seen north of the island outside of the reef. At the Gins, spinner dolphins are occasionally seen with ¼ mile on the west side of the islets. To further reduce possible impacts speakers may be oriented toward the island and away from open water. Bottlenose dolphins are occasionally observed within the atoll typically at distances of several miles from the proposed deployment locations.

(If not otherwise cited, all exposure information is from Southhall et al., 2007)

LITERATURE CITED IN APPENDIX D

Adair, R.K, R.D. Astumian, and J.C. Weaver.
1998. Detection of weak electric fields by sharks, rays and skates. Chaos 8(3): 576-587.

Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway.
2000. Temporary shift in masked hearing thresholds (MTTS) of bottlenose dolphins and white whales after exposure to intense tones. J. Acoust Soc Am, 107, 3496-3508.

Southhall, B. L., A. E. Bowles, W. T. Ellision, J. J. Finneran, R. L. Gentry, C. R. Greene, D. Kastak, D. R. Ketten, J. H. Miller, P. E. Nachtigall, W. J. Richardson, J.A. Thomas, and P. Tyack.
2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations, Aquat. Mamm., 33(4).

Thomas, J. A., P. Moore, R. Withrow, and M. Stoermer.
1990. Underwater audiogram of a Hawaiian monk seal (*Monachus schauinslandi*). J. Acoust. Soc. Am. 87 (1): 417–419.

(This page is intentionally left blank.)

APPENDIX E: SHARK RESEARCH AT FRENCH FRIGATE SHOALS, 2008 (CARL MEYER, HAWAI‘I INSTITUTE OF MARINE BIOLOGY)

The following material is abstracted from the 2008 research permit application, submitted by Dr. Carl Meyer, to conduct shark studies within the Papahānaumokuākea Marine National Monument. As recommended in the workshop proceedings, one objective of the work is to "quantify the frequency of visits by Galapagos sharks captured outside the barrier reef at French Frigate Shoals to monk seal pupping sites inside the atoll lagoon." As of June 2008, 12 Galapagos sharks and 4 tiger sharks were captured and instrumented, and receivers were installed at Tern, Trig, Round/Mullet, East, Gins, La Perouse and south of Disappearing (Rapture Reef). A subsequent trip was planned for August to increase the Galapagos shark sample to 40 sharks, and to deploy additional units outside the barrier reef north of Tern and east of East.

Workshop participants also recommended that weaned monk seal pups be instrumented with sonic tags so that their movement patterns could be monitored using the same receivers as those used for the shark study. The objective was to instrument 25 pups. Results were not available at the time this report was prepared.

State of Hawaii
DEPARTMENT OF LAND AND NATURAL RESOURCES
Division of Aquatic Resources
Honolulu, Hawaii 96813

May 9, 2008

Board of Land
and Natural Resources
Honolulu, Hawaii

Request for Authorization and Approval to Issue a Papahānaumokuākea Marine National Monument Research Permit to Carl Meyer, University of Hawaii, Hawaii Institute of Marine Biology, for Access to State Waters to Conduct Top Predator Population Research Activities

The Division of Aquatic Resources (DAR) hereby submits a request for your authorization and approval for issuance of a Papahānaumokuākea Marine National Monument research permit to Carl Meyer, assistant researcher, Hawaii Institute of Marine Biology, pursuant to § 187A-6, Hawaii Revised Statutes (HRS), chapter13-60.5, Hawaii Administrative Rules (HAR), and all other applicable laws and regulations.

The research permit, as described below, would allow entry and activities to occur in the Papahānaumokuākea Marine National Monument (Monument), including the NWHI State Marine Refuge and the waters (0-3 nautical miles) surrounding the following sites:

- Nihoa Island
- Necker Island
- French Frigate Shoals
- Gardner Pinnacles
- Maro Reef
- Laysan Island
- Lisianski Island
- Pearl and Hermes Atoll
- Kure Atoll State Seabird Sanctuary

The activities covered under this permit would occur from June 1, 2008 through September 1, 2008.

The proposed activities are a renewal of work previously permitted and conducted in the Monument.

INTENDED ACTIVITIES

The applicant proposes to equip top predators (sharks and large fishes) with electronic tags, and monitor their movements using acoustic receivers (deployed on the sea floor) and satellites. The purpose of the applicant's research is to provide Monument managers with empirical data on top predator movement patterns, spawning habitats and population sizes in Monument waters. The research project has the following specific goals and objectives;

1. Download 23 underwater receivers currently stationed in the Monument to retrieve stored movement data from 150 top predators tagged with acoustic transmitters in 2005, 2006, and 2007;

2. Determine how widely these animals have ranged since September 2007;

3. Improve receiver coverage by deploying 6 additional underwater receivers at French Frigate Shoals, Midway and Kure;

4. Equip up to 85 additional top predators with acoustic tags detectable by a listening array;

5. Determine the locations of ulua (Caranx ignobilis) spawning aggregation sites;

6. Quantify the frequency of visits by Galapagos sharks captured outside the barrier reef at French Frigate Shoals to monk seal pupping sites inside the atoll lagoon.

All activities would be carried out by the principle investigator and an assistant. Researchers would access sites using small boats launched from the NOAA ship HI'IALAKAI. Predator capture and tagging would be conducted exclusively from these small boats. Servicing of receivers would be done by snorkelers and SCUBA divers.

In addition to servicing existing receivers, researchers would create several new temporary receiver moorings at sites described in the permit application using a system that has been demonstrated to successfully withstand seasonal high surf. Moorings would consist of sand screws in areas of soft sediment, and chain around uncolonized substrate in hard bottom areas (live substrates will be avoided). The receivers would be anchored to the moorings and suspended 1-4 m above the ocean floor. The receivers would identify and record the presence of any acoustic transmitters within range (up to 500 m). Researchers would remove these moorings when acoustic monitoring is completed (receivers would be in place for at least 2 years).

Researchers would also implant acoustic transmitters into 6 species of top predator (4 shark and 2 fish species) at several locations within the Monument. Target species would be captured by trolling (towing an artificial lure), handlining (using a single baited hook), and using a bottom-set, 10 hook shark line (for large sharks). Captured predators would be brought alongside the skiff, tail-roped and inverted to initiate tonic immobility. In this trance-like condition, sharks and fishes remain docile while transmitters are surgically implanted through a small incision in the abdominal wall. The incision would then be sutured closed, the hook removed and the animal released. This entire handling process can be completed in less than 10 minutes. Predator handling & tagging activities would be carried out in accordance with the animal use protocols of the University of Hawai'i (protocol #05-053-3).

(This page is intentionally left blank.)

APPENDIX F: COMMENTS FROM DAVID W. LAIST, SENIOR POLICY AND PROGRAM ANALYST, MARINE MAMMAL COMMISSION

These comments were based on Mr. Laist's review of the draft workshop report and are consolidated and edited for inclusion herein.

1. FURTHER CONSIDERATION OF HARASSSMENT: The harassment/tagging work done before 2000 must have been responsible for most of the reported decline in predation between 1997 and 2000 (based on the proportion of cohorts lost to sharks). Since efforts shifted from harassing to killing sharks, predation rates have crept back up to mid-1990s levels. If shark catching work actually involved reducing harassment in hopes of improving prospects for catching wary sharks, simple harassment along the lines of what was done between 1997 and 2000 might yet be as or even more helpful in the future. Thus, one alternative under the nonlethal options should be taking a careful look at whether and how harassment activities pre- and post-culling differed to determine whether the pre-culling approach should be reinitiated and perhaps improved.

2. IDENTIFY PROCEDURAL STEPS FOR LONG-TERM PLANNING: The minutes do not describe procedural steps for seeking timely advice on future work after 2008 from the Recovery Team (RT) and other experts. NMFS should identify a schedule and plan to review the 2008 results immediately after the field season, develop a proposed course of action for 2009 and beyond, and allow the RT and other experts to review and comment on those plans. The schedule should allow sufficient time to incorporate any modifications before permits must be submitted to the Monument for 2009.

3. EXPERIMENTAL DESIGN: The minutes lack details on how mitigation measures will be monitored and assessed for effectiveness. At one point the report advises that steps should "avoid doing multiple things at one site as their effects will be confounding." But then the proposed approach in the appendix appears to propose "a suite" of mitigation measures in seeming contradiction to that advice and to alter mitigation measures during the field season if unspecified data suggests adjusting those measures is warranted. An experimental design for evaluating effectiveness should be proposed and planned in order to test and measure any mitigation strategy.

4. CONSULTATIONS WITH NATIVE INTERESTS: The presentation on Hawaiian perspective (Presentation 8: William Aila) noted that the culling of sharks is not necessarily inconsistent with their majority perspective, but that the animals taken should be fully used to the extent possible. Consultations with Kahea (or other native groups) should be part of NMFS planning efforts to ensure that any animals killed during mitigation efforts are used or disposed of in a manner respectful of native values.

5. EFFECTS OF MAGNETIC FIELDS ON TURTLES: A recent publication (*Animal behaviour: Geomagnetic map used in sea-turtle navigation;* Lohmann et al., Nature 428, 909–910) discussed evidence that the green sea turtle possesses a map sense that relies on geomagnetic cues. This observation indicates that the use of magnets to deter sharks

could affect turtle nesting or the ability of hatchlings to return to nesting beaches. This possibility should be thoroughly investigated before deploying these types of devices.

6. SHARK BEHAVIORAL STUDIES: More details should be provided with regard to needs and plans for additional research on shark behavior and movements in the *Research Objectives, Questions, and Methods* section of the report. Shark movement data could be valuable for identifying areas where problem sharks might be caught when they are less wary, and for refining future catch methods.

7. CULLING AFTER 2008: The information provided in Appendix A might be interpreted to suggest that current plans are to resume culling in 2009 if deterrents tried this year are not demonstrably effective. However, it is not clear how the proposed shark removal methods described in that section differ from the removal methods that were used in 2007 and were unsuccessful in capturing Galapagos sharks. Some clarification would be helpful.