Review of shark predation mitigation as a tool for conservation of the Hawaiian monk seal

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Executive Summary

Despite almost total protection, the endemic Hawaiian monk seal (*Monachus schauinslandi;* HMS) is declining at approximately 4% per year and comprises 1,100 individuals (Baker et al. 2011). Shark predation on juvenile monk seals French Frigate Shoals (FFS) has apparently contributed to low rates of juvenile survival and declining rates of population growth in the NWHI. The Pacific Islands Fisheries Science Center (PIFSC) of the National Marine Fisheries Service (NMFS) is proposing to implement shark predation mitigation by culling Galapagos sharks at FFS to improve HMS survival. The objective is to reduce early mortality of these individuals, which is very high during the first two years of life and is thought to be the primary factor limiting population recovery at FFS.

The information that I reviewed represents the best *available* scientific information, although data are sparse. There is reasonable evidence that shark predation is acting on this population. However, the specific mechanisms that influence shark predation on monk seals are not well understood and the assumption that only a few sharks attack monk seals is not supported by data. Evidence is insufficient to conclude that Galapagos sharks are the *primary* predators on juvenile monk seals. The PIFSC has not observed tiger shark predation events, although such predation certainly seems possible. Genetic and tagging studies are needed to understand the potential impact of shark removal on shark population viability and associated community structure, and to develop effective predation-reduction management strategies.

I recommend that the PIFSC complete a comparative cost-benefit evaluation that addresses opportunity costs of all mitigation practices, which can be used to guide predation management decisions. In such an evaluation it is critical to identify the cost of removing "nuisance animals" and how these removals will improve the viability of monk seals over a 10-20 year planning window. Direct and indirect costs to food web dynamics should also be assessed. A *sustained* program to remove sharks will likely reduce shark predation in localized areas and may reduce predation enough to have a positive effect on juvenile monk seal survival. Nevertheless, because of the uncertainties associated with shark population abundance, and the magnitude of predation, it is essential that monitoring (of sharks and predation) be implemented prior to a shark culling program. A photo ID library would assist with both monitoring efforts by providing an inexpensive means for marking individuals and for identifying potential nuisance animals that would yield high return on investment in terms of mitigating predation. Establishing a mark-recapture program combined with a shark photo ID library should be considered as a way to document movement patterns over the long term. I also encourage the NMFS to pursue research on the efficacy and feasibility of a wide range of non-lethal deterrent options.

In conclusion, I agree that mitigating shark predation could plausibly improve the *short term* survival of monk seal pups at FFS. However, the extent to which such a strategy can be maintained over time and possibly a larger spatial area makes me question the viability of such a strategy in the *long-term*. I am also concerned about the potential for culling to have an impact on shark populations (which have been impacted by bycatch issues globally). Thus, I recommend that the impact of various sources of uncertainty be evaluated in terms of their impact on long-term recovery of monk seals. I also suggest that NMFS conduct a comprehensive evaluation of the costs and benefits of alternative shark predation mitigation strategies to identify the greatest likelihood of success given logistical and financial constraints. Finally, I recommend that NMFS undertake a careful monitoring program to quantify shark population status and predation.

Background

The Papahānaumokuākea Marine National Monument (PMNM) was established in 2006, representing one of the largest conservation areas in the world, spanning 36,207,439 hectares and including all of the Northwestern Hawaiian Islands (NWHI). Within the PMNM, most human activities, including all commercial and recreational fisheries, are prohibited. Despite almost total protection, the endemic Hawaiian monk seal (hereafter 'HMS') (*Monachus schauinslandi*) is declining at approximately 4% per year (Baker et al. 2011). Listed as critically endangered by the IUCN, approximately 85% of the remaining 1,100 animals inhabit the relatively pristine NWHI. This decline appears to be driven by low rates of juvenile survival (Baker & Thompson 2007; Baker 2008). Shark predation on juvenile monk seals is an important factor in the demography of some sub-populations in the NWHI, notably at French Frigate Shoals (FFS). This has apparently contributed to low rates of juvenile survival and declining rates of population growth throughout the NWHI. In fact, predation by Galapagos sharks (*Carcharhinus galapagensis*) is reported to be the single greatest mortality source for pre-weaned HMS pups in the FFS (Harting *et al.* in review).

Sharks and rays make up a large portion of incidental catch in many fisheries, and approximately 30% of bycatch in Hawaii longline fisheries (Harting 2010). With the reduction in fishing due to the establishment of PMNM, this bycatch likely has been reduced. However, there is now evidence suggesting that predators are attaining high abundance levels within the monument (Parrish & Boland 2004). The Pacific Islands Fisheries Science Center (PIFSC) of the National Marine Fisheries Service (NMFS) is proposing to implement shark predation mitigation by culling Galapagos sharks at FFS to improve juvenile HMS survival. The objective is to reduce early mortality of these individuals, which is very high during the first two years of life and is thought to be the primary factor limiting population recovery. Moreover, shark predation is thought to be the primary factor contributing to low juvenile survival of monk seals at FFS.

Description of the Individual Reviewer's Role in the Review Activities

***Requirements for CIE Reviewers*:** Three CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. The combined expertise among the CIE reviewers shall consist of working knowledge and recent experience in shark ecology, marine mammal ecology, population viability, conservation of endangered species, wildlife management and/or predator control. Each CIE reviewer's duties shall not exceed a maximum of 10 days to complete all work tasks of the peer review described herein.

Summary of Findings for each ToR

Evaluation, findings and recommendations of data collection operations

Observations of shark predation appear to be primarily anecdotal. It appears that the HMS Recovery Program (HMSRP) has only observed Galapagos sharks attacking pups in shallow water in the nearshore environment (Gobush 2010). Apparently such observations are rare, yet they form the basis for conclusions that shark predation is significant and hence, that shark culling will lead to higher juvenile monk seal survival. The HMSRP assumes that, unless there is inclement weather, any pup that disappears is taken by a shark (Gobush 2010), underscoring the qualitative rather than quantitative nature of evidence supporting the relationship between sharks and seals in this case. Figure 7 of (Gobush 2010) summarizes mitigation activities. Only recently has effort been devoted to developing non-lethal deterrents.

Evaluation and recommendations of data quality

In my view, the nature and extent of shark predation on seals is speculative, yet many far reaching conclusions are drawn from these speculations. For example, there is a list of consensus statements starting on page 18 of Gobush (2010) that appear to be based on expert opinion, with little empirical support. Some notable examples are described here.

- It is stated that human activity deters sharks around pupping sites. What is the evidence for this?
- The statement is made that the Hawaii population of Galapagos sharks is healthy, but data suggest great uncertainty in the population size and structure of sharks. The most recent estimate (Dale *et al.* 2011) indicates a population size of 668 with 95% CI ranging from 289-1720 for Galapagos sharks at FFS. The confidence limits around this population estimate suggest considerable uncertainty (Dale *et al.* 2011).
- What evidence did the authors use to conclude that a small number of sharks are responsible for predation at FFS?
- Figure 5 shows the distribution of shark incidents across the islets of FFS Atoll from 1984 to 2008. I would be very curious to know what more current patterns look like.

Perhaps data are available to support these conclusions; in this case it would be useful to provide appropriate support (references) to go with each item listed in the consensus statement.

Evaluation of strengths and weaknesses, and recommendations of analytic methodologies

The monk seal demographic data are remarkably comprehensive and the various analyses are reasonably compelling. However, the specific mechanisms and causes of mortality in monk seals are not well understood. For example, there is a great deal of uncertainty about how many pups are actually killed by sharks. Methods used to substantiate predation-related mortalities are questionable. For example, Figure 5 of Harting (2010) shows a range of an order of magnitude between "possible kills" and "confirmed kills." I recommend that future analyses carefully examine the relative impacts of each known source of juvenile mortality on monk seal viability.

Evaluation and recommendations of assumptions, estimates, and uncertainty

Galapagos sharks appear to be the most common species of shark at Trig Island, possibly due to increases in monk seal pupping at this site (Lowe *et al.* 2006). Galapagos shark predation at Trig Island apparently became a problem in 1997 when sharks were first attracted to the island by pup carcasses left in the water after incidences of aggression by adult male seals (Harting *et al.* in review). The presence of drowned pups in the water attracted sharks and presented them with new resources that were then sustained (Bertilsson-Friedman 2006). Although Galapagos sharks have been reported to prey on pinnipeds, predation on monk seals was not documented before 1997, which represents the peak in adult male seal aggression (Harting *et al.* in review). Sharks may have learned to feed on pups at specific locations in the FFS. Galapagos sharks are not social and will eat their own offspring; the feeding behavior of sharks is basically exploratory and not transmitted between individuals (Gobush 2010). Sharks are long-lived animals which have the ability to develop detailed spatio-temporal maps of productive prey habitats (Meyer *et al.* 2010). Because the feeding strategy (i.e., targeting pups) would not necessarily be "lost" when apparent problem sharks are removed, it is possible that this behavior would be learned by other sharks that encounter monk seal pups. It is plausible that sharks will locate other monk seal colonies, such that shark mitigation will be needed throughout the NWHI. The apparent build-up of predators (Parrish & Boland 2004) and the complexity of the ecosystem may make the control of shark predation infeasible at a broad spatial scale.

Evaluation, findings, and recommendations of result interpretation and conclusions

The HMS population is significantly impacted by predation on pups
Although evidence is anecdotal, Galapagos shark predation on juvenile monk seals appears to be an important factor in the demography of some sub-populations in the NWHI, notably at French Frigate Shoals (FFS). Predation is reported to be the single greatest mortality source for pre-weaned HMS pups in the FFS (Harting *et al.* in review). While do not believe that we have adequate evidence to support the conclusion that shark predation is the *most* important threat to monk seals, it is clear from the available data that monk seals are significantly impacted by sharks via predation on pups, and that certain subpopulations are more affected than others.

The primary species of shark involved in predation of seal pups is the Galapagos shark
Galapagos sharks appear to use lagoon habitats at FFS in low numbers. In general, Galapagos sharks are thought to prefer deeper habitats around FFS, which is consistent with recent observations from the Main Hawaiian Islands (Meyer *et al.* 2010). Researchers could not determine which species of sharks were responsible for particular types of injuries (Bertilsson-Friedman 2006). It should also be noted that other species of sharks in the NWHI (Kobayashi & Kawamoto 1995; Gillespie 2010; Papastamatiou *et al.* 2010; Honebrink *et al.* 2011) are known to attack pinnipeds. These observations suggest that the prevailing evidence is insufficient to conclude that Galapagos sharks are the primary predators on juvenile monk seals.

A relatively small number of sharks are responsible for the majority of pup predation.
There is speculation that the problem is with just a few nuisance animals, but the data are not available to substantiate this. According to Bertilsson-Friedman (2006), the assertion that only a few sharks attack monk seals is not confirmed. A workshop discussion (Gobush 2010) indicates there is probably a subset of individuals exhibiting the pup predation within the lagoon at FFS that are adults. It is suggested that, even if a small number of sharks are responsible, the impact of a few predators can be significant, particularly for small populations such as HMSs (Hiruki *et al.* 1993; Bertilsson-Friedman 2006). Dale *et al.* (2011) also report that "even relatively small numbers of sharks may be a significant source of predation," and that "low shark abundance in shallow lagoon habitats suggests removal of a small number of sharks from the immediate vicinity of lagoons might reduce the short term predation on monk seal pups without impacting the Galapagos shark population." However, there are no data provided to support the latter part of this conclusion. I support the idea of establishing a Shark Photo ID library for FFS (Harting 2010) to determine how many sharks are involved in predation on monk seals.

Removing a small number of large/adult Galapagos sharks targeted in the near-shore areas near pupping islets has the potential of mitigating the predation issue.
The unintended ecological consequences of shark removal are difficult to predict. Dale and colleagues make the point that, "Additional empirical data quantifying long-term movements and

habitat use of sharks at FFS are needed to assess the likely efficacy and broader ecological impact of culling sharks to reduce predation on monk seals in shallow habitats." (Dale *et al.* 2011). Furthermore, Dale *et al.* (2011) found that sharks were significantly less abundant in the shallow lagoon than adjacent habitats (Dale *et al.* 2011). The authors infer that removal of a small number of sharks from the vicinity of the lagoonal islets will require significant fishing effort, but would likely reduce predation of monk seals, based on low shark abundance in shallow lagoons (Dale *et al.* 2011). Based on my review of available data, I agree that a *sustained* program to remove sharks will likely reduce shark predation in localized areas and may reduce predation enough to have a positive effect on local juvenile monk seal survival. However, even if we assuming that a subset of sharks are responsible for pup mortality at FFS, I have reservations about the ability to successfully identify, target and cull specific (individual) sharks responsible for predation. Furthermore, in light of the uncertainties associated with shark population abundance, and the magnitude of predation, it is essential that monitoring (of sharks and predation) be implemented prior to any shark culling program. The photo ID library would assist with both monitoring efforts by providing an inexpensive means for marking (passively) individuals and for identifying potential nuisance animals that would yield high return on investment in terms of mitigating predation.

Removing 20-40 Galapagos sharks is unlikely to cause significant deleterious impacts on that species' population at FFS nor any other unintended ecosystem consequences.
I do not think that we have the evidence to support this statement. It appears that significant population isolation in Galapagos sharks may occur over relatively short distances. As mentioned above, the best estimate of abundance for Galapagos sharks at FFS is 668 with significant uncertainty in confidence limits (Dale et al. 2011). In light of the possible impacts of culling on shark populations and the potential ecosystem-level impacts of shark removal, I encourage NMFS to aggressively pursue a range of non-invasive approaches to deter sharks from critical monk seal habitats. Within-atoll translocation of weaned pups from high shark predation islets to historically safer islets at French Frigate Shoals may prove to be a successful tool for mitigating post-weaning Galapagos shark predation. It appears that the use of deterrents were "viewed with skepticism" (Gobush 2010), although it is not clear why. From what I read, the range of deterrents that can be used to repel sharks from key monk seal habitats is promising. Table 1 of Harting (2010) provides empirical support for the efficacy of ceramic C8 magnets. A recent review of efforts to deter sharks at FFS indicates that neither shark presence nor attack rates differed significantly between treatments (Gobush & Farry in review). The authors conclude that other methods of predation mitigation, such as erecting barriers or culling sharks, may provide more benefit to improving the situation for monk seals at FFS. However, sample sizes were very small in these studies, which would obfuscate any detection of statistically significant differences between treatments. Additional research is essential to develop effective non-lethal deterrents of Galapagos sharks.

The methods used to monitor shark activity and monk seal pups are adequate to characterize the level of predation.
The methods are adequate, but more data are needed. I realize the challenge is in the remote nature of these habitats. I would encourage NMFS to consider a range of methods, such as additional video technology to monitor shark predation, radio telemetry of adults frequently seen in lagoon habitats, and photo identification tools that can be used to quantitatively estimate shark

abundance (e.g., mark-recapture methods). Finally, it is unclear from the information I reviewed whether the experimental shark removals have proven to be effective. Finally, as discussed above, detection of sharks and deterrence of predation continues to be a challenge to recovering the Hawaiian monk seal.

The methods used to study shark movement patterns represent the best available to understand the ecology of multiple shark species at FFS.

In general, I noted a great deal of speculation about shark movement patterns, and not a lot of data. It is assumed and generally accepted that shallow water around pupping sites was not characteristic habitat for Galapagos sharks, but instead reflected a distinct behavioral characteristic of the local (NWHI) population. Dale *et al.* (2011) suggest that data on long-term movements and habitat use of sharks at FFS are required to better assess the likely ecological impacts of shark culling (Dale *et al.* 2011). Establishing a mark-recapture program combined with a shark photo ID library should be considered as a way to document movement patterns over the long term.

The influence of possible covariates of predation have been adequately analyzed

There were few analyses of covariates of predation in the documents I reviewed. There is mention of an examination of covariates of shark activity in Gobush (2010), however, it is stated that results are “suspect” because of low sample size. It is clear that shark predation is not acting alone on juvenile mortality (Schmelzer 2000; Lowry *et al.* 2011). Poor nutrition due to competition has been identified as a major contributor, and there are admittedly ecosystem dynamics at play that are not understood ((Parrish & Boland 2004; Parrish 2009; Piche *et al.* 2010; Wabnitz *et al.* 2010). NMFS should carefully examine the relative effect of shark predation in relationship to these other factors. A strong (quantitative) result indicating that shark predation has a significant *relative* effect would provide stronger support for managing predation on monk seals. I encourage NMFS to embark upon such a comprehensive analysis of possible covariates.

The involvement of tiger sharks in the predation issue

The diet of tiger sharks is similar to that of Galapagos sharks (Meyer *et al.* 2010; Dale *et al.* 2011). In particular, gut contents of 3 tiger sharks out of 23 caught in 1977 at FFS included monk seal parts. At that time no monk seal remains were found in the gut contents of the 2 Galapagos sharks that were caught (Gobush 2010). PIFSC have not observed tiger shark predation events, although such predation certainly seems possible.

The Galapagos sharks display site-specific movement patterns versus wide-ranging movement patterns

Little is known about the population structure and range of this shark species (Gobush 2010; Meyer *et al.* 2010). The genetic structure of the Hawaiian “population” is currently being investigated; available data suggest that populations may be localized and resident (Gobush 2010). It is also unclear whether Galapagos sharks use FFS year-round or seasonally (Gobush 2010). Galapagos sharks appear to be limited in range to the FFS, suggesting these sharks may be residents around oceanic islands. Acoustic monitoring data from 13 tagged tiger sharks indicated that at least 70% of these sharks were year-round residents at FFS over a 3-year period (Lowe *et al.* 2006). Some individuals were detected at FFS year-round, whereas others visited

FFS atoll in summer (Meyer *et al.* 2010). Compared to tiger sharks, there are fewer data available for movement patters of Galapagos sharks at FFS (Lowe *et al.* 2006). Available data suggest that Galapagos sharks do not exhibit the same island visitation patterns as tiger sharks (Lowe *et al.* 2006). There is a significant need for research on shark movement behavior. In addition, genetic and tagging studies are needed to a) understand the impact of shark removal on shark population viability and associated community structure, and b) develop effective predation-reduction management strategies.

Determine whether the science reviewed is considered to be the best scientific information available.

PIFSC identifies an urgency to "mitigate threats in order to facilitate recovery of endangered species, including mitigating shark predation of HMS pups, often precludes the ability to gather the best possible science, instead relying on the best available science in most cases" (Gobush 2010). There is reasonable evidence that shark predation is acting on this population. However, the specific mechanisms that influence this cause of mortality in monk seals are not well understood. In short, the data that I reviewed do reflect the best *available* scientific information, although data are sparse. I encourage NMFS to think carefully about designing future studies to fill these knowledge gaps before embarking on a shark removal program.

Recommendations for further improvements

In a workshop report, Gobush (2010) recommends that a comparative cost-benefit evaluation that addresses opportunity costs of all mitigation practices could be used to guide predation management decisions. I concur with this assessment. In such an evaluation it is critical to identify the cost of removing "nuisance animals" and how these removals will improve the viability of monk seals over a 10-20 year planning window. I recommend that a model be developed to evaluate possible impacts on both shark and monk seal populations for different shark culling strategies (Gerber *et al.* 2004). Such a model can be used to evaluate the impact of predator removal on the viability of shark populations. I would like to see a quantitative analysis to identify the level of shark removal that would be needed to improve survival of monk seal pups at FFS. Would yearly culls be required to effectively decrease predation rates? Or are more frequent culls required? A thorough evaluation of the costs and benefits of alternative management strategies is needed to identify the greatest likelihood of success given logistical and financial constraints. Recent literature suggests that "trigger" harvest of nuisance predators may be not only more effective, but in some cases more cost effective than other methods of predator culling for increasing the viability of a target prey species (Sabo 2005; Baxter *et al.* 2008).

Brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations

As indicated above, the risks associated with shark removal have not been adequately explored. In addition, nonlethal deterrents were described in the documents I reviewed, and many of these show promise as non-lethal and effective alternatives to culling. My understanding is that permanent magnets appear to be the most promising of available approaches, but the optimal method for deploying these magnets in the field is not well articulated. I encourage NMFS to pursue research on the efficacy and feasibility of a wide range of non-lethal deterrent options before embarking upon a predator removal program.

Conclusions and Recommendations

In reviewing various documents, I identified a number of unsupported hypotheses and statements that require clarification. These issues are summarized in the context of each ToR above. I am particularly concerned about uncertainty in the magnitude and mechanisms of shark predation and the potential for culling to have an impact on shark populations (which have been impacted by bycatch issues globally). Clearly, this is a case of "conservation triage." NMFS must decide whether they want a FFS with a viable population of HMS, or if they want to maintain the virtues of having a marine ecosystem with a full complement of apex predators. If healthy HMS populations are preferred, then shark mitigation makes sense for the *short term*. The hope is that short term culling would stabilize HMS population dynamics enough, while maintaining a viable shark population and a diverse community structure within the Monument. Thus, I agree that mitigating shark predation will improve pup survival at FFS in the *short-term*. However, the extent to which such a strategy can be maintained over time and possibly a larger spatial area makes me question the viability of such a strategy in the *long-term.* Thus, I **recommend** that the impact of various sources of uncertainty identified above be evaluated as to their impact on long-term recovery of monk seals. I would also **recommend** that NMFS conducts a comprehensive evaluation of the costs and benefits of alternative shark predation mitigation strategies to identify the greatest likelihood of success given logistical and financial constraints. Finally, I **recommend** that NMFS undertake a careful monitoring program to quantify shark population status and predation.

Appendix 1: Bibliography of materials considered in review, including background material

Baker J.D. (2008) Variation in the relationship between offspring size and survival provides insight into causes of mortality in Hawaiian monk seals. *Endang. Species Res.*, 5, 55-64

Baker J.D., Harting A.L., Wurth T.A. & Johanos T.C. (2011) Dramatic shifts in Hawaiian monk seal distribution predicted from divergent regional trends. *Mar. Mamm. Sci*

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Gillespie A. (2010) No more shark fin soup for Hawaii. *Frontiers in Ecology and the Environment*, 8, 342-342

Gobush K.S. (2010) Shark predation on Hawiian monk seals: Workshop II & Post-Workshop Developments, November 5-6, 2008. In: *U.S. Dep. Commer., NOAA Tech. Memo.*, p. 43+ Appendices

Gobush K.S. & Farry S.C. (in review) Efforts to deter shark predatoin of Hawaiian monk seal pups. *Journal of Wildlife Management*

Harting A.L. (2010) Shark predation on Hawaiian monk seals workshop, Honolulu, Hawaii, January, 8-9, 2008. . In: *Pacific Island Fish. Sci. Cent. Admin. Rep.* (ed. PIFSC-NMFS-NOAA), p. 36 p. NOAA, Honolulu, HI

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Hiruki L.M., Gilmartin W.G., Becker B.L. & Stirling I. (1993) WOUNDING IN HAWAIIAN MONK SEALS (MONACHUS-SCHAUINSLANDI). *Canadian Journal of Zoology-Revue Canadienne De Zoologie*, 71, 458-468

Honebrink R., Buch R., Galpin P. & Burgess G.H. (2011) First Documented Attack on a Live Human by a Cookiecutter Shark (Squaliformes, Dalatiidae: Isistius sp.). *Pacific Science*, 65, 365-374

Kobayashi D.R. & Kawamoto K.E. (1995) EVALUATION OF SHARK, DOLPHIN, AND MONK SEAL INTERACTIONS WITH NORTHWESTERN HAWAIIAN ISLAND BOTTOMFISHING ACTIVITY - A COMPARISON OF 2 TIME PERIODS AND AN ESTIMATE OF ECONOMIC-IMPACTS. *Fisheries Research*, 23, 11-22

Lowe C.G., Wetherbee B.M. & Meyer C.G. (2006) Using acoustic telemetry monitoring techniques to quantify movement patterns and site fidelity of sharks and giant trevally around French Frigate Shoals and Midway Atoll. *Atoll Research Bulletin* 543, 281-304

Lowry L.F., Laist D.W., Gilmartin W.G. & Antonelis G.A. (2011) Recovery of the Hawaiian Monk Seal (Monachus schauinslandi): A Review of Conservation Efforts, 1972 to 2010, and Thoughts for the Future. *Aquatic Mammals*, 37, 397-419

Meyer C.G., Papastamatiou Y.P. & Holland K.N. (2010) A multiple instrument approach to quantifying the movement patterns and habitat use of tiger (Galeocerdo cuvier) and Galapagos sharks (Carcharhinus galapagensis) at French Frigate Shoals, Hawaii. *Marine Biology*, 157, 1857-1868

Papastamatiou Y.P., Wetherbee B.M., O'Sullivan J., Goodmanlowe G.D. & Lowe C.G. (2010) Foraging ecology of Cookiecutter Sharks (Isistius brasiliensis) on pelagic fishes in Hawaii, inferred from prey bite wounds. *Environmental Biology of Fishes*, 88, 361-368

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Sabo J.L. (2005) Stochasticity, predator-prey dynamics, and trigger harvest of nonnative predators. *Ecology*, 86, 2329-2343

Schmelzer I. (2000) Seals and seascapes: covariation in Hawaiian monk seal subpopulations and the oceanic landscape of the Hawaiian Archipelago. *Journal of Biogeography*, 27, 901-914

Wabnitz C.C.C., Balazs G., Beavers S., Bjorndal K.A., Bolten A.B., Christensen V., Hargrove S. & Pauly D. (2010) Ecosystem structure and processes at Kaloko Honokohau, focusing on the role of herbivores, including the green sea turtle Chelonia mydas, in reef resilience. *Marine Ecology-Progress Series*, 420, 27-U392

Appendix 2: Statement of Work for Dr. Leah Gerber

External Independent Peer Review by the Center for Independent Experts

Review of shark predation mitigation as a tool for conservation of the HMS

Scope of Work and CIE Process: The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. The Statement of Work (SoW) described herein was established by the NMFS Project Contact and Contracting Officer's Technical Representative (COTR), and reviewed by CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest. CIE reviewers are selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee and the report is to be formatted with content requirements as specified in **Annex 1**. This SoW describes the work tasks and deliverables of the CIE reviewer for conducting an independent peer review of the following NMFS project. Further information on the CIE process can be obtained from www.ciereviews.org.

Project Description: The genus *Monachus* is in crisis; with just two extant representative species, the HMS offers the best chance of its persistence. However, the HMS population itself is heading toward extinction. Numerous threats afflict the species across its range. Shark predation on preweaned and newly weaned pups contributes to a unique and extreme situation at French Frigate Shoals (FFS) that peaked in 1997–1999 and stands out from the trends observed at other sites in the Northwest Hawaiian Islands (NWHI). Since then, predation has declined to 6-11 pups a year, an unsustainable rate as a result of falling birth rates. Galapagos sharks (*Carcharhinus galapagensis*) and tiger sharks (*Galeocerdo cuvier*) both potentially feed on marine mammals; however, the HMS Research Program (HMSRP) has only observed Galapagos sharks attacking and killing pups in nearshore water. Mitigation activities by HMSRP conducted over the last decade include harassment of sharks, intensive observation, translocation of weaned pups, deployment of devices to deter predation, and shark removal. HMSRP has developed premises about the identity and number of sharks likely involved, shark wariness to human activity, and opinions about shark culling based on peer reviewed science, inference, expert opinion and ample experience with the situation at FFS. Permitting for removal activities continues to be decisive given the sensitive topic and that removals are occurring within a marine national monument. One point of contention is the thoroughness of the science supporting NMFS course of action. This review is of particular importance as NMFS considers applying for additional permits in the future. The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**.

Requirements for CIE Reviewers: Three CIE reviewers shall conduct an impartial and independent peer review in accordance with the SoW and ToRs herein. The combined expertise among the CIE reviewers shall consist of working knowledge and recent experience in shark ecology, marine mammal ecology, population viability, conservation of endangered species, wildlife management and/or predator control. Each CIE reviewer's duties shall not exceed a maximum of 10 days to complete all work tasks of the peer review described herein.

Location of Peer Review: Each CIE reviewer shall conduct an independent peer review as a desk review, therefore no travel is required. Each reviewer will communicate with the Pacific Islands Fishery Science Center (PIFSC) Project Contact or the appropriate designated PIFSC staff by email and phone during the course of the review.

Statement of Tasks: Each CIE reviewer shall complete the following tasks in accordance with the SoW and Schedule of Milestones and Deliverables herein.

<u>Prior to the Peer Review</u>: Upon completion of the CIE reviewer selection by the CIE Steering Committee, the CIE shall provide the CIE reviewer information (full name, title, affiliation, country, address, email) to the COTR, who forwards this information to the NMFS Project Contact no later than the date specified in the Schedule of Milestones and Deliverables. The CIE is responsible for providing the SoW and ToRs to the CIE reviewers. The NMFS Project Contact is responsible for providing the CIE reviewers with the background documents, reports, and other pertinent information. Any changes to the SoW or ToRs must be made through the COTR prior to the commencement of the peer review.

<u>Pre-review Background Documents</u>: Two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to the CIE reviewers the necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE Lead Coordinator on where to send documents. CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein. The CIE reviewers shall read all documents in preparation for the peer review.

<u>Desk Review</u>: Each CIE reviewer shall conduct the independent peer review in accordance with the SoW and ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs can not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COTR and CIE Lead Coordinator.** The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements.

<u>Contract Deliverables - Independent CIE Peer Review Reports</u>: Each CIE reviewer shall complete an independent peer review report in accordance with the SoW. Each CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the Schedule of Milestones and Deliverables.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Conduct an independent peer review in accordance with the ToRs (**Annex 2**).
3) No later than October 28, 2011, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and Dr. David Die, CIE Regional Coordinator, via email to ddie@rsmas.miami.edu. Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in **Annex 2**.

Schedule of Milestones and Deliverables: CIE shall complete the tasks and deliverables described in this SoW in accordance with the following schedule.

September 28, 2011	CIE sends reviewer contact information to the COTR, who then sends this to the NMFS Project Contact
October 4, 2011	NMFS Project Contact sends the CIE Reviewers the report and background documents
October 7-21, 2011	Each reviewer conducts an independent peer review as a desk review.
October 28, 2011	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
November 16, 2011	CIE submits the CIE independent peer review reports to the COTR
November 23, 2011	The COTR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: Requests to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the COTR within 10 working days after receipt of all required information of the decision on substitutions. The COTR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the CIE reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

Acceptance of Deliverables: Upon review and acceptance of the CIE independent peer review reports by the CIE Lead Coordinator, Regional Coordinator, and Steering Committee, these reports shall be sent to the COTR for final approval as contract deliverables based on compliance with the SoW and ToRs. As specified in the Schedule of Milestones and Deliverables, the CIE Coordinator shall send the contract deliverables (CIE independent peer review reports) to the William Michaels (COTR) via William.Michaels@noaa.gov).

Applicable Performance Standards: The contract is successfully completed when the COTR provides final approval of the contract deliverables. The acceptance of the contract deliverables shall be based on three performance standards:

(1) each CIE report shall completed with the format and content in accordance with **Annex 1**,
(2) each CIE report shall address each ToR as specified in **Annex 2**,
(3) the CIE reports shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Distribution of Approved Deliverables: Upon acceptance by the COTR, the CIE Lead Coordinator shall send via e-mail the final CIE reports in *.PDF format to the COTR. The COTR will distribute the CIE reports to the NMFS Project Contact and Center Director.

Support Personnel:

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Key Personnel:

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Annex 1: Format and Contents of CIE Independent Peer Review Report

1. The CIE independent report shall be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether the science reviewed is the best scientific information available.

2. The main body of the reviewer report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Summary of Findings for each ToR in which the weaknesses and strengths are described, and Conclusions and Recommendations in accordance with the ToRs.

3. The reviewer report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of the CIE Statement of Work

Annex 2: Terms of Reference

Review of shark predation mitigation as a tool for conservation of the HMS

1) Evaluation, findings and recommendations of data collection operations
2) Evaluation and recommendations of data quality
3) Evaluation of strengths and weaknesses, and recommendations of analytic methodologies
4) Evaluation and recommendations of assumptions, estimates, and uncertainty
5) Evaluation, findings, and recommendations of result interpretation and conclusions
    i. The HMS population is significantly impacted by predation on pups.
    ii. The primary species of shark involved in predation of seal pups is the Galapagos shark.
    iii. A relatively small number of sharks are responsible for the majority of pup predation.
    iv. Removing a small number of large/adult Galapagos sharks targeted in the near-shore areas near pupping islets has the potential of mitigating the predation issue.
    v. Removing 20-40 Galapagos sharks is unlikely to cause significant deleterious impacts on that species' population at FFS nor any other unintended ecosystem consequences.
    vi. The methods used to monitor shark activity and monk seal pups are adequate to characterize the level of predation.
    vii. The methods used to study shark movement patterns represent the best available to understand the ecology of multiple shark species at FFS.
    viii. The influence of possible covariates of predation have been adequately analyzed
    ix. The involvement of tiger sharks in the predation issue?
    x. The Galapagos sharks display site-specific movement patterns versus wide-ranging movement patterns
6) Determine whether the science reviewed is considered to be the best scientific information available.
7) Recommendations for further improvements
8) Brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations