Peer review report of shark mitigation as a tool for conservation of the Hawaiian Monk Seal

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1 Executive summary

The French Frigate Shoals (FFS) subpopulation of Hawaiian monk seal is at its lowest historical level after a steep decline since the end of the 1980s. Multiple causes are affecting this population including shark predation, which lately believed to have an unsustainable impact. Through a review of two workshop reports and other peer-review literature on abundance, movement and survival and ecology of both sharks and seals, I provided comments and recommendations on data, analyses, conclusions, and proposed shark predation mitigation tools to improve the conservation of the species.

The science reviewed revealed a great amount of effort in collecting information on several aspects of monk seal and shark biology and their interaction. Data available on population dynamics of seals are excellent. Information on population structure, abundance, and movement of sharks is increasing, but it is still not optimal to characterize the behavior of the species involved in monk seal predation. Many of the hypotheses concerning the causes of monk seal decline and the possible involvement of the Galapagos shark are still untested. There are many aspects of the interaction between the two species that are still unexplored empirically and/or analytically. Therefore, culling Galapagos sharks to reduce monk seal mortality remains unjustified, and possibly ineffective and detrimental in the long term.

Data gathered on multiple aspects of seal and shark behavior and biology, and from shark deterrent and harassment experiments, have a high informative potential that could be extracted by switching from an explorative to an inferential analytical stage. A combination of appropriate statistical analyses and auxiliary demographic models could effectively characterize the level and kind of shark predation, explain changes in survival and population abundance of the monk seal, and also make predictions on the likely effect of shark removal on monk seal recovery, shark populations, and ecosystem structure.

To ensure a long-term persistence of the monk seal in FFS, it is necessary to take a systematic approach by acting on the principal causes of monk seal decline. Malnutrition emerges as the most important stressor for the population. This in turn might indirectly increase the incidence of other sources of mortality including predation. Pursuing initiatives that increase the survival of weaning and post weaning seals such as artificial nutrition, rehabilitation programs, translocations to predator-free islands, debris removal, and other non-lethal initiatives (aimed to limit shark and seal interactions) seems the best approach to increase seal survival immediately and in the long-term.

2 Background

The Hawaiian monk seal population declined by about 60% in the last 60 years (Antonelis *et al.*, 2006). Its current population counts between 1200 and 1300 seals (1247 and falling by 4%/year (Baker, 2008)) distributed among 7 subpopulations. Six are in the NWHI, while a marginal fraction is in the MHI (83 seals (Gobush 2010)). Changes in population abundance have been variable among islands. In some atolls, sub-populations recently increased (Antonelis *et al.*, 2006). In the last decade, the French Frigate Shoals (FFS)'s sub-population recorded the steepest decline, and now it numbers about 300 seals (Antonelis *et al.*, 2006)

Causes for monk seal decline are multiple. In order of importance, these include food limitation (Craig & Ragen, 1999; Baker, 2008), habitat reduction, presence of debris, shark predation, human presence, and interference with fishing; however, their relative importance changes among sub-populations and over time (Antonelis *et al.*, 2006). Moreover, malnutrition seems the principal cause for all, caused by a reduced productivity of the area due to changing oceanographic conditions (i.e., there is less availability of food per seal (Harting 2010)). This is confirmed by stage structured analyses that revealed a strong size-dependent variation in survival across all life stages, even though at FFS there was a substantial size-independent mortality possibly attributed to predation. Yet, predation might also be considered size-dependent because Galapagos sharks and juvenile tiger sharks might have a lower success rate to prey on large seals than large tiger sharks. Notwithstanding malnutrition, predation and other stressors are likely interconnected and act synergistically.

There is a concern that the FFS subpopulation is now substantially impacted by shark predation. Historically, monk seal predators were primarily tiger and to a lesser extent Galapagos sharks (Wetherbee *et al.*, 1994; Papastamatiou *et al.*, 2006). Both have diets including marine mammals and monk seals (Papastamatiou *et al.*, 2006). However, only Galapagos sharks were observed to prey on seal pups in the last decades with an increased frequency raising concerns for the population viability and recovery (Gobush, 2010). Consequently, the Hawaiian Monk Seal Recovery Program and others have proposed and/or carried out a suite of actions devoted to reduce this source of predation through indirect and direct shark harassment, sonic, magnetic, chemical and electric deterrents, physical barriers, and most importantly, Galapagos shark reduction by dedicated fishing campaigns.

Most of the inferred shark attacks in FFS are on nursing seals (Figure 6 in Gobush, 2010). This is exceptional if compared to other islands where sharks have been observed to prey only on post-weaned young. Pups tend to remain in close contact with their mother from birth to weaning, from 0.2 meters on land to about 1.3 meters when they are in the water (24% of the time observed (Gobush, 2010)). It is estimated that since 2000 about 20% of newborn pups were killed each year due to shark predation (Harting, 2010). Juveniles and adults suffer shark predation too with a decreasing intensity (Bertilsson-Friedman 2006). Not all shark injures on adults seem related to predation attempts, but rather a result of competitive interactions (Bertilsson-Friedman, 2006).

Seven shark species are more or less frequently detected by fishing or underwater visual censuses in the NWHI (Dale *et al.*, 2011; Holzwarth *et al.*, 2006; Friedlander & DeMartini, 2002). Abundance and composition change with survey techniques, but the general pattern indicates that Galapagos and tiger sharks are among the most abundant sharks in the area, while they are much less abundant in the Main Hawaiian Islands (MHI) (Dale *et al.*, 2011; Friedlander & DeMartini, 2002).

Information on abundance and distribution of both species is scant, highly variable and heterogeneous. In 1984, DeCrosta (1984, Master Thesis, unknown method, cited in Gobush 2010) estimates that there are 703 Galapagos sharks within the 30 depth-contour around FFS (DeCrosta, 1984). Holzwarth *et al.* (2006), from diving survey data in 2000-2003, estimated 4380 individuals (no confidence intervals provided). In 2009, Parrish estimated 1604 individuals from an Ecopath model (personal communication in Gobush, 2010; no model details and confidence intervals provided). Finally, Dale *et al.* (2011) provided a set of contemporary estimates from tag-recapture data ranging from 104 to 668 sharks (CI: 83 to

2180). None of these estimations took into account sampling error for long line catches, bias of visual census data (Ward-Paige *et al.,* 2010), and the varying attitude of sharks to be attracted or repelled by diving operations (Parrish *et al.,* 2008). However, it might be safe to say that the population ranges from a few hundred to a few thousand.

The Galapagos shark is a relatively sedentary species, with home ranges of 30-40 km, though able to swim across trenches over length of 30 km (Meyer *et al.*, 2010). It is primarily detected offshore, preferentially at depths between 30 and 50 m around the outer reef (between the reef and the open ocean, Lowe *et al.*, 2006). Lagoons constitute the shark's nursery habitat but are otherwise rarely visited (Lowe *et al.*, 2006; Dale *et al.*, 2011). Because of its sedentary nature, it is thought that the Northwest Hawaiian Islands (NWHI) Galapagos shark population is isolated from other populations across the Pacific, and is possibly the biggest among all (Harting, 2010).

The tiger shark is a wide-ranging fish. It can patrol hundreds of kilometers of reef, move from an island to another, go inside lagoons and shallow waters to forage close to shore, and swim for long distances, even to the middle of the ocean, to forage into oceanic fronts (Meyer *et al.*, 2010). In FFS, tiger sharks occur all year round, aggregating seasonally (in summer) in areas where albatrosses fledge, and in winter, remaining in the periphery of the atoll (Lowe *et al.*, 2006; Meyer *et al.*, 2010).

It is unknown how local shark populations have changed over time. Rough comparisons between shark control programs in the 1960s and recent long-lining experiments suggest that sharks might have remained stable or increased in abundance. Catch rates of Galapagos and tiger sharks increased by almost 2 times, and sandbar by 7 times (comparing Papastamatiou *et al.* 2006 and Dale *et al.* 2011). It is hard to say whether these differences are statistically significant, and whether they can be attributed to better performance of long line gears or changes in fishing methodology (e.g. fishing in areas where they knew sharks were). Holzwarth *et al.* (2006) hypothesize that Galapagos sharks might have benefited from the restriction of commercial longline fishing within 50 nm of the Hawaiian Islands (effective since 1993). While tiger sharks would still be exploited offshore, Galapagos sharks became sheltered from fishing mortality and might have expanded in habitat previously occupied by tiger sharks. Dedicated analyses of catch rates and sighting data would be required to confirm these back of the envelope estimations and test such hypotheses.

The idea that the Galapagos shark is the only species responsible for nursing and post-weaned seal kills comes from observations of its predatory behavior in the surrounding of pupping sites, and inferences based on its habitat, dietary habit, behavior, and lack of alternative hypotheses. Yet, a marginal percent of pup mortalities attributed to Galapagos sharks has actually been witnessed (Harting, 2010; Gobush, 2010).

Galapagos sharks do not tend to enter lagoons or shallow waters (seal habitats). However, it is thought that few individuals might have learned to do so. FFS has lost about 50% of its original extension since the 1950s (Antonelis *et al.*, 2006). Important islets and beaches where seals used to haul out disappeared for subsidence and consequently, there was a relocation of seals in other areas. It seems that the disappearance of Whaleskate Island in 1989-99 congregated seals in Trig island, which is in the periphery of FFS and hence close to the Galapagos shark domain (Antonelis *et al.* 2006). In addition, in 1999, several baby seals were killed by adult male seals thereby making them available for scavenging sharks. This might have contributed to attract nearby Galapagos sharks (Bertilsson-Friedman 2006). It was reasoned that such a hypothesis was consistent with the exploratory feeding behavior of sharks, which is not transmitted between individuals, and adapt to changing circumstances (Meyer in Harting, 2010). Other shark species demonstrated this capacity to learn and increase their skills in successfully preying upon other species (e.g., white sharks (Skomal 2010 in Harting, 2010)).

3 Role in the Review Activities

My role as a reviewer was to evaluate the body of science behind the proposed actions for mitigating shark predation on monk seal. The primary literature provided with the assignment included four peer reviewed papers (Bertilsson-Friedman, 2006; Dale *et al.*, 2011; Lowe *et al.*, 2006; Meyer *et al.*, 2010) and two workshop reports (Gobush, 2010; Harting, 2010). I read the provided background material and additional references to elucidate the Monk seal and Galapagos shark status in the area, the potential involvement of Galapagos sharks in seal predation, and the consequential effect of this predation on seal populations. Additionally, I evaluated other peer-reviewed literature on monk seals and sharks at FFS, in the NWHI, and in the overall Hawaiian archipelago to clarify aspects of the predator-prey dynamics unfolding in the area.

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

4.1 Evaluation, findings and recommendations of data collection operations

There has been a great effort to evaluate the population dynamics of monk seal in FFS. There has also been a considerable investment of research effort on understanding the distribution and movement of tiger and Galapagos sharks in the area. Less comparable data have been gathered on the movements of juvenile and baby seals, which mostly came from daytime observation surveys. Monitoring monk seals and sharks in the surroundings of pupping grounds promises to reveal important information on the causes of baby seal mortality. However, the information collected appears limited spatially (mainly at Trig) and temporally (in 1998-99, 2001-04 and summer of 2009 at Trig and Gin), even though a clear picture of the distribution of observation effort among FFS sectors is now emerging from Gobush (2010) and Harting (2010). Having a clear understanding of how monitoring effort changes across islands and atolls is crucial to test whether differences in baby seal mortality related to sharks are merely artifacts of changing monitoring conditions.

The use of crittercams and deploying satellite, acoustic or radio tags on seals promise to increase the ability to assess the nature of seal-shark interactions, and quantify the predation level, especially when observation surveys cannot be easily carried out (e.g., at night).

Tag-recapture data constitute valuable aids for estimating fish stock abundance. However, catch rates extracted from these programs are not optimal in characterizing the population structures of the sampled sharks. These catch-per-unit effort (CPUE) rates do not come from dedicated sampling surveys but from fishing operations meant to capture sharks for further monitoring. Hence, these catches might overestimate the actual abundance of these species. Carrying out stratified random sampling surveys dedicated to assess the standing stock and population structure of Galapagos and tiger sharks seems a necessary further step.

4.2 Evaluation and recommendations of data quality

Data on monk seal population abundance are excellent. The population is virtually in an emergency room where all demographic rates are constantly monitored.

Shark telemetry data provided a good picture of spatial habits of tiger and Galapagos sharks (Meyer *et al.*, 2010), although the latter seem under detected by the current monitoring protocol. Possibly, an increase of bathymetric and spatial coverage of acoustic receivers deployed at sea might be necessary. Currently, these do not optimally overlap with the preferential spatial domain of the species. Additionally, as these sharks seem more approachable when doing underwater sampling surveys (Dale *et al.* 2011), the possibility of underwater tagging might be explored.

Assessing the quality of visual monitoring survey data is hard because only the collection protocols have been described in detail. Considering the large number of observation types to be recorded for each individual sighting, and the reported low frequency of occurrence of each sighting, I imagine that the subset of observations instrumental in identifying correlations between shark and seal behaviors is low.

Data collected during experimental tests of shark deterrent devices were insightful to reveal the devices' action ranges, whether or not they cause a response on sharks within this range, relative differences in performance, and all the logistic problems associated with their application and maintenance. However, given their short temporal span, deterrent experiment data are less instrumental in evaluating long-term mitigation effects of tested devices on reducing observed or inferred shark predation cases. The same considerations hold for harassment actions.

Although data on observed, predicted and inferred shark incidents span for more than two decades, the picture is less clear for the observation effort that recorded these cases. It is evident that observation effort is more intense at Trig, but it is unclear how this compares to the other islets inside the atoll, and consequently, how the records on shark incidences might be affected.

4.3 Evaluation of strengths and weaknesses, and recommendations of analytic methodologies

Combining different telemetry techniques is effective in exploring aspects of tracked animals' spatial behavior. So far, the analyses of the results are more descriptive than inferential. Analyses of spatial and temporal patterns of sharks detected with telemetry devices could be implemented by teaming up with analysts specialized in modeling telemetry data. State-space models are now becoming customary analytical tools to interpret such data, as well as to extract meaningful behavioral signals from apparently complex patterns (Block *et al.,* 2011; Breed *et al.,* 2009).

The analyses of shark CPUEs and other indices of abundance pay little consideration to the intrinsic statistical structure of the data. Catches and sightings are analyzed with statistics assuming normal distributions of data with the risk of producing misleading conclusions when comparing differences of indices of abundance between locations and periods. For example, by assuming that catches, shark sightings, or predation events follow a homogeneous Poisson process, or are distributed according to a negative-binomial distribution, or to zero-inflated versions of the two PDFs, might improve the analytical capability to detect the effect of any covariate potentially important to explain the predation rate, changes in CPUEs over time, and stock abundance from tag-recapture data. Because of the scant nature of the some of the information and the multiple sources of uncertainty in the processes, Bayesian and hierarchical modeling frameworks could be employed to increase the inferential power of these analyses.

Collecting, integrating and analyzing all data on past and recent shark sighting surveys and shark culling programs present a future research priority. The analysis would require some involved modeling, i.e., a meta-analytical and Bayesian approach to combine a likely heterogeneous amount of data. This integrative effort, however, promises to extract a noteworthy amount of information on abundance of sharks, their interaction with seals, potential effect of shark reduction programs, and identity of predators, in a cost-effective fashion.

Finally, more effort is required to develop modeling frameworks (e.g., density dependent predator-prey models) to characterize the level and kind of shark predation, to explain changes in survival and population abundance of monk seal, and to make predictions on the likely effect of shark removal on the future survival and abundance of the population (more below).

4.4 Evaluation and recommendations of assumptions, estimates, and uncertainty

Most of the conclusions reached to justify shark culling are based on untested theoretical grounds. It is uncertain whether Galapagos sharks are responsible for all predation cases, whether there are few Galapagos sharks involved in all predation cases, and whether it is true that Galapagos sharks recently learned to prey on baby seals. Shark culling is dependent on all these hypotheses, but unfortunately, little analytical effort has been spent on testing them.

Although observations of inferred nursing pup mortalities, and previous shark culling campaigns suggest a certain correlation, a set of covariates, caveats on data, and the variable nature of predator-prey interactions might have generated these patterns. The classification of baby seal disappearances as shark-inferred might appear hasty in light of the yet unclear temporal and spatial distribution of observation effort. Uncertainty on these cases might be especially high in areas where continuous monitoring is deficient (e.g., elsewhere than Trig).

It is speculated that a recent discrepancy between inferred and observed shark predation trends is explained by the increased wariness of Galapagos sharks to human presence. It is hypothesized that some Galapagos sharks switched their predatory activity from day to night thereby affecting detection but not predation rate. However such a hypothesis seems weakly rooted on empirical grounds, and contradicted by multiple reports suggesting that Galapagos sharks are, in fact, unaffected, if not attracted by underwater human presence (Parrish 2008; Gobush 2010), human decoys, and devices producing sounds imitating human activity on land and water (Gobush and Farry, in prep).

4.5 Evaluation, findings, and recommendations of result interpretation and conclusions

4.5.1 The Hawaiian monk seal population is significantly impacted by predation on pups.

This statement is conditional on whether all inferred shark-related pup mortalities are genuine, and whether the monk seal decline is principally caused by predation. Again, both conditions are untested. Most of the shark-related mortalities are inferences. Predation might be significant but whether it is unsustainable for monk seals is not evaluated. There are no reported demographic analyses indicating that monk seals would decline to extinction as an effect of the sustained level of predation. It is worth exploring whether the predation rate will continue to have the same incidence as seals decline. Predation effort might become too high for sharks to continue preying on seals at low population abundance. Furthermore, predation might just decline because there will be less combined chances for predators and prey to meet and engage in successful predation events. A sensible approach to test these hypotheses would be developing population dynamic models to evaluate the effect of different levels of predation in a density-dependent context. These analyses could be used to investigate the relative magnitude of predation mortality and other monk seal stressors, and the number of sharks involved in monk seal predation. Input data could be monk seal abundance, prior estimates of shark abundance, assumptions on their chances to interact, and on the likelihood of sharks to successfully prey on seals when they encounter each other. The last two pieces of information could come from monitoring programs of sharks and seals such as telemetry studies, tower observation monitoring surveys, crittercam observations, etc. I believe there is already a sufficient amount of data to parameterize a working model.

Multiple sources indicate that malnutrition is indeed the principal cause of monk seal decline. Antonelis *et al.* (2006), Craig & Ragen (1999), Baker & Thompson (2007), and Baker (2008) have pointed out that malnutrition is due to a significant reduction of FFS carrying capacity. Walters (in Gobush (2010)) suggests a 40-50% decline of primary productivity in the NWHI since the 1990s. Population dynamic models incorporating such a decline in carrying capacity could reveal whether malnutrition could explain the observed change in monk seal abundance, and whether predation is just a more detectable consequence of such a deteriorated physiological regime. Malnutrition might create the conditions for an increased predation rate, in turn having a negative multiplicative effect on seal population abundance. In addition, survival analyses showed that declines of monk seal survival precede the reduction of fishing for sharks (Baker & Thompson 2007), thereby rejecting one of the hypotheses used to explain the supposed increased Galapagos shark predation on baby seals.

4.5.2 The primary species of shark involved in predation of seal pups is the Galapagos shark.

This statement is mostly inferred from a scant amount of observations, and hypotheses involving large-scale phenomena, which, however, are not backed by empirical analyses. Indeed, the Galapagos shark is the only species recently observed to harass, chase, and attack baby seals, even though tagging studies revealed that Galapagos sharks do not range in lagoons or areas usually inhabited by seal colonies. It is possible that a few individuals learned to exploit seals. The close vicinity of Trig Island to the habitat domain of Galapagos sharks could have created the conditions for this species to be in close contact with suitable food. Other observations on different species confirm the possibility of this behavior. However, these hypotheses cannot exclude the incidence of other species, especially the tiger shark. Tiger sharks are likely greater predators of monk seals. Their habitat overlaps conspicuously with that of monk seals (Dale et al., 2011). They are bigger than Galapagos sharks and thus able to exploit a larger spectrum of seal sizes. The fraction of mammals in the tiger shark diet is the greatest among all shark species occurring in the area (Papastamatiou *et al.*, 2006). Tiger sharks forage at night, which is the period when the majority of shark-related pup losses have been recorded.

Re-analyzing sighting data collected during 2001-2004 (Gobush, 2010) accounting for observation effort, differences between inferred and observed shark-related mortalities (e.g. size distributions, weaning stage, etc.), pup abundance, and assuming different statistical distributions for the data (using Generalized Linear Models), might be insightful to: 1) understand whether there is, in fact, a trend in sighting rate and predation rate; 2) test the hypothesis that Galapagos sharks actually changed their predatory behavior from day to night; 3) get a better understanding on the identity of possible seal predators.

Having monitoring data only at Trig makes testing whether Galapagos sharks expanded in other sites difficult (as it has been proposed). Only tiger sharks have been detected inside the atoll near pupping islets, even at night (Meyer *et al.*, 2010). Are any of the remaining five locations hosting monk seal sub-populations pupping islets close to Galapagos shark habitats? If so, why did Galapagos sharks not prey upon baby seals/or learn to prey upon them in these other areas? Can we use crucial differences between FFS and the other NWHI sectors to understand the factors for this peculiar behavior to occur? How does the observation effort in other islands compare to the one in FFS? Why does Tern (which is another island close to Galapagos sharks' habitat) seem not to be affected by shark predation? Can spatial differences between Tern and Trig explain the occurrence of predation on baby seals only at Trig? An answer to all these questions might help researchers gain insights on the identity of the major predators for baby seals, and eventually understand how to efficiently mitigate the observed predation level.

4.5.3 A relatively small number of sharks are responsible for the majority of pup predation.

So far, this remains an untested hypothesis based on observing low catch rates of Galapagos sharks inside habitats close to seal nursing grounds, and also because of the fact that preying upon baby seals is a peculiar Galapagos shark behavior not observed elsewhere (Gobush, 2010). No data or analyses confirmed that all shark-related pup deaths are indeed to be attributed to sharks, and that the same or few redundant individuals were responsible for these cases. Working on developing a demographic model suggested above might be useful to estimate the number of sharks required to produce the observed predation mortality.

4.5.4 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.

This is contingent on the veracity of the above conditions, on the success in catching genuine monk seal predators, and on a scenario where no other sharks would eventually substitute (and learn to feed on seals) those culled.

Testing these hypotheses can be attempted by using data on previous shark reduction programs carried out in the area. After the removal of 50 Galapagos sharks in 1999, there is coincidental evidence that mortality on pups declined at Trig. However this was also coincident with the removal of aggressive adult monk seals, pup translocations, and a decrease in birth rate. The following removal of other 12 individuals over 2000-2006 did not produce tangible effects on predation rate. It would be useful to analyze the effects of the control program carried out in NWHI during the 1970s, when 31 Galapagos shark where removed between 1978 and 1980 (although not of all of them at FFS (Papastamatiou *et al.,* 2006)). However, I am not aware of whether data on pup mortality prior to 1984 can be retrieved.

While previous culling programs might have reduced predation, it is evident they did not solve the problem. The observed reduction is indeed quite ephemeral with short transient periods. If Galapagos sharks involved in baby seal predation have no behavioral differences with other local conspecifics, shark culling might just dispatch few individuals for the immigration of others and the resulting effect on predation would not last for long.

4.5.5 Removing 20-40 Galapagos sharks is unlikely to cause significant deleterious impacts on that species population at FFS nor any other unintended ecosystem consequences.

Whether a limited removal of Galapagos sharks would affect that species population and ecosystem functioning is admittedly not well understood (Dale *et al.,* 2011). It would depend on the estimated Galapagos shark abundance in FFS, on the abundance of other nearby populations, and on whether Galapagos shark can easily move from one atoll to another so that immigration could potentially mitigate the effect of a limited population decline.

There is high uncertainty on Galapagos shark abundance, but it seems that FFS' stock goes from a few hundred to a few thousand sharks. If there were sufficient interchange between Galapagos shark populations at different atolls, a one-time removal of 40 individuals would not irreversibly affect the population. Not marginal instead would be the effect of removing such an amount from a population in the lower range of abundances estimated by Dale *et al.* (2011). However, if after a shark cull, sharks recruit from elsewhere and start preying on seals again, additional culling sessions will be required, and this might not be sustainable for the Galapagos shark population. Constructing a stage- or age structured models for Galapagos sharks, and evaluating different levels of fishing mortality that different population abundances could sustain would provide better answers to these questions.

As for ecosystem consequences, predators might generate a large array of behavioral responses on potential prey even without trophic interactions (Heithaus *et al.,* 2008). Removing 40 sharks is going to remove from the system their direct and indirect effects on other species. These will be more tangible if those sharks were habitual inhabitants of the shallow ecosystems close to breading colonies. ECOSIM and ECOPATH models are analytical frameworks to use with caution when giving management advice (Plaganyi & Butterworth 2004). They provide valuable exploratory indications that, however, need validation with statistical analyses taking into account sampling and process errors propagating throughout the hierarchies of the model under study. In Harting (2010) a summary of one of these models concludes that Galapagos shark removal might relieve predation on jacks, thereby causing an increase of these fishes (Parrish's presentation in Harting 2010). Although, no model details were given, and this might be of concern especially considering that malnutrition seems the primary cause of monk seal decline. If jacks and seals are competing for food, removing sharks might even enhance such a competitive interaction, lowering seal survival even further. Thus even if culling sharks would increase the survival of weaning seals, the long-term effects on the whole population would be compounded by an increased mortality at later life stages. This effect has been predicted elsewhere after modeling the consequences of culling predatory seals to mitigate their effect on hake fish stocks (Yodsiz 1998; Yodsiz 2001).

Natural meso-predator populations are rarely exempt from predation. Predation is a crucial feature of species population dynamics. Boosting recovery of monk seals by removing such a selective force might have unpredicted consequences for the long-term survival of the population, and as anticipated, might possibly result in weak population increases. Together with preventing a possible release of monk seal competitors, predation might have a beneficial compensatory effect on demographic rates and survival of juveniles (Krebs, 2001; White & Garrott, 2005).

4.5.6 The methods used to monitor shark activity and monk seal pups are adequate to characterize the level of predation

The methods used are useful to characterize the kind of predation. Unfortunately, they are less efficient in evaluating the level of predation. Up to now, analyses on telemetry data have revealed the preferential habitats of tiger and Galapagos sharks, and they provided insights on their spatial behavior. An increasing monitoring effort in islets inside the atoll, continuing the deployment of crittercams on seals (e.g., Parrish *et al.,* 2008) and an increasing use of telemetry devices on baby seals, might be useful to explain the great portion of shark-related pup mortalities now attributed to Galapagos sharks by inference. Also, this increasing monitoring effort would be useful to parameterize predator-prey population models mentioned above for making scenarios of predation levels able to explain the observed trajectories.

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

Multiple tagging methods are excellent in characterizing the spatial behavior of sharks at FFS. Plenty of insightful data have been gathered, but their full informative potential can still be extracted. The analyses published so far appear in an exploratory and descriptive stage. Logistic issues for signal detection of Galapagos sharks are hampering the ability of researchers to extract clear behavioral signals. However, even the limited amount of available data could be used to make good inferences on Galapagos shark predatory behavior and movements. For example, satellite-tagging data and state-space models have been used to infer state changes of animal behavior from foraging to travelling (Breed *et al.*, 2009), and this can be applied to decipher Galapagos shark data detected near colonies.

4.5.8 The influence of possible covariates of predation have been adequately analyzed

The influence of possible covariates of predation has been explored but not analyzed. As it is remarked above, using the scant amount of data coming from shark incident records, observation surveys and mitigation endeavors (translocation, use of deterrent, and shark culls) is intrinsically difficult for disentangling the effect of each single factor on predation rate. It is also difficult to make an assessment of analytical procedures and datasets used having just a brief description of methods, data, and results provided in Gobush (2010, pages 29 and 30), which most of the time links to publications in preparation and grey literature that is difficult to access. However, an analytical approach focused on multiple tests of single variables, making adequate assumptions on the statistical distributions of sightings (most of the time not normal), predation incidences, observed behaviors, etc., might reveal useful insights on the process under investigation. This requires the employment of statistical techniques, even regression analyses, able to deal with such data peculiarities.

4.5.9 The involvement of tiger sharks in the predation issue?

The issue concerning the involvement of tiger sharks was partly discussed in subsection 4.5.2. The incidence of tiger shark predation cannot be ruled out, especially in islets inside the atoll (e.g. Gin and East islands) where tiger sharks are more frequent and even congregate in summer months. Most of the inferred predation cases occurred at night (not seen by researches) when tiger sharks are actively feeding. Even daytime records might be inconclusive given the overall limited and occasional observation effort. Dedicated monitoring surveys were done only at Trig between 2001-2004 and for a few months in 2009 at Trig and Gin (Gobush, 2010).

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

Movement and tag-recapture data (Meyer *et al.*, 2010; Dale *et al.*, 2011) seem to confirm this thesis.

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

At this stage, I believe there is a notable amount of data on the behavior, population structure and abundance of monk seal. Less information is available for sharks, especially on population abundance. Because of the multifaceted nature of the problem, many conclusions would require a greater support by published peer-reviewed science. However, crucial conclusions are frequently based on untested hypotheses, results published in grey literature that are difficult to access, and on manuscripts still in preparation.

4.7 Recommendations for further improvement

The massive amount of information gathered on many aspects of monk seal and shark interactions requires a dedicated integrative analytical stage. Multiple pieces of information could be combined to test hypotheses that constitute the rationale for undertaking important and controversial management actions. There is an objective problem on seal survival (Baker & Thompson 2007) that urges immediate effort on understanding the major causes of monk seal population decline. Acting on these principal causes will ensure a long-term persistence of the population in the area.

In the past, rehabilitation programs were undertaken for post weaning seals. This might be a good option, as it tackles the most important factor reducing survival in FFS monk seals. I am not aware of the array of consequences that feeding artificially newborn seals would have on their long-term survival. However, if there are any, these would be limited to the population under protection and should be evaluated against the effect of alternative management actions. It does not require removal of native animals from the system, and therefore, it is an action that limits possible ecosystem effects.

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

The following is a list of comments, suggestions and discussion topics presented in Gobush (2010) and Harting (2010) that I found particularly relevant for evaluating the necessity and effectiveness of the proposed actions of shark predation mitigation.

I echo the workshop participants calling for an improvement of the experimental design used to test deterrent devices. Currently, it appears unbalanced and unable to gather a sufficient amount of data to make significant inferential conclusions about the efficacy of these devices in reducing predation rate. Additionally, most of these devices have limited action ranges and proven logistic limitations in maintenance and application. Therefore, unless some of them will be successfully glued to baby seals (ensuring that their action range will hit on the interaction between seal and shark when it occurs), spending additional research on these tests might not result the most efficient way to tackle the problem concerning seal survival in the area.

If the HMSRP is concerned about the long-term survival and recovery of the species, I share the view of Steve Martel that taking a systemic approach would be preferable. A limited cull of Galapagos sharks might have a short-term positive effect, but it is likely to fade out over time because other factors are still in action. For reasons outlined above, a population structured in the absence of predation might result even more vulnerable to other stressors including food limitation due to intra-specific and inter-specific competition. Concentrating recovery effort by limiting exposure to stressors having the highest contribution to monk seal decline might be more efficient. Malnutrition is recognized as the principal cause of monk seal decline. Focusing on increasing the energetic state/health of pre-weaned and juvenile seals might lower their risk of being preyed upon, lower their chances of dying in interactions with debris, increase their capacity to recover from injuries, and reduce their engaging in risky behaviors when searching for food (Heithaus *et al.*, 2008).

Artificial nutrition, rehabilitation programs, translation to predator-free islands, debris removal, using shark decoys with electric devices to teach baby seals not to approach shark-shaped objects, and removing nursing pups from their mothers to feed them in captive care situations seemed valid alternatives that deserve more consideration. An interesting idea is that of deploying barriers around pupping sites to prevent the access of sharks. It is an invasive approach for many reasons, but probably less invasive than removing other sea-life from the area. Fine-tuning an optimal framework for these structures could be implemented by using results of behavioral analyses on baby seals. Here, the use of deterrent devices might be effective to shield openings devoted to the passage of sea life other than sharks.

As for translocation, the earliest time of premature weaning could be estimated by evaluating the trade-off between increased survival due to sheltering seals in shark-free areas, and its decrease due to premature weaning. A predator-prey density-dependent model developed to evaluate the level of predation sustained by the declining seal population might be used for this scope too.

As already mentioned, I share the view that there is a need for data mining and analyses on previous information (shark sighting data, predator controls and their effect), collection of additional data on seal and shark behavior (to characterize the pool of predators). More effort should be spent on characterizing baby seal movements by using telemetry devices in addition to the monitoring programs using visual observations at pupping sites (especially for nighttime observations).

If limited shark culling is approved (e.g., 40 sharks), I agree with others suggesting to maximize the information to be extracted from these programs, and eventually use the results to test some unproven hypotheses. A prompt change of predation rate might not be evident after an initial removal of Galapagos sharks (as proposed in Appendix G of Gobush (2010)). However, evaluating whether the Galapagos sharks caught were monk seal predators might be feasible with isotopic analyses (Estrada *et al.,* 2006). This could be a first check on whether the program has to continue.

Fishing methods should limit bycatch as much as possible. Spear guns or harpoons are valid options. These should be operated when sharks are observed to engage in predation to be certain that only potential monk seal predators are killed. Conversely, I agree that using expanded bottom sets has the risk of producing excessive bycatch mortality, even though any other species caught will be released.

5 Specific comments on Gobush (2010)

- Page 12 "…but could be a distinctive behavioral characteristic of the local (NWHI) population" - This is speculation.
- Page 12 "sharks had clearly become exceedingly wary of traditional hook-and- line fishing near Trig Island" - What is the evidence for this?
- Page 16 "..Galapagos sharks that have learned this predatory behavior, is a reasonable and likely assessment" - Why did they not learn to do so before?
- Page 17 "The HMSRT was informed of the increased rate of predation of Galapagos sharks.." - Are they referring to any particular paper?
- Page 17 "A primary concern of the HMSRT has been that the behavior may spread within the shark population" - How? Is there any empirical evidence for this?
- Page 20 "Methods used to answer these questions center on acoustic tagging of Galapagos and tiger sharks at FFS" - How can these methods respond to the third question?
- Page 23 "However, unlike 2007, the site that accounted for the most predation in 2008 was Gin, rather than Trig" - I agree that these results are equivocal. Predations at Gin lower the likelihood that the predator is the Galapagos shark. Also observation effort at Gin might be not sufficient to be certain about the cause of mortalities.
- Page 23 "In 2007, at least 7 of the 43 pre weaned pups born at FFS were lost because of shark predation" - How does this figure compare to other seal colonies affected by shark predation around the world?

- Page 28 "If above is true, then removal of the problem sharks at FFS would have a positive effect on pre-weaned pup survival and, in turn, on the HMS population." - This is not really consequential because we do not know whether only few sharks exhibit this unusual behavior at FFS.
- Page 28 "The Hawaii population of Galapagos sharks is healthy (essentially unexploited). [1]" – How can we explain the nearly absence of Galapagos sharks in the MHI? (Friedlander & DeMartini, 2002)
- Page 38 "multivariate analysis was not conducted" - Testing one variable at a time would suggest some effect.
- Page 39 "the number of mother-pup pairs was the only significant factor tested and it was only weakly positively related to shark density" - It is unclear how these tests were carried out.
- Page 40 "Galapagos shark sighting rates did not significantly differ on fishing days (i.e., 12 days of attempted or successful removal of sharks) versus non-fishing days (paired t-test: p = 0.0893)." - This might suggest that fishing does little to remove predation risk from these shores, but again these numbers are very inconclusive.
- Page 41 "However, predation was later detected at Gin and East, so the majority of translocations continued to occur at Tern" – It is probably worth investigating why shark attack is not occurring at Tern given that for the previously postulated hypotheses we should expect more Galapagos shark predation here than in other islets inside the lagoon.
- Page 42 "Galapagos sharks continued to feed and appeared to be deterred at a distance of approximately 1 m" - One meter is a really short distance to expect some substantial deterrent effect on very mobile organisms such as sharks and seals.
- Page 45 "but the total number of incidents (confirmed and inferred attacks) did not decline and the number of inferred attacks increased" - I see an overall decline from figures 4, 5 and 6 in Gobush (2010).
- Page 45 "A report on shark densities and their proximity to human population centres showed a highly significant negative relationship between grey reef and Galapagos shark densities and proximity to human population centers" - Then why are Galapagos sharks sighted with dive surveys? In fact, this shark species show high underwater sighing rates that seem scarcely related to population abundance (e.g. Dale *et al.,* 2011). When parallel surveys are undertaken with distinct methods, indices of abundance are different. Furthermore, the above statement is unfair because the relationship between human and shark densities does not imply a direct negative effect of human presence on sharks, but a more indirect link to the negative effect of human activities on habitats and marine communities.
- Page 65 "If a shark sighting occurs, record the shark's distinguishing features and use the sketch as desired/necessary" - Why not take a picture?

6 Specific comments on Harting (2010)

- Page 17 "That is, what were the best/worst possible consequences that would result from doing nothing," - Why is removing sharks just an alternative of doing nothing. I see from above that there are many other options: translation and artificial nutrition, for example.

- Page 20 "Observations in 1997-1999 indicated that 15-20 individual sharks were probably responsible for the predation losses (i.e., a small number of sharks)" - Where is this figure coming from?
- Page 20 "This spread to other sites across the atoll may have been a result of, at least in part, human harassment/presence at Trig" - This is speculation.
- Page 42 "Use of chemicals" - Why not spray pups with chemicals?

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Appendix 1: Background material

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Appendix 2: A copy of the CIE Statement of Work

External Independent Peer Review by the Center for Independent Experts

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

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 Hawaiian monk seal offers the best chance of its persistence. However, the Hawaiian monk seal 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 Hawaiian Monk Seal 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.

Prior to the Peer Review: 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.

Pre-review Background Documents: 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.

Desk Review: 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.

Contract Deliverables - Independent CIE Peer Review Reports: 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.

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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 Hawaiian monk seal

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
    a. The Hawaiian monk seal population is significantly impacted by predation on pups.
    b. The primary species of shark involved in predation of seal pups is the Galapagos shark.
    c. A relatively small number of sharks are responsible for the majority of pup predation.
    d. 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.
    e. Removing 20-40 Galapagos sharks is unlikely to cause significant deleterious impacts on that species' population at FFS nor any other unintended ecosystem consequences.
    f. The methods used to monitor shark activity and monk seal pups are adequate to characterize the level of predation.
    g. The methods used to study shark movement patterns represent the best available to understand the ecology of multiple shark species at FFS.
    h. The influence of possible covariates of predation have been adequately analyzed
    i. The involvement of tiger sharks in the predation issue?
    j. 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