FINAL SUMMARY REPORT

ENVIRONMENTAL SCIENCE PANEL FOR MARBLED MURRELET UNDERWATER NOISE INJURY THRESHOLD

Panel Conducted

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Lacey, Washington

Prepared by

Science Applications International Corporation
Bothell, Washington

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MARBLED MURRELET UNDERWATER NOISE INJURY THRESHOLD SCIENCE PANEL

JULY 27–29, 2011

Participants:

- Danielle Buonantony, U.S. Navy, Biologist
- Dr. Robert Dooling, University of Maryland, Professor
- Dr. Jim Finneran, U.S. Navy, Acoustician
- Dr. Dorian Houser, NMMF, Director of Biological Research
- Craig Johnson, NOAA, Biologist
- Cindi Kunz, U.S. Navy, Biologist
- Dr. Zach Peery, University of Wisconsin – Madison, Assistant Professor
- James Reyff, Illingworth and Rodkin, Acoustician
- Dr. Hans Slabbekoorn, Leiden University Institute of Biology, the Netherlands, Assistant Professor, Behavioral Biology
- Mike Slater, SAIC, Acoustician
- Dr. John Stadler, NOAA Fisheries, Biologist
- Dr. Bernice Tannenbaum, SAIC, Biologist
- Emily Teachout, WFWO USFWS, Biologist
- Lyn Wiltse, PDSA Consulting, Facilitator

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ACRONYMS AND ABBREVIATIONS

ABR	auditory-evoked brainstem response
BA	Biological Assessment
budgie	budgerigar
dB	decibel
EIS	Environmental Impact Statement
ESA	Endangered Species Act
FHWG	Fisheries Hydroacoustics Working Group
Hz	Hertz
kHz	kilohertz
msec	millisecond
NAVFAC	Naval Facilities Engineering Command
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NMMF	National Marine Mammal Foundation
NOAA	National Oceanic and Atmospheric Administration
PDSA	Plan, Do, Study, Act Consulting
psi	pounds per square inch
PTS	permanent threshold shift
RMS	root mean square
SAIC	Science Applications International Corporation
SEL	sound exposure level
SPAWAR	Space and Naval Warfare Systems Command
TS	threshold shift
TTS	temporary threshold shift
USFWS	U.S. Fish and Wildlife Service
WFWO	Western Washington Fish and Wildlife Office

1.0   INTRODUCTION

The multi-disciplinary science panel for establishing an interim marbled murrelet underwater noise injury threshold was held on July 27–29, 2011, at the offices of the U.S. Fish and Wildlife Service (USFWS) in Lacey, WA. The panel was convened by the U.S. Navy and USFWS to develop recommended interim criteria for evaluating onset of injury to the marbled murrelet from underwater sounds resulting from pile driving. A description of the issues that led to this panel and preliminary questions for the panel's consideration are included in Attachment 1 (Draft Issues/Questions for Multi-Disciplinary Panel for Marbled Murrelet Injury Threshold). The panelists represented technical experts and scientists affiliated with federal agencies, academia, and consulting firms who have expertise in underwater acoustics (including pile driving acoustics); sound impacts on fish, marine mammals, and terrestrial and marine birds; and the life history and demography of the marbled murrelet. This report summarizes the presentations, highlights of the discussions, and recommendations developed by panelists at this meeting. The intent is to document the technical reports and other information that were evaluated by the panel, demonstrate the range and depth of technical discussions, and provide the rationale developed in support of the panel's recommendations. Outstanding issues related to data availability and potential refinements to the recommended interim criteria are also summarized. An overall summary of conclusions is presented at the end of the report. Additionally, references cited and attachments are included.

2.0   OPENING COMMENTS BY KEN BERG (USFWS) AND CAPTAIN PAT RIOS (U.S. NAVY)

Ken Berg (USFWS, Manager, Washington Fish and Wildlife Office) provided a context for the panel and why participant input is valuable to address the goals of the panel: To develop recommended interim criteria for evaluating onset of injury to the marbled murrelet from underwater sounds resulting from pile driving. He indicated the panel would be working under interagency cooperation Section 7 of the Endangered Species Act (ESA). Federal agencies undertaking activities that potentially could impact endangered species must act together to ensure those species are not jeopardized. The action agency, the Navy, identifies federally listed species and completes an analysis (Biological Evaluation or Biological Assessment) to determine impacts on endangered species that is submitted to the USFWS for concurrence or comment. The ESA recognizes that scientific uncertainties and disagreements can occur among experts. Therefore the USFWS makes the final determination after considering all scientific information based on rational conclusions. The end result is the USFWS issuance of a final opinion, termed a Biological Opinion.

The USFWS has asked the panelists to consider the question, What is the effect on murrelets from the underwater sounds produced by pile driving. Since there are no directly applicable data on marbled murrelets in the area where the Navy is proposing activity, the USFWS may need to use surrogate information or extrapolate information from other studies. Upon completion of the panel review, John Grettenberger (USFWS) will likely sign the Biological Opinion on behalf of Ken Berg and the USFWS will defend the activities in developing the Biological Opinion.

Captain Pat Rios (U.S. Navy, Commanding Officer, Naval Facilities Engineering Command Northwest) thanked the participants and requested their expertise and best opinions. The Navy is building a munitions handling wharf that handles all of the maintenance for the entire Pacific fleet inventory of ballistic missile submarines. This project has substantial visibility at the ESA level and supports an international mission the Navy performs. The Navy is preparing an Environmental Impact Statement, which will result in a record of decision signed by the Principal Deputy Assistant Secretary of the Navy. The Navy is committed to the stewardship of the environment and is looking to the panel to sort through the issues on this particular topic.

Discussion

A panelist asked about the schedule for the Navy's wharf project. Capt. Rios indicated that the Navy is proceeding with this munitions wharf to comply with Strategic Arms Treaty requirements and that the wharf is to be constructed and operational by the end of 2016. The wharf would have a short trial before being put to use. Construction needs to start by next summer (2012), which means the Navy has to get through the ESA consultation and the EIS and a number of other regulatory requirements prior to beginning construction.

3.0   CONFERENCE OVERVIEW AND PANELIST INTRODUCTIONS

Handouts: Agenda, Meeting Norms, Agreed-upon Set of Questions, List of Panelists, CVs, U.S. Navy and USFWS proposals to modify current injury criteria (Attachment 1)

Lyn Wiltse reviewed the agenda and ground rules for the conference. **Cindi Kunz** and **Emily Teachout** reviewed packet materials and meeting logistics.

Brief Panelist Introductions: Each panelist stated his background and expertise:

Dr. Finneran – Research scientist at Navy SPAWAR. He has expertise in bioacoustics and hearing abilities of marine mammals and fish, and he has helped the Navy develop acoustic impact criteria for these species groups.

Dr. Houser – Director of biological research at the National Marine Mammal Foundation. He has expertise in biology and marine mammal physiology and hearing, and he works with the Navy on acoustic impact issues related to NEPA.

Mr. Johnson – National Coordinator for NMFS Section 7 Consultation. He has expertise in risk assessment for threatened and endangered species related to Navy activities, particularly acoustic criteria.

Dr. Peery – Assistant Professor at University of Wisconsin, Madison. He has worked with marbled murrelets for 12 years and has expertise on demography, genetics, and at-sea studies of movement patterns and foraging behavior.

Ms. Buonantony – Marine Resources Specialist, NAVFAC – Atlantic. She has a background as a sea turtle biologist, and was the Navy's lead biologist on the Test Pile Program. She is the

marine mammal lead for the munitions wharf project and also worked on the acoustic sections for fish, marine mammals, and birds.

Dr. Dooling – Professor at University of Maryland. He is a specialist in avian hearing as related to noise exposure.

Mr. Reyff – Acoustician, Ilingworth and Rodkin. He works on measuring sound and most recently measuring underwater sound from pile driving; participated in the fisheries hydroacoustics working group (FHWG).

Dr. Slabbekoorn – Leiden University Institute of Biology. He is a behavioral biologist who has worked on auditory perception and communication in birds; also is working on underwater acoustics and noise impact on fish behavior.

Mr. Slater – Engineering and underwater acoustics specialist with SAIC, Poulsbo, WA. He designs and operates underwater and airborne measurement systems, and conducts underwater noise monitoring, data processing, and analysis for pile driving noise and other noise sources.

Dr. Stadler – Marine Habitat Coordinator, NMFS marine fish biologist. He is the pile driving lead for NMFS Northwest Region and participated in the FHWG.

Ms. Teachout – USFWS WFWO Biologist. She is the lead for murrelets as related to Section 7 consultation and is the lead for assessing the effects of underwater sound.

Panel Support

Ms. Kunz – Lead biologist for Naval Facility Engineering Command. She is working with USFWS as the lead biologist on this consultation, and was the coordinator for this panel.

Dr. Arthur Popper – Professor at University of Maryland. He was advisor to the Navy; he presented recent results on barotrauma in fishes to the panel and will review panel documents.

Dr. Tannenbaum – Biologist with SAIC, Bothell, WA. She is the author of the marbled murrelet sections in the Navy's EIS and the biological assessment for the munitions wharf project.

4.0 FRAME THE ISSUE: PANELIST PRESENTATIONS OF BACKGROUND INFORMATION FOR EVALUATING INJURIOUS EFFECTS OF UNDERWATER SOUND ON MARBLED MURRELET

EMILY TEACHOUT
IMPULSIVE UNDERWATER SOUND – EVALUATING ITS EFFECT ON THE MARBLED MURRELET

Presentation (Attachment 2):

Ms. Teachout provided an overview of the marbled murrelet including distribution, life history, and current status. Marbled murrelets are not like other sea birds in that they fly up to 60 miles inland to nest in forests on large branches or other platforms. They spend about 80% of their

time at sea. They lay one egg and the nestling is alone while the parents are commuting up to 60 miles every day.

Key Facts about Marbled Murrelets:

- Dive for up to 115 seconds
- Dive to depths up to 90 feet
- Forage from close to shore out to 400 m depths
- Aerial vocalizations at sea
- Frequency range of vocalizations 480 Hz to 11 kHz
- Weight at sea >157 g (range 157 – 269 g)
- Present in Puget Sound year-round

Ms. Teachout showed a map depicting the extent of where marbled murrelets are listed as threatened in the U.S. coast (note: the map depicts 6 zones under the monitoring plan along the Washington, Oregon, and California coasts, including inland waters of Washington). Graphs presented showed decreases in populations at sea for all 6 monitored zones during the period 2001–2010 from an average of 23,673 marbled murrelets in 2002 to 16,700 in 2010. In particular, there have been annual declines in Washington marine waters (Zones 1 and 2) of 7.31%. This equates to a 50% population decline in these zones over the past decade. She emphasized that the USFWS has concerns about these downward trends, given that their productivity is very low, as determined by juvenile-to-adult ratios at sea, and they are not replacing themselves.

Marbled murrelets are currently listed as threatened under the ESA. There are two categories for listing species under the ESA, endangered or threatened, but from an implementation and consultation standpoint there is not much difference. With regard to underwater sound, the USFWS has done a lot of consultations in Puget Sound primarily related to impact pile driving, including bridges, private docks, piers, and ferry terminals. Other consultations have included underwater detonations and some types of sonar. Pile size range includes 12" to 64" diameter piles. Analysis is needed where these impacts overlap with murrelet occurrence. Because underwater sound effects can occur over considerable distances, pile driving projects can end up with very large areas of effect. The USFWS uses at-sea survey data to predict how many murrelets might be in the area, or the probability of exposing those murrelets to project-generated sounds.

Ms. Teachout explained that projects where fish kills were being noted during pile driving brought the problem of underwater sound effects to the agencies' attention. She showed slides depicting bruising, damaged eyes, internal hemorrhaging, and burst swim bladders. The Fisheries Hydroacoustic Working Group (FHWG) was formed to recommend interim thresholds for fish similar to what this panel is considering for marbled murrelets, but they had the advantage of several years of discussion before coming together to develop a proposal for decision-makers. The FHWG (2008) recommended interim criteria that are currently used for fish consultations on the west coast.

A literature review focusing on the effects of underwater sound on birds revealed very little information, most of which involved observations of behavioral responses. Yelverton et al.

(1973) tested the underwater effects of explosives on ducks and various mammals; these rapid changes in sound pressure level caused internal hemorrhaging and mortality. The mallard ducks used in these experiments are much larger than murrelets (weight of ducks reported in Yelverton tests: 1,190 gm vs. weight range of murrelets at sea 157–269 gm). Yelverton et al. defined the onset of injury differently from the USFWS's definition in the endangered species context. Therefore, the USFWS finds it difficult to apply these results to the problem being addressed by the panel.

Monitoring of marbled murrelets during pile driving indicates that birds may come within the range of harmful effects of pile driving activity [Hood Canal Bridge Project monitoring]. The range of effects the USFWS is investigating includes physical injury in the form of sublethal injuries, lethal injuries, and auditory effects, as well as non-physical behavioral effects. Ms. Teachout explained the analysis framework in the context of ESA prohibitions and definitions. The analysis utilizes pathways that can lead to conclusions that animals may be in an injury zone or in a behavioral effects zone (i.e., where physical injury does not occur). The question for this panel is "What is the appropriate criterion for evaluating onset of injury?" There is a continuum of injurious effects ranging from injury through death. The USFWS expects that onset of injury is indicated by loss of inner ear hair cells because these effects are the ones that are brought on with the least amount of sound exposure. Currently there are dual criteria for injury: 206 dB re 1µPa (peak[1]) and 183 dB re 1µPa^2-sec cumulative SEL[2]. Ms. Teachout then discussed the process followed by the USFWS to arrive at a biological opinion, terms and conditions, or (in the case of a jeopardy opinion) reasonable and prudent alternatives to the project.

Ms. Teachout described risk assessment and management, including use of vibratory pile installation as an alternative to impact pile driving, use of bubble curtains, and marbled murrelet monitoring. In summary, she stated that current rates of decline must be arrested for recovery to be possible, the USFWS must address difficult questions conservatively, and the analysis needs to be refined using information contributed by the bioacoustics, fisheries, and marine mammal science communities.

DISCUSSION

Question: What time frame is the 183 dB (re 1µPa^2·sec) cumulative SEL level based on?

Response: Ms. Teachout described that it includes all the strikes in a day. The single strike criterion is 206 dB re 1µPa (peak), and the cumulative exposure criterion is 183 dB re 1µPa^2-sec accumulates across all strikes for a given day. Cumulative exposure resets every day.

Question: Does USFWS consider effective quiet in measuring cumulative exposure?

Response: Yes.

Questions: What time of year will the construction occur? And where is it? Are you avoiding pile driving early in the morning and late in the evening?

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[1] Peak = Peak sound pressure level is the instantaneous maximum overpressure or underpressure observed during an event.
[2] SEL = Sound exposure level (SEL) is the time-integrated sound pressure squared, expressed in dB re 1µPa^2-sec.

Response: Ms. Teachout and Ms. Buonantony indicated that pile driving projects may occur year round throughout the Puget Sound and the outer coast. Pile driving for the Navy munitions wharf project is scheduled from July 15 to February 16, which is the in-water work window established in Hood Canal, Washington, to protect salmonids. The areas of effect are about 300–400 meters. This consultation will apply more broadly than for this wharf project. The Navy estimated 200–400 days of pile driving during daylight hours; pile driving will not start until 2 hours after sunrise and will cease 2 hours before sunset during breeding season (July – September 15) to avoid murrelet foraging times.

Question: In calculating the SEL, does it include sound exposure during dive times only or sound exposure while a bird is present in the area?

Response: Ms. Teachout explained that the USFWS definition of the area of effect considers exposure during the entire time the bird is present in the area.

Question: Can you provide clarification about the relationship between the definition of harm and the actual threshold levels selected, which appear to be a much lower level of effect? Is the definition getting more at actually killing or injuring?

Response: Ms. Teachout explained that the first question will be addressed in subsequent presentation. The current position of the USFWS is that 183 dB re $1\mu Pa^2$-sec cumulative SEL is where there may be inner ear hair cell damage. USFWS considers that injury.

Question: For informational purposes is there any consideration for in-air noise exposure?

Response: Ms. Teachout explained that the USFWS is looking at this separately, and has an existing analytical approach that is currently being revisited.

JAMES REYFF
HYDROACOUSTICS AS IT RELATES TO PILE DRIVING

Presentation (Attachment 3)

Mr. Reyff reviewed basic underwater acoustic principles. He indicated decibels are the convenient way to measure sounds and showed the mathematics behind calculating decibels from sound pressure levels in air and underwater. There is a 26 dB difference between airborne and underwater sound levels because sounds are referenced to different pressure levels in the two media. He showed typical underwater sound levels and indicated that because of the density of water, sound travels 4.5 times faster than in air and has longer wave lengths. Sound does not easily propagate from air into water due to large impedance differences between air and water.

Three basic types of sounds are encountered in his work: continuous sound, explosive sound, and pile driving impulse sound. Explosive sound has very high overpressure, high amplitude, and very short duration (in the example shown about 0.002 sec.). Typical pile driving strike-type sound shows pressure fluctuations above and below the static pressure of zero over a very short time (in the example shown, about one eighth of a second).

Pile driving sound descriptors often include Peak (instantaneous, absolute maximum over or underpressure), RMS (root mean square of pressures over pulse duration or some fixed time), and SEL (summation of energy over a single pulse or multiple events over variable periods of time). RMS over the effective part of the sound (for example, defined as the area between where 5 to 95 percent of the energy accumulates) has been the traditional descriptor. SEL is a convenient descriptor because it can be used to calculate the accumulation of sound for an event such as a single pulse, a day, or other metric. SEL has been applied to the effects of pile driving sounds on fish, based on Hastings and Popper (2005) because their research indicates that it is best correlated with injuries to fish. Mr. Reyff then showed graphics typical of pile driving sound reports, showing the waveform indicating peak pressure and the RMS time window, the frequency spectra, and the temporal accumulation of sound energy (SEL). Another graphic was shown depicting how individual pile strikes (showing measured peak, RMS, and single-strike SEL values) can accumulate into a sound exposure level or SEL for an entire day of pile driving. To avoid contamination by other sounds during an entire day of pile driving, cumulative SEL can be estimated from single-strike SEL + 10 log (number of pike strikes). Mr. Reyff's final slide showed the frequency spectra of sound pressure of an impact driven pile, which indicates that the peak is around 500 Hz for a 36" hollow steel pile.

DISCUSSION

Question: Why are there noise level differences between piles?

Response: Mr. Reyff explained that multiple factors contribute to noise produced during pile driving, including bottom substrate type, positioning of the hydrophone, and how hard the pile is struck could account for differences. However, levels have been shown to vary a bit through each pile driving event.

DR. ROBERT DOOLING
BACKGROUND INFORMATION ON AVIAN HEARING

Presentation (Attachment 4)

Dr. Dooling presented slides comparing avian hearing with mammalian hearing. High frequency hearing in birds is relatively limited by having a single bone in the middle ear, and low frequency hearing is limited by having a small eardrum and small middle ear cavities. Behavioral audiograms show 3 kHz peak hearing in almost all birds. In a series of audiograms, he showed the relationships between best frequency and the size of basilar papilla and body weight, from which he would feel comfortable predicting the marbled murrelet's audiogram. He summarized the relation among noise levels, distance from source, and potential behavioral and physiological effects on birds along a continuum ranging from hearing damage and permanent threshold shift (PTS) closest to an intense noise source, to temporary threshold shift (TTS) (which is recoverable) farther from the source, to places where noise levels do not cause threshold shift or hearing damage. Dr. Dooling described the process of threshold shift using data for budgerigars (budgies) exposed to 72 hours of continuous noise to address this point. Growth of the threshold shift reaches asymptote between 12 and 24 hours regardless of exposure level. The amount of threshold shift at asymptote is dependent on level. When the noise is turned off gradual recovery

occurs. If the amplitude is high enough some of the shift is permanent and is correlated with damage in the inner ear.

Dr. Dooling reviewed the results of the Ryals et al. (1999) study of noise exposure on four bird species and added data from two more bird species. He noted that the Ryals et al. (1999) results were interpreted differently by the USFWS (Teachout 2011) and the Navy (Navy 2011) in their white papers on marbled murrelets and noise. There are major differences (30 or 40 dB) in the amount of threshold shift and hair cell loss among some of the bird species that were exposed to the same pure tone or bandpass noise levels, and he concluded that we cannot predict which species is going to be more susceptible to damaging effects of noise exposure from the audiograms. The only study of impulsive sound that Dr. Dooling found was Hashino et al. (1988), which reported recovery following exposure to pistol shots. All of these studies evaluated airborne noise effects.

With regard to possible mechanisms that may account for the differences between the species, Dr. Dooling indicated that some bird species may control air pressure in the middle ear; exposure to noise is followed by a decrease in the intracranial air pressure and middle ear pressure, making the animal less sensitive to noise. This sort of protective mechanism may be relevant underwater. Dr. Dooling suggested that the human audiogram in-air and underwater may be a reasonable model for bird audiograms. Low frequency thresholds stay about the same whereas some high frequency sensitivity is lost underwater.

Summary Points:

- The audiogram of the marbled murrelet in air is easily estimated from existing data on other birds.
- Sensitivity to higher frequencies in the audiogram is likely reduced in water.
- Birds are generally resistant to TTS/PTS compared to mammals.
- There are huge species differences in TTS/PTS in birds that were not due to variations in experimental conditions. At present we cannot account for the differences among species. This creates a problem in trying to pick a surrogate species for the marbled murrelet.
- Some of the resistance to TTS/PTS and the species variability is possibly due to regulation of air pressure in the middle ear.

Dr. Dooling shared two recent papers (Kujawa and Liberman 2009; Lin et al. 2011) that are relevant to the issue of the onset of auditory injury. Conventionally, TTS means there is no hair cell damage. These studies involving mouse and guinea pig subjects are problematical because they created a 40–50 dB TTS measured 24 hours post-exposure with no hair cell loss, normal auditory-evoked brainstem response (ABR) thresholds, and normal otoacoustic emission; however, there was a 25 to 50 percent loss of auditory nerve fibers.

DISCUSSION

Question: The experiments all centered on the portion of the audiogram where the species are most sensitive. What happens when you expose them to noise above or below their (best) sensitivity area; in other words, is there frequency dependence for the noise level?

Response: Dr. Dooling indicated that the greatest loss is at particular frequencies. Birds are more narrowly tuned than mammals, so that the spread to high frequency is less than for mammals.

Questions: Is damage related to sensitivity across the hearing range? If you exposed at an equal sensation level across the audiogram, would you get equal damage in different places?

Response: Dr. Dooling did not think this has been studied so he could not answer the question.

Question: Are any of the studies related to impulses?

Response: Dr. Dooling could recall only one study involving pistol shots (Hashino et al. 1988), which represent broadband explosive noise.

Comment: Recovery times are important because it is important how long the birds cannot hear after exposure. Diminished hearing could interfere with individual survival and/or care of offspring, potentially removing individuals from the population.

Response: Dr. Dooling indicated that diminished hearing depends on the level of exposure and species differences. The papers on nerve damage raise issues of anatomical problems down the road.

Question: When a bird dives does the ear stay air-filled?

Panel Discussion: Diving birds may trap air bubbles on both sides of the tympanum by various means such as venous cavities that swell and close the external auditory meatus, feathers that close off the ears, or other adaptations. Panelists could not answer the question and requested that Dr. Peery research the topic in the literature and report his findings. Panelists were uncertain how birds hear underwater — whether tympanal mechanisms are at work or bone conduction such as is seen in phocid seals.

Dr. Dooling noted that the avian respiratory system is a connected system, and different from mammals; he indicated that the panel can treat the whole bird as an airbag. For example, one can vent an avian skull and see air pressure changes in the middle ear.

EMILY TEACHOUT
CURRENT USFWS INJURY CRITERIA

Presentation (Attachment 5)

Ms. Teachout indicated that Section 7 of the ESA requires that when the science is unknown, consultation should err on the side of the species. When the USFWS has little data they cast a wider net to include the best available information including grey literature and anecdotal data. They look to similar situations and make inferences with care. The USFWS rationale paper (Teachout 2011, see Attachment 1) explains how they define injury. She showed slides from Ryals et al. (1999) for some zebra finches exposed to bandpass noise in which extensive hair cell loss was visible post-exposure but hair cells appeared normal in other zebra finches 90 days after exposure. Hair cell loss is associated with different levels of threshold shift. Of the range of

injuries it is auditory injuries that occur at the least sound exposure level. When the USFWS does the sound analysis for consultations, they use the SEL value to determine the area in which birds would be injured, without distinguishing different levels of severity due to distance from the pile.

Ms. Teachout indicated that it is not important for the purposes of the USFWS analysis to distinguish between PTS or TTS because their interpretation of the existing information (including Ryals et al. 1999) was that it indicated that hair cell loss might occur at all levels of threshold shift. Given that there are no data on hair cell loss and TS due to impulsive sounds on birds, the USFWS turned to pinnipeds as the best surrogate for seabirds because they are adapted to living both in and out of water, have some overlap in hearing ranges, and are expected to have similarities in auditory mechanisms (Ketten 2008). Kastak et al. (2005) reported a significant relationship between cumulative sound exposure level (SEL), where sound was an octave-band noise, and the amount of threshold shift in three pinniped species. The USFWS currently uses the onset of TTS for the most sensitive species in these experiments (183 dB re $1\mu Pa^2$-sec cumulative SEL, harbor seal) as its interim criterion, recognizing that the sound types and durations were different from pile driving sound. They also use 206 dB re 1µPa (peak) for a single strike in order to capture brief peak pressures that may be damaging. She noted that the amount of recovery between strikes is not known, and that summing exposures through the day is a conservative approach. This approach is similar to that which is used for fishes and marine mammals exposed to impulsive sound.

Summary Points:

- There is a dearth of information on sound impacts on seabirds.
- We must give benefit of the doubt to the species, apply best available information, and make legally defensible decisions.
- Given the declining status of murrelets it is important to avoid reductions in productivity (i.e., injury).
- The USFWS cannot afford type II errors (i.e., concluding there is no effect when there really is an effect).
- Approach is not perfect; but is considered interim.
- The USFWS looks forward to input that strengthens their analysis.

DISCUSSION

Panelists requested that Ms. Teachout clarify the statement "Auditory injuries appear to occur with least sound pressure exposure" in her presentation slide. She responded that she is looking for the lowest sound exposure that will cause injury. The panel questioned whether we can talk about hair cell loss with TTS and reviewed the results of Ryals et al. (1999). Panelists noted that the magnitude of the shifts (40 dB or more) is much greater than what the marine mammal community uses (3 to 6 dB) to determine TTS onsets. Dr. Dooling stated that the bird literature doesn't provide any examples of much lower-magnitude threshold shifts because the focus of research is on hair cell regeneration where the objective is to cause more damage/threshold shift. He indicated that some of the discrepancies in interpretation of this study are due to the fact that birds regenerate hair cells. Ms. Buonantony pointed out that injury to zebra finch hair cells in the bandpass experiments was associated with a 10 dB permanent shift; thus, it was PTS. Dr.

Slabbekoorn pointed out that hair cell loss is not the whole story: chemical changes may lead to immediate loss of sensitivity, and may have quicker turnaround time, but there are likely also lasting effects like the degeneration of nerves. There are temporal shifts that are not related to hair cell loss. Dr. Dooling indicated that there is a continuum of changes that happen in hair cells that can cause the threshold to be elevated temporarily, such as fatigue that would not be considered injury. Mr. Reyff noted that the 183 dB re $1\mu Pa^2$-sec cumulative SEL level in the harbor seal was linked to an octave-band noise centered at 2.5 kHz, and asked how that affects the hearing for the frequency band most affected by pile driving sound, i.e., where dominant frequency is about 500 Hz? Ms. Teachout responded that the USFWS recognizes that the sounds used in the experiments may not have the same frequencies that occur in pile driving.

DANIELLE BUONANTONY
NAVY'S PROPOSED ALTERNATIVE SEL CRITERION

Presentation (Attachment 6)

Ms. Buonantony reviewed the Navy's consultation with the USFWS on the pile driving project previously mentioned by Capt. Rios and a smaller test pile project as background for the Navy's proposed alternative SEL injury criterion. During the Test Pile Program consultation, the Navy submitted a white paper in response to the USFWS' proposal to revise the injury criterion from 180 dB re $1\mu Pa$ (peak) to 183 dB re $1\mu Pa^2$-sec cumulative SEL. The Navy's white paper questioned the use of harbor seals as a suitable proxy species for marbled murrelets because their best sensitivity bands do not overlap much. They also questioned the use of TTS data to set the onset of injury; to be consistent with the criteria for marine mammals it should be set at the PTS level. In the Navy's alternative criterion proposal paper, the Navy recommended setting the injury threshold based on non-auditory physiological injury (i.e., barotrauma), which studies have shown to be correlated to the mass of the animal and would allow us to look at a wider range of data from other species. The recommended value was 210 dB re $1\mu Pa^2$-sec cumulative SEL.

In the Navy's alternative criterion paper, the Navy considered data related to both auditory and non-auditory injury for establishing an appropriate injury criterion. However, the Navy did not consider TTS to be injurious in this evaluation. The Navy determined the most relevant data for establishing the non-auditory injury metric to be from studies involving fish. The fish in these studies ranged in size from 0.02 gram to 744 grams (most marbled murrelets are less than 200 grams). However, most of the data from these studies were not reported in the SEL metric. Cumulative SEL was calculated for these studies by Hastings and Popper (2005) and Hastings (2007) for the FHWG, and Carlson et al. (2007) combined the information in a regression that would predict, based on mass (up to 200 g), what the cumulative SEL would be at the onset of non-auditory tissue damage. The Navy used the weight of a juvenile fledgling murrelet (124 g) to calculate a threshold of 210 dB re $1\mu Pa^2$-sec cumulative SEL to apply to both non-auditory and auditory injury until more data became available. The Navy considered using duck data from Yelverton et al. (1973) instead of the fish data, but since non-auditory injury has been shown to correlate with the mass of the animal, the Navy concluded that the fish data were more appropriate because mallard ducks are more than four times larger than a marbled murrelet. Ms. Buonantony noted that injuries and mortality associated with explosive sound were predicted to be more severe than with pile driving because the rise time is much faster with explosives. Thus the 210 dB re $1\mu Pa^2$-sec cumulative SEL is likely to be conservative.

The Navy considered establishing an auditory injury criterion but did not feel that there was enough data to select a reasonable proxy species. The Navy recommended that the non-auditory criterion be generally applied to both types of injury (auditory and non-auditory) until more empirical data on birds became available. However, the Navy made the caveat that if the USFWS was going to move forward with using the Kastak et al. 2005 data to set an auditory metric, then injury should be set at the level of the onset of PTS. Based on this recommendation, the Navy indicated that the information in Southall et al. (2007) could be used to predict the onset of PTS from the TTS criterion level (183 dB re $1\mu Pa^2$-sec cumulative SEL) established by the Kastak et al. (2005) data.

Ms. Buonantony noted that depending on the type of acoustic signal (continuous or impulsive), Southall et al. (2007) indicated two offset values could be applied to the TTS criterion value to predict the threshold level for the onset of PTS. Southall et al. (2007) state that the offset between TTS and PTS is approximately 20 dB for a continuous sound and is approximately 15 dB for an impulsive sound. While a pile driving signal is an impulsive source, the source signal of the Kastak et al. (2005) data, from which the TTS criterion value was established, is a continuous source. As a result, Ms. Buonantony noted that further consideration may be necessary to determine the most appropriate offset value to use. In the interim, however, the Navy considered two options for calculating the onset of PTS for an impulsive sound (i.e., impact pile driving) from the 183 dB re $1\mu Pa^2$-sec cumulative SEL onset for TTS for continuous sound (Kastak et al. 2005): (1) use 203 dB re $1\mu Pa^2$-sec cumulative SEL based on the 20 dB offset between TTS and PTS for continuous noise (Southall et al. 2007), or (2) use 198 dB re $1\mu Pa^2$-sec cumulative SEL based on a 15 dB offset from TTS to PTS for impulsive noise (Southall et al. 2007). This would result in a criterion value for the onset of auditory injury between 198 and 203 dB re $1\mu Pa^2$-sec cumulative SEL based on the TTS–PTS offset information reported in Southall et al. 2007.

DISCUSSION

Panelists discussed whether the fish skeletal system is less protective of gas-filled organs than that of birds. Injuries to organs in fish other than the swim bladder may occur because the swim bladder expands and contracts when it is hit by a pressure wave. Would the bird's lungs also put more pressure on the other organs and result in other damage? Yelverton et al. (1973) found most injury in birds occurred in the lungs. Panelists speculated on physical and mechanical reasons why a bird might fare better than a fish when exposed to explosive sound, but did not reach a definitive conclusion. The panel decided to contact Dr. Art Popper regarding his studies of noise-related barotrauma in fish.

Panelists also discussed the recommended cumulative SEL criteria in Carlson et al. (2007) for auditory tissue damage, which was not size dependent, and non-auditory tissue damage. The discussion also considered the appropriateness of each of the three pinniped species studied by Kastak et al. (2005) as a proxy for auditory injury in marbled murrelets. Ms. Buonantony noted that the Navy and USFWS are examining the same data but differ on the interpretation.

DR. ARTHUR POPPER
RESEARCH ON BAROTRAUMA IN FISH

Discussion with Dr. Popper

Panelists conferred with Dr. Popper on his latest research on barotrauma in fish, which is expected to be available in the near future. Panelists addressed the following questions:

1. How relevant are SEL measurements for repetitive strike impacts (barotrauma)?"

2. How relevant are they for single strike (e.g., 5 high level sounds vs. 1,000 low-level sounds)?

3. Arguments for extrapolating from fish to birds?

Dr. Popper responded to the first two questions indicating that the trend of his data shows that when cumulative SEL is the same, and where there are large numbers of strikes, the lower number of strikes at a higher single-strike level will give potentially more effect than the larger number of strikes at a slightly lower single-strike SEL. Therefore, the single-strike SEL does have an impact but only when you are accumulating large numbers of strikes. In these experiments he always works toward the same cumulative SEL (213 dB and 216 dB in the experiments he described). Dr. Popper indicated that he monitors 30 different types of effects on the animals: hemorrhage in the swim bladder, bleeding of the anal fin, hemorrhaging of the spleen and others. There were more things that happened to a particular fish at the higher single-strike SEL than at the lower single-strike SEL, given the same cumulative SEL. Therefore, his results for fish tend to disprove the equal energy hypothesis, which states that no matter how you get to the cumulative SEL, the effects will be the same.

With respect to the issue of using peak vs. SEL, peak is not considered a good measure of the amount of damage you will get or the onset of damage because it does not provide the amount of energy in the signal. Peak pressure is also not a good metric for the purposes of the panel because it does not take into account the time that it takes to get from the static pressure to the peak pressure. The value in the single-strike SEL that you use in the calculation for the cumulative SEL is the important value. In response to question 3, Dr. Popper was comfortable extrapolating fish data to birds for barotrauma since air spaces probably behave the same in either taxon. He was not comfortable extrapolating fish data to bird data for hearing given the distinct differences in auditory structures, and does not believe that marine mammal hearing data are relevant to birds. Important points in the fish/bird comparison include how compressible birds' air spaces are during diving, and how their air spaces are damaged by sound. Dr. Popper speculated that if you accept the premise that the larger the animal the less susceptible they are, then using 210 dB re $1\mu Pa^2$-sec cumulative SEL in these birds (implying a marbled murrelet) would be a valid SEL to use. Dr. Slabbakoorn asked for clarification regarding the emphasis Dr. Popper placed on single-strike SEL levels in contrast to his overall advice based on cumulative SEL. Dr. Popper replied that cumulative SEL is the important factor; a higher single-strike level will result in a little more damage. Dr. Popper did not recall the single-strike SEL level; after some discussion it appears that it was 183 dB re $1\mu Pa^2$-sec SEL.

Following Dr. Popper's presentation, panelists discussed the implications of his findings. Mr. Reyff suggested that if the highest single-strike level is 183 dB re $1\mu Pa^2$-sec SEL (and Dr.

Popper's experiments were based on real-world pile driving), then we need to be looking at the auditory issue.

5.0   REVISED SET OF AGREED-UPON QUESTIONS

Panelists were sent a list of four questions (see Attachment 1) before the conference that were designed to lead the panel's discussion toward formulating a recommendation on interim noise criteria. Panelists addressed the initial set of questions and added a new one. The following is the revised list of questions discussed by the panel with summaries of those discussions.

Question 1 (NEW): **How are we defining "injury"?**

Rationale: The panelists recognized that sound-related injury may take many forms, including barotrauma damage to organs and tissue not involved in hearing (non-auditory injury) and damage to auditory tissue and/or threshold shift (auditory injury). For the purposes of establishing injury-onset criteria for USFWS consultations, panelists recognized the need to define what is meant by "injury." Ms. Teachout emphasized that the USFWS is looking for the type of injury that is caused with the least amount of noise exposure.

The following section summarizes key points of the panel's discussions that occurred through the 3-day conference organized around the framework of the revised Agreed-Upon Questions.

Question 1. **How are we defining "injury"?**

With respect to auditory injury, the discussion focused on whether (and how) noise levels associated with threshold shift (TS) (temporary or permanent) should be used to develop criteria, or alternatively whether noise levels associated with tissue damage such as cochlear hair cell loss should be used. Recommendations by Carlson et al. (2007) for interim sound exposure criteria for fish were reviewed. Criteria for fish cover three different effects: (1) Hearing loss due to TTS; (2) Damage to auditory tissues (generally sensory hair cells of the ear); and (3) Damage to non-auditory tissues. Panelists reviewed a number of additional relevant studies on a variety of species including work on underwater hearing and TTS in pinnipeds (Mulsow et al. 2010; Kastak and Schusterman 1999; Kastak et al. 2005, 2007), work on TS and auditory tissue damage in birds (Ryals et al. 1999; Hashino et al. 1988), and cochlear nerve degeneration in guinea pigs and mice (Kujawa and Liberman 2009; Lin et al. 2011). The literature review showed that band-limited continuous noise resulting in 40–50 dB of TS was associated with hair cell loss in budgies (Ryals et al. 1999). With one exception (Hashino et al. 1988), all these experiments utilized continuous sound, which the panelists concluded would have to be converted to impulsive sound levels in order to be useful for pile driving noise.

The panelists made the following points: TTS is generally not considered a form of injury in the sense of long-lasting damage to auditory tissue. The issue is somewhat confounded by the capacity for regrowth of hair cells in birds, a characteristic that is not shared by mammals. Panelists who work with bird species and marine mammal species generally agreed on this point. However, the transition from TTS to PTS is a continuum and the "border" between the two is not clear and would be subject to individual variability and inter-species differences. We need to keep in mind that we ignore huge variation among species when only relying on budgie data.

Studies of birds have had vastly different levels of threshold shift: up to 40–50 dB measured 24 hours post-exposure were reported compared to much lower levels of TTS reported in the Kastak pinniped studies. The panel decided that injury in marbled murrelets would be defined as hair cell damage due to impulsive acoustic overexposure. Mr. Johnson clarified that this decision to associate injury with hair cell loss is without regard to its consequences for hearing sensitivity.

The recent evidence of nerve degeneration in the absence of hair cell damage and following complete recovery from TS in small mammals (Kujawa and Liberman 2009; Lin et al. 2011) aroused concern. Panelists noted this occurred at 40 dB TS, which was the same TS detected in the budgies that experienced hair cell loss. Therefore, it may not make a difference. TS may be useful as a proxy for both nerve cell and hair cell damage. A better understanding of how nerve cell damage correlates to TS and to hair cell loss would help (Nordman et al. 2000). These papers point to another biological process that begins at the lowest levels of TTS and perhaps this is where nerve degeneration begins or where cells start to swell. The nerve damage papers did not add greatly to the present task of identifying onset of injury, but the phenomenon may have potential as an injury metric in the future, if more data become available. Ms. Teachout noted that this phenomenon may be incorporated into future injury analyses.

The discussion also considered non-auditory vs. auditory injury. The panelists considered whether auditory injury occurs before (i.e., at lower sound levels than) non-auditory injury. If this holds true for fish (for which there are more data) would it also hold true for birds? The consensus was that both types of data (evidence for auditory injury [references cited above] and evidence for non-auditory injury [such as Yelverton et al. 1973, 1975]) should be evaluated to determine whether non-auditory injury occurs at a lower level in some organisms. If there are lower values associated with barotrauma we would consider using these lower values as criteria for onset of injury.

Question 2. **In the absence of research on the effects of pile driving sounds on birds, what would be considered the most appropriate surrogate species for estimating these effects to diving seabirds?**

The panelists initially approached this question by examining adaptations of diving birds to hearing underwater, compensating for intracranial and air sac pressure changes during dives, and mechanisms for attenuating overexposure.

Dr. Peery presented information on the external auditory canal of diving birds. Penguins have venous membrane in the middle ear that helps to regulate pressure and which expands when they dive. Some diving birds have feathers over the ear that provide a watertight seal; also there is a flap of skin around the backside of the ear that can close off the outer part of the ear. Seabirds might exhale when diving. The discussion continued on the system of air sacs in diving birds and their functions in responding to sound pressure. The bird song literature provides measurements of air pressure in various air sacs: Air pressure in different air sacs can have different fluctuation patterns. A review of the limited available information on hearing underwater and mechanisms birds may use to compensate for pressure changes while diving was not conclusive. However, panelists speculated that mechanical impacts on organs might not be as severe in birds as other taxa, because of the interconnection of air sacs, their distribution throughout the body cavity, and the assumed resistance to pressure changes through inter-air sac

air flow. Thus, compression on internal organs in birds due to air pressure changes may not be as severe as in mammals (Kooyman 1989).

Mr. Johnson noted that under the ESA, the record needs to show that we looked at all lines of evidence. Therefore, panelists attempted to compare compensatory mechanisms in birds with other species such as fish, for which data are available. In particular, panelists thought that the air sac system in birds is more dispersed and interconnected compared to swim bladders in fish. Panelists thought they could use the Yelverton et al. (1973) data on effects of explosives on fish of comparable size (to murrelets) as surrogate species, and that these results would be conservative given the likelihood that birds' air spaces may be better protected. Mammals of similar weight in another Yelverton study (Yelverton et al. 1975) appeared to be more sensitive than birds to barotrauma involving lungs, eyeballs, and other organs). (It was noted that the Yelverton work defined injury differently in the two studies: for the fish the no-injury curve was estimated as 0,20 of the 50 percent mortality curve, whereas the study did more detailed necropsies of mammals to detect injury.) The panel concluded that the mallard duck data seem to fit into the continuum of fish data related to size, and also noted that although the ducks were heavier than murrelets, they are not orders of magnitude apart. Therefore, for non-auditory injury, the consensus was that fish (using Yelverton et al. 1973 data) would be the best surrogate, as the effect of acoustic exposure is size-related, with supporting data from mallard ducks and terrestrial mammals (Yelverton et al. 1975 data).

With respect to auditory injury, Dr. Dooling focused attention on the Hashino (1988) paper. He believes hair cell loss was likely associated with the energy in the pistol shot in this experiment, (although the authors did not examine hair cell loss), and noted that the hearing loss would occur where the exposure frequency is, or sometimes there would be a shift to slightly higher frequencies. Dr. Dooling noted that we cannot say TTS is always characterized by hair cell loss and that birds complicate this as they can regenerate hair cells (something mammals cannot do). If there is residual permanent loss, then we have moved from TTS to PTS. He indicated that the boundary is not precise: at the point where TTS is moving into PTS the level is high enough where sometimes an investigation may indicate some damage and sometimes not. Additional discussion ensued over the relationship between TS (temporary and permanent) and hair cell loss. Panelists noted that the discussion involves cases where exposure levels are high enough to move into PTS, whereas in the marine mammal world reported TTS is very small. With the bird studies we are looking for the "sweet spot" where TTS moves into PTS and anatomically we see hair cell loss vs. no hair cell loss. Ms. Teachout confirmed that hair cell loss followed by subsequent regeneration would still be treated as injury. The panel identified a practical issue in that the only paper that we have for impulsive noise effects in birds (Hashino et al. 1998) reports results in terms of TS, not hair cell loss. The panel agreed that since budgies are the only species for which we have hair cell loss data sets (Ryals et al. 1999), they appear to be the appropriate surrogate species for auditory injury with support from terrestrial (Dooling 1980; Saunders and Dooling 1974) and marine mammal data (Kastak et al. 2005) to make the conversion from airborne sound to underwater sound.

Question 3. **In the absence of research on the effects of pile driving sounds on birds, what could be considered the most appropriate surrogate sound sources for estimating these effects to diving seabirds?**

The panelists agreed that any impulsive sound source is better than continuous sound sources, but most available data are for continuous sound. The panel found several examples of impulsive sound effects which are explosive: the pistol shot data for budgies (Hashino et al. 1988), studies of fish subjected to underwater detonations (Govoni et al. 2003, 2008), and the Yelverton et al. (1973, 1975) experiments with explosives. They represent broadband impulsive sound but there are significant differences between explosive and pile driving sound. With pile driving sound energy is concentrated mostly at lower frequencies. The rise time of explosive sound is much faster. The panel considered differences in rise time on the likely response of an organism that is exposed to gun shot in air vs. pile driving under water. The longer the rise time the higher the peak level before you achieve injury (Hubbs and Rechnitzer 1952). The panel concluded that explosive sound would be a conservative surrogate for pile driving sound or continuous sound because the rise time for explosive sound is faster and therefore should be more damaging. <u>For non-auditory injury, panelists agreed to use explosive sound data (Yelverton et al. 1975; Govoni et al. 2003, 2008) and some continuous sound data (Popper et al. 2007).</u>

The panel addressed the problem of converting from an explosive sound in the air (the budgie/ pistol shot experiments) to a pile strike in the water. The panelists agreed that simply adding 62 dB when going from air to underwater (to account for the differences in reference pressure and impedance) is not sufficient. The conversion is more difficult because wavelengths, rise time, and sound speed are different underwater. The panel discussed several approaches to the problem, with a preference for sticking with bird data as much as it is available. Dr. Finneran suggested that the panel identify a dynamic range (defined here as the difference between the hearing threshold and onset of hair cell loss) for the birds in the hair cell loss experiments with the idea that dynamic range may be similar in-air and underwater. Panelists, however, were unsure of applying this approach to birds because of inadequate information on the dynamic range of avian hearing underwater. No data sources were found that describe underwater avian hearing. Also, Dr. Dooling cautioned that it may not be reasonable to assume that avian species would have the same dynamic range in air and underwater, citing studies involving human subjects (reviewed by Hollien 2006). The panel decided not to pursue dynamic range using the in-air bird data for calculating the transition from air to water thresholds. Instead, the panel adopted an approach that used measured data on underwater and airborne hearing from California sea lions as a proxy for underwater hearing in birds. Of the available data on pinnipeds (including California sea lion, elephant seal, and harbor seal), the sea lions were judged to be the best proxy species because they are better adapted for hearing in air than the other pinnipeds, but also submerge, comparable to the marbled murrelet.

For auditory injury, data on continuous sounds modified for the more severe effects of impulsive sounds were used. The rationale for this decision was that since impulsive sounds are more likely to cause injury than continuous sounds, but most of the available data are for continuous sounds, injury levels for continuous sounds should be reduced.

Question 4. **What is the best metric(s) for estimating onset of injury to marbled murrelets from repetitive, impulsive sounds (Cumulative Sound Exposure Level [SEL])?**

Much of the literature reviewed by the panel reported sound levels using peak pressure, RMS pressure, or, in the case of underwater explosions, impulse energy (psi•msec). However, peak

pressure or RMS, alone, are not well correlated with noise-induced injury (Hubbs and Rechnitzer 1952; Yelverton et al. 1975; Hastings and Popper 2005). As a result, Hastings and Popper (2005) proposed using sound exposure level (SEL) as the relevant metric for assessing the effects to fishes from pile driving. Using the impulse data provided in Yelverton et al. (1975), Hastings and Popper (2005) estimated the SEL from underwater blasts.

The panelists discussed how they might convert the Yelverton et al. (1973) impulse data to SEL for mammals, and discussed concerns over using SEL for non-auditory injury (with peak as an alternative). Dr. Finneran and Dr. Slabbekoorn expressed concerns that cumulative SEL is being equated to the same effect from a single high-level sound that causes direct physical damage to the tissues. Dr. Stadler explained that one of the reasons the FHWG used SEL was because it would include the energy involved in underpressure in pile driving, and pile driving was the focus of this work. Underwater blast wave forms likely do not have a substantial underpressure. In order to extrapolate from the Yelverton et al. (1973) data to pile driving, the working group felt that they had to incorporate the underpressure, and SEL was the only way to do it. Mr. Reyff explained that the FHWG applied a dual criterion using a peak threshold to protect against that single high level strike. Ms. Buonantony added that Carlson et al. (2007) stated that the literature on non-auditory tissue damage in fish with swim bladders does not correlate with peak sound pressure. The panel agreed that you must meet the minimum work requirement to cause damage, and that SEL is the relevant metric.

The panelists discussed the use of cumulative SEL (the SEL summed across all exposures) by marine mammal and fish acoustics communities because SEL correlates better (than other metrics) with hearing damage. Carlson et al. (2007) proposed using cumulative SEL for injury to non-auditory tissues as well. The panelists found no reason to suspect that cumulative SEL would not be appropriate for marine birds. The panelists discussed whether the peak data from the 1989 budgie/gunshot paper could be translated to SEL. Mr. Slater said the math would be easy if the source and duration and the wave forms are known. However, since the waveform for the gunshots in this study are not available, the SEL cannot be calculated. The physiological interpretation of responses in experimental animals would be difficult. SEL lacks a time component, so we need a cut-off for SEL duration and also the level where there is effective quiet. Mr. Reyff explained that when he does assessments for pile driving and fish, he finds that a per-strike SEL level of 150 dB re $1\mu Pa^2$-sec sometimes limits the area of take. Some panelists were concerned that use of SEL may overlook the contribution of rapid rise time to injury but data are lacking on this point. The FHWG members agreed that there are issues with SEL but it was the best metric to use at this point. Panelists discussed using a peak threshold value as well as cumulative SEL to protect against aberrantly high single strikes, which is what the FHWG did with their dual criteria (FHWG 2008). However, SEL levels invariably trump peak pressure for repetitive pile driving, so for the purposes of this effort, the panelists therefore agreed to use SEL for both non-auditory and auditory impacts.

Question 5. **What is the best value (X dB, X psi, etc.) for estimating onset of injury to marbled murrelets from repetitive, impulsive sounds?**

Based on discussions of the various forms of injury under the previous question, the panelists decided to try to identify sound level criteria for non-auditory and auditory injury separately,

The panelists developed the necessary conversions from existing data sources to arrive at criteria for estimating the onset of injury for marbled murrelets exposed to pile driving sound underwater.

The panelists estimated that the auditory injury threshold would be 202 dB re $1\mu Pa^2$-sec cumulative SEL and the non-auditory injury threshold would be 208 dB re $1\mu Pa^2$-sec cumulative SEL through the process described in Section 6.0.

6.0 RATIONALE FOR RECOMMENDED THRESHOLD FOR AUDITORY IMPACTS

The auditory group (Mr. Slater, Dr. Finneran, Ms. Teachout, Dr. Dooling, Dr. Slabbekoorn) focused on the following questions:

1. Are we certain that impulsive sound has a lower injury threshold than continuous sound? Dr. Finneran indicated that impulsive sound is more hazardous. However, remaining questions included: What about long-term exposures? U-shaped damage curve? How long does it have to be before it is less hazardous than an impulsive?

   a. Do mammal data tell us anything about how to translate damage from impulse noise exposure to damage from continuous noise exposure?

   b. Are there waveform gunshot data that we could use to estimate the SEL from gunshot wave forms?

2. How can we convert airborne data to underwater data?

The following key points and assumptions were applied to this exercise:

- A survey of the literature demonstrates that band-limited, continuous noise resulting in 40 dB of TS correlates with hair cell loss (Saunders and Dooling 1974; Dooling and Saunders 1974; Dooling 1980; Ryals et al. 1999). The time needed to reach an asymptote was 12–24 hours.
- Although no bird data are available, the comparison of impulse and continuous noise exposures shows that impulse noise is more hazardous than continuous sound for equivalent exposure levels (e.g., Hamernick et al. 1993; Buck et al. 1984; Hashino 1988).
- At an equivalent energy level and spectrum, and using the time to reach asymptote, impulse exposure in terrestrial mammals leads to a 20 dB greater permanent TS than continuous noise. Thus, for estimating the onset of injury, the TS level for continuous sound is reduced by 20 dB for impulse exposures.
- The exposure sound pressure level and duration required to induce a 20 dB TS in air was determined using data on budgies taken from Dooling (1980). These values were then used to calculate the SEL_{impact} (i.e., the SEL that would correlate with hair cell loss). The SEL_{impact} was estimated to occur at approximately 135 dB re $20\mu Pa^2$-sec cumulative SEL (in-air reference pressure).
- The California sea lion appears to be the best pinniped surrogate for the marbled murrelet because its in-air hearing is more sensitive than its underwater hearing. Seabirds are

likely to be better adapted to in-air hearing because they spend the majority of their time with ears in air and they are relatively shallow-dive hunters like sea lions, unlike other marine mammals that hear better in water than in air and that are relatively deep-dive hunters (spending more time underwater under visually more challenging conditions).

The following conversions were required for in-air to in-water noise exposures:

- The literature on pinniped hearing suggests that the typical 62 dB air-to-water conversion (consisting of 26 dB difference in reference values + 36 dB impedance) is inadequate (Kastak and Schusterman 1998).
- Using the difference in the in-air and underwater hearing sensitivities of the California sea lion, the 36 dB impedance correction was adjusted to 26 dB in the region of best hearing sensitivity (Mulsow et al. 2011; Mulsow et al. in prep.).

Calculation of the auditory injury threshold uses the impact SEL at which hair cell loss occurred in budgies (135 dB) and adds the correction factors listed above:

- Hearing sensitivity correction factor (26 dB).
- The standard correction factor for different reference pressures used in air-and under water sound (26 dB), computed as $20*\log(1\ \mu Pa/20\ \mu Pa)$.
- Pile strikes typically contain significant sound energy at frequencies below 1 kHz. These frequencies are below the most sensitive frequency range of birds (1 kHz to 5 kHz) and were assumed to contribute less to TS in birds. The panel examined the spectral signatures from a small sample of pile strikes, where the overall spectrum-level sound pressure level was 15 to 25 dB higher than the sound pressure level in the most sensitive hearing range of birds (1kHz to 5kHz) (Reyff, pers. comm.; Slater, pers. comm.). To account for this extraneous sound energy, the panel determined that a spectral correction factor should be added to the SEL threshold, and chose the lower, and more conservative, value of 15 dB.
- The resulting calculation is:

$$\text{Cumulative SEL}_{impact} = (135 + 26 + 26 + 15)\ \text{dB}$$

Cumulative SEL$_{impact}$ = 202 dB re 1μPa^2-sec

7.0   RATIONALE FOR RECOMMENDED THRESHOLD FOR NON-AUDITORY IMPACTS

The non-auditory group (Mr. Reyff, Dr. Stadler, Mr. Johnson, Ms. Buonantony) focused on the following questions:

1. Can we make an amalgam of the data from all the different species in the Yelverton et al. (1973, 1975) studies?

2. What is the relationship between psi•msec and SEL? Are we comfortable making these calculations assuming the relationship in Hastings and Popper (2005)?

The following key points and assumptions were applied to this exercise:

- The panelists found no relevant data on diving seabirds.
- The panelists looked at data for other birds, fish, and mammals with respect to barotrauma injury from impulsive sound sources (explosives).
- The approach was consistent with the approach of the FHWG, which looked at effects of explosive noise on fish estimated from psi•msec to dB SEL
- The panel used data from the Yelverton studies (1973, 1975), which examined injury of a variety of species and range of body masses from underwater explosives.

The following logic was used to determine whether fish data were a good surrogate for marbled murrelets, and to estimate the cumulative SEL that would inflict non-auditory injury on murrelets:

- A plot of the Yelverton et al. (1973, 1975) fish and mammal data for 50 percent mortality showed that there is a consistent relationship between log(mass) and impulse (psi•msec) for all species in these tests (see Figure 1). Adding a single data point for mallard ducks (1,190 gm) to the plot suggested that this general relationship holds for birds as well.
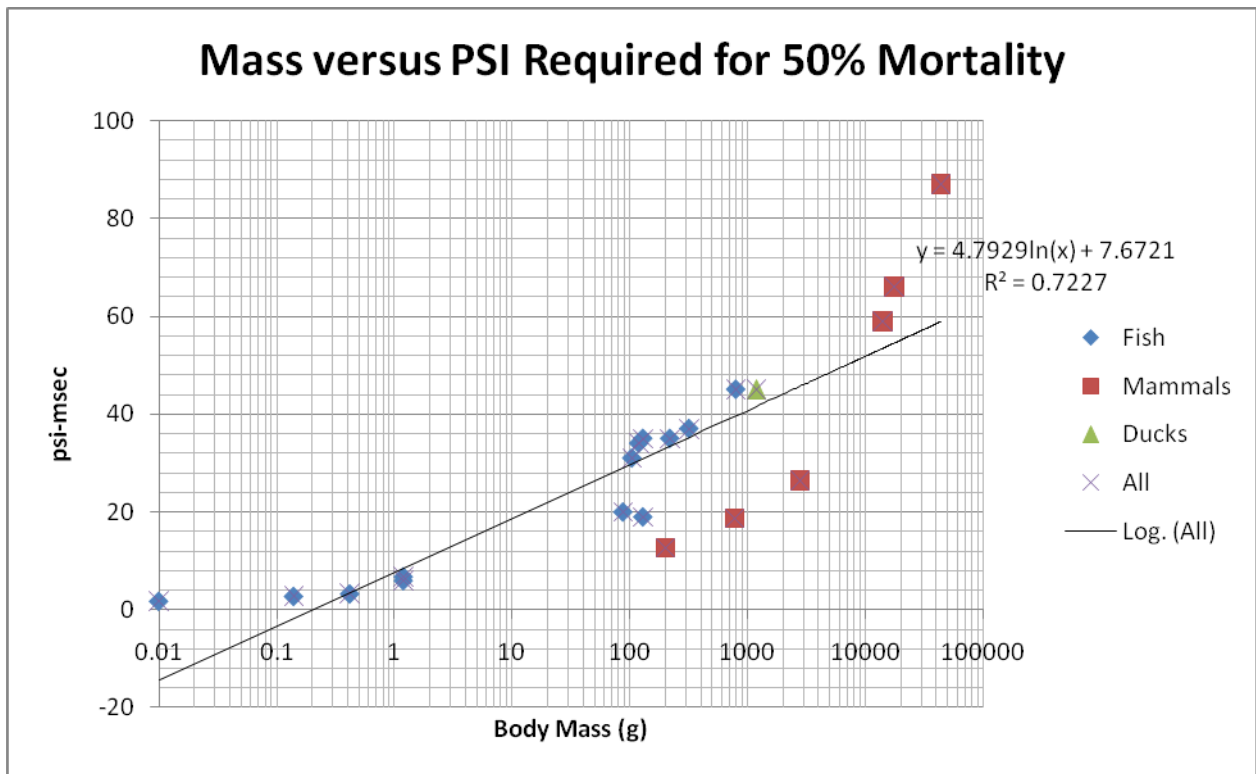

Figure 1. Mass versus psi•msec Required for 50% Mortality

- Based on this observation, the panelists assumed that the data from Govoni et al. (2003) and Popper et al. (2007), as presented by Carlson et al. (2007), for fish were relevant to the marbled murrelet because the mass of a murrelet falls within the size range of fish used in these studies. Govoni et al. (2003) looked at fish 0.5 g or smaller, while Popper et al. (2007) looked at fish 200 g or larger. These two data points were used to generate the equation for SEL injury threshold for fishes between 0.5 and 200 g (Carlson et al. 2007).

- While the study by Govoni et al. (2003) examined the effects of underwater explosions, which are assumed to be more damaging to fish than the sounds from pile driving, Popper et al. (2007) used continuous sounds. As with the auditory effects, the panelists assumed that impulsive sounds, such as pile driving, are more damaging at equal SEL than continuous sounds. Therefore, the panel applied a correction factor of 3 dB to the continuous sound data (i.e., the injury threshold for a fish of 200 g was reduced from 213 dB to 210 dB) to account for this difference (see Figure 2).

- Assuming a mass of 150 g for the smallest murrelet expected to be in marine habitats, the threshold for non-auditory injury is estimated to be:

$$\text{Cumulative SEL} = 186 + 10.37*\log_{10}(150) = \textbf{208 dB re 1}\boldsymbol{\mu}\textbf{Pa}^{\textbf{2}}\textbf{-sec}$$
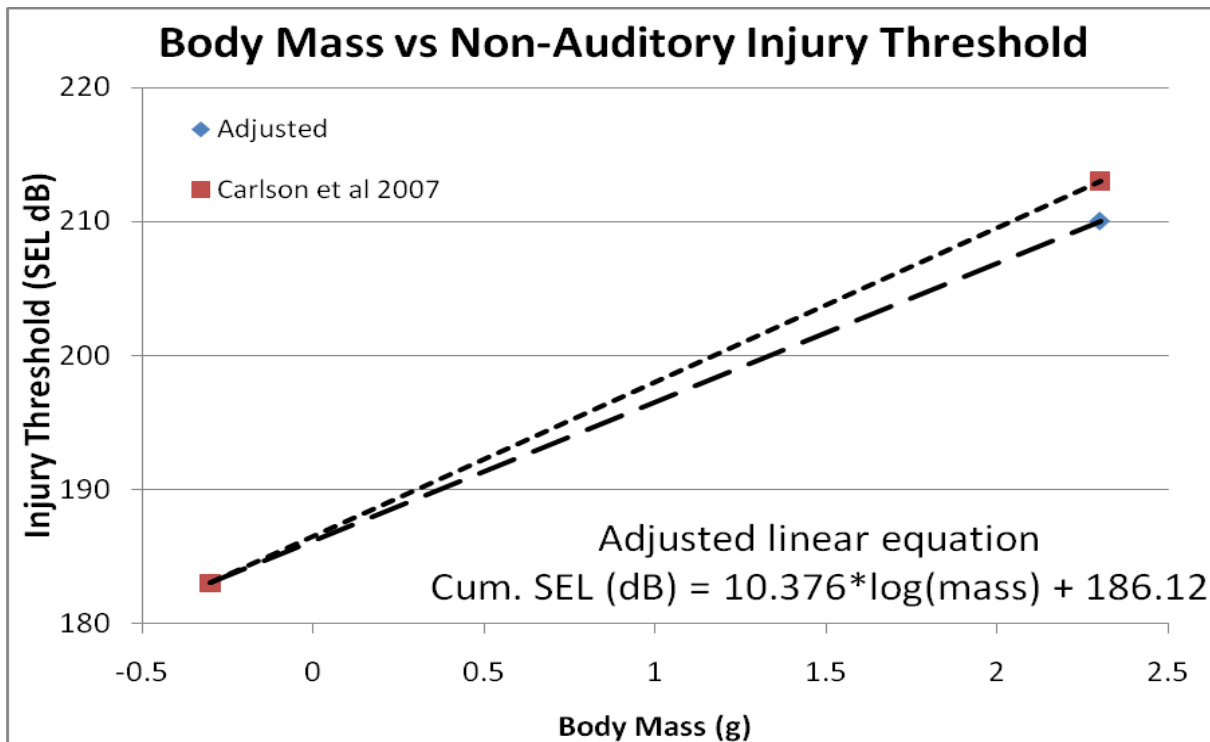

Figure 2. Body Mass versus Non-Auditory Injury Threshold

8.0   PRESENTATION TO USFWS DECISION-MAKERS AND U.S. NAVY OF PANEL APPROACH AND FINDINGS AND NEXT STEPS FOR FORMALIZING CRITERIA

Presentation (Attachment 7)

Panelists provided a presentation of their findings to Ken Berg (USFWS) and Captain Pat Rios (U.S. Navy) and other U.S. Navy and USWFS representatives.

Non-Auditory Injury

James Reyff presented the approach (described in detail above) for developing recommendations for a non-auditory injury criterion to marbled murrelets. He clarified that non-auditory injury is physical damage not including what happens within the ear.

Question: Why were bird data not used?

Panel Response: For non-auditory injury, the panelists decided that data on responses of fish to explosive sound underwater were the most relevant data as there were no data on diving birds except for one data point for mallard ducks.

Question: Did you develop a new graph to show the relationship between body size and trauma?

Panel Response: The panelists used the mass/injury threshold relationship for fish proposed by Carlson et al. (2007), but modified it to account for the difference between continuous noise and impulsive noise.

Auditory Injury

Dr. Slabbekoorn presented the approach (described in detail above) for developing recommendations for an auditory injury criterion and explained that auditory injury is defined as hair cell loss. He explained that data on continuous noise exposure in budgies indicated that a 40 dB reduction in hearing sensitivity correlated with hair cell loss. Because sounds in these experiments were in-air continuous noise exposure, and it is known that impulsive sounds will cause more harm than continuous sound, several corrections were applied to these data to result in a criterion for injury due to underwater impulsive noise.

The panelists acknowledged there are several uncertainties:

- There is huge variability among bird species in their susceptibility to noise-related injury.
- There are in-air audiograms on 50 different avian species, but the panel was not aware of any underwater audiograms. Nevertheless, a relatively straightforward high-frequency cut-off is expected as in humans. Importantly, differences in underwater audiograms and sensitivities to different frequencies are not what is missed most. The panel experts most urgently need data on differences in susceptibility to noise overexposure among species and for birds underwater, and audiograms provide little or no insight in this respect.

Question: Why did you pick budgies?

Panel Response: Budgerigars were selected because the data needed for the analysis of auditory damage were available for this species, including the asymptotic growth curve and recovery time for TS in response to continuous noise.

Question: Are some species are more sensitive than others?

Panel Response: Nocturnal birds typically have better hearing sensitivity, but susceptibility to sound-related injury is unknown. Birds are relatively insensitive to damage compared to mammals. For example, it takes longer exposure to sound to achieve 40 dB TS in birds than it does in guinea pigs.

Question to Mr. Johnson: What is your perspective on behalf of NMFS?

Response: Mr. Johnson indicated that it was a pleasure to work with this many people who know what they are talking about. Mr. Johnson is confident they have a defensible outcome.

Capt Rios Remarks: The Navy is eight days away from swinging piles out into the water. Is there anything the panel has learned here that would modify the testing from the acoustical perspective for the Test Pile Program?

Panel Response: Dr. Stadler indicated there is an enormous difference in pile-driving sites and one piece of information that would be helpful would be to know the site-specific information. Mr. Reyff agreed that the sound spectra data would be helpful in confirming these assumptions.

9.0 CONCLUSIONS

The panelists considered five questions that were designed to help identify the onset of injury to marbled murrelets from underwater pile driving noise. Their answers to these questions were as follows:

Question 1: **How are we defining "injury"?**

Injury is defined as the loss of cochlear hair cells due to impulsive acoustic overexposure. The assumption is that this type of injury occurs first (i.e., at lower sound levels) but non-auditory (barotraumas) effects are also considered.

Question 2: **In the absence of research on the effects of pile driving sounds on birds, what would be considered the most appropriate surrogate species for estimating these effects to diving seabirds?**

For non-auditory injury, fish are the basis for estimating effects with supporting data from terrestrial mammals. For auditory injury, budgerigars are the basis with supporting data from terrestrial and marine mammals.

Question 3: **In the absence of research on the effects of pile driving sounds on birds, what could be considered the most appropriate surrogate sound sources for estimating these effects to diving seabirds?**

Any impulsive sound source is better than a continuous sound source. For non-auditory injury, panelists used explosive sound data with some support from continuous sound data. For auditory injury, panelists used continuous sounds that were modified to compensate for the more severe effects of impulsive sounds.

Question 4: **What is the best metric(s) for estimating onset of injury to marbled murrelets from repetitive, impulsive sounds (Cumulative Sound Exposure Level [SEL])?**

SEL is the best metric for both non-auditory and auditory impacts from repetitive, impulsive sounds.

Question 5: **What is the best value (X dB, X psi, etc.) for estimating onset of injury to marbled murrelets from repetitive, impulsive sounds?**

The panelists recommended two thresholds for the onset of injury to marbled murrelets: the recommended auditory injury threshold is 202 dB SEL and the recommended non-auditory injury threshold is 208 dB SEL.

10.0   NEXT STEPS

5 August	Capt Rios and Ken Berg to review the information and confirm that the Panel's Approach is Workable and would continue consultation
	US Navy and USFWS to reevaluate the monitoring plans for the Test Pile Program and can look at that with the consulting biologists to determine if new data are needed.
8 August	Court Reporter Transcript Due
12 August	Draft Report Due to Panelists for Review with Comment Matrix
19 August	Final Review Meeting, if needed
31 August	SAIC submits Final Report

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