Agreement on the Conservation of Albatrosses and Petrels

Seventh Meeting of the Seabird Bycatch Working Group

La Serena, Chile, 2 - 4 May 2016

Results of initial trials to determine if laser light can prevent seabird bycatch in North Pacific fisheries

[1]Edward F Melvin, [2] William E Asher, [3] Esteban Fernandez-Juricic, and [4] Amy Lim.

[1]Washington Sea Grant, University of Washington, edmelvin@uw.edu,

[2]Applied Physics Laboratory, University of Washington, asherwe@uw.edu,

[3] Department of Biological Sciences, Purdue University, West Lafayette, IN 47907, efernan@purdue.edu

[4]Amy Lim, Environment, Health, and Safety Radiation Safety Office, University of Washington, amylhlim@uw.edu.

ABSTRACT

Here we report results of the first field trials of a laser-based seabird deterrent in North Pacific fisheries. We tested a commercially available product and a prototype device, each operating in the visible region at 532 nm (green). The optical power output measured in the laboratory was similar for both (1.26 and 1.01 W, respectively) placing them well within the class-4 laser classification. The calculated Nominal Optical Hazard Distance (NOHD) for each was also similar (102 m and 192 m, respectively). Field trials were carried out on a trawl catcher-processor off the Oregon-Washington coast in October 2015. Trawl was selected over longline because it represents a worst-case challenge for seabird deterrence: large aggregations of birds feeding on an abundant food source (continuous offal discharge from the factory) 24/7. Attending seabirds (all species) showed little detectable response to the laser beam during daylight hours. At night however, Northern fulmars (*Fulmarus glacialis*) showed a transient and localized response at lower vessel speeds (3.5 kts) while feeding in the offal plume. In contrast, gulls in flight at nighttime in pursuit of the vessel showed a strong aversion at higher vessels speeds (11 kts). These results suggest that laser beam detection by birds may be more challenging at high light levels. The implication is that lasers might be modified to increase its visual contrast during the day. From these field trials, lasers appear more likely to scare birds from an abundant food source at low light levels and success may be species and condition specific.

Resultados de los estudios iniciales para determinar si la luz del láser puede prevenir la captura secundaria de aves marinas en las pesquerías del Pacífico Norte

RESUMEN

En el presente documento notificamos los resultados de los primeros estudios de campo de un dispositivo de disuasión de aves marinas mediante el uso de láser en las pesquerías del Pacífico Norte. Evaluamos un producto que está disponible en el mercado y un dispositivo prototipo, lo cuales operan, en ambos casos, en la región visible a 532 millas náuticas (verde). La potencia de salida óptica medida en el laboratorio fue similar en ambos dispositivos (1,26 y 1,01 W, respectivamente), es decir que ambos se encuadran perfectamente dentro de la categoría de láser tipo 4. La distancia nominal de riesgo ocular (DNRO) calculada para cada uno también fue similar (102 m y 192 m, respectivamente). Los estudios de campo se realizaron en un procesador arrastrero de captura en la costa de Oregon, Washington, en octubre de 2015. Se seleccionó la opción de arrastre, en lugar de palangre, porque representa el mayor desafío en términos de disuasión de aves marinas: grandes congregaciones de aves marinas alimentándose de una fuente abundante de comida (descarga continua de vísceras de la fábrica) las 24 horas del día, los 7 días de la semana. Se detectó una escasa respuesta de las aves marinas presentes (todas las especies) al rayo láser durante las horas diurnas. Por la noche, sin embargo, los fulmares boreales (*Fulmarus glacialis*) demostraron una respuesta transitoria y localizada a menores velocidades de los barcos (3,5 nudos) mientras se alimentaban de las vísceras. En cambio, las gaviotas en vuelo nocturno en busca del barco demostraron un fuerte rechazo ante mayores velocidades de barcos (11 nudos). Estos resultados sugieren que la detección del rayo láser por parte de las aves resulta más difícil de lograrse a mayores niveles de luz. Esta conclusión implica que los láseres podrían modificarse para aumentar su grado de contraste visual durante el día. A partir de estos estudios de campo se puede concluir que los láseres parecen ahuyentar a las aves marinas de una fuente abundante de comida a bajos niveles de luz y que el éxito de este resultado parece estar sujeto a las especies y a las condiciones específicas.

Résultats des essais initiaux visant à déterminer si la technologie laser peut éviter les captures accessoires dans la pêche du Pacifique Nord

RÉSUMÉ

Nous établissons dans le présent document un rapport des premiers essais sur le terrain d’une technologie laser de dissuasion contre les oiseaux marins dans la pêche du Pacifique Nord. Nous avons testé un produit disponible dans le commerce, ainsi qu’un prototype, chacun opérant dans une région de visibilité à 532 nm (vert). Leur puissance optique de sortie mesurée en laboratoire était similaire (respectivement 1,26 et 1,01 W) les plaçant dans la catégorie des lasers de classe 4. La distance nominale de risque oculaire (DNRO) calculée pour chacun était également similaire (respectivement 102 m et 192 m). Les essais sur le terrain ont été réalisés sur un navire-usine au large des côtes de l’Oregon et de Washington en octobre 2015. Le chalut a été préféré à la palangre car il représente un plus grand défi en matière de dissuasion des oiseaux marins : de grands groupes s’alimentent à une source de nourriture abondante (rejet continu d’abats) 24 h/24. Les oiseaux marins présents (toutes espèces confondues) ont montré une réponse à peine perceptible au rayon laser pendant les heures diurnes. En revanche, de nuit, les fulmars boréals (*Fulmarus glacialis*) ont eu une réponse passagère et localisée à vitesse plus lente du navire (3,5 nœuds) lorsqu’ils se nourrissaient d’abats. Par ailleurs, les mouettes à la poursuite du navire de nuit ont montré une forte aversion au laser à une vitesse plus élevée du navire (11 nœuds). Ces résultats suggèrent que les oiseaux auraient plus de difficulté à détecter le laser à des niveaux élevés de luminosité. On peut suggérer une modification de ces lasers en vue d’augmenter leur contraste visuel pendant la journée. D’après ces essais sur le terrain, il semble plus probable que les lasers fassent fuir les oiseaux se nourrissant à une source de nourriture abondante à des niveaux de luminosité faibles, et que le succès soit spécifique à certaines espèces et conditions.

1. INTRODUCTION

The use of lasers is an emerging technology to prevent marine birds from accessing dangerous areas around fishing vessels. Mustad Autoline, in partnership with SaveWave, have developed and begun marketing the SeaBird Saver, a laser-based tool to prevent seabird interactions with longline fishing gear. Preliminary tests showed that that the spot illuminated on the ocean surface by the laser beam (and the beam itself, when visible) dispersed an assemblage of seabirds largely dominated by gulls away from the stern of the ship during dawn, dusk, cloudy, rainy or foggy conditions (Schrijver, 2014). The SeaBird Saver was awarded the 2014 World Wildlife Fund Smart Gear competition Tuna Bycatch Reduction prize[1] and second place in the Nor-Fishing Foundation competition for innovation. Based on this success, Mustad Autoline, a fishing gear supplier to the longline industry, has marketed the SeaBird Saver as a seabird bycatch deterrent since 2013. The availability of this laser-based product, coupled with promising results and awards based on these promising results, is spurring keen interest within the fishing industry worldwide, including the US, to use laser technology to prevent seabird interactions with fishing gear. However, the range of conditions under which lasers can successfully and safely deter albatrosses and petrels is unknown and untested.

Research to date on the effectiveness of lasers as a bird deterrent and the effects of laser exposure to avian visual systems is very limited (Glahn et al., 2001; Blackwell et al., 2002). This is important because the SeaBird Saver uses a Class-4 laser technology, which is many times more powerful than the Class-2 and Class-3 lasers currently in use for non-lethal bird control. Consequently, use of a Class-4 lasers to deter seabirds from fishing gear raises questions regarding possible retinal damage to birds (and the behavioural consequences), and nearby humans, that are frequently exposed to this high intensity monochromatic light. It is also unknown whether a Class-4 laser represents the minimum power level necessary to create the desired bird deterring effect.

As fishing industry-instigated efforts began to take shape to test the SeaBird saver in U.S. Pacific fisheries, the US Fish and Wildlife Service raised concerns regarding the risks posed to seabirds from acute and chronic exposure to Class-4 laser beams. The US Fish and Wildlife Service also was concerned that effectiveness of the laser on preventing seabird bycatch was unknown. These same two concerns were echoed by the Agreement for the Conservation of Albatrosses and Petrels (ACAP) in their 2014 meeting (ACAP, 2014) leading the Seabird Bycatch Working Group of ACAP to establish an intersessional working group to share information on research plans and protocols. In September 2014, a plan emerged from a meeting of US stakeholders to progress testing and possible eventual adoption of laser technology for seabird bycatch prevention in US North Pacific fisheries. That plan called for the following staged approach:

- Stage-1. Conduct pilot tests to determine if the SeaBird Saver, or similar laser-based systems, can effectively displace seabird species that typically undergo bycatch mortality in North Pacific fisheries away from dangerous fishing gear (longline hooks, trawl cables and nets);

[1] http://www.worldwildlife.org/initiatives/international-smart-gear-competition

- Stage-2. Using laboratory testing, determine if, and to what extent, the SeaBird Saver or similar laser-based systems, pose a danger to seabirds (from the perspective of retinal damage and visual behaviour);
- Stage-3. Determine the relative effectiveness of the SeaBird Saver or similar laser-based systems, to two streamer lines at keeping birds away from hooks, trawl cables or nets through field trials conducted in the course of production fishing.

This plan was accepted with the understanding that laser-based systems would not be activated in the presence of endangered short-tailed albatross *(Phoebastria albatrus)*. This condition addresses the US Fish and Wildlife Service responsibility under the US Endangered Species Act to ensure that endangered species are not harmed. It was further acknowledged that stage-3 testing and/or full adoption of laser technology would not occur until the safety of seabirds could be assured through credible research.

This paper describes results of stage-1 pilot testing of two Class-4 laser-based systems aboard a trawl catcher-processor off the Oregon coast in October of 2015. Our goals were to 1) characterize the power output of these lasers and the risk they pose to humans, and 2) establish the extent to which lasers can displace seabird species typically bycaught in US North Pacific fisheries from dangerous fishing gear and under what conditions.

2. METHODS

We laboratory and field-tested two Class-4 laser-based systems developed as deterrents to seabird interactions with commercial fishing gear:

- The SeaBird Saver produced by the Bird Control Group for SaveWave, both of Delft, Netherlands, and marketed by Mustad Autoline, Gjovik, Norway, and
- The Dazzler, a prototype product, produced by Lasersec System, Jorvas, Finland in cooperation with A. S. Fiskevegn, Flatraket, Norway.

The original manufacturer product specifications indicated that both lasers operated in the green region of the visible spectrum, and were Class-4 lasers with a maximum continuous-wave power output > 1100 mW. The SeaBird Saver had a fixed power output setting while the Dazzler was adjustable over a range of six (with nominal settings 1200 mW, 1,000 mW, 800 mW, 400 mW and 200 mW).

2.1 Laboratory Tests

We measured the maximum power output and estimated the beam divergence for both lasers in order to determine the radiant energy flux we would be introducing into the environment in the course of our field trails (Figure 2). The power output was measured pre (October 5, 2015) and post (November 12, 2015) field trials to determine the extent to which the output of the lasers was maintained throughout the testing period.

The output of both devices was observed to be green, and assumed to be operating at a wavelength of 532 nm (the visual appearance of each was consistent with a frequency-doubled Nd:YAG laser operating at a wavelength of 532 nm). Power output was measured using a Fieldmaster GS laser power meter (Coherent Inc., Santa Clara, California) connected to a LM-2 VIS silicon optical sensor (Coherent Inc., Santa Clara, California). The uncertainty in the accuracy of the calibration of the LM-2 VIS when used with the Fieldmaster GS is ±5% of the measured power. The output beam of each device was focused into the opening of the LM-2 VIS using an uncoated BK-7 planoconvex (PCX) lens with a diameter of 100 mm and a focal length of 200 mm (Edmund Optics, Barrington, New Jersey). This causes some loss of power from the laser beams due to Fresnel reflection at the front and back surfaces of the lens. Although not measured, this power loss is typically no more than 10% combined for both surfaces. In addition, it was necessary to place two absorptive neutral density filters with an optical density (OD) of 1.0 (Edmund Optics, Barrington, New Jersey) in the beam (total OD of 2.0) after the PCX lens to decrease laser power and prevent damage of the LM-2 VIS sensor. The ambient room light contribution to the measured laser power was constant regardless of laser power and equal to approximately 0.008 mW. At 150 mW, which was measured as 1.5 mW at the power meter because of the OD 2.0 filters, this represented less than 0.5% of the total measured power. Prior to recording the power output from either laser it was turned on and allowed to stabilize for approximately 5 minutes. At that point the power reading from the meter was observed for a further 2 minutes. After that time it was stable in that it fluctuated by no more than 5% of its value over a period of 30 s.

Beam divergence for a Gaussian laser beam is proportional to the angular measure of the increase in beam diameter or radius with distance from the optical aperture (Hitz et al., 2001). This was estimated for each laser by removing the PCX lens used to make the power measurements and placing an OD 3.0 neutral density filter in the beam immediately at the output of each device. This reduced the total optical power by a factor of 1000, making it possible to view the diffuse reflection of the laser beam on a piece of white card stock without eye damage. The beam diameter was measured within 20 cm of the outlet aperture of the device and again at 2.3 m. This relatively crude technique necessitated a somewhat subjective interpretation of the beam diameter.

The Nominal Ocular Hazard Distance (NOHD) of each laser was also estimated based primarily on the measured output level and beam divergence. As shown in Figure 1, the NOHD for a continuous-wave laser is defined as the distance from the laser at which the power per unit surface area does not exceed the ocular Maximum Permissible Exposure (MPE; Henderson, 1997). MPE limits indicate the greatest exposure that most individuals can tolerate without sustaining injury and a laser beam is considered dangerous to human eyes within this distance. The NOHD is determined by the following expression:

$$\mathrm{NOHD} = \frac{\sqrt{\frac{4 \times \mathrm{P_o}}{\pi \times \mathrm{M.P.E}}} - W_o}{\phi}$$

This formula assumes a Gaussian beam with a power P_0, (in W), beam diameter W_0 (in m), and a beam divergence ϕ (in rad). P_0 is the maximum power for a laser emitting a continuous wave radiation. W_0 is the beam diameter leaving the laser and ϕ is the divergence of the beam. For a continuous-wave laser beam operating in the visible region (i.e., from 400nm-700nm), the MPE = 25.5 Wm^{-2} (ANSI 2014). This implies that for a typical human iris at maximum dilation of 7 mm, the total power entering the eye cannot exceed approximately 1 mW.

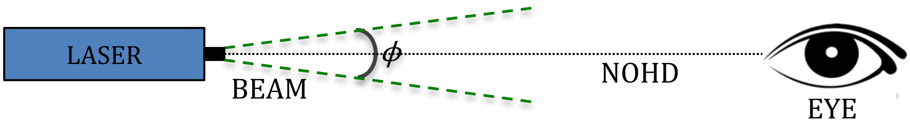

Figure 1: Nominal Ocular Hazard Distance

2.2 Field Trials

Filed trials were carried out aboard the catcher-processor F/T *Pacific Glacier* while it trawled for Pacific hake (*Merluccius productus*) off the Oregon coast from 6 to 18 October, 2015. We chose to test lasers in the context of a pelagic trawl fishery and on this specific vessel for several reasons. In trawl fisheries, seabird interactions can involve collisions with net cables (warps and netsounde cables) as birds actively feed on offal produced in the course of fish processing. The *F/T Pacific Glacier* was of particular interest for laser field testing because it discharges offal in a minced form, which attracts more birds to the vessel than vessels that process fish waste into fishmeal (Melvin et. al, 2011). As in Alaska pelagic trawl fisheries, vessels in the hake trawl fleet use a netsounde cable (third wire) to monitor fish coming into the net. These electronic cables have been banned in several fisheries because they extend far astern and can lead to seabird collisions that are difficult to prevent. In trawl fisheries seabirds can also become entangled in the net itself as the net surfaces during retrieval and as the net is deployed. These complex interactions, facilitated by the presence of an abundant food source, make seabird interactions in trawl fisheries among the most challenging to prevent, and therefore an ideal setting for initial field trials of laser-based bird deterrent technology.

The west coast hake fishery was selected for these trials because it strongly overlaps the distribution of albatrosses (Guy et al., 2013), the seabirds most at risk from bycatch mortality (Croxall et al., 2012). Short-tailed albatross, a US endangered species, occur here but are exceedingly rare, while black-footed albatross (*P. nigripes)* are abundant. The hake fishery thus provided the best opportunity to conduct our laser field trials in a fishery with a low likelihood of encountering an endangered species but a high likelihood of encountering another albatross species, which could serve as a proxy.

The two lasers were mounted to the aft rail at the stern 10 m above the water on the starboard side of the deck above the trawl deck (Figure 3). Both were powered with 110 volt AC power using an extension cord. Trials were limited to periods when the net was actively fishing (the tow) and the factory was operating and discharging offal. Prior to each trial the observation area was scanned using binoculars to determine the species mix and the presence or absence of short-tailed albatross. Daytime trials consisted of estimating the number of birds by species or species group within a 100 m hemisphere centered at the stern pre- and post-laser activation. With few exceptions, the lasers were directed into the offal plume with the most birds (the dominant plume) and held at a fixed distance of 20 m to 30 m aft of the stern. Because the birds on the water float astern at the speed of the vessel –

typically 3.5 to 4 knots during a tow – the laser is moving at that speed relative to the birds. In some cases the laser was swept toward and away from the stern to contrast fixed and scanning laser positions. Within a tow, we alternated activation of each of the two lasers separated by a 10-minute pause. Nighttime trials followed the same protocol minus bird counts as darkness prevented being able to see birds beyond 50 m of the stern. Night vision equipment failed to allow bird counts or species identifications comparable to daytime observations. This was especially true for dark plumaged birds such as black-footed albatross and the dark morph Northern fulmar (*Fulmaris glacialis)*. Consequently, night observations were limited to determining changes in behaviour to birds made visible by the vessel's lights.

The net deployment (set) and retrieval (haulback) periods were deemphasized for the purpose of laser trials as the area under observation was under constant change and the presence or absence of offal discharge was difficult to predict. However, observations were made opportunistically to determine if lasers could displace birds from sitting on or near the net as it floated at the surface.

3. RESULTS

The maximum power outputs of the SeaBird Saver (1.26 W) and the Dazzler (1.01 W) lasers were consistent with a Class-4 laser Classification (Table 1; Henderson, 1997). Minor differences in power output pre- and post- field trials suggest that power output for both lasers was maintained throughout field tests. The measured output of the Dazzler at each of its six-output setting consistently tracked the expected output at each setting. Despite similar maximum output levels for the two lasers, the NOHD calculated for the Dazzler was nearly twice that of the SeaBird Saver owing to its estimated beam divergence being half that of the SeaBird Saver.

The extent and nature of field trials was significantly constrained by the extremely poor fishing conditions we encountered. In 31 tows over 10 days, catch ranged from one to 30 tons per tow resulting in the factory often operating and discharging offal for less than one hour three times per day. These conditions, therefore allowed for 30 to 90 minute laser trials once or twice per fishing day during daylight hours. In general skies were overcast with occasional sun breaks or clear sunny conditions. Swell height ranged from 0.25 m to 3 m; wind speed ranged from 10 kn to 30 kn.

Seabird attendance within 100 m of the vessel during tows with the factory discharging offal averaged 428.3 birds per observation (SD=224.4). Northern fulmars, gulls (*Larus spp*.) and black-footed albatross attended the vessel during all daytime tow observations (Table 2). Northern fulmar was the predominant species averaging 339 birds/observation. In general, fulmars landed near the discharge point and fed aggressively in the discharge plume on the water. Gulls were the second most numerous species group averaging 69 birds/observation. The California gull (*L. californicus*) was the dominant gull species in the assemblage. Unlike fulmars, most gulls maintained flight periodically landing to modestly feed before resuming flight while maintaining proximity to the vessel. Black-footed albatross was the dominant albatross species averaging 11 birds/observation. In general black-footed albatross rarely came within 20 m of the vessel alternating flight with modest feeding on the water. A single Laysan albatross was sighted once. No short-tailed albatross attended the vessel during our trials. Pink-footed shearwater (*Puffinus creatopus*) also attended the vessel at times averaging one bird/observation.

During daylight hours the beam of the laser was not visible to the human eye and the green dot on the water created by the laser was tiny and difficult to see regardless of weather conditions. Bird response to the two lasers was nominal to absent during daylight hours; bird numbers in the observation area were unchanged with and without laser activation under all weather conditions encountered. Under brighter conditions, no behavioural response could be detected in individual birds even those struck directly by the laser. Under lower light conditions during daylight hours, birds struck directly by the laser showed some limited avoidance relocating within a meter or less of where they were struck, but this response was not consistent. Surrounding birds showed no detectable response. Given the weak response most results described here are anecdotal observations.

The opportunity to make observations during the hours of dusk was limited to one occasion. In this trial the SeaBird Saver laser was activated 35 min prior to sunset and bird numbers and behaviour were monitored every five minutes until factory discharge stopped 10 minutes after sunset. In this instance, wind was blowing onto the stern causing birds in flight –mostly gulls – to orient themselves into the wind, thus facing away from the vessel and the laser itself. Birds on the water – mostly fulmars – were random in their orientation to both the laser and the dot it created on the water. The laser was aimed into the starboard plume, which was dominant at that time, and held in a fixed position at approximately 30 m from the stern. From first activation 35 min before sunset the dot on the water was larger and more visible than during daylight hours, provoking a localized response in many but not all birds sitting on the water and directly struck by the laser dot. Birds in flight showed no detectable response. Two to 30 birds could be dispersed when the laser dot passed through a dense aggregation of birds, clearing up to a 5-m radius area around the laser dot, but not consistently. Most birds resettled on the water within 10 to 20 m of their original location, and within the 100-m observation area. As the vessel moved forward the laser approached a new group of birds, there was no evidence that those birds anticipated the approaching laser, but rather reacted only when an individual bird was struck by the laser beam or was in close proximity to a bird struck by the laser. Sweeping the laser toward and away from the stern could provoke a reaction in more birds over a wider area, but typically after a lag of several seconds. At 10 minutes after sunset, light diminished to the point that the beam became visible but unfortunately the factory began to cease operation, thus offal discharge lessened and finally stopped, dispersing the birds and ending the trial.

In darkness, the beams of both lasers were highly visible and their associated dots were larger (~ 1 m radius) and clearly visible to the human eye. The diameter of the beam emanating from the Dazzler laser was roughly half that of the SeaBird Saver and, therefore consistent with lab estimates of beam divergence. Bird response to the laser in darkness was similar to that observed during dusk: minimal and localized with one exception. In one instance, rather than redeploying the net after a haulback the vessel relocated to a new fishing location at a speed of 11 knots. With the factory operating and offal being discharged at this speed, Northern fulmars no longer occupied the offal plume, but gulls pursued the vessel in flight, thus facing the stern of the vessel and the lasers. Immediately after activating the Dazzler laser all gulls immediately dispersed leaving no birds visible from the stern. After approximately 30 seconds, gulls started to return occupying the area astern of the laser beam. After one minute, several gulls flew over or around the beam and occupied the area above the laser beam between the stern and the laser's dot on the water. This positioning of the gulls continued for the balance of the eight-minute period the laser was activated. When the laser was deactivated the gulls quickly re-established their pre laser positions and behaviours.

Attempts to displace birds from atop the codend of the net as it surfaced were unsuccessful during daylight hours. Birds sitting on the net made no detectable response to the laser. In darkness the codend was difficult to locate as it rose to the surface at several hundred meters from the vessel. Directing the laser at the codend when it became visible provoked no detectable response from birds on the net.

4. DISCUSSION

Our laboratory tests showed that the power output of both the SeaBird Saver and the Dazzler were consistent with the most dangerous laser classification – Class-4 laser (an power output of 0.5 W and above). The high power levels of these lasers are reflected in the NOHD estimates exceeding 100 m. Our finding that the NOHD calculated for the Dazzler was nearly twice that of the SeaBird Saver despite similar maximum output levels illustrates that the NOHD is strongly influenced by beam divergence. Our measurement of beam divergence was necessarily crude given the equipment available to us; however, it yielded estimates that were confirmed anecdotally by observations of the two lasers during field tests. Given the importance of beam divergence in estimating the distance at which lasers pose a risk to humans and birds, future tests for accurate beam divergence can be made by using CCD array detector for diameter measurements, in conjunction with the focal plane technique (http://aries.ucsd.edu/LMI/TUTORIALS/diverge.html) where possible. The relationship between power output levels and beam divergence also illustrates that laser classification does not fully characterize the potential safety hazards posed by laser technology.

Although the total beam power measured for the SeaBird Saver was high enough that it would be a Class-4 laser under the definition provided by the ANSI standards, it was labelled as a Class-3B laser. The difference between the apparent hazard classification as measured (Class-4) and that specified by the manufacturer (Class-3B) revolves around the methods of measurement and assumptions made in the risk assessment test report provided by the Seabird Control Group. Because that interpretation of the definitions of hazard class do not appear to adhere to ANSI laser hazard definitions, the classification of the SeaBird Saver as a Class-3B laser device cannot be confirmed by the measurements reported here.

A clear definition of the technical specifications of an embedded laser and the resulting classification of laser-based systems according to their hazard class is crucial in developing the proper control measures to minimize the risk of injury during the use of laser in field-based research environments (especially when using lasers outdoors with changing environmental conditions). The manufacturer must consider all the working possibilities of the laser system and adopt the appropriate classification that accurately represents the laser hazards.

Although the Dazzler laser used in our tests is a prototype and had yet to be labelled with a hazard class designation, the area where it lasers was mounted on the vessel was clearly posted with warning signs saying a Class-4 laser was present. A flashing red warning light was used to warn the crew that the laser was operating. Consistent with this regard for safety, laser eye protection with adequate Optical Density (OD) was provided on the vessel.

Unlike the results reported by Schrijver (2014), results from these field trials provide little evidence that the high power laser-based systems we tested could consistently displace seabirds from dangerous fishing gear, especially during daylight hours as currently configured. In our limited testing conditions, there was little evidence that the actively feeding seabirds we encountered responded to laser light during daylight hours regardless of how the laser was presented – scanning or static – or of the prevalent weather conditions. Although there was some evidence of efficacy of lasers as bird deterrents near dusk and at night, that response was nominal and inconsistent in this assemblage of birds. In only one of 14 observations with the lasers activated did we observe a dramatic avoidance response to a laser: gulls in flight pursuing the vessel (i.e., not feeding) at night and oriented such that they were directly facing the laser as the vessel travelled at a relatively high-speed speed (11 knots). This finding suggests that orientation of the birds to the laser and possibly the activity (flying or feeding on the water) of the birds may influence their response. That this dramatic response happened only at night and only with gulls suggests that seabird response to lasers may be limited to low light conditions and may be species specific. Our field tests did not answer questions about the response of albatrosses to lasers. Although albatrosses were present during daylight and dusk hours, the beam of the laser was never observed to strike an individual albatross. Like gulls and fulmars, black-footed albatross in proximity to the laser beam showed no detectable response. During nighttime observation albatross could not be detected in the lighting conditions that prevailed.

It is important to note that these field trials were deliberately staged in the most challenging environment available to us and that their extent and comprehensiveness were constrained by poor fishing conditions. A research setting such as this trawl fishery in which birds are actively feeding on an abundant food source may not be transferable to interactions in longline fisheries where food available to birds is relatively scarce and birds typically approach sinking baited hooks from the air or after briefly alighting on the water. Also in longline fisheries the area being defended from birds is possibly more linear and the interactions less complex than in trawl fisheries. Our choice of an observation area of a 100 m hemisphere centred at the stern was based on our experience in other fisheries (Melvin et al., 2001; Dietrich et al., 2008; and Melvin et al. 2011) and our anticipation of a consistently dramatic response by birds to lasers. Future studies of this kind would benefit from using a smaller response area and consider using bird interaction rates with fishing gear (the rate of cable or net strikes in trawl fisheries or the rates of seabird attacks on baits in longline fisheries) in addition to bird numbers in the response area as metrics to evaluate the response of seabirds to lasers.

These preliminary results are also limited to the configurations of the lasers we tested and should not be interpreted as representative of lasers generally. For example, a pulsed or scanning beam or different or varying power outputs may provoke a more unambiguous and sustained response. Within the last year the Bird Control Group and SaveWave developed an upgrade to the SeaBird Saver that allows the laser to sweep a user defined area automatically at a selected speed (S. Henskes, Bird Control Group, pers. comm.). Future testing should include laser units with this feature to more fully explore the potential for lasers to effectively reduce seabird interactions with fishing gear. We found manipulating the lasers used in this study to sweep an area in a consistent way was awkward and difficult to achieve. Hypothetically, a pulsed laser beam might elicit a stronger response from birds while reducing the amount of energy birds are exposed to thus minimizing safety risks. Although the Dazzler laser had the capability to manipulate power level, we did not use this feature in our field trails due to the muted response of seabirds to lasers set at maximum power. Adjusting the power level was further constrained by limited access to the power control panel, which was encased in a sealed box. Ideally future tests should be done with a laser having adjustable power output settings to resolve questions about the power level necessary to deter seabirds.

Ultimately, optimizing the effectiveness of lasers and seabird bycatch deterrents in general should be based on a firm understanding of the visual perception of seabirds. Unfortunately, relatively little is known about the visual systems of marine birds (e.g., Hart 2004, Machovsky Capuska et al. 2011) or how lasers could affect their eyes, retinas, and ultimately visual perception. Our understanding of the effects of lasers on humans, which is substantial, cannot be extrapolated to birds because avian vision is very different from human vision (e.g., birds can see more colours, including into ultraviolet wavelengths, have wider fields of view, have ocular media with different absorbance properties, and process images in their retinas at a faster rate than humans (Cuthill, 2006). This lack of knowledge not only constrains our ability to establish the degree to which the implementation of this new laser technology could negatively impact marine birds, but also prevents us from tailoring bycatch avoidance technologies in general to avian deterrence.

This void in our understanding in seabird visual systems is starting to be addressed. Just recently, one of the co-authors of this paper, Esteban Fernandez-Juricic was awarded funding from the David and Lucille Packard Foundation, the National Fish and Wildlife Foundation and the US Fish and Wildlife Service to characterize the visual systems of several North Pacific seabird species and the evaluate the risk laser radiation poses to these birds. This research includes the following objectives: (1) establish key visual properties (degree of visual coverage, type of centre of acute vision, retinal configuration, eye size and filtering properties) in select seabird species; (2) assess the degree of retinal injury morphologically under different exposure levels in gulls and fulmars; (3) assess if retinal injury affects perception and foraging behaviour in gulls; and (4) extrapolate levels of risk under different ambient light conditions and exposure levels for both species of albatrosses. We are optimistic that this research will lead to an era in which seabird bycatch prevention emerges from trial and error approaches to those that are science based and anchored in an understanding of what seabirds perceive in their environment.

6. ACKNOWLEGEMENTS

The David and Lucille Packard Foundation, the National Marine Fisheries Service Northwest Fisheries Science and Washington Sea Grant funded this work. Mustad Autoline, and SeaWave provided the SeaBird Saver laser and A.S. Fiskevegn and RENA International provided the prototype Dazzler laser for our lab and field-tests. We thank them for their dedication to developing methods to reduce seabird bycatch in commercial fisheries and working with us to make this work possible. We thank Glacier Fish Company, Seattle, for the cooperation and allowing us to stage field trials on the *F/T Pacific Glacier*. Cooperation of the fishing industry, such as we received from the Glacier Fish Company and the crew of the *F/T Pacific Glacier*, is essential to this kind of work taking place.

7. LITERATURE CITED

ACAP. 2014. Report of the Sixth Meeting of the Seabird Bycatch Working Group, Punta del Este, Uruguay, 10-12 September 2014

ANSI Z136.1-2014, "American National Standard for Safe Use of Lasers", American National Standards Institute, New York, USA, 2014.

Blackwell, B. F., Bernhardt, G. E. & Dolbeer, R. A. 2002. Lasers as non-lethal avian repellents. Journal of Wildlife Management 66: 250–258.

Croxall, J.P., Butchart, S.H.M., Lascelles, B., Stattersfield, A.J., Sullivan, B., Symes, A., Taylor, P., 2012. Seabird conservation status, threats and priority actions: a global assessment. Bird Conserv. Int. 22: 1–34.

Cuthill IC. 2006. Color Perception. Pages 3-40, in Bird Coloration: mechanisms and measurements. Vol 1. Hill GE & McGraw KJ (Eds.). Harvard University Press, Cambridge.

Dietrich, K. S., E. F. Melvin, and L. Conquest. 2008. Integrated weight longlines with paired streamer lines – Best practice to prevent seabird bycatch in demersal longline fisheries. Biol. Cons.141:1793-1805.

Glahn, J. F., G. Ellis, P. Fiornelli, And B. Dorr. 2001. Evaluation of moderate- and low- power lasers for dispersing double-crested cormorants from their night roosts. Proceedings of the Eastern Wildlife Damage Management Conference 9:34-45.

Guy, T.J.1, Jennings S.L., Suryan R.M., **Melvin E.F.**, Bellman, M.A., Anderson D.J., Ballance L.T., Blackie B.A., Croll D.A., Deguchi T., Geernaert T.O., Henry R.W., Hester, M., Hyrenbach K.D., Jahncke J., Ozaki K., Roletto J., Sato F., Shaffer S.A., Sydeman W.J., and Zamon J.E. 2013. Fisheries Research 147: 222-234Hart NS. 2004. Microspectrophotometry of visual pigments and oil droplets in a marine bird, the wedge-tailed shearwater *Puffinus pacificus*: topographic variations in photoreceptor spectral characteristics. Journal of Experimental Biology 207: 1229-1240.

Hart NS. 2004. Microspectrophotometry of visual pigments and oil droplets in a marine bird, the wedge-tailed shearwater *Puffinus pacificus*: topographic variations in photoreceptor spectral characteristics. Journal of Experimental Biology 207: 1229-1240.

Henderson, A.R., 1997. *A Guide to Laser Safety*. Chapman and Hall, London. 243 pp.

Hitz, B., J.J. Ewing, and J. Hecht, 2001. *Introduction to Laser Technology, 3rd ed*. IEEE Press, New York, 288 pp.

Machovsky Capuska GE, Huynen L, Lambert D, Raubenheimer D. 2011. UVS is rare in seabirds. Vision Research 51: 1333–1337.

Melvin, E. F., J. K. Parrish, K. S. Dietrich, and O. S. Hamel. 2001. Solutions to seabird bycatch in Alaska's demersal longline fisheries. Project A/FP-7, WSG-AS 01-01, Washington Sea Grant.

Melvin, E. F., K. S. Dietrich, S. Fitzgerald, and T Cardoso. 2011. Reducing seabird strikes with trawl cables in the pollock catcher-processor fleet in the eastern Bering Sea. Polar Biol. 34: 215–226

Schrijver, E.E., 2014. SeaBird Saver offshore trial report, West Iceland. SeaWave.

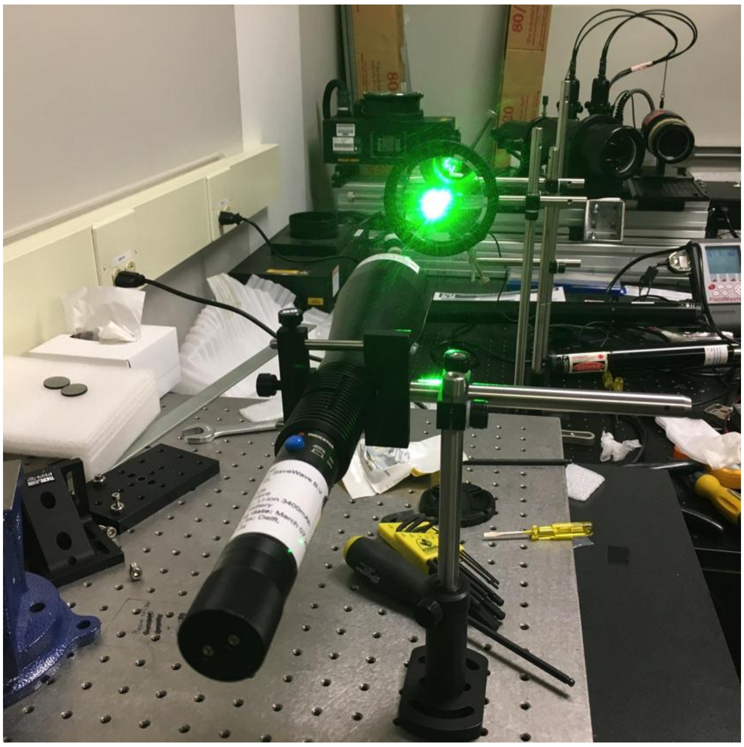

Figure 1. Laboratory testing the Shellfish Saver laser at the Applied Physics Lab, University of Washington.

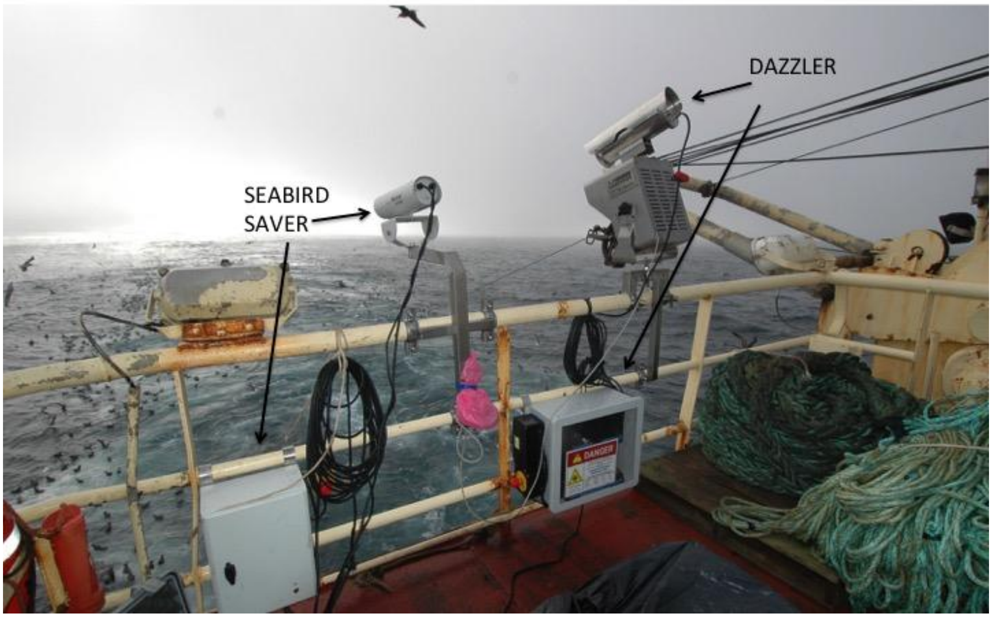

Figure 2. SeaBird Saver (left) and Dazzler (right) lasers mounted on the stern of a Pacific hake trawl catcher processor.

Table 1. Estimated beam divergence (mRad), measured power output (mW) pre and post 2015 field tests, and associated nominal optical hazard distance (m) for the Seabird Saver laser and for each available power setting on the prototype Dazzler laser.

Laser Device	Estimated Beam Divergence (mRad)	Power output 10/5/15 (mW)	NOHD (m)	Power output 11/12/15 (mW)	NOHD (m)
SeaBird Saver	2.4	1190	102	1260	105
Dazzler, 1200 mW	1.2	1070	193	1010	187
Dazzler, 1000 mW	1.2	830	170	810	168
Dazzler, 800 mW	1.2	680	154	630	148
Dazzler, 600 mW	1.2	520	134	480	129
Dazzler, 400 mW	1.2	330	107	310	104
Dazzler, 200 mW	1.2	160	75	150	72

Table 2. Seabird attendance and occurrence by species or species group in 18 tow observations over seven days during daytime laser trials.

Common Name	Species	Mean No. Tow	Tow Occurrence
Northern Fulmar	*Fulmaris glacialis*	339.4	1.0
Gull species	*Larus spp.*	69.0	1.0
Black-footed albatross	*Phoebastria nigripes*	11.1	1.0
Pink-footed Shearwater	*Puffinus creatopus*	1.0	0.3
Laysan albatross	*Phoebastria immutabilis*	0.7	0.1
Short-tailed albatross	*Phoebastria albatrus*	0.0	0.0