Review of Seabird Bycatch in Set-Gillnets with Specific Reference to Mitigating Impacts to Yellow-billed Loons

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August 2014

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A report by The Wildlife Conservation Society to US Fish and Wildlife Service with support from the National Fish and Wildlife Foundation

August 2014

Agreement #: F12PS00632

Cover Photos:

Pair of yellow-billed loons on Ayopechan Island, Chaun Delta, Chukotka. June 2012, photo by Peter Romanov.

Entangled yellow-billed loon at Chaun Delta, Chukotka. June 2012, photo by Megan Boldenow.

EXECUTIVE SUMMARY

In 2009, the US Fish and Wildlife Service (USFWS) listed the yellow-billed loon (*Gavia adamsii*) as a candidate species for protection under the Endangered Species Act (ESA) because of life history, small global population, restricted distribution, habitat requirements, and subsistence use. The ESA listing decision is being reviewed again in 2014, with particular attention to identified threats, such as the entanglement of loons in subsistence fishing nets.

Through this literature review, we have attempted to 1) update information on the prevalence of yellow-billed loon entanglement in coastal gillnets; 2) develop a clear understanding of the wider prevalence of seabird (primarily loons and eiders) entanglement in coastal fishing nets; and 3) most importantly, establish if there are lessons from mitigating unwanted seabird bycatch elsewhere that may be relevant for reducing unwanted yellow-billed loon entanglements in coastal gillnets in Alaska. Information spans peer-reviewed scientific research, agency reports, Traditional Ecological Knowledge, and interviews with key personnel familiar with the issue of seabird entanglement generally, or loon entanglement specifically.

Industrial large-scale driftnets in the northern hemisphere kill many thousands of birds as bycatch. However, it is important that we do not ignore impacts from small-scale fisheries around the world. After the ban on large-scale driftnet fishing in the high seas by the United Nations in 1991 (U.N. Resolution 46/215), the majority of the remaining gillnet fisheries are confined to coastal waters (Žydelis et al. 2009). Coastal fisheries are often operated by local subsistence fishermen involving a large number of small vessels and are inherently difficult to monitor; consequently, there are few studies about bird bycatch in these fisheries or assessment of population-level effects of bycatch (Žydelis et al. 2009, Shester and Michelli 2011). Nevertheless, putative conclusions from reviews of the effects of small-scale fisheries strongly suggest that they deserve closer attention worldwide, and that it is possible that impacts to seabird populations are currently underestimated (Žydelis et al. 2009).

Piscivorous divers such as loons are particularly vulnerable to bycatch mortality because they pursue prey underwater. Consequently, they are caught in high numbers in areas where they overlap with gillnet fisheries, particularly in their wintering ranges (Žydelis et al. 2009). Reporting of loon bycatch is often anecdotal and cannot be easily extrapolated to estimate total bycatch levels or rates, especially for rarer species like the yellow-billed loon. Overall, hundreds of loons are caught each year on their wintering grounds in the Baltic Sea and the Atlantic coast of the United States (Žydelis et al. 2009, Warden et al. 2010). Others are likely caught along the west Pacific wintering areas from Kamchatka in Russia to Japan and Korea (Zydelis et al., 2013), but reporting is sparse except for a few driftnet entanglements between 2003 and 2005 by Japanese and Russian fishermen in the Russian Exclusive Economic Zone (Artukhin et al., 2010 – reported in Žydelis et al., 2013). Individuals to tens of these birds are caught each year on their breeding grounds in Alaska, Canada, and Chukotka (Sformo et al. 2012, Solovyeva 2013). Coupled with concerns over potentially large subsistence-related mortality on St. Lawrence Island, these numbers could be significant to the health of the yellow-billed loon population. However, recent reassessment of the St. Lawrence subsistence harvest has shown that this mortality source is smaller than originally thought. Mortality of yellow-billed loons in the Arctic is exacerbated by their large size and aggressive nature, which places fishermen trying to disentangle them at great personal risk, reducing their chance of release while alive. Eiders are less vulnerable to bycatch in summer breeding areas, since they are benthic feeders and forage very little on the breeding grounds, but they can experience high entanglement mortality in winter when they congregate in large flocks in areas with a high concentration of gillnets. Thousands of eiders are found entangled in gillnets each year in their wintering areas in Greenland – an order of magnitude greater than mortality for loons (Merkel 2011). However, we found no evidence for eider bycatch in Alaska.

Bycatch rates vary by a number of factors including bird abundance and species composition, overlap between bird foraging areas and fishing grounds, fishing gear characteristics, water clarity, and meteorological conditions (van Eerden et al. 1999, Žydelis et al. 2009). However, to date, there has been very little research into the mitigation of bird bycatch in coastal gillnets. This is changing though as bycatch of avifauna continues to gain international attention. Successful mitigation of this problem, where it exists, will depend on the willingness of fishermen and authorities to tackle the problem and to promote the co-existence of fisheries and bird populations. This could be achieved by research that tailors fisheries-specific combinations of mitigation measures for specific regions (Žydelis et al. 2009).

Based on the data currently available, the number of yellow-billed loons entangled in subsistence fishing nets on St. Lawrence Island (Zeller et al.,2012; Naves and Zeller, 2013) and in Chukotka (Soloveyva, 2013) appears relatively small. Entanglement assessment on the North Slope of Alaska suggests persistent unintentional mortality of between 2 and 15 yellow-billed loons per year (Acker and Suydam, 2006; Acker and Suydam 2007; Hepa and Bacon 2008; Hepa and Bacon 2010; Sformo et al. 2012) Federal regulation authorized use in the North Slope region of a maximum of 20 yellow-billed loons per year if found unintentionally entangled in fishing nets (Federal Register vol. 79, NO. 67, 8 April 2014, page 19456). Because of inherent difficulties in precisely estimating entanglement mortality and because this mortality may be unnecessary and avoidable, there remains a desire by all parties to explore opportunities for minimizing bycatch of yellow-billed loons and other birds in coastal gillnets.

Through mutual identification of effective mitigation strategies that can be self-implemented by fishermen, where and when they are needed, we expect that conservation outcomes can be achieved in conjunction with ongoing subsistence fisheries. We have identified the following potentially effectual avenues to consider in mitigating unwanted entanglements of yellow-billed loons, or seabirds more generally, in coastal gillnets; their relative merits are discussed in the body of the report:

1. Restrictions in traditionally used brood rearing areas
2. Training in removing yellow-billed loons safely from the net
3. Bycatch quotas (in place already for yellow-billed loons)
4. Net monitoring in areas of high loon density
5. Visual alerts including predator decoys
6. Alternative gear such as fish traps and modified trap-nets
7. Increased visibility of upper panels of coastal gillnets

TABLE OF CONTENTS

SECTION 1: BACKGROUND TO REVIEW

The yellow-billed loon (*Gavia adamsii*) is an international species of concern, with the global population estimated at 16,650 to 21,000 birds. The International Union for the Conservation of Nature (IUCN) categorized yellow-billed loons as "vulnerable," the United States ESA as a candidate species warranting protection and Russian Red Book Data Books list the yellow-billed loon as rare of low population at risk, while the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assigned a "not at risk' status.

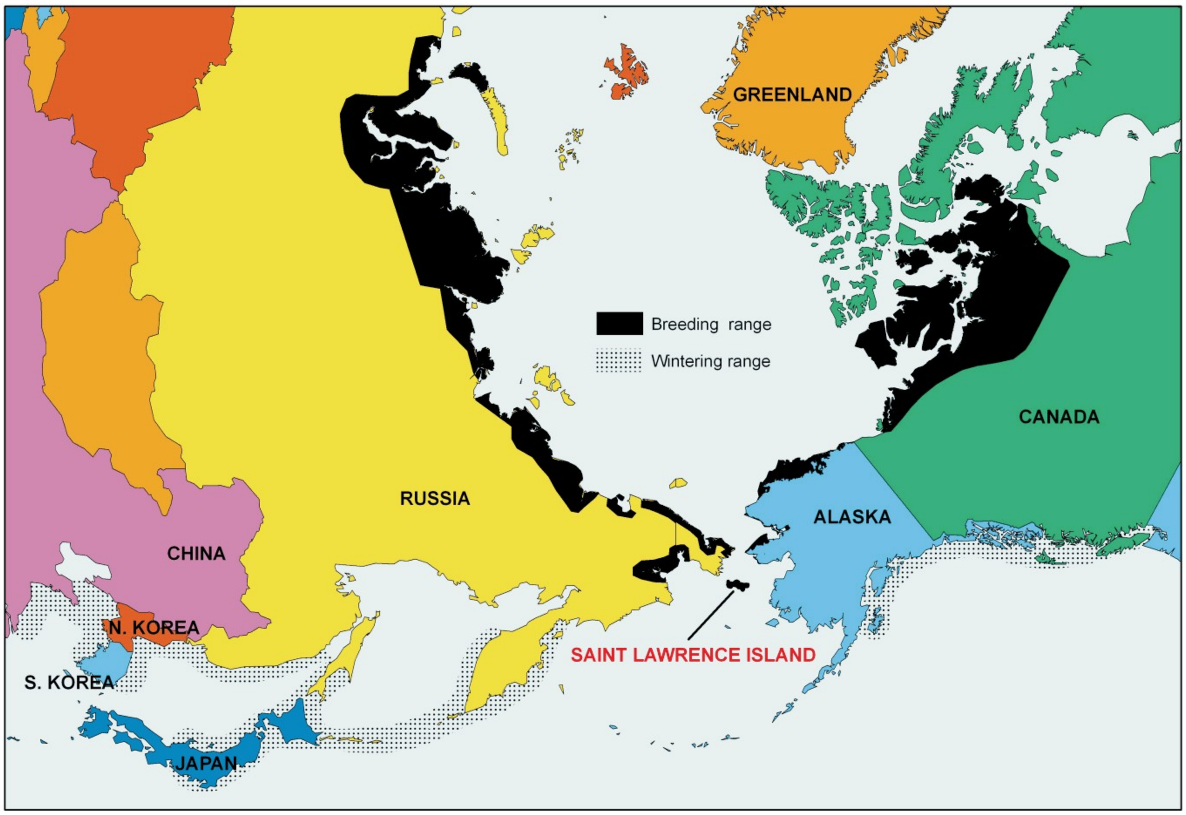

Figure 1. Range of yellow-billed loons

About 20-25 percent of the global population of the yellow-billed loon occurs seasonally in Alaska (Figure 1). Of these yellow-billed loons, approximately 3,300 breed in Alaska across the tundra of the North Slope, and western Alaska north of Unalakleet. In northern Alaska, the loons breed in their greatest concentrations within National Petroleum Reserve-Alaska (NPR-A) lands managed by the Bureau of Land Management (BLM), on State of Alaska lands between the Colville and the Canning Rivers (all areas which have been or will be open to petroleum exploration and development, with accompanying conservation concerns such as loss of habitat and disturbance), and on Alaska Native-owned lands within the North Slope Borough. In western Alaska, yellow-billed loons breed primarily along the coastal fringe of the Seward Peninsula on Selawik National Wildlife Refuge, administered by the U.S. Fish and Wildlife Service, Cape Krusenstern National Monument and Bering Land Bridge National Preserve, administered by the National Park Service (NPS), and on scattered small parcels of BLM and Alaska Native-owned lands. Small numbers of yellow-billed loons also nest on Alaska Native-owned lands located on St. Lawrence Island.

In 2004, multiple United States and Russian organizations petitioned the USFWS to list the yellow-billed loon as threatened or endangered under the Endangered Species Act (ESA), either throughout its range, or as a Distinct Population Segment in the United States, and to designate areas of critical yellow-billed loon habitat. In 2009, the USFWS listed the yellow-billed loon as a candidate species "warranted but precluded by other higher priority listing actions" for protection under the ESA because of life history, small global population, restricted distribution, habitat requirements, and subsistence use. Hunting of yellow-billed loons is closed in Alaska, but a 2005 exception was incorporated into the subsistence regulations for the North Slope, allowing possession of up to 20 yellow-billed loons (annual regional total) inadvertently caught in subsistence fishing nets (50 CFR Part 92) for customary and traditional uses. The ESA listing decision is being reviewed again in 2014, with particular attention to identified threats, such as the entanglement of loons in fishing nets. The goals of this report are to:

1. Place yellow-billed loon entanglement in coastal gillnets in the broader context of entanglement of seabirds;
2. Synthesize data about entanglement of yellow-billed loons across their breeding range to assess if and where there are areas of significant entanglement;
3. Identify significant gaps or uncertainties in the data on entanglement; and
4. Identify the range of mitigation options available for areas where entanglement of yellow-billed loons is regarded as significant.

While small-scale fisheries provide over half the world's wild caught seafood, employ over 99% of fishers, the use of set gillnets in these fisheries has led to some of the highest overall impacts on non-target species, including birds and mammals, and highest discard rates compared to other fishing methods, (Shester and Micheli, 2011). Gillnet fishing is widespread across the Arctic, for offshore and inshore commercial, and subsistence fisheries, as well as for some other purposes such as to remove fish during de-watering of diamond mine lakes in Canada.

Subsistence fishing is important for the customs, traditions, and economies of many indigenous groups in the Arctic. Across the entire breeding range of the yellow-billed loon, rural residents primarily catch fish using gillnets. While gillnets are an efficient method to catch fish, they are also widely regarded as the fishing gear most likely to impact non-target species, such as through bycatch (Žydelis et al., 2013). Furthermore, bycatch rates are species specific; species such as yellow-billed loons that hunt fish by pursuit diving can be ten times more likely

Figure 2. Elijah Kakinya. Photo courtesy and copyright Grant Spearman.

to be caught in fishing nets than benthic-feeding ducks (Dagys and Žydelis, 2002 – reported in Žydelis et al., 2013).

Gillnet use in the Arctic is localized near villages and camps in marine inlets and lagoons, lakes, and rivers, depending on season and target fish species. During the breeding season, yellow-billed loons forage in large lakes close to their nests, as well as other nearby lakes, rivers, and marine areas, where the potential for bycatch in subsistence fisheries exists. Yellow-billed loons may be most susceptible to entanglement during spring and fall migrations when foraging in near-shore marine habitats, and non-breeding birds may be more susceptible than adults, because they spend more time foraging in near-shore environments during the subsistence-fishing season (although this is unverified). Yellow-billed loons are long-lived, with low reproductive potential. Consequently, if being caught in significant numbers, the loss of younger, non-breeding loons in near-shore gillnets could affect recruitment into the breeding population and result in a decline in population as territorial adults age and are no longer able to breed. However, while fisheries bycatch was determined as a threat in the ESA Status Review, the overall frequency, magnitude, and character of mortalities are unknown. For the most part, the ability to quantify the prevalence of yellow-billed loon entanglement in coastal gillnets across their range has been limited to occasional and often anecdotal observations of inadvertent captures in subsistence gillnets in Canada, Russia, and the United States. Survey data are sparse, and frequently subject to numerous biases, including misidentification of species.

Despite the uncertainties regarding prevalence of entanglement of yellow billed loons in coastal gillnets, the acknowledged mortality of these birds in subsistence fisheries in Alaska and elsewhere prompts the need for action among local stakeholders prior to the 2014 ESA Review. On the one hand, ensuring that fishing does not threaten populations of yellow-billed loons is challenging, but experience elsewhere strongly emphasizes that solutions to any unintended bycatch of birds in coastal gillnet fisheries can be found through collaboration between fishermen, scientists, and managers (Chardine et al. 2000; Žydelis et al. 2009; Merkel 2011; Schester and Micheli 2011).

Prior to the USFWS listing action under the ESA, a Conservation Agreement for yellow-billed loons was developed as a cooperative effort among local (including the North Slope Borough), state, and federal resource agencies in northern and western Alaska in order to take measures necessary for the conservation of the species. Strategies in the conservation agreement include: 1) elucidating the frequency and magnitude of loon entanglement in gillnets on the North Slope; 2) assessing the potential population-level effects of entanglement; and 3) conducting outreach efforts to foster reductions in the number of yellow-billed loons incidentally caught in fishing nets.

Our project seeks to build on the efforts made by entities operating on the North Slope under the Conservation Agreement as they operationalize strategies for yellow-billed loons in Alaska, with a particular focus on an additional objective: identifying mitigation options for minimizing the entanglement of yellow-billed loons through review of bycatch mitigation efforts elsewhere and consultation with Alaska Natives. Results from this project will be relevant to the overall conservation of this species by informing international efforts to reduce bycatch.

SECTION 2: GENERAL SEABIRD ENTANGLEMENT IN SUBARCTIC GILLNETS

Incidental catch in fishing gear, along with oil pollution, are considered to be the main anthropogenic factors in seabird mortality (Stempniewicz 1994). When seabirds, fish and fishermen converge in space and time around the world, large numbers of birds, mainly piscivorous diving birds (auks, penguins, shearwaters, gannets, loons, grebes, sawbills, diving ducks), frequently drown as a result of being entangled in fishing gear. Convergence of fishermen and piscivorous diving birds is not by chance; both fishermen and birds are keying in on productive marine areas for the same reason – plentiful prey. Seabirds in particular are vulnerable to a relatively large number of fisheries with hundreds of thousands killed annually after swallowing or being caught by hooks on pelagic and bottom-set longlines (Brothers et al. 1999, Gilman et al. 2005) or when entangled in pelagic driftnets, trawl nets and pelagic and bottom-set gillnets (Piatt et al. 1984, Piatt & Nettleship 1987, Melvin et al. 1999, Žydelis et al. 2013).

Seabirds are typically long-lived, mature late in life, exhibit low fecundity and have variable annual rates of non-breeding; therefore their populations are vulnerable to additional anthropogenic mortality including incidental mortality from encounters with fishing gear (bycatch; Goudie et al. 2000, Furness 2003).

Gillnets are a fishing gear generally made of panels of monofilament or multifilament netting of varying mesh size (~15mm to > 250mm), depending on the target species (Manville 2005). The net hangs in the water, buoyed at the top with floats or a cork line and weighted or anchored at the bottom. This net type, designed to entangle the target species (e.g. salmon, lumpsuckers) by the gillplates, also entangles non-target species including seabirds, turtles, and marine mammals (Manville 2005). These other species may both be feeding in the same area as gillnets or attracted to fish already caught in the nets. Entanglements also occur in lost or discarded nets, and while mortality rates may be low, this type of debris pollution is increasing considerably (Montevecchi 1991).

Gillnets may either be anchored (set-net or fixed gillnet) or attached to a free-floating buoy or the stern of the fishing vessel (driftnet) and vary in length from a few meters to >2.5 km. Gillnets have been used for thousands of years and traditional materials were somewhat visible to seabirds (e.g. hemp and multifilament nylon), but the use of monofilament nylon, which is less visible to birds and practically impossible to break free from, is increasingly common. The large-scale driftnet operations on the high seas using monofilament nets up to 2.5 km in length have very high bycatch, however, the smaller coastal driftnets can also kill a significant number of birds (Sea Around Us Project, 2013).

Entanglement in gillnets occurs both during the breeding season, especially in the vicinity of large seabird colonies, and in molting and wintering areas such as for large eider aggregations (Ainley et al. 1981, Piatt et al. 1984, Piatt and Nettleship 1987, DeGange and Day 1991, Merkel 2011), and varies by species, region, and net parameters. Diving and pursuit-foraging species have been found to be very vulnerable to gillnet fisheries (King 1984, Tasker et al. 2000, Ainley et al. 1981, King 1984, Piatt and Nettleship 1987, Atkins and Heneman 1987). Although bycatch in gillnets is a global issue, the specifics of the problem vary somewhat by region due to variation in type of fishery, abundance and distribution of seabirds both temporally and spatially, and to differences in fishery regulations.

The global magnitude and significance of bird bycatch in gillnet fisheries has not been adequately evaluated, especially for small-scale fisheries. However, Žydelis et al. (2013) estimated that a minimum of 400,000 seabirds die in gillnet fisheries around the world every year. This estimate should be considered a minimum because it does not include regions where bycatch estimates are unavailable, data collection methods that underestimate mortality, birds that drop out of the net, and lost undocumented fishing gear which continues to kill birds (Žydelis et al. 2013). Nevertheless, seabird bycatch was estimated to be even higher prior to the UN moratorium on gillnets longer than 2.5 km on the High Seas in 1992, at which time drifting gillnets in the North Pacific alone were killing an estimated 500,000 birds per year (DeGange et al. 1993, see Žydelis et al. 2013). The highest bycatch by gillnet fisheries worldwide has been reported in the Northwest Pacific, Iceland and the Baltic Sea (Žydelis et al. 2013). Species suffering potentially significant impacts of gillnet mortality include common guillemot, thick-billed guillemot, red-throated loon, Humboldt penguin, Magellanic penguin, yellow-eyed penguin, little penguin, greater scaup, and long-tailed duck (Žydelis et al. 2013).

Below we summarize regional prevalence of coastal gillnet bycatch of seabirds.

North Atlantic

Newfoundland/Labrador – The coastal waters of the northwest Atlantic contain a high concentration of seabird species susceptible to gillnet bycatch including auks, fulmars, seaducks, loons, gannets and cormorants (BirdLife International 2004). Prior to the early 1990s most seabird bycatch in Newfoundland occurred in the Atlantic cod fishery (Piatt et al. 1984, Chapdelaine 1997), which was responsible for approximately 27,500 birds killed per year, 80% of them common guillemots (Piatt and Nettleship, 1987) before widespread fisheries closures in 1992 and 1993 (Benjamins et al. 2008). The near-shore cod fishery was partly reopened in 2001 and it is estimated that 5,000 to 10,000 common guillemots, >2,000 shearwaters (mainly great shearwater), and several hundred loons, gannets, Atlantic puffins and black guillemots were captured in Newfoundland and Labrador each year, mostly in cod and lumpsucker gillnet fisheries (Benjamins et al. 2008). Additional gillnet fisheries include those directed at monkfish, skates, white hake, and Greenland halibut but bycatch associated with those fisheries appears to be low (Benjamins 2008). The inshore fishery in Newfoundland has been concentrated during a few weeks in June and July, when massive schools of capelin (an important food fish for marine piscivorous birds) move into coastal waters to spawn on beaches (Tasker et al. 2000). These schools of capelin are pursued by predatory cod that are caught in traps, gillnets, trawls, and on hand-lines (Tasker et al. 2000).

The risk of entanglement varies by species and depends on the abundance, feeding behavior, diving capacity and behavior near fishing vessels (Benjamins 2008). For example, deeper diving seabirds (e.g. shearwaters and alcids) are generally caught in bottom fishing monofilament gillnets and shallow diving seabirds (e.g. Atlantic puffin, black guillemot, northern gannet) in surface fishing salmon gillnets (Lien 1988, Piatt and Nettleship 1987). Gillnets set for cod in Newfoundland are made of colored monofilament nylon with a mesh size of 14cm generally at or near the bottom in shoal water (20-220m; Bakken and Falk 1998). Salmon gillnets in Newfoundland are made of braided twine of about 13 cm (5 inch) mesh set near the surface. Cod gillnets accounted for 79% of the seabird bycatch in the 1980s while salmon gillnets accounted for 18% (Piatt and Nettleship 1987). The lumpsucker fishery, which expanded rapidly in the 1990s, uses a 22-25 cm mesh at 5-50 m depth, close to shore (Bakken and Falk 1998). Most murres and puffins are killed in fishing gear within 40 km of breeding colonies, and many of the best fishing grounds are in the vicinity of large seabird colonies.

Piatt and Nettleship (1987) recommended that bycatch be reduced through the regulation of timing of use of gillnets to avoid critical periods, the restriction of gillnet use in sensitive areas, and the use of a bycatch quota. However economic and other pressures prevented the implementation of these actions prior to the Atlantic groundfish moratorium in 1992, and since the moratorium there is little pressure to establish any guidelines (Bakken and Falk 1998).

USA Atlantic Coast – Seabird bycatch in Atlantic USA gillnet fisheries is generally thought to have little impact on seabird populations (Soczek 2006, Hata 2006, Žydelis 2013), and no seabird bycatch mitigation measures are required in Atlantic fisheries (Moore et al. 2009). Shearwaters are the most common bycatch (81%) but gulls, loons, auks, gannets, and fulmars are also killed (Soczek 2006). Red-throated loon mortality in nearshore shad gillnets could be unsustainable (Forsell 1999, Warden 2010). Common loons and red-throated loons winter and migrate along the North American Atlantic coast, an area where there are commercial gillnet fisheries operating year round, and there are associated loon mortalities (Forsell 1999, Soczek 2006, Moore et al. 2009). The gillnet fisheries extending north from Rhode Island, primarily use monofilament, anchored, bottom-tending nets, set in strings of 5-15 nets (91m each) of small (<14 cm), large (14-20 cm) and extra-large (>20 cm) mesh sizes. Fisheries from Rhode Island south to North Carolina use monofilament drift and bottom-tending nets in strings of 1 to 10 nets (91m each) with mesh sizes of 6.5 cm to >20 cm. Loon bycatch rates were higher for strings without spacing between nets versus strings with spacing, and for strings that fished ≥24 h versus strings that fished <24 h, possibly because spaces allow birds to pass through the gillnet string (Warden 2010).

Greenland – Historically, seabird bycatch was very high in Greenland due to a large population of seabirds and the commercial gillnet fishery for salmon that killed an estimated 500,000 birds per year in the 1960s and 1970s and may have caused population declines in thick-billed guillemots (Tull et al. 1972, Evans and Waterstone 1978). However, salmon gillnetting has been greatly restricted in recent decades, with mortality reduced to an estimated 50-100,000 birds/year by the 1980s and is thought to be lower still now (Žydelis 2013).

Since the decline of the salmon fishery, the lumpsucker gillnet fishery has expanded and is estimated to kill up to 20,000 eiders per year (Merkel 2011). Common murres, great cormorants, little auks, black guillemots, common loons and black-legged kittiwakes are also reported to be killed, but in numbers that are not expected to impact populations levels (Merkel 2011). We discuss the Greenland lumpsucker fishery in more detail below. There is also a personal use set net salmon fishery in Southwest Greenland and the very limited driftnet commercial fishery that uses 1-3 km monofilament drift nets at the mouth of the fjords or outside the archipelago. There is also a small fishery that uses setnets for Arctic Char (Bakken and Falk 1998). However, we found no reports of entanglement in these latter fisheries.

Iceland – Iceland is home to some of the largest seabird colonies in the world with millions of diving birds at local colonies (BirdLife International 2004) and a large fishing industry (Žydelis 2013). Gillnet fisheries, primarily the lumpsucker fishery, are estimated to have killed as many as 70,000 murres in 1997, the only year for which data are available (Žydelis 2013). Black guillemot and red-throated loons are estimated to be the most susceptible species in proportion to their populations (Žydelis 2013). Overall, an estimated 120,000 birds were killed as bycatch in

2000, and, as in other regions, different species were vulnerable to different gear: alcids are primarily killed in cod nets; whereas inshore feeders such as eiders, loons, and guillemots are caught in lumpsucker nets; and shag, cormorants, and loons are caught in trout and salmon nets (Bakken and Falk 1989; BirdLife International 2012).

Baltic and North Sea – Žydelis et al. (2009) estimated that between 100,000 and 200,000 seabirds are killed annually in near shore gillnet fisheries in the Baltic and North Sea alone. Generally, bycatch composition is correlated with species distribution; sea ducks dominate bycatch in the eastern Baltic, sea ducks and diving ducks dominate in the southern Baltic, auks were most commonly caught in the western Baltic and the North Sea, and diving ducks, mergansers, and grebes were caught in lakes (Ijsselmeer and Markermeer; in Žydelis et al. 2009).

While there is little data on bycatch of eiders in gillnets during the breeding season, Christensen (2008) observed that many common eider ducklings are drowned in gillnets in traditional shallow water brood rearing areas within the first month of hatch in Denmark and suggested that fishing restrictions in traditionally used brood rearing areas could reduce bycatch.

Birds in the Gulf of Gdańsk are at elevated risk for entanglement since fishing is intensive and there are large numbers of birds in the winter, fall and spring. In this area, there are three main fisheries; cod are caught in bottom-set gillnets (mesh size 55 mm) between 10 and 80 m deep, flatfish are caught in bottom-set gillnets (mesh size 60-70 mm) in shallow water (2.5 - 8 m) and herring are caught in surface gillnets (mesh size 24-26 mm) set 1-2 m below the surface in waters >10 m. Nets are generally deployed for a 24 hour period (Stempniewicz 1994).

Although nets are set year round in the southern Baltic, the main fishing season coincides with wintering diving birds. (Stempniewicz 1994). A number of factors seem to influence bycatch rates in the region. Bird entanglement rates varied by fishery; the highest bycatch was recorded with nets of mesh size >35 mm set in shallow water (<20 m), and in areas with higher aggregations of birds (Stempniewicz 1994). Bottom diving birds were at greatest risk from nets set loosely, such as flatfish nets while herring nets were relatively safe for birds because of the small mesh size, unless set loose in very shallow water (Stempniewicz 1994). Additionally, Stempniewicz (1994) found that bycatch increased after storms as birds moved closer to shore, nets were looser, and water transparency dropped. Although herring nets seem to have lower bird bycatch rates than nets of a larger mesh size, common eiders wintering in the southern Baltic are caught at very high numbers relative to their (low) abundance, possibly because eiders concentrate where herring aggregate (Stempniewicz 1994).

Farther north in Lithuania there are both inshore (cod, herring, smelt and salmon) and offshore gillnet fisheries mostly fishing from September through May, which coincides with the wintering and migrating aggregations of seabirds (BirdLife International 2012). Gillnets in this region are generally 600-2,000 m long and soak for 1 day, with mesh size from 18 mm to 120 mm, depending on the target species (Dagys and Žydelis 2002). The salmon fishery uses a large mesh size (> 60 mm) and operates mainly in December; the cod fishery uses a medium mesh size (50-60 mm) and is more active in December, March and April; the smelt and herring fishery uses a small mesh (18-25 mm) and is mostly active in January, February, March and April. Long-tailed ducks, Steller's eiders and red-throated and arctic loons were the most regularly entangled birds in this area (Dagys and Žydelis 2002). Nets of larger mesh sizes, especially salmon nets of >60 mm mesh size, pose the greatest threat (Dagys and Žydelis 2002). Loons were more than 10 times more likely to be entangled than the next most vulnerable species, the long-tailed duck.

Gillnets with a mesh size over 60 mm were almost three times more likely to entangle seabirds than nets with a medium sized mesh and more than five times more likely that nets with a small mesh size (Dagys and Žydelis 2002).

In Latvia there is a coastal gillnet fishery which kills primarily long-tailed ducks and red-throated and Arctic loons (Urtans and Preidneiks 2000, BirdLife Conference). Most bycatch mortality occurs during the spring and fall when birds are migrating and utilizing water depths of 2.5-5 m where the coastal gillnet fishery overlaps with the highest concentrations of seabirds (Urtans and Priednieks 2000). During this time there is a very shallow water fishery (1-3 m) targeting salmon, sea trout, and whitefish. Urtans and Preidneiks (2000) reported that the highest levels of entanglement occurred at night or in the early morning. Bycatch levels were low in June and August, primarily because the birds have moved to their breeding areas in northern Scandinavia or Russia (Urtans and Priednieks 2000). Bycatch was also lower in the winter months (December and January) during years when ice conditions forced the seabirds far from the coast (sea depths of 20-30 m; Urtans and Preidnieks 2000) and the period for the coastal fishery was shortened (Urtans and Priednieks 2000). As was found in the Lithuanian fisheries, salmon gillnets (mesh size 50-60 mm; 5-10 m deep) had the highest entanglement rates, especially in the upper part of the net (Urtans and Priednieks 2000).

Very high seabird bycatch was reported in salmon and cod gillnet fisheries on the Norwegian coast in the 1980s with over 100,000 birds killed per year, mainly murres (Strann et al 1991). A reduction is fishing effort as well as bird populations have resulted in an estimated 7-8,000 birds per year now being killed in the salmon, cod and lumpsucker fisheries (Fangel et al. 2011). The combination of large numbers of diving seabirds and the high density of gill-nets represents a great hazard for the birds and a serious nuisance to the fishermen because of the time needed to disentangle dead birds. Entanglement is particularly high when the capelin spawn in shallow water in northern Norway in late winter (Strann et al. 1991). The spawning capelin are followed by predators such as cod and diving seabirds to their spawning areas, where large numbers of gillnets are set for the fish (see Strann et al. 1991). The salmon driftnet fishery using large mesh nets of 600-1,200 m in length has been significantly reduced since 1989 but was particularly hazardous to seabirds with more than 1,000 auks commonly being caught in a single 1-3 hour drift when the fishery peaked between 1977 and 1984 (Strann et al. 1991).

Great Lakes

Common loons are caught in commercial trap net fisheries in the Great Lakes (Evers 2004). Trap nets differ from gillnets in that they have long, strung-out wings of netting and are used to capture schools of trout and whitefish, but they have a similar problem with entanglement. Loons are attracted to the fish activity in the trap net and readily enter the heart of the net where they are entangled and often drown (Evers 2004). Shallow sets, where the top of the net is at the water surface, can have an even greater impact; if the loon is able to surface but remains trapped, its struggling movements attract nearby loons that are eventually caught in the same way and drown (Evers 2004).

North Pacific

*Northwest Pacific-.*The northwestern waters of the Pacific Ocean bordering China, Russia, Japan, and the western Aleutian chain have an exceptionally high diversity and abundance of diving birds, including auks, seaducks, loons, grebes, cormorants and shearwaters (Žydelis 2013). There were two large Japanese drift gillnet fisheries for salmon, a mothership fishery and a land-based fishery that developed after the 1950s. The land-based fishery has an offshore component and an inshore component. The inshore land-based fishery killed an estimated 151,000 seabirds in 1977 which decreased to ~57,000 seabirds in 1987 because of a reduction of fishing effort (DeGange and Day 1991). In the 1970s it was estimated that hundreds of thousands of birds were dying annually in the region (Ainley et al. 1981, DeGange and Day 1991). Catch-rates of seabirds varied by oceanographic zone with the highest seabird bycatch in the waters north of the subarctic front (DeGange and Day 1991).

The UN banned large-scale driftnet fishing on high seas in 1991 and the US Exclusive Economic Zone (EEZ) was also closed. However, Russia has allowed the Japanese drift-net fleet to salmon fish in the Russian EEZ. The estimated annual bycatch of seabirds in this fishery was 94,330 (CI 70,183–118,478) between 1993 and 2001, primarily auks, murres and short-tailed shearwater (see Žydelis et al. 2013). Yuri Artukhin estimated that Japanese vessels operating in the Russian EEZ killed 1.6 million birds between the early 1990s and 2008 while the Russian vessels killed 645,000 birds resulting in a total bycatch of 140,000 birds/year in the Russian EEZ (BirdLife International 2012). The Japanese and Taiwanese large mesh fishery for albacore and billfish may also entangle seabirds, but little data are available to assess mortality (DeGange et al. 1990)

Gillnet kills in inshore areas of the north Pacific are fewer, but may be having a proportionately greater impact on seabird populations (Tasker et al. 2000). For example, off the coast of Japan, 1,650 ancient murrelets were found drowned in inshore nets in 1990 alone (see Tasker et al. 2000).

Northeast Pacific-. The coastal and offshore waters of the US and Canada support a high diversity and abundance of seabirds in areas where modern gillnetting has been ongoing since the 1930s, with fishing effort increasing in the 1970-80s (DeGange et al. 1993). High levels of bycatch of common murres were estimated in the 1990s (Julian and Beeson 1998, Forneyet et al. 2001) resulting in increased regulation of this fishery. By 2000 the coast of California was closed to gillnets <60 fathoms deep (Žydelis 2013) which has greatly reduced the bycatch of murres (Carretta and Chivers 2004). In British Columbia seabird bycatch in the salmon gillnet fishery was estimated to be ~12,000 seabirds per year, primarily common murres, rhinoceros auklets, and lower numbers of marbled murrelets, sooty shearwaters, pelagic cormorants, pigeon guillemots, common loons, Pacific loons, Brandt's cormorants and Cassin's auklets (Smith and Morgan, 2005). Žydelis et al. (2013) estimated that ~20,000 birds were caught annually in gillnets along the Pacific coast of US and Canada in recent years. Vessels licensed to catch salmon in British Columbia catch fish with gillnets and seine nets. Coastal gillnet vessels are generally less than 15 meters in length, set below the surface and are typically constructed of a multi-strand mesh comprised of 30 or more filaments in each twine. The Alaska Twist, which is made from 6 or more filaments twisted together in each twine, has also been in use since 2005 (Smith et al. 2005). The Alaska Twist nets caught fewer birds than the multi-strand net (38% versus 62%) and caught more sockeye, coho and pink salmon than multistrand nets (Smith et al. 2005).

In British Columbia, some nets were modified with a drop weedline to reduce the bycatch of steelhead and other fish species; the fishing industry also speculating that drop weedlines could secondarily reduce seabird bycatch. Drop weedlines consist of a 1-2 m net-free area, directly below the cork line. However, the drop weedline may actually increase seabird bycatch because the net-free area gives the appearance that there is nothing hanging below the surface and birds become entangled in the unmodified net hanging further down (Smith et al. 2005).

In the late 1990s, a modification of the monofilament gillnets was tested; the upper 20 to 50 meshes were constructed of white seine twine, which became known as “high visibility panels”. Melvin et al. (1999) found that seabird bycatch rates declined with the use of the modified nets and there was no reduction in the target catch, probably because most birds were entangled in the upper five meters of unmodified nets and the high visibility panels alerted birds to a net below the cork line and caused them to avoid it. Melvin et al. (1999) also suggested using acoustic pingers because they reduced seabird bycatch. Unfortunately, nets with pingers attracted more seals than nets without them, increasing conflict with fishermen (Smith et al. 2005). Timing of the period when gillnets can be deployed is most important during the breeding season because many nocturnal seabirds travel to and from the colony at dawn and dusk. Smith et al. (2005) reported that nets set at dawn caught the most birds, no birds were caught in the dark, but that it also varied by species; common murres were caught with equal frequency at dawn or dusk, while rhinoceros auklets were caught most frequently at dawn.

Relatively little gillnet bird entanglement information is available from Alaska (Žydelis et al. 2013), although seabird diversity and abundance are very high and therefore there is a potential conflict with the extensive gillnet fisheries (Piatt et al. 2007). Only two salmon fisheries were monitored as of the early 1990s; the Prince William Sound salmon drift and set gillnet fishery was estimated to kill 1,230 birds annually in the early 1990s, and the Unimak Pass salmon drift gillnet fishery, which killed on average 337 birds annually (Bakken and Falk 1998). The Kodiak Island salmon set gillnet fishery reported bycatch of 528-1,097 seabirds per year in the early 2000s, with the most common species being common guillemot, tufted puffin, pigeon guillemot, marbled murrelet, red-faced cormorant, pelagic cormorant and lower numbers of other species (Manly 2007). Overall in Alaska, there is little overlap between commercial gillnet fisheries and loons or eiders; the Alaskan commercial fisheries in the Gulf of Alaska and Southeast Alaska primarily operate during the summer when adults and some proportion of immature birds have moved north to Arctic habitats, limiting their impact (Federal Register Notice Vol.74 No. 56 March 25, 2009). Nevertheless, red-throated loons have been reported to be killed from bycatch in the summer in salmon gillnet fishery in Yakutat Bay, Alaska, (Schoen et al. 2013).

SECTION 3: ENTANGLEMENT OF YELLOW-BILLED LOONS

For this study we define Arctic oceanographically by the presence of seasonal or perennial sea ice.

Subsistence Bycatch

Loons are piscivorous, diving seabirds and as such, are particularly vulnerable to entanglement in gillnets in both breeding and wintering areas (Dagys and Žydelis, 2002, Schoen et al. 2013). Yellow-billed loon entanglement is of current concern (this review). Across the breeding range of the yellow-billed loon, rural residents fish primarily using gillnets. Gillnet use is localized near villages and fish camps, in marine inlets and lagoons, lakes, and rivers, depending on season and target fish species. During the breeding season, yellow-billed loons will forage in large lakes close to their nests, as well as other nearby lakes, rivers, and marine areas (Earnst 2004), where the potential for bycatch in subsistence fisheries exists. Because yellow-billed loons are widely dispersed across their nesting grounds, however, a large proportion of the breeding population is likely not exposed to localized subsistence fishing. Yellow-billed loon bycatch data are primarily anecdotal and cannot be extrapolated to estimate total bycatch levels or rates. Seasonal variation in loon bycatch is dependent on the temporal overlap of fisheries and bird presence.

Limited observations confirm that yellow-billed loons have been inadvertently caught in subsistence gillnets in Canada (Parmelee et al. 1967), Russia (Solovyeva 2013), and the United States (Sformo et al. 2012), although the level of bycatch is not extensively documented. In Alaska, detailed information on loon bycatch from subsistence fishing is available only for the Arctic Coastal Plain (Sformo et al. 2012). In 2005 in the USA, an exception to the 2003 Alaska spring/summer migratory bird subsistence harvest regulations for the North Slope region was incorporated into the regulations allowing possession for subsistence use of up to 20 (total for the region each year) yellow-billed loons inadvertently caught in subsistence nets (50 CFR Part 92), for subsistence and ceremonial purposes (Hepa and Bacon 2008).

Under the Alaska Migratory Bird Co-Management Council (AMBCC) regulation allowing possession of yellow-billed loons, fishermen on the North Slope are required to report their catch to North Slope Borough Department of Wildlife Management (NSBDWM), which provides a summary report to the AMBCC at the end of the fishing season. While participation by fishermen is incomplete and data is subject to several biases, NSB can estimate total bycatch from these surveys, finding that between two and 15 yellow-billed loons were annually killed in subsistence nets between 2005 and 2011 in Barrow (Acker and Suydam, 2006; Acker and Suydam 2007; Hepa and Bacon 2008; Hepa and Bacon 2010; Sformo et al. 2012). Some loons, including yellow-billed loons, were found entangled but alive in fishing nets, and were released. Numbers of mortalities are a minimum estimate of yellow-billed loon subsistence bycatch in the Barrow area because not all fishermen were contacted (Hepa and Bacon 2008). Additionally, evidence suggested that some yellow-billed loons accidentally killed in fishing nets in Alaska are only reported as part of the subsistence harvest, and not specifically as fishing bycatch (USFWS 2010) making monitoring difficult. An unknown proportion of loons, including yellow-billed loons, reported in the subsistence harvest survey for the North Slope region were actually harvested after unintentional entanglement in fishing nets rather than through hunting. For all loon-species, 33 of 60 (47%) loons reported as harvested in 2007 and 2008 were entangled in fishing nets. For the other loons reported, there is no information on whether they were shot or entangled in fishing nets (Naves 2010a, pg. 170; Naves 2010b, page 56; USFWS 2010, pg 21).

This suggests that in the North Slope region, additional loons (potentially including yellow-billed loons) may be taken as fisheries bycatch. Furthermore, there is no ethnobiographic information indicating that loons are currently hunted on the North Slope at all (J. Bacon, North Slope Borough, personal communication in USFWS 2010, pg 21). The contributions of hunting and entanglement to the total take of loons in subsistence harvests may differ among regions. For instance, on St. Lawrence Island, tens to a few hundred loons (of all species combined) are estimated to be taken annually through hunting, while numbers of loons entangled in fishing seem relatively small (see below; Naves and Zeller, 2013; Naves 2014).

To better quantify yellow-billed loon bycatch, the North Slope Borough developed a new bycatch survey tool in 2011. All potential fishers who may have fished near Barrow, Atqasuk, and Nuiqsut were surveyed to estimate the number of yellow-billed loons inadvertently entangled in subsistence fishing nets (Sformo et al. 2012). One hundred and twenty five surveys were conducted (97% response rate) and 26 entangled yellow-billed loons were reported, with seven released alive (Sformo et al. 2012). Of these, four loons were kept for traditional and ceremonial purposes (Sformo et al. 2012).

On St. Lawrence Island, two loons (a red-throated and an unidentified non-breeding loon) were reported as harvested after their entanglement in summer fishing nets during 2011 and 2012 (Naves and Zeller, 2013). Based on this information, the number of loons entangled in fishing nets on St. Lawrence Island seems to be low. Naves and Zeller (2013) report loon species composition for fall, but note that species composition on SLI is most likely very different in summer when there are a few resident breeding loons versus the fall when many loons pass through on migration. Based on the two entangled loons killed between 2011-2012 in subsistence gillnets and reported as subsistence harvest (8% of harvest), extrapolated to 330 loons to account for non-surveyed households, an estimated 2.64 loons of all species combined over 2 years, or 1.3 loons of all species combined per year were entangled. Given the loon species composition in fall on St. Lawrence Island is comprised of less than 5 % yellow-billed loons (Naves and Zeller 2013), this would result in a catch rate of less than 1 yellow-billed loon every 10 years. Despite the substantial uncertainty in such a calculation, the result is indicative of relatively low bycatch of this species on St. Lawrence Island.

Gillnet fishing impacts on yellow-billed loons in Russia are generally unknown; however, there are fishermen using gillnets in nearshore marine areas between July and September, in rivers June through October, and in lakes August through September targeting whitefish (Solovyeva 2013). The Red Data Book of the Russian Federation (2001: 366-367) states that yellow-billed loon mortality in fishing nets is the main threat to the species, with bycatch rates described as "catastrophic" in the Chukchi Peninsula region (Red Data Book of the Russian Federation 2001, p. 366-367). Syroechkovski (2008) reports recent accidental entanglement of yellow-billed loons in fishing nests and deliberate shooting to scare loons from fishing areas. However, it appears that the prevalence of entanglement of loons (any species) in fishing nets in West Chukotka is low (although there have been occasional uncharacteristically high numbers of birds caught (e.g., 12 in year), based on a survey conducted in Chaun Bay and associated rivers (Solovyeva 2013). Although a few loons could be removed alive from nets, fishermen generally prefer to kill the loons prior to disentanglement as live loons can do significant damage to a fishermen with their beaks (Solovyeva 2013).

There are local subsistence fisheries and some small commercial enterprises in arctic Canada (including the waters of the Yukon, Northwest Territories, and Nunavut) but little if any data on seabird bycatch (Bakken and Falk 1998). The most important fishery in Arctic Canada is for Arctic Char, which are caught in monofilament gillnets set close to shore, often in the mouths of rivers (Bakken and Falk 1998) which do have the potential to entangle diving birds such as guillemots, eiders and loons since these species frequent very near-shore waters. Anecdotal evidence exists for Victoria Island, Nunavut and NWT, where yellow-billed loon entanglement in nets was reported on several occasions, including one instance where seven birds were killed in nets in a single day (Sutton 1963; Parmelee et. al. 1967). There is potential for entanglements of wintering yellow-billed loons on the British Columbia coast, but no records were found.

Commercial Bycatch

Yellow-billed loon bycatch in commercial fisheries has been documented anecdotally or by observer programs in Washington State, Russia, and Norway. No data exist from large portions of the species' wintering range (Yellow Sea, Sea of Japan, and coastal Japan), but bycatch is likely to occur due to extensive gillnet fisheries that overlap with wintering yellow-billed loons. Yellow-billed loons have been reported entangled by the Russian and Japanese driftnet fleet fishing in the Russian EEZ, 1993-2005 (Žydelis et al. 2013).

The Alaskan commercial fisheries most likely to catch yellow-billed loons are gillnet fisheries in the Gulf of Alaska (Prince William Sound and Cook Inlet) and Southeast Alaska (Federal Register Notice Vol.74 No. 56 March 25, 2009). While these fisheries overlap spatially with areas used by yellow-billed loons during winter, the fisheries operate primarily during summer when adults and an unknown proportion of immature loons have moved north to arctic habitats.

Other Loon Species

In Alaska, other species of loons (at least Pacific) are anecdotally reported as caught in subsistence and research fishing nets in northern and northwest Alaska (Larry Moulton and Rich Driscoll, pers. comms. with Debbie Nigro, 2012; Willie Goodwin, pers. comm. with Melanie Flamme, 2012). Red-throated, and Pacific loons have been reported entangled in gillnets in the Canadian Arctic (see Barr et al. 2000, Russell 2002), but only qualitatively. Common Loons are known to be killed in commercial fishing activities in freshwater lakes in the breeding areas at Lac La Biche, Alberta, Great Slave Lake, NWT, Lake Winnipigos Manitoba and Cambridge Bay NWT (see Vermeer 1973). Additionally, during the dewatering of tailings ponds around mines fish are caught by gillnet and have resulted in occasional loon entanglements across the Canadian north (Diavik 2006).

SECTION 4: ENTANGLEMENT OF EIDERS

Eiders are benthic-feeding, diving seabirds and although less vulnerable than piscivorous species, are killed in gillnets in very high numbers when their wintering areas overlap with commercial or subsistence fisheries (Merkel 2011). Eiders are caught in gillnets set in coastal waters, rivers and lakes (Atkins and Heneman 1987, Forsell 1999, Dagys and Žydelis, 2002, Benjamins 2008, Warden 2010, Merkel 2011). Eiders are a large seabird which spend part of their life cycle in coastal areas and are caught in large numbers in gillnets, and they are a species where mitigation has been discussed extensively; therefore we have devoted this section to eiders as being comparable to yellow-billed loons.

Common eiders experience levels of entanglement mortality, primarily in commercial fisheries, that are of thought to be of a conservation consequence (Tasker et al. 2000, Merkel 2011). Subsistence fisheries may also be of concern. Across the Arctic, gillnets are used in subsistence and commercial fisheries (Evers 2004, Spearman 2005) in areas where eiders occur. Russia has two main northern fishing areas. The western area, comprised of the Barents and White seas, and the eastern area, comprised of the Chukchi, Bering and Okhotsk Seas. There is a salmon fishery using mesh nets at river mouths in both the eastern and western areas and a fishery using mesh nets at sea in the eastern area, but these are assumed to have low bycatch mortality, probably less than 10,000 birds annually (Bakken and Falk 1998).

In Alaska, spectacled, king, and common eiders feed very little during the breeding season, and males are generally only on land for 1-2 weeks (Goudie et al. 2000, Petersen et al. 2000, Powell and Suydam 2012) likely limiting their vulnerability to entanglement. However, there is the potential for entanglements at staging areas such as Harrison and Smith Bays if gillnets are used there, although no information on entanglements was found.

In Greenland, lumpsucker and cod gillnets have been identified as key sources for bycatch of eiders in several countries, and entanglement mortality is especially high in Greenland (Bakken and Falk 1998, Merkel 2004, Žydelis et al. 2009). Common and king eiders winter sympatrically in the shallow coastal waters of southwest Greenland in high numbers (Merkel et al. 2002), where they are an important game species both commercially and for subsistence (Christensen 2001), both populations experienced declines in the 1990s (Gilchrist et al. 2001, Merkel 2004), but the common eider population appears to have increased more recently (Merkel 2010). Both species are vulnerable to bycatch mortality in lumpsucker, cod, and seal gillnet fisheries in Greenland (Merkel 2004). The lumpsucker and cod fisheries have increased considerably since the 1990s, and the lumpsucker fishery in particular seems to be of conservation concern to wintering king and common eider populations where it is estimated to kill up to 20,000 eiders/year in Greenland (Merkel et al. 2002, Merkel et al. 2004, Merkel 2011). Lumpsuckers are mainly caught for their roe, which is produced in March, April and May, in shallow bays along the outer coastline or in the fjords using monofilament nets (see Merkel et al. 2004). These spawning areas often overlap with the foraging areas of the eiders and occasionally the birds feed directly on the eggs (Merkel et al. 2007). The lumpsucker fishery accounted for 86% of the eider bycatch in the early 2000s, while the cod fishery accounted for 11% and the seal gillnet fishery for 3% (Merkel 2004). Gillnet bycatch of eiders in Greenland, as extrapolated from market surveys, removed 30% of the reproductive potential for the region’s eiders. There is significant variability in the bycatch numbers and the relative impact on the eider populations (proportion of adults killed) between different fishing areas (Merkel 2004) suggesting that regulation of fishing by areas could be a viable mitigation option. Bycatch is particularly high in April; and is of high management concern for common eiders in the fjords, as the fjord system is used by a disproportionally high number of adult birds. Eiders primarily feed during the dark or at dusk in the fjords of Greenland and feed during the day in coastal areas and are consequently killed in higher numbers as bycatch during these times (Merkel 2004).

SECTION 5: BYCATCH REDUCTION AND MITIGATION

Thus far there are no technological solutions known that universally mitigate seabird entanglement in gillnets. This is partly due to the large variety of gillnet configurations, and the high diversity of target fish species and affected birds, but it also reflects the modest investment in mitigation research to date. Mitigation options can be loosely grouped into three categories; reduction in fishing effort, spatio-temporal measures, and gear modification (Melvin et al. 2009, Žydelis et al. 2013). Spatio-temporal measures are those that separate effort from bird distribution in space or time (e.g. time of day fishing restrictions). While the numbers of birds being caught in some regions is justification alone for mitigation, there is also evidence that mitigation does not necessarily have to come at the expense of fishing. For example, one study from the 1990s indicates that it is possible to reduce gillnet bycatch by up to 70-75% (without serious reductions on target fishing efficiency) by means of three complementary tools—gear modification, abundance-based fishery openings (see below), and time-of-day restrictions (Melvin et al.1999).

Reduction in fishing effort

Protected areas (e.g. near seabird colonies), regulation of overall fishing effort, buy-outs and/or instituting bycatch quotas may be some of the most effective measures for reducing entanglement of seabirds in fishing nets (Piatt and Nettleship 1987, Lien 1988, Senko et al. 2013, Žydelis et al. 2013). However, these measures are clearly among the least attractive to fishermen, particularly locally where fish may be a critical component of local economies or food security. A buy-out involves either the purchasing of fishers' vessels, permits or gear, or the compensation of fishers for reducing fishing time or for switching gear types (Senko et al. 2013). Bycatch limits are usually determined by the calculated "potential biological removals" and biological opinions. Imposed costs on a fishery for exceeding the cap require observers on most vessels to implement this regulation and are particularly difficult to enforce in small-scale fisheries and in countries that cannot afford observer programs (Senko et al. 2013).

Spatio-temporal measures

Many authors have considered spatio-temporal management of fishing effort as one of the most viable solutions for bycatch mitigation in gillnet fisheries, which, when fine-tuned for local conditions, could allow coexistence of gillnet fisheries and critical bird habitats. These restrictions fall roughly into four categories; time-of day, area, depth, and abundance-based fishery management.

Time-of day restrictions. Bird bycatch rates can vary throughout the day depending on the abundance and behavior of birds in the area. By obtaining an understanding of the patterns of abundance of both target and bycatch species, fishing operations can be adjusted to minimize chances of bycatch events while not reducing target species catch rates (Bull 2007). Timing of openings are most important during the breeding season because many nocturnal seabirds travel to and from colonies at dawn and dusk. Smith et al. (2005) reported that nets set at dawn caught the most birds in several areas, no birds were caught in the dark, and rates vary by species; common murres were caught with equal frequency at dawn or dusk, while rhinoceros auklets were caught most frequently at dawn (Melvin et al. 1999). Adjusting the daily timing of fishing operations to avoid peaks in entanglement from at-risk bird populations significantly reduced bycatch without heavily impacting catch rates of target species (Melvin et al. 1999). In Newfoundland the highest bycatch occurs when the capelin come inshore to spawn. Regulating the timing of use of gillnets would likely minimize bird bycatch (Piatt and Nettleship 1987). Eiders in Greenland are mainly caught in the fjords in gillnets at night because these birds only feed during the dark or at dusk, while eiders at coastal areas mainly feed during daytime. Although untested, it would likely be effective to introduce time-of-day restrictions, allowing lumpsucker gillnetting only during daytime in the fjords (Merkel 2004, Merkel 2008). This would, however, mean less flexibility for the fishermen, and it is not clear how this would affect lumpsucker catches, and successful bycatch reduction will rely heavily on the acceptance and cooperation with the local fishermen (Merkel 2004, Merkel 2011).

Area restrictions. Restrictions on the use of gillnets in particularly sensitive areas, such as around major seabird colonies and important wintering areas, possibly on a temporal basis, would limit bird bycatch for colonial nesting species and species which winter in large flocks (Piatt and Nettleship 1987, Dagys and Žydelis 2002). Benjamins et al. (2008) highlighted that seasonal closure of the Newfoundland and Labrador lumpsucker fishery during the arrival of birds at their breeding colonies would be a useful mitigation tool. In Greenland, Merkel (2011) suggested that a mitigation option would be to restrict the lumpsucker fishery in areas with the highest bycatch as wintering aggregations of eiders are not distributed evenly across the area. Wintering bird abundance and distribution is very uneven on the Lithuanian coast (Dagys and Žydelis 2002) and restrictions on gillnets in some areas may lessen bycatch rates. Fine scale regulation of gillnets within regions requires detailed area-specific information on bycatch and may not be feasible for all regions and species.

Davoren (2007) found that the biomass of birds, primarily common murres, was concentrated and formed a biological hotspot with marine mammal species near two persistent (across years) capelin spawning sites along the Newfoundland coast. The formation of this hotspot was well defined in space and time from the middle of July to the middle of August, likely coinciding with the spawning chronology of capelin. Within this hotspot, there was a high spatial and temporal overlap of common murres and cod gillnets, resulting in high bycatch rates. This is an example of a system where restricting use of gillnets during a short period of time in a relatively limited area would minimize murre bycatch and would help maintain ecosystem integrity, although catching pre-spawned fish would be impacted (Davoren 2007).

Restrictions in fishing depth. The majority of diving birds prefer shallow waters and most seabird bycatch in gillnets occurs in depths of less than 20 m (Stempniewicz 1994, Melvin et al. 1999, Urtans and Priednieks 2000, Žydelis et al. 2002, Bellebaum et al. 2013). Therefore restrictions on fishing depth may be a potential mitigation measure (Crawford 2013). However, this is only viable where the target species can continue to be caught at greater depths, and where reaching these depths to fish is operationally feasible. In California, the ban on gillnetting in depths <60 fathoms has nearly eliminated formerly high bycatch of common murres (Carretta and Chivers 2004). In the Japanese high-seas drift gillnet fishery for flying squid, seabird entanglements were compared between nets submerged 2 m below the surface and traditional surface nets. Seabird bycatch was significantly reduced in submerged nets; however, fishing efficiency was also reduced by up to 95% (see Løkkeborg 2011). It was also found that submerging driftnets at 2 m below the surface significantly reduced seabird bycatch in the northern Pacific (Hayase and Yatsu 1993). According to these findings, regulating the depths at which gillnetting occurs could substantially reduce bird mortalities. Consideration would need to be given to the impacts that this would have on fish catch rates.

Abundance-based fishery openings-. Abundance-based fishery openings represent the idea of allowing the target fishery only in periods when catch per unit effort is very high. The total fish catch can be secured by only a small increase in effort at such times, and bycatch will be reduced because total fishing effort is reduced. For example, Merkel (2011) suggested that if the lumpsucker fishery in Greenland was postponed until May, a large proportion of the eider bycatch could be avoided, as many eider have left the wintering areas by this time, and that fishermen may have the opportunity to compensate for lost income in April by increasing fishing effort in May. A comparison of the eider bycatch and lumpsucker landings in April and May, suggests that the bycatch rate in May was only half of the level in April. This could be implemented throughout Southwest Greenland, or limited to the fishing areas with the highest bycatch risk. An alternative option would be to restrict the lumpsucker fishery in areas with the highest bycatch, however this option would require detailed area-specific information on bycatch (Merkel 2011). Similarly, in Puget Sound, Melvin et al. (1999) showed that restriction of fisheries to the period of peak salmon abundance could reduce seabird bycatch whilst maintaining a good fish catch.

Gear modification

Certain net characterizations have been shown to be important in determining bird bycatch, including mesh size, net visibility, net droopiness, height and number of buoys, acoustic alerts, visual alerts, and net acoustic reflective properties (van Eerden et al. 1999, Dagys and Žydelis 2002, Žydelis et al. 2013).

Net mesh size-. Net mesh size differs depending on the target fish species and is an important feature affecting bird entanglement. For example, surface set nets with a large mesh size (>60 mm) set for cod or salmon had entanglement rates almost six times higher than bycatch rates in small mesh nets (18-25mm) set for herring and smelt on the Lithuanian coast (Dagys and Žydelis 2002). As a result of this research, restrictions on the gillnet fishery were proposed in certain areas, for the protection of wintering seabirds. These restrictions included a ban on the most dangerous gillnets (mesh size 50 mm and larger) during the seabird wintering period in waters up to 15 m in depth.

It is important to note that any reduction in mesh size (if deemed a suitable bycatch mitigation option) would be detrimental to fish stocks through capture of smaller sized fish, and would have to be carefully considered. Also, it can be a challenge to decoupling certain design features of gillnets (e.g. mesh size and filament thickness are linked). Further work is required to identify if this is a viable mitigation option, with consideration of the potential impact on fish stocks (i.e. risk of excessive capture of smaller size classes of fish; Crawford 2013).

Net visibility. Net visibility (filament thickness, color, material), can affect bycatch rates (van Eerden et al. 1999, Žydelis et al. 2013). The introduction of monofilament netting has increased seabird bycatch rates as a result of reduced net visibility (DeGange et al. 1993). There is a need to take into account foraging methods of bird species at risk, especially the difference between benthic feeders (forage in turbid waters and also nocturnally) and pursuit feeders (highly visual hunters) when considering visual gear modifications. Increasing net visibility may have little effect for species which come in contact with fishing gear in poor visibility conditions (e.g. benthic foraging eiders are often caught at night in Greenland). It is important to address the fact that more visible nets may also reduce catches of target species. Ten years ago, attempts were made to increase visibility of gillnets in the Baltic, but these nets proved difficult to operate for unspecified reasons so the attempt was abandoned (BirdLife International 2012).

Most birds are entangled in the upper five meters of gillnets and high visibility panels at the top of the net may alert the birds that there is a net below the cork line and allow them to avoid it. In the late 1990s, a modification of the monofilament gillnets was tested; the upper 20 to 50 meshes were constructed of white seine twine, which became known as "high visibility panels". Melvin et al. (1999) found that seabird bycatch rates declined with the use of the modified nets and there was no reduction in the target catch with the 20-mesh high visibility panels although 50-mesh high visibility panels did reduce target catch.

Salmon gillnets in British Colombia are typically constructed of a multi-strand mesh comprised of 30 or more filaments in each twine. Alternatively, the Alaska Twist, which is made from 6 or more filaments twisted together in each twine, may be used (Smith et al. 2005). The Alaska Twist nets caught fewer birds than the multi-strand net (38% versus 62%) and caught more sockeye, coho and pink salmon than multistrand nets (Smith et al. 2005). However, it is unclear which attributes of the two types of nets caused these differences. Nets may also be modified with a drop weedline to reduce the bycatch of steelhead and other fish species; however, the drop weedline seemed to increase seabird bycatch because the net-free area gives the appearance that there is nothing hanging below the surface and birds become entangled in the unmodified net hanging further down.

The visibility of the net may also be affected by age of the net and material. Fishermen in Cordova, Alaska tend to use as low a strand count as possible (given that monofilament is illegal, and that multi-strand twine needs to have at least 6-8 strands to be strong enough to hold a fish). The reason for wanting low-strand count web is partly that silt gathers in the strands, making the web more and more visible over the life of the net. (Rosemary McGuire, Cordova gillnetter, pers. comm). Gillnetters in Alaska chose their gillnets from a whole palette of colors, with the aim of matching net color to water color to reduce visibility (Raphael McGuire, Haines gillnetter, pers. comm), and as far we can determine, there have not been any studies of net colors (beyond white) and bird entanglement rates to determine if there are certain colors that optimize fish catch and limit bird bycatch.

Visual alerts. Visual deterrents including Light Emitting Diodes (LEDs), pingers, decoy predators (e.g., eagles or owls) mounted on buoys, colored corks, and light sticks have been suggested as possible visual deterrents to birds. Light sticks and LEDs have been used to increase the visibility of nets, but primarily as a mitigation measure for sea turtles (Crawford 2013). Some preliminary work in Peru suggests they may also be effective in reducing seabird bycatch in gillnets, but the evidence is anecdotal at present (Crawford 2013). Melvin et al. (1995) tested whether nets with red rather than the traditional white corks would reduce seabird entanglement in Washington, USA, and found that there was no difference in entanglement rates. Žydelis et al. (2009) reported work in the Netherlands (Witteveen and Bos, 2003) showing that buoys equipped with visual bird deterrents reduced the number of drowned birds, however the details of the study are unavailable in English and were only cursorily addressed in this report (Žydelis, pers. comm. 2014). Žydelis (pers comm. 2014) experimented with different net fixes in Lithuania over the last decade, but with no success. These included bright red floats at the surface (birds were observed diving next to them), nets of different colors, and nets with bright ropes stretched through the net meshes, but there were no reliable results suggesting lower entanglement rates.

A preliminary study was done in Iceland in 1977, using common loon decoys to deter ducks and grebes from trout nets as loons are aggressive toward them. This study was inconclusive, likely because the decoys were not very realistic, and had the side effect of attracting loons to the net (Aevar Petersen, pers. comm. 2014).

Acoustic alerts. Acoustic pingers were initially developed to act as a warning device to reduce entanglement of marine mammals in gillnets. Melvin et al. (1999) tested pingers with a frequency within the generic hearing range of birds, and found that common murre bycatch was reduced by 50% while there was no effect on bycatch of rhinoceros auklets and fishing efficiency was not compromised. In contrast however, higher bird bycatch rates were found in nets when pingers tuned to deterring marine mammals were used in Kodiak Island salmon fisheries for unknown reasons (Manly 2007). The disadvantages of acoustic alarms include habituation, mechanical failure, noise pollution, and habitat displacement (Trippel et al. 2003).

The details of how and where acoustic pingers are effective have not been worked out completely. Melvin et al. (1999) found that pingers are effective only for a small number of bird species and Smith et al. (2009) report that nets with pingers attracted more seals than nets without them. Pingers can transmit noise up to 4 km away, thus reducing feeding habitat of birds/marine mammals (BirdLife International 2012 and the hearing ranges of different species of seabirds need to be evaluated. Further work is clearly needed to shed light on the effectiveness of acoustic alerts.

Nylon gillnets with barium sulphate powder amalgamated into the nylon so as to be more acoustically reflective were designed to lower bycatch of echolocating odontocetes (toothed cetaceans; Mooney 2003) and have been suggested to also lower rates of seabird bycatch. A study conducted on the east coast of Canada in 1998 and 2000 (Trippel et al. 2003) showed that there was no difference in the target fish catch in nets treated with barium sulfate but that there was a significant reduction of seabird bycatch in the commercial demersal gillnet fishery. However, it is not clear whether reduced marine mammal bycatch in these nets is due to increased acoustic target strength of the net or that the nylon net is now a stiffer material than traditional nylon gillnets (Mooney 2003). A reduction in the seabird bycatch may also be due to increased visibility of the barium sulphate nets which had been dyed blue to mask the white opaque color of the barium sulphate and were therefore less transparent than the control nets (traditional monofilament nylon; Trippel et al. 2003). More research is required to test if net color was primarily responsible for lowered bird bycatch rates in this study as this could be an easy mitigation tool for piscivorous bycatch species such as loons.

Alternative fishing gear. An alternative approach is to switch from gillnets to other types of fishing gears. Often there are alternative means to catch target fish species, some of which may also be viable from a practical and economic perspective. In the German Baltic Sea, replacing gillnets with longlines has been proposed as a means to decrease seaduck bycatch since a study showed that bird bycatch was approximately three times lower for longlines compared to gillnets (Bellebaum et al. 2013). Similarly, a switch to longlines in the Baltic has been predicted to nearly eliminate bycatch of birds and offer a viable alternative for cod fishing, and possibly salmon (Žydelis et al. 2009). However, longlines may increase mortality in fish-eating birds, thus shifting the problem between species groups. Baited pots for cod in the German sector of the Baltic Sea had almost no bird bycatch, while birds were caught in standard gillnets nearby (Bellebaum et al. 2013). In Lithuania fish traps for herring and other fish have been tested and were found to be more efficient in catching fish compared to traditionally used gillnets and had no bycatch of birds (Vetemaa and Ložys 2009). Switching to alternative fishing gear must be approached cautiously as longlines, fish traps, and pots do cause considerable seabird mortality in some areas and for some species. Shester and Micheli (2011) noted that long-line gear is more selective and possibly more damaging to certain species.

Gillnets were banned in the Great Lakes and replaced with trap nets in the 1970s (Carey 1993). It is estimated that over 450 common loons are entangled in trap nets set along the Michigan shores of the Great Lakes annually (Carey 1993). However, trap nets can be modified by replacing the mesh on the roof of trap with a larger size mesh that loons can swim through (10.2-17.8 cm) which has been shown to allow ~80% of entrapped loons to escape. The trap net can also be modified with rectangular windows cut in the roof of the net. Commercial fishermen have tested these modfied nets and found no reduction in target fish catch (Carey 1993). Use of trap nets could be evaluated as an alternative to gillnet use in the arctic.

Net attendance

Net attendance and removal of entangled birds may be an additional mitigation measure, although only for small fisheries and for certain species and would certainly need to be supported by training in the safe removal and release of birds. This mitigation measure has been used in the fishery at Filey Bay, UK, where fishermen are required to attend their nets during June to remove any entangled birds (Crawford 2013), although it is unclear how effective this is.

Compliance

Modifications to fishing gear and other methods of minimization must have local input and support, as monitoring and enforcement will be difficult and largely ineffective in the Arctic.

SECTION 6: YELLOW-BILLED LOON BYCATCH – RECOMMENDED NEXT STEPS

Through identification of effective mitigation strategies in partnership with Alaska Native fishermen that can be self-implemented, where and when they are needed, we expect that reductions in seabird entanglements could be achieved without significantly impeding subsistence fisheries. We have identified the following potentially fruitful avenues to consider in mitigating unwanted entanglements of yellow-billed loons in coastal gillnets.

We emphasize that there are few good examples of successful bycatch mitigation in gillnets, except for Melvin's (1995, 1999) study in Puget Sound, emphasizing the challenge of finding a technical fix for preventing bycatch of seabirds.

It is also very difficult to get representative sample sizes during experiments, as entanglements are relatively rare events when considered at the scale of a few fishermen. Furthermore, several researchers note that changes in net design (working together with fishermen and net manufacturers) often resulted in challenges with use in marine conditions due to one confounding reason or another making attributing cause and effect difficult..

The most predictable solutions will be temporal and spatial regulation of fisheries effort that seeks to minimize overlap with bird concentrations, or fishing gear substitution. Mitigation options include the following.

1. Restrict net use in key nesting and brood rearing areas.

2. Training in removing yellow-billed loons safely from the net may be of value if liability issues for trainers are resolved. There is data suggesting that yellow-billed loons can be removed alive from gillnets suggesting that net attendance supported by training could be effective. Efforts to accomplish this solution are currently being administered by the North Slope Borough.

3. Bycatch quotas (already in place for the North Slope Borough in Alaska for yellow-billed loons).

4. Net monitoring in areas of high loon density as is currently being practiced on the North Slope of Alaska (Sformo, *pers. comm.*).

5. Visual alerts including predator decoys. Very little information on how effective this would be. However, it warrants further investigation as an easy, cheap fix.

6. Alternative gear such as fish traps and modified trap-nets. Fish traps have been suggested as a viable alternative gear to gillnets in the Baltic. Trap nets are used in the Great Lakes, USA, as an alternative to gillnets and can be modified to allow loons to escape alive.

7. Increase visibility of upper panels of coastal gillnets

Table 1. Methods for minimizing bycatch in gillnets that may be effective for seabirds as a group and for yellow-billed loons, specifically (X indicates that data is available supporting this mitigation method).

Mitigation Type	Specific Technique	Seabirds in general	Yellow-billed loons specifically
Reduction in Fishing Effort	Protected areas	X	X
	Bycatch quotas	X	X
Spatio-Temporal Restrictions	Time of day	X	No data
	Area	X	X
	Depth	X	X
	Abundance-based openings	X	No data
Gear Modification	Mesh size	X	X
	Net visibility	X	X
	Acoustic Alerts	X	No data
	Visual Alerts	X	No data
	Acoustic reflective properties	X	No data
Alternative gear	Long-lines	X	X
	Fish traps	X	X
	Modified trap-nets	X	X

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