GHOSTS OF THE SALISH SEA: THREATS TO MARINE BIRDS IN PUGET SOUND AND THE NORTHWEST STRAITS FROM DERELICT FISHING GEAR

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SUMMARY

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Marine bird populations in the Salish Sea (Puget Sound and the straits of Juan de Fuca and Georgia) are affected by a variety of anthropogenic factors, many of which threaten seabirds globally. Derelict fishing gear—lost or abandoned commercial and recreational fishing nets, lines, pots and traps that sit or float underwater—can remain in the marine environment for years, trapping and killing marine birds. Since 2002, a project to remove derelict nets from Puget Sound and the US portions of the straits of Georgia and Juan de Fuca has documented the mortality of marine birds and other taxa. More than 1200 derelict fishing nets have been recovered from areas throughout Puget Sound and the Northwest Straits. Of 870 gillnets recovered, 50% were documented to have been derelict for at least one year, but many were much older and still entangling birds. Most derelict gillnets recovered were from the San Juan Islands and northern Puget Sound, from high-relief rocky and boulder habitats, relatively small in size (≤1000 m^2 in area), of relatively recent construction and in relatively good condition, stretched open to some extent (i.e. maximum suspension more than zero meters), and recovered from depths above 20 m. Of the marine organisms recovered from these gillnets, 514 were marine birds representing at least 15 species, all of which were recovered dead. Marine birds occurred in 14% of recovered gillnets. Marine birds were more likely to be present in gillnets recovered less than one year after being reported to the project, recovered from the San Juan Islands or Strait of Juan de Fuca, large in size (1000–14 000 m^2), relatively new and in good condition, having a maximum suspension of more than one meter, and recovered from minimum depths of 20–40 m. Mortality from derelict fishing gear should be recognized as an additional risk for several marine bird species of conservation concern or declining wintering populations in Puget Sound and throughout the Salish Sea.

Key words: Derelict gillnets, location and recovery, marine bird mortality, species composition, gear characteristics, management concerns

INTRODUCTION

Marine birds, including threatened species listed by the International Union for the Conservation of Nature, face a variety of challenges globally. Serious anthropogenic threats include direct or indirect effects from loss or degradation of habitat, human disturbance, introduced species, oil and other marine pollution, contaminants, fisheries interactions and the introduction of debris into the marine environment (Mills *et al.* 2005, Wilcox & Donlan 2007). Debris-related mortality of marine birds increased substantially at the end of the 20th century (Tasker *et al.* 2000).

Marine birds in the Salish Sea are affected by many of these factors, including oil spills (O'Hara *et al.* 2009), changes in forage fish populations (Therriault *et al.* 2009), toxins and pollution (Calambokidis *et al.* 1985, Carter & Kuletz 1995), and fisheries bycatch (Melvin 1995, Melvin & Conquest 1996, Melvin *et al.* 1999, Hamel *et al.* 2009). Introduced mammals in some colonies may be usurping burrows (Leschner 1976); altering and destroying breeding habitat (T. Good pers. obs.); or preying on nesting seabirds, eggs and chicks. Changes in marine bird abundance since the 1970s (Anderson *et al.* 2009, Bower 2009) may reflect these known factors and others yet to be identified. At present, 23 of 128 bird species (18%) that use the marine waters of the Salish Sea are listed by one or more Canadian or US jurisdictions as species of concern (Gaydos & Brown in press).

Derelict fishing gear—recreational or commercial fishing nets, lines, pots and traps lost or abandoned in the environment—has yet to be fully investigated in the Salish Sea. Historically, hemp, cotton, jute, sisal, manila, silk and linen were the primary natural fibers used to make fishing gear (Brainard *et al.* 2000). In the 1950s, synthetic nylon, polyethylene and polypropylene materials replaced natural fibers in fishing gear in most of the world's fisheries (USOAP 2004). The newer fishing gear is much less prone to degradation in water, and when discarded or lost in the marine environment, it lasts for decades, inhibiting access to, suffocating or physically destroying underwater habitats (Morton 2005).

Derelict fishing gear in the marine environment can entangle and kill target and non-target fish species through "ghost fishing" (Breen 1990), and such gear is also known to entangle and kill a variety of other non-target vertebrates, including marine birds (Piatt & Nettleship 1987, Schrey & Vauk 1987, Jones & DeGange 1988), cetaceans (Volgenau *et al.* 1995) and seals (Hofmeyr *et al.* 2002, Boland & Donohue 2003, Page *et al.* 2004). In one review, 136 marine species were reported as prone to entanglement in waters of the United States, including six species of sea turtles, 51 species of seabirds and 32 species of marine mammals (Laist 1996). In the northwestern Hawaiian Islands, derelict fishing gear originating from throughout the North Pacific abrades, enshrouds and breaks fragile coral reefs, and injures or kills federally endangered Hawaiian Monk Seals *Monachus schauinslandi,* protected sea turtles and cetaceans. In response to hundreds of Hawaiian Monk Seals having been entangled in derelict gear since 1982 (Boland & Donohue 2003), an extensive multiagency debris removal program removed 511 metric tons of derelict fishing gear from various sites in the northwestern Hawaiian Islands from 1996 to 2005 (Friedlander *et al.* 2005).

Derelict gear in the Salish Sea

Several observations have raised the profile of potential problems associated with derelict fishing gear in the Salish Sea. Transboundary bottom trawl surveys by the Washington Department of Fish and Wildlife (WDFW) have estimated the weight of fishing gear debris in benthic habitats in the US portions of the eastern Strait of Juan de Fuca (95.1 t; Palsson 2002), the Strait of Georgia (35.6 t; Palsson 2003), and the San Juan archipelago (93.9 t; Palsson 2003). The Northwest Straits Commission independently estimated that as many as 4000 derelict fishing nets litter the sea floor in Puget Sound and the Northwest Straits south of the US–Canada border (NWSF 2007). The Puget Sound gillnet fleet, which has primarily targeted Pacific salmon *Oncorhynchus* spp., but also Pacific Herring *Clupea pallasi* and Spiny Dogfish *Squalus acanthias,* may have lost thousands of nets over the past 30 years (WDFW unpubl. data). Finally, single instances of derelict gillnet reporting or removal have highlighted the risk to marine populations in Puget Sound. During recovery operations off the southwest corner of Lopez Island in the San Juan Islands, divers reported piles of marine bird and mammal bones up to a meter deep under a derelict gillnet suspended between rocks (NRC 2004b). Older reports in Puget Sound noted nets draped over wrecks and other human-origin obstructions killing fish and marine birds for two to three years (High 1981). Steadily accumulating reports and recognition of the potential risks posed by derelict fishing gear has raised removal of that gear to an immediate priority for a healthy Puget Sound by 2020 (PSP 2008).

Little is known about the occurrence of derelict gear in the BC portion of the Salish Sea. Cetaceans have been reported entangled along the coast of British Columbia (Baird *et al.* 1991, 1994, Willis *et al.* 1996), although the majority appear to have been bycatch in active fisheries and economic losses from ghost fishing have been estimated in fisheries for Dungeness Crab *Cancer magister* (Breen 1987). Transboundary bottom trawl surveys (WDFW) have estimated fishing gear debris in benthic habitats within Canada at considerably lower levels than in US portions of the same bodies of water: Strait of Juan de Fuca (0.01 t; Palsson 2002), Strait of Georgia (0.04 t; Palsson 2003) and Haro Strait and Boundary Pass (0.00 t; Palsson 2002). Still, the potential for derelict gear accumulation in the waters of southern British Columbia is high. A variety of trap and net fisheries have been operating for decades in British Columbia, just as in the US portion of the Salish Sea, and there is neither a current inventory nor a system of collecting and storing data for derelict fishing gear. These factors led Canadian officials to gather in October 2008 with their counterparts in Washington State for a two-day transboundary workshop on removal of derelict fishing gear (NWSC 2008a).

Since 2002, the Northwest Straits Commission, working with Natural Resources Consultants, Inc., the Washington Department of Fish and Wildlife and the National Oceanic and Atmospheric Administration Fisheries, has documented and removed more than 94 t of derelict nets, pots and traps from inland marine waters in Washington State (NWSC 2008b). The objective of the removal project is to locate and remove existing derelict gear in Puget Sound and the Northwest Straits. The goal of the analyses presented here is to identify and explore patterns of gear type, condition, orientation and spatiotemporal relationships for the derelict gillnets recovered, particularly with respect to marine birds entangled therein.

METHODS

Recovery of derelict gear occurred at sites throughout Puget Sound and US portions of the straits of Juan de Fuca and Georgia (Fig. 1). Some sites were previously identified and included in a database compiled from reports from the fishing community; sport and research divers; and recreational, commercial and research vessels that encountered gear. Many of the nets are a legacy of past fishing; however, the fishing community is encouraged to use a "no-fault" reporting mechanism to report any fishing gear that they lose, which has resulted in quick recovery of new derelict nets. Others sites were identified and visited after side-scan sonar surveys conducted by a dedicated vessel or as the result of dive surveys or previous gear recovery efforts. To locate derelict gear, a chartered 40-foot dive-support and gear recovery vessel was equipped with a laptop computer linking a GPS-referenced database to onboard Nobeltec navigation software (Jeppesen Marine, Portland, OR, USA).

To recover derelict gear, a lead weight attached by line to a surface float was deployed at the recorded site of the derelict gear and the support vessel was anchored nearby. Divers followed the buoy line to the seabed, while two-way radio communication was maintained at all times between the support vessel and the divers. Upon locating the derelict nets, divers attached a recovery line and freed the gear from the seabed by hand. The gear was then hauled aboard the recovery vessel by hand or with a hydraulic winch. In some cases, divers attached an air-lift bag to the derelict net and floated it to the surface for retrieval by the vessel.

Data recorded for each recovered net included location (GPS coordinates), benthic habitat type, type of net, age (older or newer construction judged on style and estimated vintage), condition (judged good or poor), maximum and minimum water depth, approximate length and width (used to calculate net area), maximum net suspension and any observations of impact on habitats. Information specific to marine birds included the number and identity (where possible) of specimens entangled in the net, their status (alive or dead, whole or partial remains) and any evidence of cumulative mortality in the vicinity of the net reported by the divers. Specimens composed partially or entirely of bone elements were identified to the lowest taxon possible by comparison of skull and postcranial characters to reference skeletal material. Skeletal elements observed below the net and likely attributable to the net were also collected, identified and enumerated. An estimated minimum number of individuals (MNI) represented by the skeletal material was based on the most frequently occurring skeletal element. The total MNI of vertebrates in derelict gear was calculated for a variety of taxonomic levels (e.g. MNI of family, genus, species) based on the sum of whole carcass counts and the MNI values obtained from skeletal material.

Data analyses

We collated data to reveal patterns in "soak time" (difference between the date reported and the date recovered, habitat types, net age, net condition, net area, maximum height of net suspension, minimum and maximum depth at sites where nets were recovered, and mortality of marine taxa. We examined patterns graphically and using univariate nonparametric tests (SYSTAT 2007). The calculated "soak time" is the minimum amount of time spent in the marine environment, because the total time between loss and recovery was unknown for all but a handful of gillnets. We subdivided Puget Sound and the US portions of the Juan de Fuca and Georgia straits into six geographic regions corresponding roughly to subregions used in local recovery planning for Endangered and Threatened natural resources—the San Juan Islands, Northern Puget Sound, Central Puget Sound, Hood Canal, the Strait of Juan de Fuca and Southern Puget Sound (PSP 2008). Because of small sample sizes in some regions, we combined the San Juan Islands with the Strait of Juan de Fuca and Central Puget Sound with Hood Canal and Southern Puget Sound for analysis of regional effects. We classified habitats where gillnets were recovered as

- high-relief rocky substrate,
- low-relief rocky substrate,
- boulders on sand/mud/gravel,
- mud/sand/gravel/vegetation, or
- underwater obstructions (e.g. sunken vessels, pier pilings, buoy anchors).

We categorized gillnets as being of newer or older construction based on net characteristics (old: net tattered, material weak, appearing to have been in place for several years; new: net appeared recently lost, little or no algal growth, material remained strong) and as being in good or poor condition (good: net still in fishable condition; poor: net in overall poor condition). We recorded the minimum number of individuals and species of marine birds identified during and after gear recovery operations. We used two-way chi-square analyses (SYSTAT 2007) to examine associations

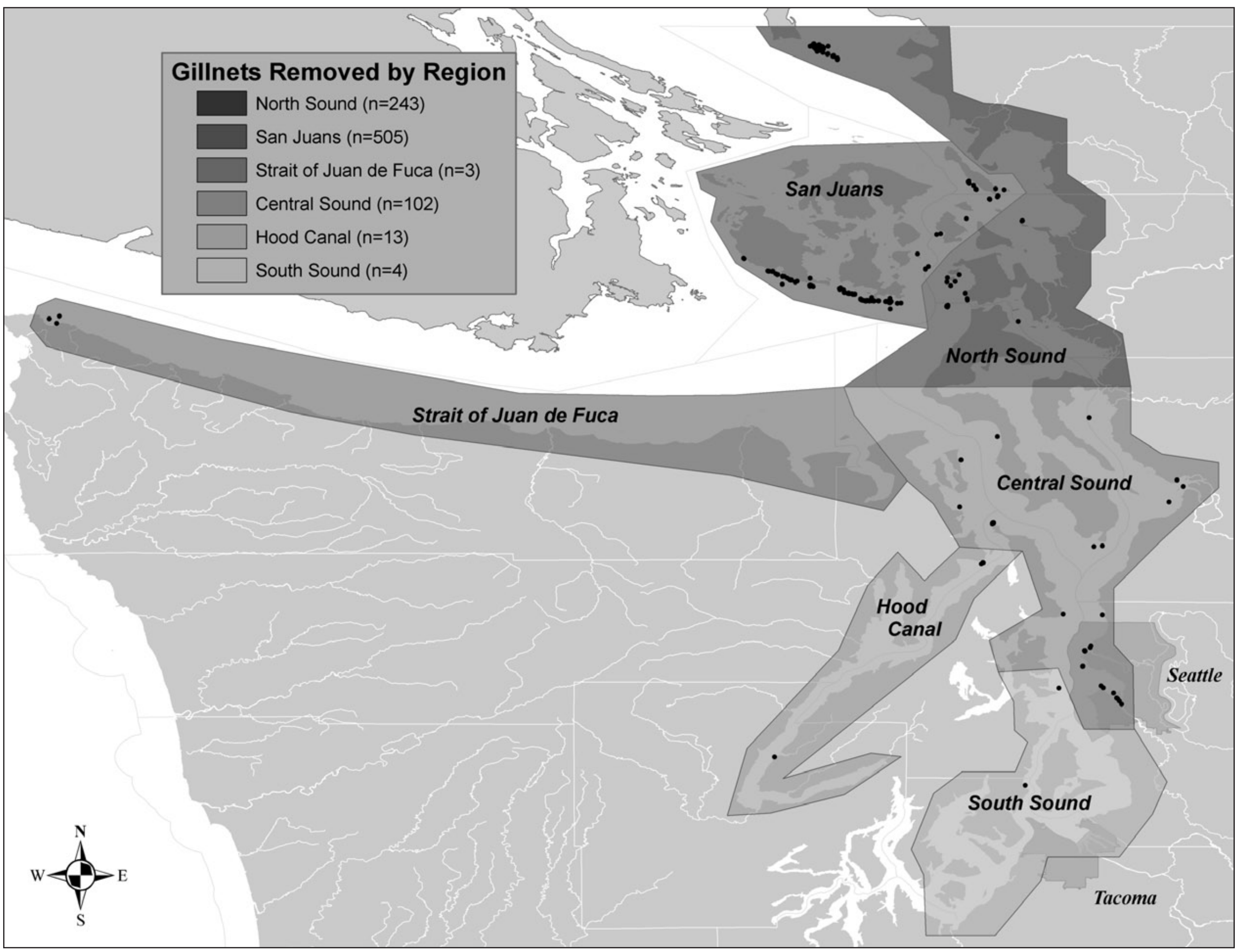

Fig. 1. Locations of 870 derelict gillnets recovered throughout Puget Sound and US portions of Juan de Fuca and Georgia straits.

between marine bird mortality and gillnet characteristics—"soak time", region, benthic habitat type, net area, age and condition, and maximum net suspension.

RESULTS

Spatial patterns and properties of derelict fishing gear

Of the 902 derelict fishing nets recovered from Puget Sound and the US portions of the straits of Juan de Fuca and Georgia from 2002, 876 were gillnets; the remaining nets were purse seines (n = 23), trawl nets (n = 2), and an aquaculture net (n = 1). Most of the gillnets were recovered from the San Juan Islands (n = 499) and Northern Puget Sound (n = 244), followed by Central Puget Sound (n = 108), Hood Canal (n = 14), the Strait of Juan de Fuca (n = 3) and Southern Puget Sound (n = 2; Fig. 1). Of the 876 gillnets, 870 had datasets complete enough to examine spatial patterns and properties of derelict fishing gear and mortality patterns of marine birds entangled therein.

One quarter of the nets (n = 216) were recovered on the day they were detected or reported, 36% (n = 308) were known to have been derelict for periods of up to one year, and 25% were derelict for between five and 24 years (Fig. 2). Excluding nets recovered on the same day, the median time gillnets were documented to have been derelict was more than one year.

Most derelict gillnets were recovered from habitats with high-relief rocky substrate (n = 363) or boulders on sand/mud/gravel (n = 297), with lower numbers being recovered from low-relief rocky substrate

TABLE 1
Marine bird species and numbers of carcasses identified in derelict fishing nets recovered from inland marine waters of Washington

Taxon		Identifications (n)
Seabird (unidentified)		148
Phalacrocoracidae		
Cormorant (unidentified)	*Phalacrocorax* spp.	95
Brandt's Cormorant	*Phalacrocorax penicillatus*	59
Pelagic Cormorant	*Phalacrocorax pelagicus*	41
Double-crested Cormorant	*Phalacrocorax auritus*	8
Anatidae		
Surf Scoter	*Melanitta perspicillata*	31
Scoter (unidentified)	*Melanitta* spp.	22
White-winged Scoter	*Melanitta fusca*	15
Greater Scaup	*Aythya marila*	1
Merganser spp.	*Mergus* spp.	1
Gaviidae		
Common Loon	*Gavia immer*	9
Pacific Loon	*Gavia pacifica*	32
Red-throated Loon	*Gavia stellata*	27
Podicipedidae		
Western/Clark's Grebe	*Aechmophorus* spp.	7
Grebe (unidentified)	*Podiceps* spp.	7
Red-necked Grebe	*Podiceps grisegena*	2
Scolopacidae		
Shorebird (unidentified)		1
Alcidae		
Common Murre	*Uria aalge*	1
Pigeon Guillemot	*Cepphus columba*	1
Ardeidae		
Great Blue Heron (Pacific)	*Ardea herodias fannini*	1
Total		514

(n = 77), mud/sand/gravel/vegetation (n = 71) and underwater obstructions (n = 62). Most derelict gillnets recovered (66%) were of relatively small size (≤1000 m^2): 35% were 200 m^2 or less in size, 31% were between 200 m^2 and 1000 m^2. Only 11 (1%) were larger than 6000 m^2 (Fig. 3). Most of the gillnets recovered (54%) were judged to be of relatively recent construction; 46% were of older construction. Most gillnets recovered (71%) were in relatively good condition; the remaining 29% were in poor condition. Most gillnets recovered (81%) were open to some extent (i.e. maximum suspension greater than zero meters). Maximum suspension ranged from zero meters to 36.6 m (Fig. 4), with a median value of 0.6 m. Gillnets were recovered primarily from depths less than 22 m; the minimum depth of recovered gillnets ranged from zero meters to 36.6 m (mean: 17.0 m), and the maximum depth ranged from 1.2 m to 42.7 m (mean: 19.8 m).

Mortality patterns in derelict fishing gear

We documented 514 marine birds of at least 15 species in derelict gillnets recovered from the waters of Puget Sound and US portions of Juan de Fuca and Georgia straits (Table 1). The birds most commonly found were cormorants, particularly Brandt's Cormorant *Phalacrocorax penicillatus* and Pelagic Cormorant *Phalacrocorax pelagicus*; loons, particularly Pacific Loon *Gavia pacifica* and Red-throated Loon *Gavia stellata*; and seaducks, particularly Surf Scoter *Melanitta perspicillata* and White-winged Scoter *Melanitta fusca.* We found evidence of marine bird mortality (whole or partial dead birds) in 14% (n = 124) of the derelict gillnets recovered; all birds recovered were dead. On average, a derelict gillnet contained 0.59 marine birds, but individual gillnets ranged from having 0 to 142 birds. In addition to marine birds, we documented at least 31 278 marine invertebrates (76 species), 1036 marine fishes (24 species) and 23 marine mammals (four species; T. Good *et al.* unpubl. data).

Birds occurred most frequently in nets recovered less than one year after being reported and in nets recovered from the San Juan Islands/Strait of Juan de Fuca subregions (Table 2). Bird mortality was not associated with the habitat where gillnets were recovered, but varied significantly and positively with total area of netting recovered. More birds occurred in nets judged to be of recent construction and in those in relatively good condition. Entanglement varied directly with the amount of openly suspended netting material, ranging from 2% to 50% in nets with exposed heights of zero to two meters or more. Finally, mortality varied significantly with the minimum depths from which gillnets were recovered, with nets at medium depths having the highest incidence of dead marine birds (Table 2).

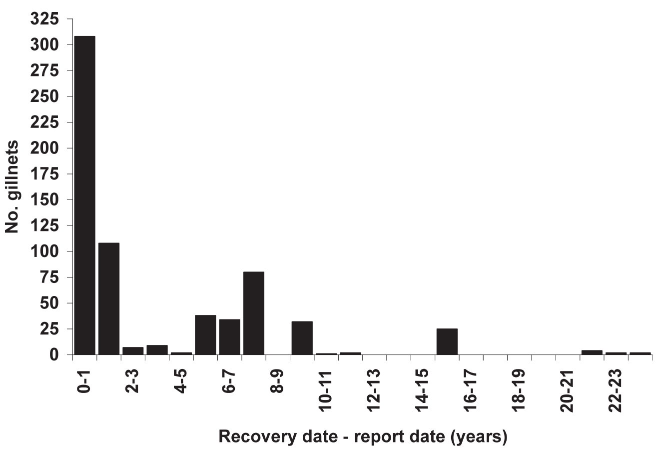

Fig. 2. Estimated minimum time (years) that 870 derelict gillnets were underwater (date recovered to date reported), excluding gillnets recovered on the day they were detected or reported.

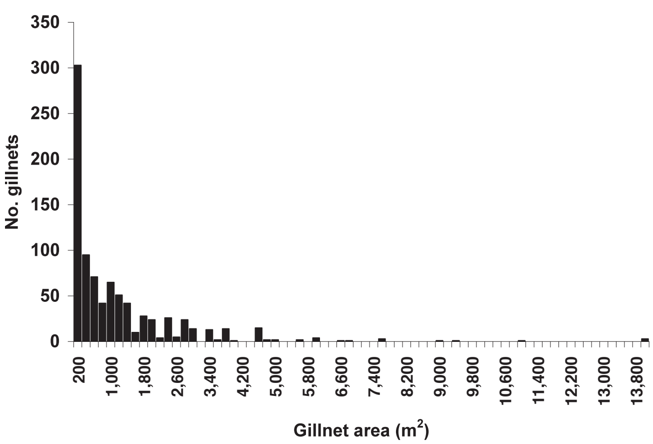

Fig. 3. Distribution of calculated areas (square meters) of 870 derelict gillnets recovered in Puget Sound and US portions of Juan de Fuca and Georgia straits.

DISCUSSION

Derelict gillnets have been recovered from throughout Puget Sound, and the continued presence of thousands of nets in a variety of habitats poses a substantial risk for a variety of marine bird species. Most of the gillnets were recovered from locations in the San Juan Islands and northern Puget Sound, reflecting the historical extent of the gillnet fishing effort in the northern parts of Puget Sound (PFMC 2008). That history prompted a series of targeted gear-removal projects (NRC 2003, NRC 2004a, NRC 2004b) and resulted in the discovery and recovery of tons of previously unreported derelict gear. Historical fishing pressure, superimposed on the region's complex bottom topography and oceanography, created "hotspots" of derelict fishing gear accumulation in northern Puget Sound and the San Juan Islands. Modeling using geospatial data on bottom topography, fishing effort, hydrodynamics and important foraging and breeding areas for marine birds wil enable us to predict the location of hotspots of risk to resident and transient marine bird

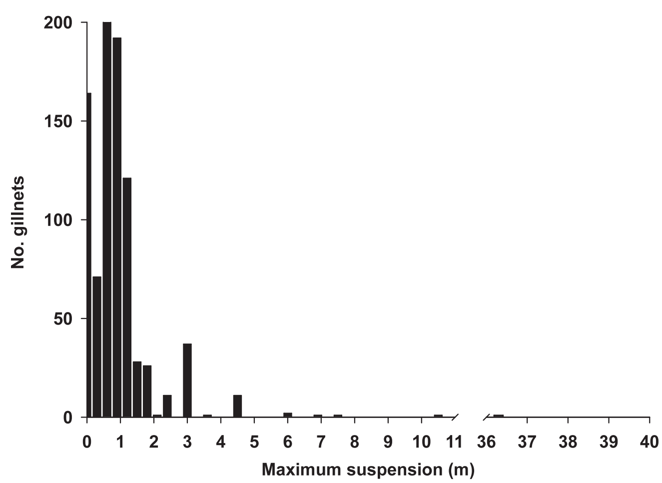

Fig. 4. Distribution of maximum suspension (meters) of 870 derelict gillnets recovered in Puget Sound and US portions of Juan de Fuca and Georgia straits.

species (J. Davies & T. Good unpubl. data). Similar modeling of derelict net accumulation has facilitated maintenance of Hawaiian reefs previously cleaned of derelict trawl nets (Donohue *et al.* 2001, Dameron *et al.* 2007).

No other recovery effort has documented the abundance (n > 500) and diversity of marine birds (15 species, including eight of regional conservation concern) entangled and killed by derelict fishing nets in Puget Sound. Almost half the identified marine

TABLE 2
Entanglement of marine birds in relation to characteristics of derelict gillnets recovered in Puget Sound and US portions of the straits of Juan de Fuca and Georgia

Net characteristics	Total nets	Nets with bird remains (n)	Nets with bird remains (%)	χ^2	df	*P*
Minimum time derelict ("soak time")				7.1	2	0.03
<1 year	308	53	17			
1–6 years	164	17	10			
7–24 years	182	18	10			
Region where recovered				23.9	2	<0.001
San Juan Is./Strait of Juan de Fuca	502	92	18			
Central Puget Sound/Hood Canal/Southern Puget Sound	124	20	16			
Northern Puget Sound	244	12	5			
Habitat where recovered				5.8	4	0.2
High relief rocky substrate	363	54	15			
Low relief rocky substrate	77	11	14			
Boulders on sand/mud/gravel	297	33	11			
Mud/sand/gravel/vegetation	71	13	18			
Underwater obstructions	62	13	21			
High relief rocky substrate	363	54	15			
Size (total area)				41.9	2	<0.001
Large (1000–14 000 m^2)	294	72	24			
Medium (200–1000 m^2)	273	33	12			
Small (<200 m^2)	303	19	6			
Inferred age				27.1	1	<0.001
Recent construction	472	94	20			
Older construction	398	30	7			
Condition				27.2	1	<0.001
Good	614	112	18			
Poor	256	12	5			
Suspension in water column (maximum)				120.9	3	<0.001
0 m	163	3	2			
0–1 m	464	42	9			
1–2 m	174	45	26			
≥2 m	68	34	50			
Minimum depth where recovered				6.8	2	0.03
0–10 m	82	14	17			
10–20 m	540	64	12			
20–40 m	248	46	19			

birds were species (scoters, loons and grebes) whose wintering populations have been declining in Puget Sound (Nysewander *et al.* 2005). In contrast, in the Hawaiian Islands, taxa found in recovered trawl nets are primarily marine invertebrates (13 species), fish (10 species) and endangered Hawaiian Monk Seals (Donohue *et al.* 2001). In Australia, animals recorded in derelict nets include juvenile Hawksbill Turtles *Eretmochelys imbricata,* catfish *Arius* spp., triggerfish (Balistidae) and shark *Carcharhinus* sp. (White 2006). DeGange & Newby (1980) documented 99 seabirds of five species entangled in a derelict salmon driftnet recovered in the western North Pacific, and an abandoned salmon gillnet recovered from Agattu Island in Alaska in 1979 had more than 400 seabirds entangled (Jones & DeGange 1988). Thus, derelict gillnets appear to pose a particular risk to marine birds.

In the US portion of the Salish Sea, marine birds were more often present in derelict gillnets recovered less than one year after being reported, no doubt because degradation of entangled birds occurs fairly quickly underwater. Our observations suggest that marine birds entangled in derelict nets can be completely skeletonized in two to four weeks, depending on scavenger density and other factors, and we are conducting experiments to evaluate carcass degradation in nets over time. Except for a handful of nets documented through a "no-fault" reporting procedure available to fishermen who lose nets, the period over which derelict nets pose a hazard to marine birds in the environment is likely much longer than the minimum "soak time" calculated in the present analysis. Derelict gillnets reported 15 years ago can still catch organisms at a high rate today (NRC 2009). Close examination of some derelict gillnets indicated they may have been 20–30 years old, based on mesh size and construction material. This finding underscores the potential to vastly underestimate the extent of marine bird mortality in the derelict gillnets recovered.

Bottom topography and benthic habitat type play a role in the deposition and orientation of derelict nets, given that rocky ledges, boulders and human-origin obstructions are common throughout Puget Sound. Nets can often be stretched open several feet on underwater features and human-origin obstacles, posing a persistent danger to marine animals over time (Nakashima & Matsuoka 2005). Derelict nets in more flat, featureless open sandy or muddy habitats tend to ball up, posing less risk to target species (reviewed in Matsuoka *et al.* 2005) and presumably to non-target species such as marine birds. Marine bird mortalities were documented across habitats, reflecting the diversity of foraging habitats used by the species of marine birds affected (cormorants, loons, grebes, seaducks). Nevertheless, one derelict gillnet over a muddy habitat in the Port Susan area of central Puget Sound entangled some large, heavy commercial crab pots and woody debris, stretching the gillnet to around six meters off the seabed in places. In this one net, we documented 50 fish, 142 marine birds (64 freshly killed) and one marine mammal; piles of bones beneath the net were testimony to the larger numbers it likely killed. Indeed, if that gillnet had constant rates of recruitment and carcass degradation over the 23 weeks it was derelict in the environment, it may have killed upwards of 1800 marine birds (J. June unpubl. data).

The threat posed to marine birds appears to increase with increasing size of derelict gillnets, although nets were often just a portion of the full-size fishing nets used in Puget Sound today (16 500 m^2). Many nets were recovered with intact lead lines, but no float lines—evidence that they became entangled on the bottom and were manually cut to salvage as much of the fishing net as possible. That finding is in marked contrast to derelict trawl nets recovered from reefs in the northwest Hawaiian Islands, where derelict nets were primarily small pieces of material less than 10 m^2 in size (Donahue *et al.* 2001). The latter have entangled a smaller number and variety of organisms overall, no doubt because of the relationship between derelict net area and probability of entanglement.

Derelict gillnets were recovered in relatively good condition, despite reporting times that ranged widely. Many appeared to have little algal growth, and they retained nearly all of their original breaking strength. Newer nets were more deadly, with the likelihood of documenting marine bird mortality being nearly three times that for older nets. The difference between derelict gillnets in poor and good condition was also measurable, with the likelihood of documenting marine bird mortality being nearly four times greater in good-condition nets. Biofouling has been found to profoundly alter the configuration and catch rates of some nets (Santos *et al.* 2003), but that factor appeared to be less important in Puget Sound.

Net configuration may vary little over the course of the derelict gillnet "soak time," especially if the net has been stretched open between rock pinnacles or pier pilings or been draped over a derelict vessel. Gillnets stretched open more than one meter had a 50% chance of having entangled and killed marine birds, underscoring the deadly consequences of modern gillnet design and longevity for target and non-target species alike. The lower marine bird mortality documented in the intermediate-depth category was unexpected and may reflect chance associations of minimum depth with habitat, net suspension, condition and age. Nets deeper than 40 m were beyond the scope of our recovery efforts, but it is probable that these nets influence marine birds to a lesser extent than they influence deep-water invertebrates and fish.

In Puget Sound, we are constrained in conducting experiments to determine the effects of derelict gillnets over time, because such deployments pose a risk to various threatened and endangered marine birds, Pacific salmon, Killer Whales *Orcinus orca* and other animals. Still, the tendency of nets in Puget Sound to remain stretched open over long periods and the piles of bones beneath a number of nets suggest that, unlike elsewhere, rates of entanglement and mortality do not decline to negligible levels. Despite the longevity of derelict gillnets, newer nets seem to pose a particular risk, as evidenced by the greater diversity and number of birds they entangled and killed.

The mortality we documented in derelict gillnets is different from seabird bycatch in active Puget Sound fisheries. The birds most commonly entangled in tended salmon gillnets in the mid-1990s were Common Murres *Uria aalge* and Rhinoceros Auklets *Cerorhinca monocerata* (Beattie & Lutz 1994, Erstad *et al.* 1994, Pierce *et al.* 1994), but only one Common Murre occurred in derelict gear recovered from the same fishing areas. Species less commonly entangled in tended salmon gillnets included Common Loon *Gavia immer,* Pacific Loon, Tufted Puffin *Fratercula cirrhata* and Western Grebe *Aechmophorus occidentalis.* Some species common to the waters of Puget Sound were rarely or never seen: gulls and terns, ducks (apart from one White-winged Scoter in a non-tribal gillnet), other grebes, and cormorants (apart from one Pelagic Cormorant) were not observed to be entangled by either tribal or non-tribal gillnets (Beattie & Lutz 1994, Erstad *et al.* 1994, Pierce *et al.* 1994). By contrast, cormorants made up the bulk of identified specimens recovered from derelict gillnets, and scoters *Melanitta* spp., loons *Gavia* spp. and grebes *Aechmophorus* spp. and *Podiceps grisegena* predominated in some nets. Although the threat posed by derelict gear may be considered a special case of seabird bycatch, solutions to the problem will differ considerably from those intended to address other seabird bycatch issues in Puget Sound and the Salish Sea (Hamel *et al.* 2009).

Management plans

Goals for management programs addressing derelict fishing gear include assessment of damage to marine organisms and ecosystems and identification of possible remedies. The Derelict Fishing Gear Assessment, Recovery, Training and Outreach Program of the Northwest Straits Initiative will continue to

- quantify and understand the loss or abandonment of fishing gear,
- recover and dispose of existing derelict fishing gear, and
- prevent derelict fishing gear through education, regulation and compensation.

Future studies should prioritize areas for gear survey and removal. For example, areas near wildlife refuges may have derelict gear that entangles and kills diving seabirds, affecting their protection and numbers in Puget Sound and perhaps throughout the Pacific Northwest. Modeling efforts will continue to assist the process of prioritization and to reduce and prevent new derelict gear by identifying potential hotspots of accumulation. Several factors should reduce the problem of impacts from derelict gillnet once the legacy gillnets are removed. First, commercial net fishing effort has substantially declined in recent years in response to reduced abundance of target salmon species and policies for the protection of endangered species. Net fishers now have modern navigation and electronic charting capabilities that help avoid net loss. Finally, the "no-fault" reporting system for lost gear minimizes the time that such gear remains in the environment. The real challenge lies in finding and removing the gear that has accumulated over the past 50 years of net fishing in inland waters of the Salish Sea.

Perhaps the most urgent task is to address the problem of derelict gear in the BC portion of the Salish Sea. Needed action includes surveying likely areas of derelict gear accumulation, creating an inventory of derelict gear, instituting a no-fault reporting procedure and encouraging its use, and developing a database for collating, storing and analyzing data on derelict gear and the marine taxa it affects. New initiatives are underway to meet those needs.

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