U.S. West Coast Groundfish Fisheries

Seabird Bycatch 2002-2018

Seabird Conservation Status

Species	Mortality 2002-2018 Hook & Line	Trawl	Pot
Short-tailed Albatross	🐦		
Pink-footed Shearwater	🐦🐦	🐦🐦	
Leach's Storm-Petrel		🐦🐦	
Black-footed Albatross	🐦🐦🐦🐦	🐦🐦	🐦
Sooty Shearwater	🐦🐦🐦	🐦🐦🐦	
Laysan Albatross	🐦	🐦	
Cassin's Auklet		🐦🐦	
Western Gull	🐦🐦🐦	🐦🐦	
Northern Fulmar	🐦🐦	🐦🐦🐦	🐦
Arctic Herring Gull	🐦🐦	🐦	
Brown Pelican	🐦🐦🐦		
Glaucous-winged Gull	🐦🐦		
Common Murre	🐦🐦🐦	🐦🐦🐦	
Brandts Cormorant	🐦🐦	🐦🐦🐦	🐦🐦🐦
California Gull	🐦	🐦	
Double-crested Cormorant	🐦🐦		🐦🐦
Common Loon	🐦🐦		
Mew Gull	🐦		
Red-necked Phalarope	🐦		
Ring-billed Gull	🐦		
Green-winged Teal		🐦	
White-winged Scoter		🐦	
Shearwater Unidentified	🐦🐦🐦	🐦🐦🐦	
Gull Unidentified	🐦🐦🐦	🐦🐦🐦	🐦
Bird Unidentified	🐦🐦	🐦🐦	
Cormorant Unidentified	🐦🐦	🐦🐦🐦	🐦🐦🐦
Alcid Unidentified	🐦🐦		
Tubenoses Unidentified		🐦	
Storm-Petrel Unidentified		🐦	🐦
Murre Unidentified		🐦	

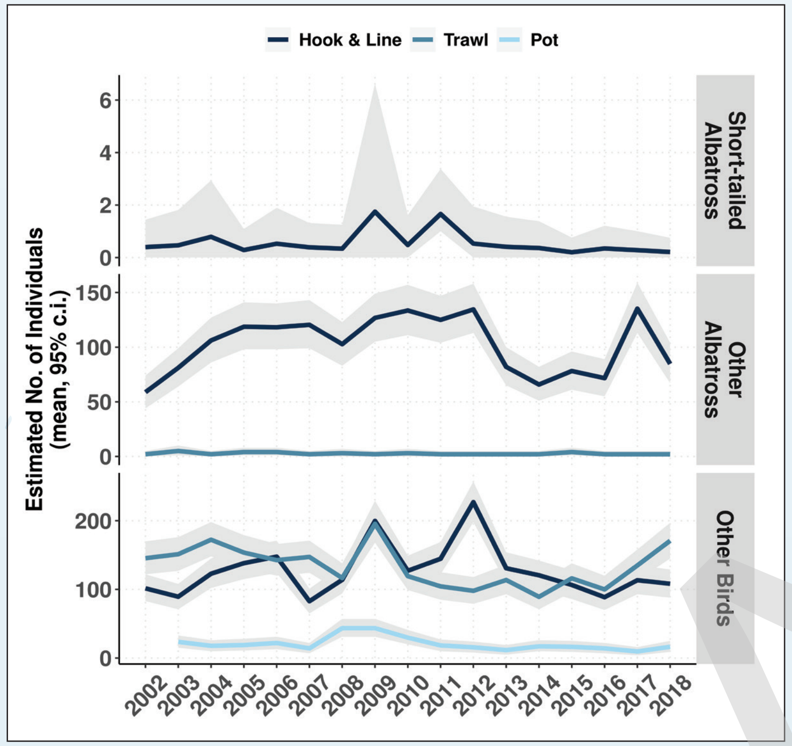
Number of birds
- 🐦 1-10
- 🐦🐦 11-100
- 🐦🐦🐦 101-1000
- 🐦🐦🐦🐦 1000+

Conservation status
- Endangered* (red): Short-tailed Albatross
- Vulnerable (red-orange): Pink-footed Shearwater, Leach's Storm-Petrel
- Near threatened (orange): Black-footed Albatross, Sooty Shearwater, Laysan Albatross, Cassin's Auklet
- Least concern (teal): Western Gull through White-winged Scoter
- Unknown (white): Shearwater Unidentified through Murre Unidentified

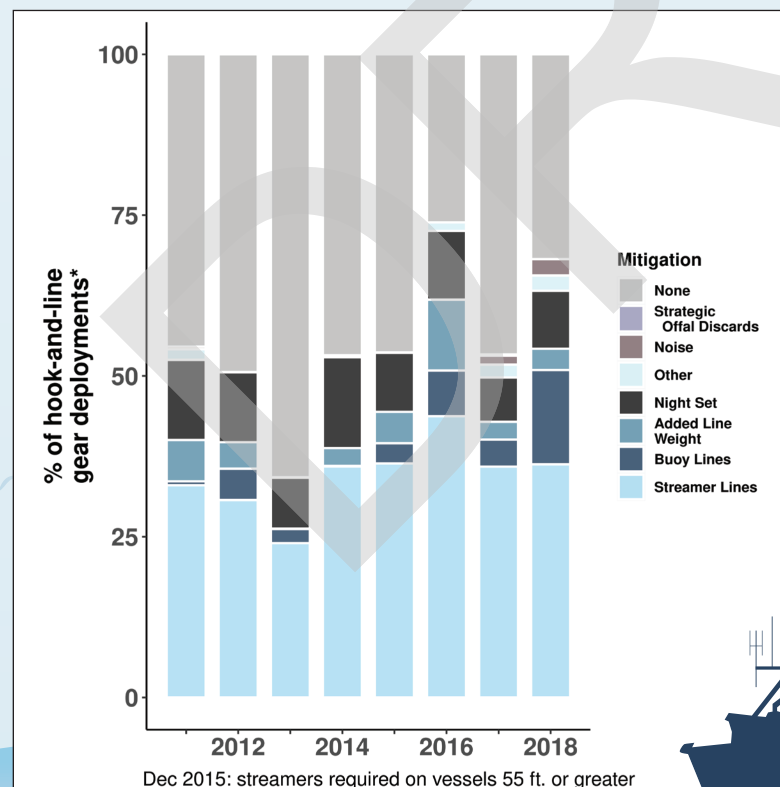
*Endangered under US ESA; all other categories are IUCN

ESA = Endangered Species Act
IUCN = International Union for the Conservation of Nature

Temporal Trends

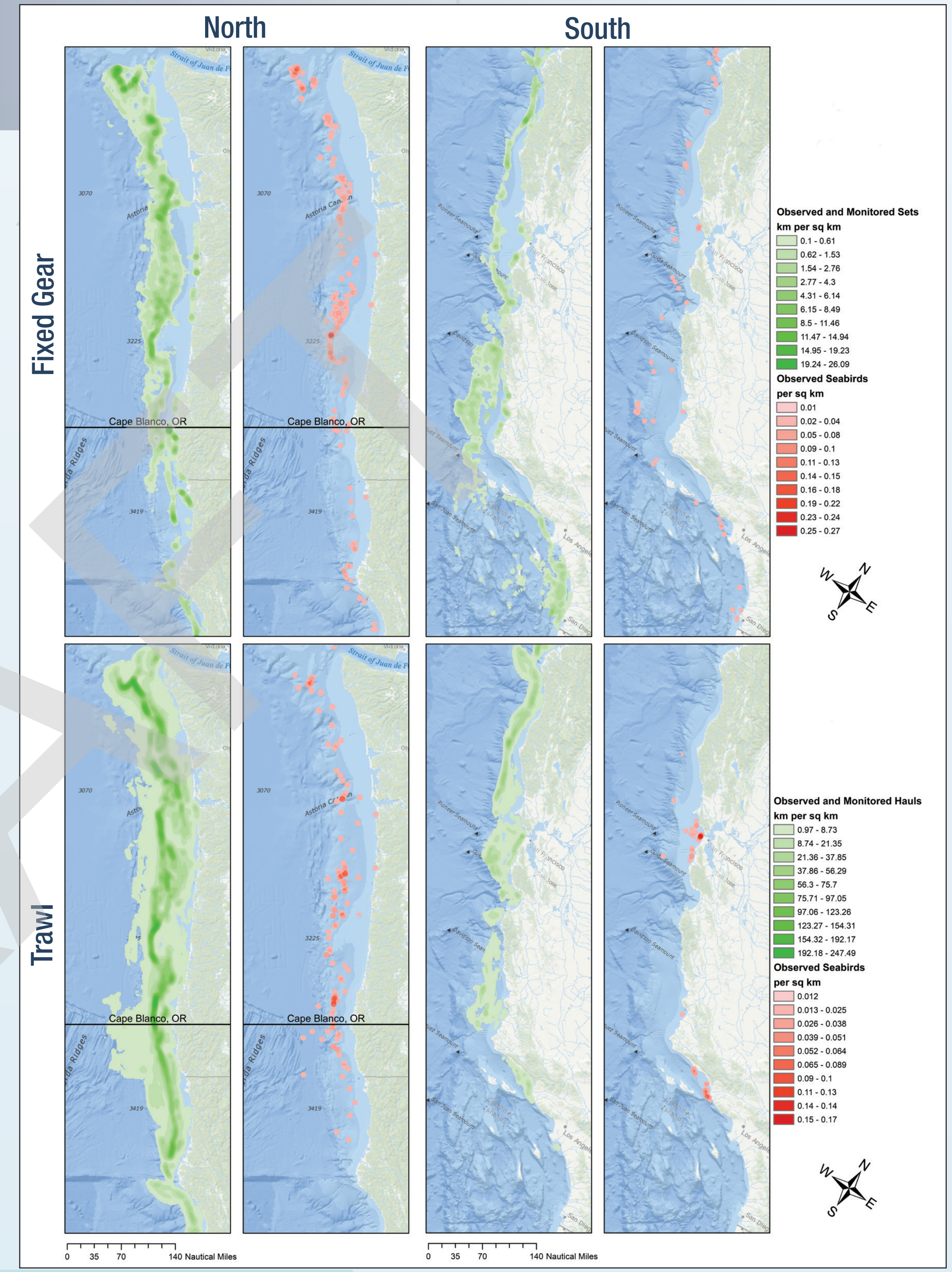


Mitigation Strategies in Hook & Line Fisheries



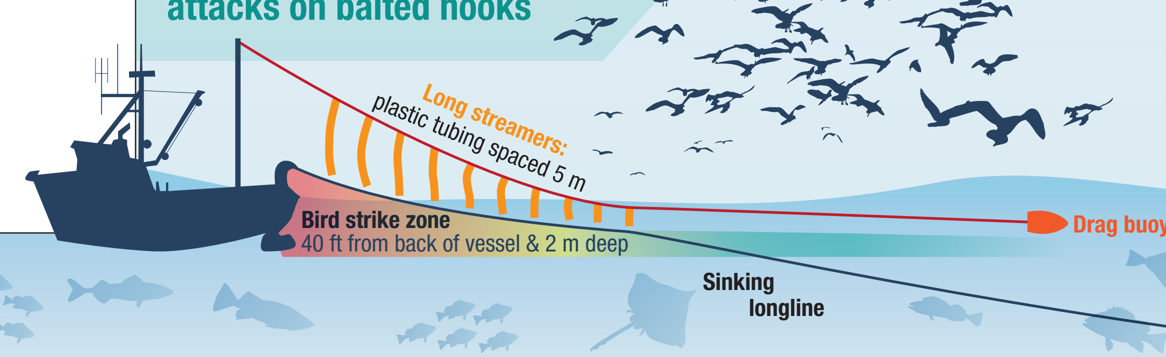
*Includes vessels using hook & line gears in the Sablefish, Daily Trip Limits, and Open Access Fixed Gear fisheries.

Spatial Distribution



Maps created by K. Somers, FRAM/FOS, NWFSC

Streamer lines prevent bird attacks on baited hooks



Management & Policy

JAN 2020
PFMC and NOAA regulation requires streamer lines or night-setting on non-tribal longline vessels 26 ft or longer (84 FR 67674).

MAY 2017
USFWS issues second Biological Opinion regarding Short-tailed Albatross in US West Coast Groundfish Fisheries.

DEC 2015
PFMC and NOAA regulation requires streamer lines on non-tribal longline vessels 55 ft or longer (80 FR 71975).

JUN 2013
PFMC convenes Groundfish Endangered Species Work Group.

NOV 2012
U.S. Fish & Wildlife issues first Biological Opinion regarding Short-tailed Albatross in US West Coast Groundfish Fisheries.

APR 2011
ESA-listed Short-tailed Albatross take on a hook-and-line vessel in the Sablefish fishery.

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Agenda Item G.2.a
NMFS Report 3
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Seabird Bycatch in U.S. West Coast Fisheries (2002-2018)

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2020-07-09

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Table A-2: A description of permits, gears used, target groups, vessel length range, fishing depth range, and management of fisheries, sectors and subsectors in federally managed, non-catch shares, U.S. west coast groundfish fisheries. For brevity, management descriptors are generalized for the given time period and are not meant to be complete or comprehensive.

Table A-3: A description of permits, gears used, target groups, vessel length range, fishing depth range, and management of fisheries, sectors and subsectors in state-managed U.S.

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Appendix B Tables

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Supplemental Table Captions

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Supplemental Table 3: Estimated seabird mortality in U.S. West Coast Limited Entry Sablefish fishery 2002-2018 for vessels fishing with hook-and-line gears. Estimates include both randomly and opportunistically sampled birds (see text for full explanation). LCL = lower 95% confidence limit, UCL = upper 95% confidence limit

Supplemental Table 4: Estimated seabird mortality in U.S. West Coast Limited Entry Daily Trip Limits fishery 2002-2018 for vessels fishing with hook-and-line gears. Estimates include both randomly and opportunistically sampled birds (see text for full explanation). LCL = lower 95% confidence limit, UCL = upper 95% confidence limit

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Supplemental Table 13: Estimated seabird mortality in U.S. West Coast Limited Entry (LE) California halibut vessels fishing with trawl gears for 2002-2009. The 2010 LE California halibut estimates are included in the 2010 Open Access California halibut values to maintain confidentiality (Supplemental Table 13). Since 2011, LE CA Halibut values are included with Catch Shares Trawl values (Supplemental Table 11) Estimates include both randomly and opportunistically sampled birds (see text for full explanation). LCL = lower 95% confidence limit, UCL = upper 95% confidence limit

Supplemental Table 14: Estimated seabird mortality in U.S. West Coast Open Access (OA) pink shrimp vessels fishing with shrimp trawl gears for 2004-2018. WCGOP began observing OR and CA pink shrimp fisheries in 2004 and WA pink shrimp in 2010. Estimates include both randomly and opportunistically sampled birds (see text for full explanation). Asteriks (*) are confidential data and (–) are years when this fishery was unobserved. LCL = lower 95% confidence limit, UCL = upper 95% confidence limit

Supplemental Table 16: Estimated seabird mortality in U.S. West Coast pot fisheries for 2002-2018. Estimates include both randomly and opportunistically sampled birds (see text for full explanation). LCL = lower 95% confidence limit, UCL = upper 95% confidence limit

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Supplemental Table 21: Observed non-lethal seabird interactions on U.S. west coast Open Access Fixed Gear vessels, all gear types, 2002-2018.

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Supplemental Table 27: Observed non-lethal seabird interactions on Oregon and California Nearshore vessels, all gear types 2003-.2018.

Supplemental Table 28: Seabird sightings on Oregon and California Nearshore vessels, all gear types 2003-2018. Sightings are opportunistic (i.e., non-random) records, often only for ESA listed species.

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Supplemental Table 33: Seabird sightings on U.S. west coast Limited Entry Trawl vessels, 2002-2010. Sightings are opportunistic (i.e., non-random) records, often only for ESA listed species.

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Figure 1: Estimated short-tailed albatross, other albatross and other birds mortality (mean no. individuals, 2002-2018).

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Figure 3: Total estimated seabird mortality from vessels using hook-and-line gear observed by the NWFSC Groundfish Observer Program. Dashed gray lines represent total bird mortality from all gear types and are the same as those shown in Figure 2. Solid black lines represent mortality from hook-and-line gears. Shaded gray area represents the 95% confidence interval. Table 5 reports the values.

Figure 4: Spatial distribution of observed seabird bycatch (mt/km2) and observed or monitored fishing gear sets on fixed gear vessels (hook-and-line and pot) off the coasts of Washington, Oregon, and northern California monitored by the NWFSC Observer Program (2002–18) and the PSMFC Electronic Monitoring Program (2015–18) . The ten catch classifications were defined by excluding any zero values and then applying the Jenks natural breaks classification method. Cells (200 km2) with less than three vessels were omitted from the map to maintain confidentiality.

Figure 5: Spatial distribution of observed seabird bycatch (mt/km2) and observed or monitored fishing gear sets on fixed gear vessels (hook-and-line and pot) off the coast of southern California monitored by the NWFSC Observer Program (2002–18) and the PSMFC Electronic Monitoring Program (2015–18) . The ten catch classifications were defined by excluding any zero values and then applying the Jenks natural breaks classification method. Cells (200 km2) with less than three vessels were omitted from the map to maintain confidentiality.

Figure 6: Albatross and other birds observed bycatch rates, as either number of observed birds per 1000 hooks or per metric ton of landed targeted fish, from hook-and-line fisheries observed by the NWFSC Groundfish Observer Program. Birds per 1000 hooks is the international standard for reporting seabird bycatch. LE = Limited Entry, OA = Open Access, DTL = Daily Trip Limits.

Figure 7: Observer coverage (observed retained fish [mt] / total landed target catch [mt]) in hook-and-line fisheries monitored by the NWFSC Observer Program. LE = Limited Entry, OA = Open Access, DTL = Daily Trip Limits.

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Figure 9: Spatial distribution of observed seabird bycatch (mt/km2) and monitored fishing sets on bottom, midwater, and shrimp trawl vessels along the Washington, Oregon, and

Northern California coasts observed by the NWFSC Observer Program (2002–18) and the PSMFC Electronic Monitoring Program (2015–18) . The nine catch classifications were defined by excluding any zero values and then applying the Jenks natural breaks classification method. Cells (200 km2) with less than three vessels were omitted from the map to maintain confidentiality.

Figure 10: Spatial distribution of observed seabird bycatch (mt/km2) and monitored fishing sets on bottom, midwater, and shrimp trawl vessels along the Southern California coast observed by the NWFSC Observer Program (2002–18) and the PSMFC Electronic Monitoring Program (2015–18). The nine catch classifications were defined by excluding any zero values and then applying the Jenks natural breaks classification method. Cells (200 km2) with less than three vessels were omitted from the map to maintain confidentiality.

Figure 11: Percentage of observed hauls with seabird mitigation type by year for the 2011-2018 period. More than one type could be used on a single haul. Data on seabird mitigation type was not collected prior to 2009. Only vessels using hook-and-line gears are shown. Vessels over 55 feet in length using hook-and-line gear were required to use streamer lines starting in December 2015.

Figure 12: Percentage of observed hauls with seabird mitigation for each fishery by year for the 2011-2018 period. More than one type of mitigation could be used on a single haul. Data on seabird mitigation type was not collected prior to 2009. Only vessels using hook-and-line gears are shown. Vessels over 55 feet in length using hook-and-line gear were required to use streamer lines starting in December 2015.

Figure 13: Spatial distribution of observed non-lethal interactions and sightings of short-tailed albatross from observers on fishing vessels along the U.S. Pacific coast (WA, OR, CA; 2002-2018). Data are not considered to be randomly sampled.

Figure 14: Spatial distribution of observed non-lethal interactions and sightings of marbled murrelets from observers on fishing vessels along the U.S. Pacific coast (WA, OR, CA; 2002-2018). Data are not considered to be randomly sampled.

Figure 15: Spatial distribution of observed non-lethal interactions and sightings of California least tern from observers on fishing vessels along the U.S. Pacific coast (WA, OR, CA; 2002-2018). Data are not considered to be randomly sampled.

Figure 16: Observed number of nonlethal, non-feeding seabird interactions by year, gear type, and nonlethal interaction type, 2002-2018. Feeding interactions are shown in Figure 16.

Figure 17: Observed number of seabirds feeding on bait, catch, or discards, by year and gear type, 2002-2018.

Figure B-1: Randomly sampled and opportunistic samples as a fraction of total samples, by year.

Acknowledgements

The authors gratefully acknowledge the hard work and dedication of observers and staff from the NWFSC Fisheries Observation Science Program (FOS). We thank Su Kim of the NWFSC Scientific Communications Office for producing the infographic in this report. We thank Eric Ward (NWFSC) for developing the R code package, `bycatch`, which is used for the Bayesian models and MCMC simulations. We thank our partners at Pacific States Marine Fisheries Commission who provide us with data from the IFQ Electronic Monitoring EFP and landings data from PacFIN. Funding for Anna Wuest was generously provided by the 2019 NOAA Hollings Scholar Program.

A note about tables:

Only a small subset of tables been typeset and included in this draft report. All tables are available in the accompanying Excel file: `NWFSC_Seabird_Bycatch_2002_2018_Supplemental_Tables.xlsx`.

Executive Summary

The California Current marine ecosystem on the United States (U.S.) west coast (Washington, Oregon, California) supports a diversity of marine organisms, including seabirds. This report summarizes interactions between U.S. west coast fisheries and seabirds and presents estimates of fleet-wide bycatch for seabirds based on data from fisheries and federal observer programs for the years 2002-2018.

Lethal and non-lethal interactions, as well as sightings, are presented for six fisheries using hook-and-line gear, eight fisheries using trawl gear, and five fisheries using pot gear. In 2017, three new fisheries were added for observation by the Northwest Fisheries Science Center (NWFSC) Observer Program: Pacific halibut (*Hippoglossus stenolepis*) hook-and-line fishery, California ridgeback prawn (*Sicyonia ingentis*) trawl fishery, and the California sea cucumber (*Parastichopus californicus*) trawl fishery. The Pacific halibut fishery had relatively high black-footed albatross bycatch and the CA ridgeback prawn fishery had relatively high bycatch of Brandt's cormorant compared to other fisheries. No birds were observed as bycatch in the CA sea cucumber fishery. Recreational and tribal fisheries are not covered in this report.

A total of 47 bird species interacted with or were sighted in these fisheries over the 2002-2018 period, up from 41 in the last report (Jannot et al. 2018). Thirteen species are considered endangered, threatened, vulnerable, or near threatened by the U.S. Endangered Species Act (ESA) or the International Union for Conservation of Nature. The remaining 34 species are not listed or are categorized as "Least Concern" (i.e., not at risk).

All three north Pacific albatross species interact with these fisheries: black-footed, Laysan, and the ESA-listed short-tailed albatross. To date, only one short-tailed albatross has been observed taken by these fisheries, and the mean estimated mortality for most years is less than 1 individual per year (Figure 1). However, black-footed albatross are caught annually in a number of fisheries reported here, primarily hook-and-line fisheries. Laysan albatross have occasionally been taken by fisheries reported here, but the mortalities are few and infrequent. The estimated mean mortalities of black-footed plus Laysan albatross ranged from a low of 60.77 individuals in 2002 to a high of 139.58 individuals in 2010 (see 'Other albatross' in Figure 1). The 2018 estimate, across fisheries, for black-footed and Laysan albatross was 88.69 individuals (Figure 1). Other birds (i.e., non-albatross) showed a peak in mortality during 2009 of 439.76 birds taken and the 2018 mean estimated mortality of other birds was 296.48 (Figure 1).

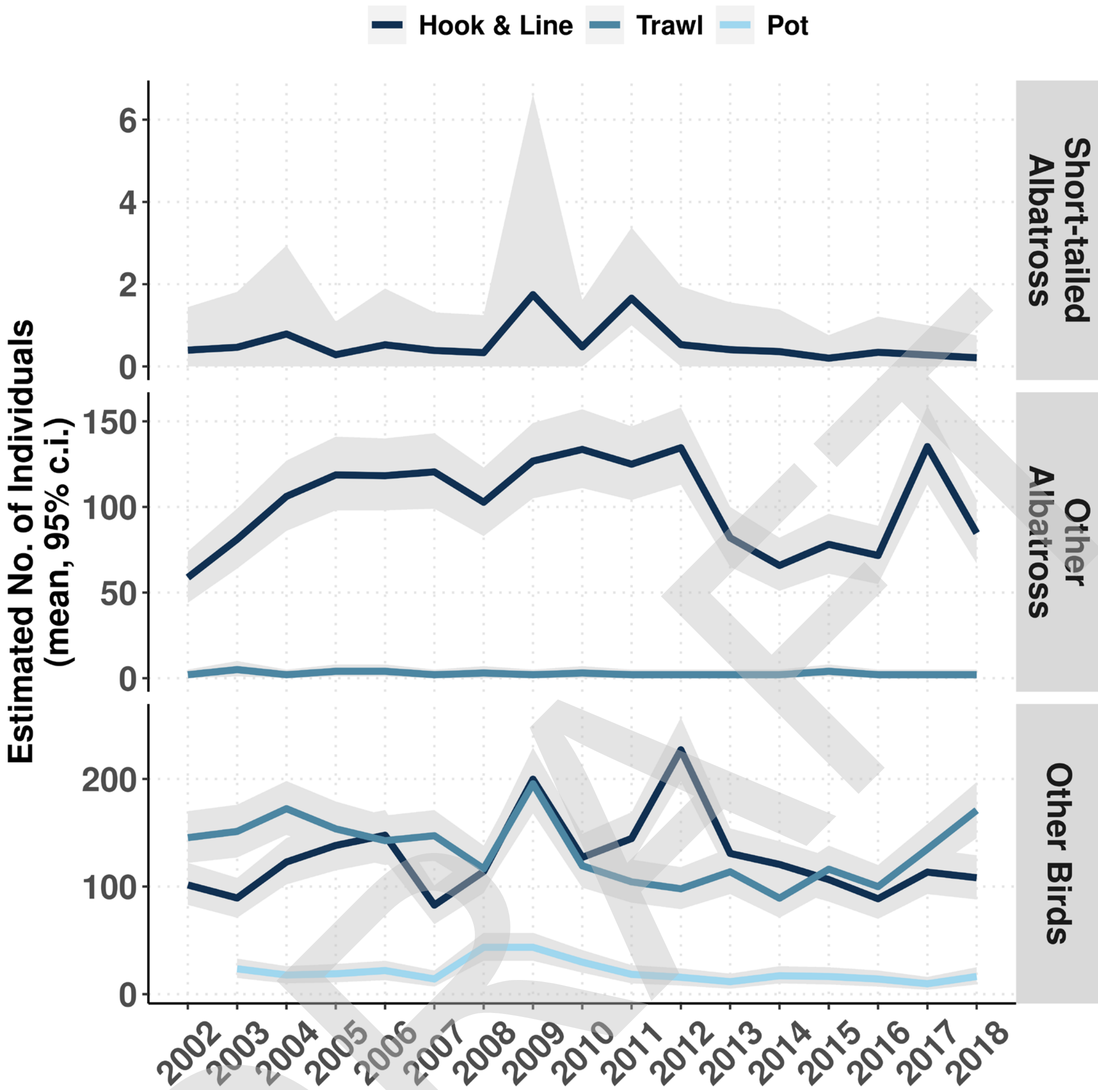

Figure 1: Estimated short-tailed albatross, other albatross and other birds mortality (mean no. individuals, 2002-2018).

Hook-and-line fisheries account for the largest number of albatrosses taken among the three gear categories (hook-and-line, trawl, pot). Over the last six years, hook-and-line fisheries account for 50-63% of seabird mortality, followed by trawl fisheries at 31-45%, and pot fisheries at 2-6% of bycatch (Table 1. The largest number of albatross taken comes from Limited Entry (LE) sablefish vessels fishing hook-and-line gears. This prompted regulations requiring streamer-lines on hook-and-line vessels fishing in U.S. west coast groundfish fisheries which were implemented in December 2015 for vessels 55 feet or longer (NOAA 2019). Beginning in January of 2020, all vessels 26 feet or longer fishing with hook-and-line gear north of 36° N. latitude must use stream-lines during daylight hours (1 hour before sunrise to 1 hour after sunset). Alternatively, night-setting (1 hour after sunset to 1 hour before sunrise) can be used to reduce seabird bycatch on hook-and-line vessels in lieu of stream-lines.

Bycatch of non-albatross species is generally split evenly between hook-and-line and trawl gears. Seabird mortality is likely underestimated on trawl vessels because seabirds can be killed or injured by striking cables that exit aft of the vessel during trawling. These cables are not routinely monitored in these fisheries. Significant levels of bycatch, especially of albatross, have been recorded in similar trawl fisheries around the globe (Favero, et al. 2011; Maree, et al. 2014; Tamini, et al. 2015). In this report, we provide estimates of seabird mortality by cable strikes in the at-sea hake catcher-processor fleet. Pot gears appear to catch very few seabirds.

In earlier versions of this report (Jannot et al. 2011) we used ratios to estimate seabird bycatch. In the previous report (Jannot et al. 2018) we implemented an improved method for bycatch estimation. We applied Bayesian models to estimate total bycatch and associated error for fisheries with less than 100% observer coverage. These methods have been used with other rare bycatch species, including cetaceans, delphinids, pinnipeds, sea turtles, and sharks (Martin et al. 2015). The Bayesian method better estimates uncertainty and provides fleet-wide estimates even in years when no seabird mortality was recorded by fisheries observers.

In the previous report (Jannot et al. 2018), we assumed the estimated bycatch rate, θ, was constant through time. In this report, we explicitly test for constant bycatch rate. We also compare models using alternative measures of fishing effort (# gear deployments, # gear units, amount of landed catch) and alternative distributions of the bycatch process (Poisson versus negative binomial). The results presented here represent the optimal model when comparing these parameters.

Sector	**Gear**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**
Limited Entry Sablefish	Hook & Line	83.64	91.18	75.28	90	63.27	79.01
LE Fixed Gear DTL	Hook & Line	52.52	52.21	48.96	52.25	78.15	88
Nearshore	Hook & Line	26.7	30.73	26.12	31.53	31.79	32.13
2A Directed P. halibut	Hook & Line	15.24	58.68	--	--	--	--
OA Fixed Gear	Hook & Line	13.75	15.09	11.24	11	8.75	13.95
Catch Shares	Hook & Line	1.24	1	--	--	4.76	--
Ridgeback Prawn	Trawl	61.42	35.06	--	--	--	--
Catcher Processor	Trawl	53	53.01	64.01	64	49	113
OA CA Halibut	Trawl	34.01	28.41	16.56	13.63	8.6	23.11
Pink Shrimp	Trawl	26.45	22.39	25.34	46.49	32.54	34.47
MS Catcher Vessels	Trawl	0	0	1	2	2	0
Catch Shares	Trawl	--	1	4	2	1.02	4.09
Midwater Hake EM	Trawl	--	1	--	--	--	--
Nearshore	Pot	16.41	9.65	14.08	16.39	17.1	10.59
Catch Shares EM	Pot	1	--	--	--	--	--

Limited Entry Sablefish	Pot	--	--	--	--	1	--
Catch Shares	Pot	--	--	--	--	--	1
Totals							
	Hook & Line	193.09	248.89	161.6	184.78	186.72	213.09
	Trawl	174.88	140.87	110.91	128.12	93.16	174.67
	Pot	17.41	9.65	14.08	16.39	18.1	11.59
Percentages							
	Hook & Line	50%	62%	56%	56%	63%	53%
	Trawl	45%	35%	39%	39%	31%	44%
	Pot	5%	2%	5%	5%	6%	3%

Table 1: Estimated seabird mortality (numbers of individuals) and the percent of total mortality by gear type and year in U.S. west coast fisheries, 2012-2018. OA = Open Access, DTL = Daily Trip Limits, MS = Mothership

Introduction

The California Current marine ecosystem on the United States (U.S.) west coast (Washington, Oregon, California) supports a diversity of marine organisms, including seabirds. Managing and conserving marine biodiversity requires accounting for human-induced mortality to seabirds. Seabirds overlap with commercial fisheries operating within the U.S. Exclusive Economic Zone (EEZ) on the U.S. west coast, which can cause incidental human-induced mortality, or bycatch, of these species. This report summarizes interactions between U.S. west coast fisheries and seabirds and presents estimates of fleet-wide bycatch for seabirds based on fishery and federal observer program data for the years 2002-2018.

More species of seabirds are threatened or endangered than any other bird group, and seabird populations have declined faster than other bird groups (Croxall et al., 2012; Lascelles et al., 2016). Seabird bycatch is considered a major threat to seabird populations, and, on a relative scale, is a threat to seabirds second only to invasive species (Croxall et al., 2012). Furthermore, bycatch affects a larger proportion of seabird populations than most other human threats to these species. Fishing vessels using longline gear kill 160,000 - 320,000 seabirds globally each year (Anderson et al., 2011). Although global estimates are lacking for trawl fisheries, individual studies indicate that global seabird mortality from trawl gear is likely to be of a similar scale (Bartle, 1991; Weimerskirch et al., 2000; González-Zevallos et al., 2007; Watkins et al., 2008; Tamini et al., 2015). Quantifying the lethal and sub-lethal effects of fisheries on seabirds is the first step in understanding the impact of fisheries on seabird populations and developing solutions to minimize seabird bycatch.

Species-specific characteristics such as feeding locations and times, diet preferences, sizes, and individual physical conditions play a role in susceptibility of seabirds to fishing mortality. Albatross populations are especially vulnerable to the impact of bycatch mortality because they exhibit delayed maturity, low annual fecundity, and long life spans – life history characteristics that make populations vulnerable to decline from even small increases in mortality. Commercial fisheries have been implicated in the decline of many albatross and petrel species (Weimerskirch et al., 1997; Lewison and Crowder, 2003; Baker et al., 2007). Fifteen of 22 albatross species (Family Diomedeidae) are threatened with extinction, which is one of the highest proportions for any bird family (Butchart et al., 2004; Croxall et al., 2012; IUCN, 2020).

The U.S. Fish and Wildlife Service (USFWS) manages seabird populations in the U.S. by enforcing laws and regulations pertaining to seabirds and other migratory birds. NOAA's Northwest Fisheries Science Center (NWFSC) and West Coast Regional Office (WCRO) in collaboration with the USFWS gather data on fishery related mortality of seabirds in U.S. west coast fisheries to aid USFWS and other agencies in their efforts to quantify and mitigate seabird bycatch. Albatross are one of the most threatened groups of seabirds and the most frequently observed bycatch species in the fisheries reported here, we highlight albatross mortality in this report.

Seabirds in the California Current

The U.S. west coast supports a diversity of seabirds of both national and international importance; these species exhibit a wide range of life history characteristics. Seabirds interacting with west coast fisheries include species that breed locally. For example, west coast populations of nesting Brandt's cormorants (*Phalacrocorax penicillatus*) and western gulls (*Larus occidentalis*) represent the majority of the global populations of these species (USFWS, 2005). In addition to resident species, the California Current ecosystem hosts millions of seabird migrants including three species of global conservation concern: the short-tailed albatross (*Phoebastria albatrus*) is listed as endangered under the U.S. Endangered Species Act (ESA) and the black-footed (*Phoebastria nigripes*) and Laysan albatrosses (*Phoebastria immutabilis*) are listed as near-threatened on the IUCN Red List (International Union for Conservation of Nature). Other west coast seabirds that are ESA-listed include California least terns (*Sternula antillarum browni*, endangered) and the marbled murrelet (*Brachyramphus marmoratus*, threatened; Table 2: U.S. Endangered Species Act (ESA) status, International Union for the Conservation of Nature (IUCN) status, number of observed mortalities (takes), number of non-lethal interactions, and number of sightings for all birds recorded by observers on U.S. west coast fishing vessels observed by the Northwest Fisheries Science Center Observer Program, 2002-2018. Estimated fishing mortality by year for each species is given in Table 3.). All three of these species interact or have the potential to interact with commercial fishing vessels in this region. In addition to the albatross and ESA-listed species already mentioned, 8 others categorized by the IUCN as vulnerable or near threatened also interact with U.S. west coast fisheries (Table 2: U.S. Endangered Species Act (ESA) status, International Union for the Conservation of Nature (IUCN) status, number of observed mortalities (takes), number of non-lethal interactions, and number of sightings for all birds recorded by observers on U.S. west coast fishing vessels observed by the Northwest Fisheries Science Center Observer Program, 2002-2018. Estimated fishing mortality by year for each species is given in Table 3.).

Common.Name	**Species**	**ESA**	**IUCN**	**Observed takes**	**Interactions**	**Sightings**
Short-tailed Albatross	*Phoebastria albatrus*	Endangered	Vulnerable	1	69	176
California Least Tern	*Sternula antillarum browni*	Endangered	Not Assessed	0	0	5
Marbled Murrelet	*Brachyramphus marmoratus*	Threatened	Endangered	0	1	11
Ashy Storm-Petrel	*Hydrobates homochroa*	Not Listed	Endangered	0	1	0
Pink-footed Shearwater	*Ardenna creatopus*	Not Listed	Vulnerable	5	5	48
Leach's Storm-Petrel	*Hydrobates leucorhous*	Not Listed	Vulnerable	29	13	30
Black-legged Kittiwake	*Rissa tridactyla*	Not Listed	Vulnerable	0	0	1
Sooty Shearwater	*Ardenna grisea*	Not Listed	Near Threatened	58	26	7858

Snowy Plover	*Charadrius nivosus*	Not Listed	Near Threatened	0	1	0
Heermanns Gull	*Larus heermanni*	Not Listed	Near Threatened	0	3	34
Laysan Albatross	*Phoebastria immutabilis*	Not Listed	Near Threatened	3	55	87
Black-footed Albatross	*Phoebastria nigripes*	Not Listed	Near Threatened	383	2933	4534
Cassin's Auklet	*Ptychoramphus aleuticus*	Not Listed	Near Threatened	11	37	3
Green-winged Teal	*Anas crecca carolinensis*	Not Listed	Not Assessed	10	0	0
Short-tailed Shearwater	*Ardenna tenuirostris*	Not Listed	Least Concern	0	1	0
Wilsons Warbler	*Cardellina pusilla*	Not Listed	Least Concern	0	1	0
South Polar Skua	*Catharacta maccormicki*	Not Listed	Least Concern	0	1	0
Pigeon Guillemot	*Cepphus columba*	Not Listed	Least Concern	0	0	99
Rhinoceros Auklet	*Cerorhinca monocerata*	Not Listed	Least Concern	0	2	2
Semipalmated Plover	*Charadrius semipalmatus*	Not Listed	Least Concern	0	1	0
Tufted Puffin	*Fratercula cirrhata*	Not Listed	Least Concern	0	1	17
Northern Fulmar	*Fulmarus glacialis*	Not Listed	Least Concern	269	2559	193
Common Loon	*Gavia immer*	Not Listed	Least Concern	1	1	0
Pacific Loon	*Gavia pacifica*	Not Listed	Least Concern	0	0	2
Fork-tailed Storm-Petrel	*Hydrobates furcatus*	Not Listed	Least Concern	0	101	6
California Gull	*Larus californicus*	Not Listed	Least Concern	2	1	32
Mew Gull	*Larus canus*	Not Listed	Least Concern	1	0	0
Ring-billed Gull	*Larus delawarensis*	Not Listed	Least Concern	1	0	0
Glaucous-winged Gull	*Larus glaucescens*	Not Listed	Least Concern	4	4	7
Western Gull	*Larus occidentalis*	Not Listed	Least Concern	72	7681	157
Arctic Herring Gull	*Larus smithsonianus*	Not Listed	Least Concern	13	0	1
Orange-crowned Warbler	*Leiothlypis celata*	Not Listed	Least Concern	0	3	0

White-winged Scoter	*Melanitta deglandi*	Not Listed	Least Concern	3	0	0
Fox Sparrow	*Passerella spp.*	Not Listed	Least Concern	0	1	0
American White Pelican	*Pelecanus erythrorhynchos*	Not Listed	Least Concern	0	0	0
Brown Pelican	*Pelecanus occidentalis*	Not Listed	Least Concern	6	11	101
Red-billed Tropicbird	*Phaethon aethereus*	Not Listed	Least Concern	0	0	1
Double-crested Cormorant	*Phalacrocorax auritus*	Not Listed	Least Concern	2	2	0
Pelagic Cormorant	*Phalacrocorax pelagicus*	Not Listed	Least Concern	0	0	7
Brandts Cormorant	*Phalacrocorax penicillatus*	Not Listed	Least Concern	28	5	0
Red-necked Phalarope	*Phalaropus lobatus*	Not Listed	Least Concern	1	1	0
Lesser Goldfinch	*Spinus psaltria*	Not Listed	Least Concern	0	1	0
Long-Tailed Jaeger	*Stercorarius longicaudus*	Not Listed	Least Concern	0	1	0
Pomarine Jaeger	*Stercorarius pomarinus*	Not Listed	Least Concern	0	1	1
Brown Booby	*Sula leucogaster*	Not Listed	Least Concern	0	5	2
Ancient Murrelet	*Synthliboramphus antiquus*	Not Listed	Least Concern	0	0	1
Common Murre	*Uria aalge*	Not Listed	Least Concern	70	8	96

Table 2: U.S. Endangered Species Act (ESA) status, International Union for the Conservation of Nature (IUCN) status, number of observed mortalities (takes), number of non-lethal interactions, and number of sightings for all birds recorded by observers on U.S. west coast fishing vessels observed by the Northwest Fisheries Science Center Observer Program, 2002-2018. Estimated fishing mortality by year for each species is given in Table 3.

All seabirds in the California Current ecosystem are highly mobile and require an abundant food source to support their high metabolic rates (Ainley et al., 2005). Thus, oceanic productivity and prey availability drive seabird abundance along the U.S. west coast (Tyler et al., 1993; Ainley et al., 2005). Coastal upwelling, which delivers nutrient rich water to the surface, determines the seasonal and latitudinal distribution of prey biomass, which seabirds follow (Tyler et al., 1993). On the U.S. west coast, upwelling is most intense south of Cape Blanco, OR (42° 50′ N latitude) (Bakun et al., 1974; Barth et al., 2000), which appears to support a large percentage of the nesting sites of locally breeding seabirds (Tyler et al., 1993). The location of stable nesting sites reflects oceanographic conditions that support long-term food availability (Tyler et al., 1993, Naughton et al. 2007). Transient species to the California Current system are also most abundant in areas of strong upwelling intensity and high productivity (Briggs and Chu, 1986; Hyrenbach et al., 2002).

The U.S. west coast upwelling not only varies by latitude, but also by season, thereby influencing both the latitudinal and seasonal distribution of seabirds. The U.S. West coast has three distinct oceanic seasons: the Upwelling, Oceanic, and Davidson Current seasons (Ford et al., 2004). The Upwelling season coincides with late spring and summer, when northerly winds transport surface waters southward and away from the coast. The distribution of breeding species in summer largely reflects the location of nesting colonies, which are most prevalent adjacent to the central and northern portion of the California Current system (Tyler et al., 1993; Ford et al., 2004). However, during this time, productivity and prey abundance associated with upwelling bring visiting species to the U.S. west coast which outnumber the breeding species. Commonly observed visiting species in summer include the sooty shearwater (*Puffinus griseus*), northern fulmar (*Fulmarus glacialis*), and black-footed albatross (*Phoebastria nigripes*) (Tyler et al., 1993). During the fall Oceanic season, northerly winds and upwelling intensity decrease, and sea surface temperature reaches its annual maximum. Several species that nest further south in Mexico and southern California move northward, including the brown pelican (*Pelecanus occidentalis*) and storm-petrels (Hydrobatidae). As winter approaches, southern nesters return south and breeders from boreal nesting colonies become more abundant, particularly along the California coast (Tyler et al., 1993). In winter, warmer water delivered by the Davidson current reduces primary production along the U.S. west coast (Davidson Current season). Seabird abundance during this time is generally low (Tyler et al., 1993).

Seabird Management

NOAA's National Marine Fisheries Service is responsible for managing marine ecosystems, including accounting for all fisheries bycatch, including seabirds. NOAA Fisheries works closely with the primary agency responsible for seabird management, USFWS, to assist in seabird management.

Currently, there are multiple U.S. laws, U.S. regulations and NOAA policies that govern seabird bycatch in commercial fisheries, including:

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* Migratory Bird Treaty Act of 1918 (MBTA)
* Endangered Species Act (ESA) of 1973
* U.S. National Plan of Action for Reducing the Incidental Catch of Seabirds
in Longline Fisheries (NPOA-Seabirds)
* Executive Order 13186 "Responsibilities of Federal Agencies to Protect Migr
atory Birds"
* NOAA Fisheries' National Bycatch Strategy
* Magnuson-Stevens Act
* National Environmental Policy Act
* Fish and Wildlife Coordination Act
* National Marine Sanctuaries Act
* USFWS's List of Birds of Conservation Concern (USFWS 2008)
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The MBTA, passed in 1918, affirms and implements the U.S.'s commitment to four international conventions with Canada, Japan, Mexico, and Russia for the protection of a shared migratory bird resource. The MBTA protects all migratory birds and their parts (including eggs, nests, and feathers). Migratory birds live, reproduce, or migrate across international borders at some point during their annual life cycle. In total, 836 bird species are protected under the MBTA. The MBTA applies to the area in U.S. coastal waters extending 4.8 km from shore and violations carry criminal penalties.

The purpose of the ESA (1973) is to protect and recover imperiled species and the ecosystems upon which they depend. Currently, there are over 1400 species in the United States listed as threatened or endangered under the ESA. The ESA offers seabirds additional protective measures beyond the MBTA. The ESA authorizes protective measures for listed species, which include restrictions on taking, transporting, or selling specimens. The USFWS has jurisdiction over all endangered birds in the U.S., including the Short-tailed albatross, which is found along the U.S. west coast and overlaps and interacts with U.S. west coast fisheries.

U.S. West Coast Fisheries Management

Fishery Descriptions

The U.S. west coast fisheries that catch groundfish are multi-species fisheries that utilize a variety of gear types (Appendix A Tables A-1, A-2, & A-3). These fisheries harvest species designated in the Pacific Coast Groundfish Fishery Management Plan (FMP; PFMC 2019) or incidentally catch FMP groundfish in pursuit of non-groundfish target species. These fisheries are managed by the Pacific Fishery Management Council (PFMC) in collaboration with the states of Washington, Oregon, California, Idaho and other stakeholders. Over 90 species are listed in the groundfish FMP, including a variety of rockfish, flatfish, roundfish, skates, and sharks. These species are found in both federal (> 4.8 km off-shore to the EEZ) and state waters (0-4.8 km). Groundfish are both targeted and caught incidentally by trawl nets, hook-and-line gears, and fish pots.

Under the FMP, the groundfish fishery consists of four management components:

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* The Limited Entry (LE) component encompasses all commercial fishers who hol
d a federal limited entry permit. The total number of limited entry permits a
vailable is restricted. Vessels with an LE permit are allocated a larger port
ion of the total allowable catch for commercially desirable species than vess
els without an LE permit.

* The Open Access (OA) component encompasses commercial fishers who do not ho
ld a federal LE permit. Some states require fishers to carry a state issued p
ermit for certain OA fisheries.

* The Recreational component includes recreational anglers who target or inci
dentally catch groundfish species. Estimates of seabird bycatch in recreation
al fisheries are not covered by this report.
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* The Tribal component includes native tribal commercial fishers in Washingto
n state that have treaty rights to fish groundfish. Estimates of seabird byca
tch from tribal fisheries are not included in this report.
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The LE and OA components can be further subdivided into fishery sectors based on gear type, target species, permits and other regulatory factors (Appendix A, Tables A-1, A-2, & A-3).

In 2011, the limited entry (LE) bottom trawl fishery of the U.S. west coast groundfish fishery began fishing under an Individual Fishing Quota (IFQ) management program. An IFQ is defined as a federal permit under a limited access system to harvest a quantity of fish, representing a portion of the total allowable catch of a fishery that can be received or held for exclusive use by a person (MSA 16 UlC 1802(23)). The implementation of the IFQ management program in 2011 resulted in a mandate that vessels must carry NMFS observers or electronic monitoring (EM) equipment on all IFQ fishing trips. Prior to the IFQ program, vessels in this fishery could only fish with bottom trawl gear. Since the IFQ implementation, bottom and midwater trawl, as well as hook-and-line and pot gears are allowed to be fished under this permit.

NWFSC Groundfish Observer Program

The NWFSC Groundfish Observer Program places at-sea observers on commercial fisheries that catch groundfish as target species or bycatch in the U.S. west coast EEZ. At-sea observer data inform independent estimates of the amount and types of species caught and discarded in these fisheries. The observer program has two units: the At-Sea Hake Observer Program (A-SHOP) and the West Coast Groundfish Observer Program (WCGOP). The WCGOP and A-SHOP observe distinct sectors of the groundfish fishery (Appendix A, Tables A-1, A-2, & A-3).

At-sea Hake Observer Program (A-SHOP)

The A-SHOP observes the fishery that catches and delivers Pacific hake at-sea (a.k.a. Pacific whiting, *Merluccius productus*, henceforth referred to as hake) including non-tribal catcher-processors and catcher vessels delivering to motherships (Appendix A, Table A-1). The A-SHOP has conducted observations of the U.S. west coast at-sea hake fishery since 2001. Prior to 2001, observer coverage of the U.S. west coast at-sea hake fishery was conducted by the North Pacific Groundfish Observer Program. Information on the A-SHOP and data collection methods used can be found in the A-SHOP observer manual (NWFSC, 2019). The at-sea hake fishery has mandatory observer coverage, with each vessel over 38 meters carrying two observers. Beginning in 2011, under IFQ/Co-op Program management, all catcher vessels that deliver catch to motherships are required to carry observers or use electronic monitoring equipment.

Observers on at-sea hake vessels take a random sample of the total catch, including both the component that will be retained and that which will be discarded. With one or two observers on-board each vessel, nearly 100% of tows are sampled. However, because of the large volume of catch from each tow, it is typically only possible to sample 30 to 60% of the total tow catch. When a sample is collected, the species within it are identified, counted, and weighed. The resulting data are expanded to the tow level and used to summarize catch by species in the fleet as a whole.

West Coast Groundfish Observer Program (WCGOP)

The WCGOP program was established in May 2001 by NOAA Fisheries (a.k.a., National Marine Fisheries Service, NMFS) in accordance with the Pacific Coast Groundfish Fishery Management Plan (50 CFR Part 660) (50 FR 20609). This regulation requires all vessels that catch groundfish in the U.S. EEZ from 4.8-322 km offshore to carry an observer when notified to do so by NMFS or its designated agent. Subsequent state rule making and permitting processes has extended NMFS's ability to require some vessels fishing in the 0-4.8 km state territorial zone to carry observers.

The WCGOP observes multiple Federal groundfish fisheries, including IFQ shoreside delivery of groundfish and Pacific hake, LE and OA fixed gear fisheries, and the fishery that targets Pacific halibut (Appendix A, Tables A-1, A-2). The WCGOP also observes several state-permitted fisheries that target or incidentally catch groundfish, including the Washington, Oregon, and California pink shrimp trawl fisheries, the Oregon and California nearshore fixed gear fisheries, California halibut trawl, California ridgeback prawn fishery, and the California sea cucumber fishery (Appendix A, Table A-3).

Shoreside IFQ vessels are required to carry an observer on 100% of fishing trips. In 2015, some vessels obtained an exempted fishing permit (EFP) which allowed them to carry electronic monitoring (EM) equipment for catch monitoring in lieu of a human observer. These IFQ EM vessels have 100% monitoring of catch of quota species; scientific observers are placed on about 30% of IFQ EM vessels to provide estiamtes of non-quota species catch. In non-IFQ fishery sectors, there is no mandate for 100% coverage and the amount of observer coverage varies among sectors and within sectors among years (Somers et al., 2019). In these sectors, permits are selected for observation by the WCGOP using a random sampling design without replacement. First, the WCGOP determines the amount of time (based on available resources) it will take to observe the entire fleet; this is termed the selection cycle. Next, the WCGOP aggregates locations along the U.S. west coast into port groups. The permits or vessels in each fishery sector are assigned to a port group based on the location of their previous year's landings. Within each port group, the permits or vessels are randomly selected for coverage. Permits in the LE bottom trawl fishery prior to the IFQ program (2002-2010), LE sablefish fixed gear non-endorsed (non-primary), OA fixed gear, Oregon and California nearshore, California halibut, state-managed pink shrimp, California ridgeback prawn, and California sea cucumber fisheries are selected for one or two month periods, which coincide with cumulative trip limit periods used in management. LE fixed gear sablefish endorsed (primary) permits are selected for the entire sablefish season (April 1 through October 31) until their quota is caught. The Pacific halibut fishery is selected for the entire season which consists of anywhere between one and three 24-hour openers per year. This selection process is designed to produce a logistically feasible sampling plan with a distribution of observations throughout the entire geographic and temporal range of each fishery. Once a permit or vessel has been selected for coverage, the

WCGOP attempts to observe all trips and sets that the vessel makes during the coverage period.

The annual percentage of observer coverage in non-hake fisheries ranges from < 1% to over 30% (Somers et al., 2019), as defined by the proportion of targeted fishery landings that are observed. Coverage varies among fisheries based on priority. Higher priority fisheries receive the highest observer coverage. A list of fisheries in order of coverage priority can be found in the WCGOP manual (NWFSC, 2020).

Fisheries observers monitor and record catch data on commercial fishing vessels by following protocols in the WCGOP manual (NWFSC, 2020). Observer sampling focuses on discarded catch and supplements existing fish ticket landing receipt data to inform weights of retained catch. Observers generally sample 100% of tows/sets made during a trip. On trawlers, the total weight of discarded catch is estimated, and the discarded catch is then sampled for species composition. The species composition sample could represent either a complete census or a subsample of all discarded catch. On fixed gear (hook-and-line and pot gears) vessels, observers sample from 50 to 100% of the catch from each set (similar to at-sea hake observer sampling methodology).

Seabird Mortality

Observer Sampling for Seabirds

All observers receive training on seabird data collection and identification, including the three ESA-listed species: short-tailed albatross, California least tern, and marbled murrelet. A-SHOP and WCGOP place sampling seabird bycatch as the highest priority of observer duties. Observers sample and document seabirds when any of the following occur:

1. Fishing gear catches any seabird, regardless of whether the individual lived or died.
2. A seabird interacted with the fishing vessel but was not caught in the gear.
3. An ESA-listed seabird is sighted.

Observers identify each bird to species or the lowest possible taxonomic unit, and they count, weigh (if bird in hand), and photograph the bird(s). If the seabird has a tag or band, observers remove (from dead birds only) or document tag number(s) and/or band color(s) and note the banding pattern (which leg(s), order of colored bands, etc.). Bird band numbers, colors, and associated information are reported to NWFSC and USFWS staff. Observers must document all sightings of ESA endangered or threatened seabirds (Table 2: U.S. Endangered Species Act (ESA) status, International Union for the Conservation of Nature (IUCN) status, number of observed mortalities (takes), number of non-lethal interactions, and number of sightings for all birds recorded by observers on U.S. west coast fishing vessels observed by the Northwest Fisheries Science Center Observer Program, 2002-2018. Estimated fishing mortality by year for each species is given in Table 3.). When time allows, sightings of other species could be documented.

Observed Fishery Interactions

Observers record a variety of fishery interactions with seabirds. Both observer programs use a system of coded categories to document interactions:

Interaction Category	Interaction Description
Lethal Removal-Not Trailing Gear	Animal(s) killed by vessel personnel to prevent serious damage to or loss of gear, catch, or human life. No gear attached to animal(s).
Lethal Removal-Trailing Gear	Animal(s) killed by vessel personnel to prevent serious damage to or loss of gear, catch, or human life. Pieces of gear, including parts of net or line, attached to animal(s) when returned to sea.
Killed by Gear	Animal(s) killed by interaction with gear.
Vessel Strike	Animal(s) is struck by some part of the vessel, including hull, mast, rigging or cables.
Rig Strike	Animal(s) made contact with vessel's rigging, excluding third wire, paravane, or warp cable interactions. (currently only used in A-SHOP)
Third Wire, Paravane, or Warp Cable Contact	Animal(s) came in contact with the third wire, paravane, or warp cables. (currently only used in A-SHOP)
Entangled in Gear - Not Trailing Gear	Animal(s) entrapped or entangled in fishing gear, but escapes or is released alive. Includes instances where an individual is hooked. No gear attached to animal(s) when returned to sea.
Entangled in Gear - Trailing Gear	Animal(s) entrapped or entangled in fishing gear, but escapes or is released alive. Includes instances where an individual is hooked. Pieces of gear, including parts of net or line, attached to animal(s) when returned to sea.
Feeding on Bait - Attached to Hook	Animal(s) feeding on bait that is still attached to hooks.
Feeding on Bait - Floating Free	Animal(s) feeding on bait that has come free of gear.
Feeding on Discarded Catch	Animal(s) feeding on any part of discarded catch.
Feeding on Offal	Animal(s) feeding on the discarded products of fish processing (e.g., fish guts).
Feeding on Catch	Animal(s) feeding on fish prior to the fish being brought on-board vessel.
Foraging, Not Bait	Animal(s) was foraging or feeding near the vessel but not feeding on bait or discards. (currently only used in A-SHOP)
Deterrence Used	Vessel personnel attempted to deter interaction with animal(s) using: Firearm, Gaff, Acoustic Device, Yelling, or Other method.
Boarded Vessel	Animal(s) boarded the fishing vessel of own volition.
Unknown	The vessel or vessel personnel interacted with animal(s), but the observer did not directly view the interaction nor ascertain what

	the interaction was. Observer notes describe interaction details when possible.
Other	Animal(s) involved in interaction(s) with the vessel; however, the interaction(s) type is not included in list of interaction codes. Observer notes describe interaction details when possible.
Sighting Only	Animal(s) did not interact with vessel but animal(s) was within observation distance of vessel and/or observer.

Table 3: Descriptors used by fishery observers to describe types of seabird interactions with U.S. west coast fishing vessels.

Interactions need to be screened for inclusion (or exclusion) from bycatch estimation, as not all interactions would lead to mortality. To aid this process, in 2015, WCGOP instituted a protocol to record one of five possible outcomes of the interaction:

```
*Alive - No visible signs of injury*: Individual(s) alive and showing no visi
ble signs of injury because of the interaction.

*Alive - Visible signs of injury*: Individual(s) alive, but showing signs of
injury that might be a result of the interaction.

*Dead or Unresponsive Carcass*: Individual(s) dead or unresponsive.

*Not Applicable*: Code only used for sightings.

*Unknown*: Observer is unsure of outcome. Observer notes describe interaction
details when possible.
```

A-SHOP observers began recording one of six possible interaction outcomes in 2010:

```
*Flew Off*: Individual flew off or left the immediate area of the interaction
.

*Released Flew Off*: Any bird that was removed from the vessel or gear and fl
ew off upon release.

*Released To Water*: Individual was removed from the vessel or gear and retur
ned to the water.

*Died*

*Carcass Salvaged*: Whole specimen of dead birds was recovered and preserved.

*Observer End Observing*: Observer stops recording the event because other du
ties take priority.  Common outcome for sightings.
```

We defined any interaction that was immediately lethal or thought to lead to mortality, as a mortality, even if the animal was alive at the time of the observation. Using language adopted from the ESA, we refer to these lethal interactions as ‘takes’. Section 3 of the ESA specifies the term 'take' to mean 'harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct' (16 U.S.C 1532). The combination of the interaction category, interaction outcome, and specific details in observer notes recorded at the time of the interaction informed take designations. Observers typically detail the nature of the injury and changes in the animal's behavior following its release. Noted factors indicating a potential mortality included birds with visible bleeding, broken bones, lost feathers, and birds that did not fly away or return to normal behavior within a few minutes of the interaction. Not all interactions resulted in a mortality and were thus judged to be non-lethal (i.e., not a take).

For ESA-listed seabirds, observers are instructed to collect and freeze the carcass of any dead birds and transfer them to the USFWS. Regulations also require observers to care for any short-tailed albatross (STAL) brought on board injured until USFWS takes possession. The WCGOP (NWFSC, 2020) and A-SHOP (NWFSC, 2019) sampling manuals describe protocols for the collection of dead, and care of injured, ESA-listed seabirds.

Opportunistic Takes - For takes to be used in bycatch estimation, they must either be obtained from a randomly sampled portion of the haul or a complete census of the haul. In some cases observers witness seabird interactions that occur outside of sampled catch (e.g., informed of an interaction by the crew, bird struck vessel or rigging, etc.). Observers record these non-random, opportunistic observations of seabird takes whenever they occur. Opportunistic data are excluded from bycatch expansion because they are not randomly sampled. However, opportunistic samples are included in the final total mortality estimate, by simply adding the number of opportunistic takes to the expanded bycatch estimate. Table B-1 in Appendix B presents both the randomly sampled and opportunistically sampled seabird takes by year, fishery and gear type. B-1 in Appendix B presents opportunistic samples as a proportion of all samples across all fisheries by year for albatross and other birds.

Seabird Bycatch

In this report, we applied a Bayesian modeling approach to estimate total bycatch and associated variability for fisheries with less than 100% observer monitoring, similar to Jannot et al. (2018). These methods have been used with other rare bycatch species, including cetaceans, delphinids, pinnipeds, sea turtles, and sharks (Martin et al. 2015). We modeled bycatch rate and inferred annual expected mortality, given a specified level of effort. Fleet-wide bycatch for fisheries with less than 100% observer coverage was estimated using observer coverage rate (observed landings/total landings). All estimates reported in the tables are based on the Bayesian estimates (±95% confidence limits).

Even though ratio estimators have been widely used in discard estimation (Stratoudakis et al., 1999; Borges et al., 2005; Walmsley et al., 2007), including in the U.S. west coast fisheries (e.g., Jannot et al., 2011), ratio estimators are known to make restrictive assumptions and can be biased, especially when bycatch events are rare (Martin et al. 2015, Carretta and Moore 2014, Rochet and Trenkel, 2005). Ratio estimators rely heavily on the assumption that bycatch is proportional to some metric or proxy of fishing effort, such as fishery landings, an assumption not often supported by data (Rochet and Trenkel, 2005). In some cases, bycatch might vary nonlinearly or even be unrelated to the ratio estimator denominator. Most seabird species reported here are rarely caught. The rarity of seabird bycatch combined with less than 100% observer monitoring in many of these fisheries makes it difficult to assess the link between seabird bycatch and fishing effort. Low levels of observer coverage can produce biased estimates when ratio estimators are used to calculate fleet-wide bycatch of protected species (Carretta and Moore 2014, Martin et al. 2015).

Because albatross are one of the most threatened groups of seabirds (Butchart et al., 2004; Croxall et al., 2012; IUCN, 2020) and the most frequently caught group along the U.S. west coast (Table 4, Figure 2), we present results for the three albatross species combined and compare those results with patterns of bycatch for non-albatross birds combined.

Total Fishing Mortality

Total seabird mortality for all species across all fisheries, is shown, by year in Table 4. Estimates in Table 4 are the combined sum of the observed mortality of individuals from 100% observed fisheries, the sum of the opportunistically sampled individuals, and the mortality estimated from randomly sampled individuals in fisheries with less than 100% observer coverage. The 'exact' confidence intervals are given as "lower confidence limit (LCL) - upper confidence limit (UCL)" in the adjacent column of Table 4 and as a gray ribbon around the lines in Figure 2. Details of the confidence interval calculations can be found in the Methods section.

Species	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL
Year	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018
Black-footed Albatross	134.73	112.9-159.5	85.31	68.2-105.4	69.29	53.9-87.6	82.83	66-102.7	76.14	60-95.3	137.78	115.7-162.8	88.36	70.9-108.8
Laysan Albatross	2.83	0.5-8.5	1.63	0.1-6.6	0.51	0-4.7	0.3	0-4.3	0.5	0-4.7	0.45	0-4.6	0.33	0-4.4
Short-tailed Albatross	0.53	0-4.7	0.41	0-4.5	0.36	0-4.4	0.2	0-4.1	0.34	0-4.4	0.28	0-4.3	0.21	0-4.1
Leach's Storm-Petrel	0	0-3.7	2	0.2-7.2	0	0-3.7	2	0.2-7.2	5	1.6-11.7	3	0.6-8.8	0	0-3.7
Storm-Petrel Unid	0	0	2.04	0.3-7.3	0	0	0	0	0	0	0	0	0	0
Pink-footed Shearwater	8.88	4-16.9	5.8	2.1-12.8	5.43	1.9-12.3	6.45	2.5-13.7	5.23	1.8-12	5.53	1.9-12.4	5.95	2.2-13
Sooty Shearwater	42.13	30.4-56.9	47.62	35.1-63.2	31.28	21.3-44.3	43.22	31.3-58.2	27.84	18.5-40.3	26.41	17.3-38.6	46.03	33.7-61.4
Shearwater Unid	58.57	44.5-75.6	52.51	39.3-68.8	50.34	37.4-66.3	50.03	37.1-66	37.77	26.7-51.9	45.27	33.1-60.5	38.72	27.5-53
Northern Fulmar	20.51	12.6-31.5	59.45	45.3-76.6	11.5	5.8-20.3	19.34	11.7-30.1	16.21	9.3-26.2	11.15	5.6-19.9	8.68	3.9-16.7
Tubenoses Unid	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7
Common Murre	11.93	6.2-20.9	16.96	9.9-27.2	11.31	5.7-20.1	18.34	10.9-28.9	14.53	8-24.2	20.16	12.3-31.1	16.02	9.2-26
Murre Unid	1.07	0-5.7	0	0	0	0	0	0	0	0	0	0	0	0
Cassin's Auklet	0	0-3.7	2	0.2-7.2	2	0.2-7.2	0	0-3.7	1	0-5.6	2	0.2-7.2	0	0-3.7
Alcid Unid	0.76	0-5.1	0.58	0-4.8	0.55	0-4.8	0.3	0-4.3	0.51	0-4.7	0.4	0-4.5	0.32	0-4.3
Brandts Cormorant	13.31	7.1-22.6	16.33	9.4-26.4	16	9.1-26	17.45	10.2-27.8	14.12	7.7-23.6	52.99	39.7-69.3	91.23	73.5-112
Double-crested Cormorant	9.39	4.4-17.6	5.56	1.9-12.4	6.48	2.5-13.7	4.45	1.3-10.9	4.68	1.4-11.2	4.61	1.4-11.1	6.41	2.4-13.6
Cormorant Unid	14.74	8.2-24.4	11.28	5.7-20	10.49	5.1-19	8.52	3.8-16.5	11.6	5.9-20.4	10.12	4.9-18.5	12.95	6.9-22.2
California Gull	1.57	0.1-6.5	0.47	0-4.6	1.4	0.1-6.3	0.2	0-4.1	0.35	0-4.4	0.31	0-4.3	0.21	0-4.1
Glaucous-winged Gull	3.37	0.8-9.3	1	0-5.6	0.82	0-5.3	0.5	0-4.7	0.83	0-5.3	0.79	0-5.2	0.61	0-4.9
Arctic Herring Gull	10.35	5-18.8	5.68	2-12.6	1.41	0.1-6.3	0.89	0-5.4	1.5	0.1-6.4	1.44	0.1-6.3	1.11	0-5.8
Mew Gull	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ring-billed Gull	1.56	0.1-6.5	0.44	0-4.6	0.39	0-4.5	0.21	0-4.1	0.34	0-4.4	0.28	0-4.3	0.21	0-4.1
Western Gull	73.75	57.9-92.6	23.07	14.6-34.6	19.23	11.6-30	16.5	9.5-26.6	15.42	8.7-25.3	20.18	12.4-31.1	15.12	8.5-24.9
Gull Unid	38.43	27.3-52.7	29.72	20-42.5	29.77	20.1-42.6	30.53	20.7-43.4	26.35	17.3-38.5	27.75	18.4-40.2	23.74	15.2-35.4
Brown Pelican	14.47	8-24.1	12.56	6.6-21.7	12.68	6.7-21.8	11.32	5.7-20.1	11.6	5.9-20.4	13.27	7.1-22.6	11.15	5.6-19.9
Common Loon	2.94	0.6-8.7	3.1	0.7-8.9	3.57	0.9-9.6	2.86	0.6-8.6	2.91	0.6-8.6	3.03	0.6-8.8	2.57	0.4-8.1

Green-winged Teal	0	0	0	0	0	0	0	0	0	0	0	0	0	0
White-winged Scoter	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Red-necked Phalarope	0	0	0	0	0	0	0	0	1	0-5.6	0	0	0	0
Seabird Unid	8	3.5-15.8	8	3.5-15.8	8	3.5-15.8	8	3.5-15.8	8	3.5-15.8	9	4.1-17.1	8	3.5-15.8
Warbler Unid	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7	4	1.1-10.2
Bird Unid	4.88	1.6-11.5	5.84	2.1-12.8	5.16	1.7-11.9	4.82	1.5-11.4	2.82	0.5-8.5	3.17	0.7-9	3.45	0.8-9.4

Table 4: Estimated seabird mortality in U.S. west coast fisheries 2012-2018. Estimates include both randomly and opportunistically sampled birds (see text for full explanation). Estimates for the entire time series can be found in the Supplemental Tables. LCL = lower 95% confidence limit, UCL = upper 95% confidence limit).

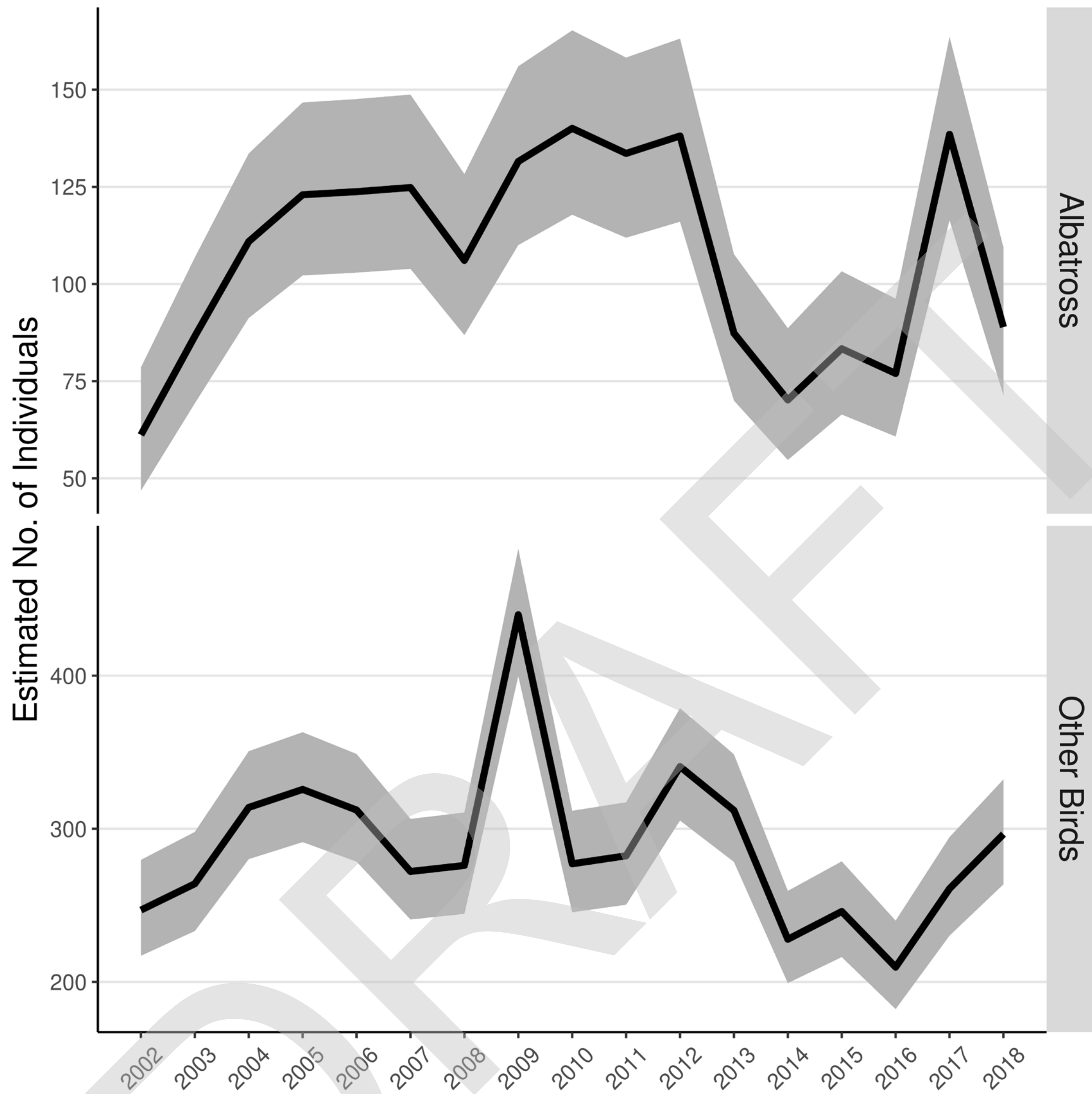

Figure 2: Total estimated seabird mortality (no. individuals = black line; gray ribbon = 95% c.i.) from all fisheries, 2002-2018.

Black-footed albatross (BFAL) are the most frequently caught species (Table 4). From 2012 to 2018, black-footed albatross mortality went from a near high of 135 black-footed albatross in 2012 to a low of 69 birds in 2014, increased to 138 in 2017 and dropped to 88 in 2018 (Table 4) averaging 96 BFALs estimated from 2012-2018. Bycatch estimates of Laysan and short-tailed albatross were much smaller than black-footed estimates, an average of less than one per year of each species from 2012-2018. Pink-footed shearwaters, a species of conservation concern, show a consistent but low amount of annual fishing mortality ranging between five and nine birds per year for the 2012-18 period. Sooty and unidentified shearwaters, followed by gulls, northern fulmars, and common murres make up the remainder of the most common bird bycatch in these fisheries.

Notably, estimated bycatch of Brandt's cormorant from 2012-2016 ranged between 13 and 18 birds per year. However, estimated bycatch of Brandt's cormorant increased to 53 birds in 2017 and 91 birds in 2018. This sudden increase is due, in part, to previously unavailable observations obtained in a the California ridgeback prawn fishery in 2017 and 2018 (see Table 18). The WCGOP began observering this fishery in 2017 and a large number of birds were observed taken in this fishery in the first two years of observation. Low observer coverage and lack of historical observations in the CA ridgeback prawn fishery contribute to both the large estimates and large variance around estimates for Brandt's cormorant.

In all, 32 species or taxa have been observed as bycatch in at least one year during the 17 year period from 2002-2018 (Table 4).

Seabird Bycatch in Hook-and-Line Fisheries

Groundfish fisheries using hook-and-line gear on the U.S. west coast account for the majority of seabird bycatch among these fisheries. Hook-and-line fisheries were responsible for almost all of the albatross bycatch, the majority being black-footed albatross (Figure 3). The spatial distribution of observed seabird bycatch and observed fishing effort for fixed gear fisheries is shown in Figures 4 & 5. Albatross mortality in hook-and-line fisheries drives the time-series of seabird bycatch across all fisheries (Figures 2 & 3. As with the total mortality, hook-and-line mortality was at a near high in 2012 of 132 black-footed, dropping down to a low of 65 birds in 2014, and then increasing again to a high of 135 BFAL in 2017 (Table 5). Laysan and short-tailed albatross mortality was less than one bird per year from 2013-2018 (Table 5). There were an estimated three Laysan albatross mortalities in 2012, dropping to less than one estimated Laysan mortality from 2013-2018. Short-tailed albatross mortality was estimated to be less than one bird per year for 2013-2018.

Hook-and-line vessels also contribute to a large fraction of the non-albatross mortality (Figure 3). Other (non-albatross) seabirds also show an increase in estimated bycatch from about 100 birds in 2002 rising to about 220 seabirds in 2012, with a smaller peak in 2009. Mortality of other seabirds on hook-and-line vessels declined from roughly 210 in 2012 to a little more than 100 in 2018 (Figure 3).

After black-footed albatross, annual bird bycatch on hook-and-line vessels was largely comprised of, in decreasing order, shearwaters, gulls, and brown pelicans (Table 5). Pink-footed shearwaters comprise a small, but consistent portion of the bycatch in hook-and-line fisheries, with annual bycatch estimates between three and eight birds per year (201-2018; Table 5). A smaller number of other species are recorded annually with a total of 23 species or taxa observed as bycatch in these hook-and-line fisheries over the 17-year period (Table 5).

Observed bycatch rates in hook-and-line fisheries are shown in Figure 6. These rates are calculated from the observed data and are not expanded to the whole fleet. Hook-and-line vessels fishing on the U.S. west coast are not required to maintain or submit logbooks, therefore hook counts for these fleets are not available. The international standard for reporting seabird bycatch on hook-and-line vessels is dead birds per 1000 hooks. To compare bycatch rates in our fisheries to global fisheries, we present the observed bycatch rates based on observed number of hooks as well as observed landed catch. Landed catch is the only measure available as a fleet-wide effort metric in these fisheries (Somers et al. 2018). For context we also provide observer coverage rates (Figure 7), which are calculated as the weight of observed retained catch divided by the total weight of landed catch from fish sales receipts.

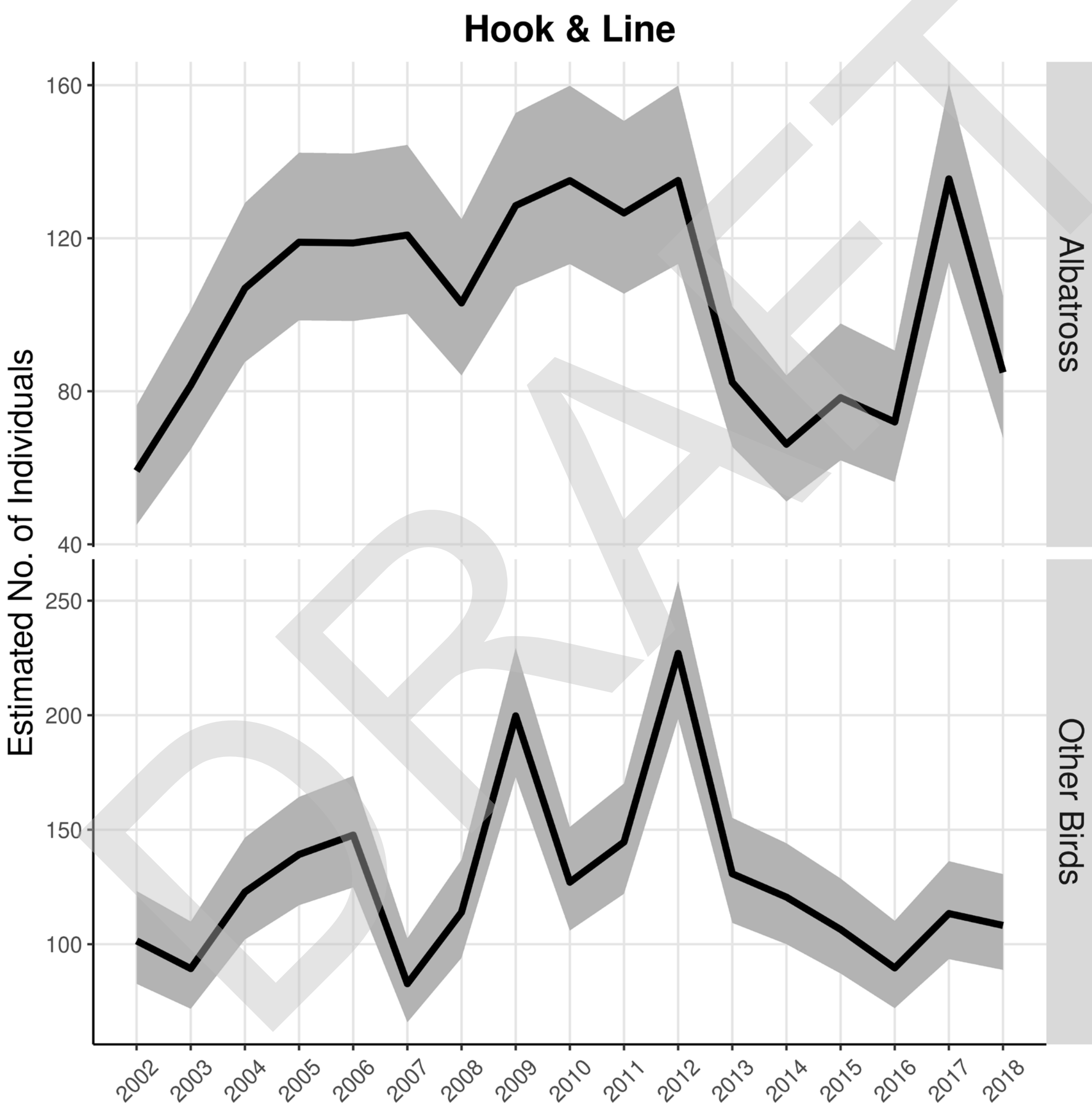

Figure 3: Total estimated seabird mortality from vessels using hook-and-line gear observed by the NWFSC Groundfish Observer Program. Solid black lines represent mortality from hook-and-line gears. Shaded gray area represents the 95% confidence interval. Table 5 reports the values.

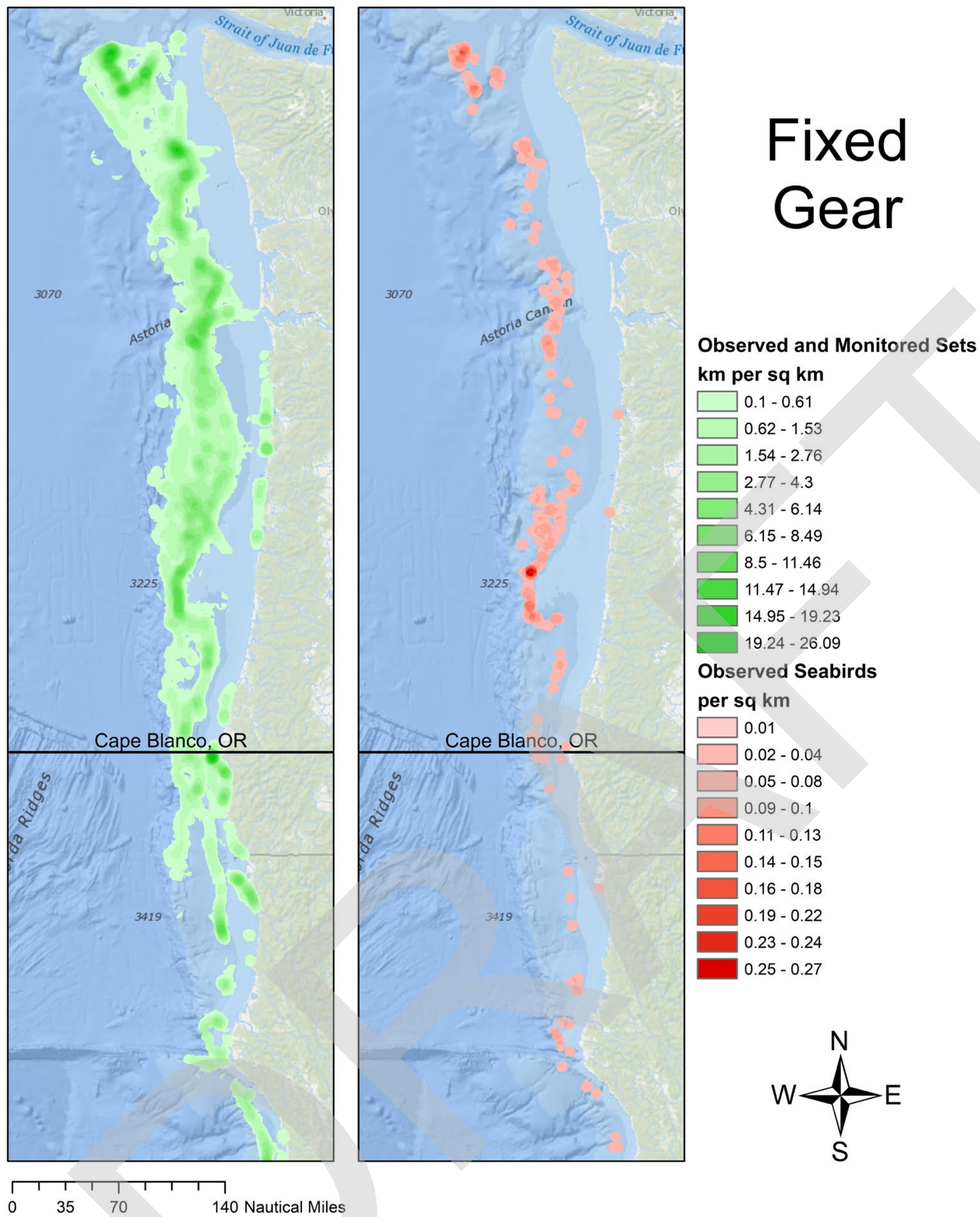

Figure 4: Spatial distribution of observed seabird bycatch (mt/km2) and observed or monitored fishing gear sets on fixed gear vessels (hook-and-line and pot) off the coasts of Washington, Oregon, and northern California monitored by the NWFSC Observer Program (2002–18) and the PSMFC Electronic Monitoring Program (2015–18). The ten catch classifications were defined by excluding any zero values and then applying the Jenks natural breaks classification method. Cells (200 km2) with less than three vessels were omitted from the map to maintain confidentiality.

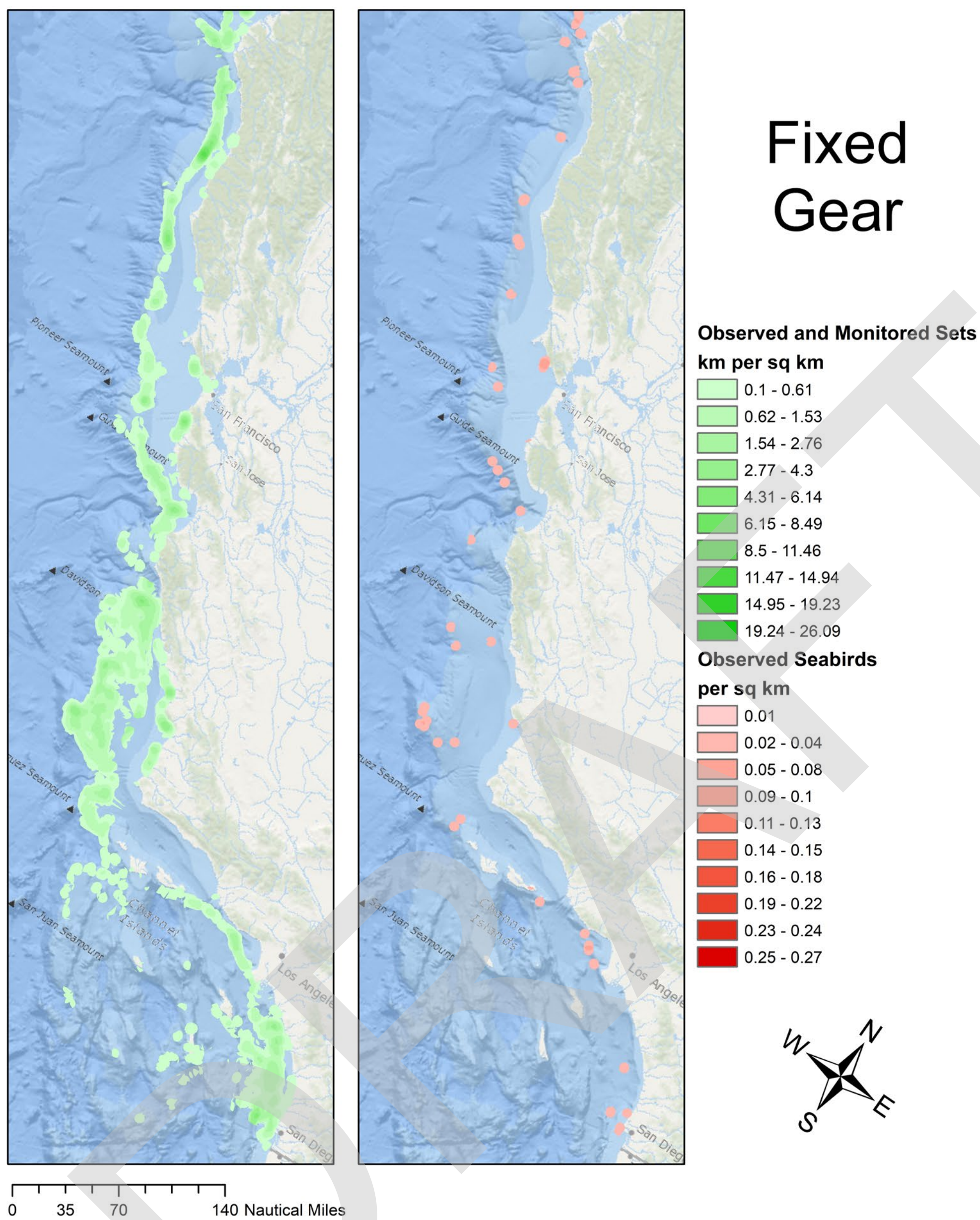

Figure 5: Spatial distribution of observed seabird bycatch (mt/km2) and observed or monitored fishing gear sets on fixed gear vessels (hook-and-line and pot) off the coast of southern California monitored by the NWFSC Observer Program (2002–18) and the PSMFC Electronic Monitoring Program (2015–18). The ten catch classifications were defined by excluding any zero values and then applying the Jenks natural breaks classification method. Cells (200 km2) with less than three vessels were omitted from the map to maintain confidentiality.

Species	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL	Estimate	LCL - UCL
Year	2012	2012	2013	2013	2014	2014	2015	2015	2016	2016	2017	2017	2018	2018
Black-footed Albatross	131.73	110.2-156.2	81.31	64.6-101	65.29	50.4-83.2	77.83	61.5-97.2	71.14	55.6-89.7	134.78	113-159.6	84.36	67.3-104.4
Laysan Albatross	2.83	0.5-8.5	0.63	0-4.9	0.51	0-4.7	0.3	0-4.3	0.5	0-4.7	0.45	0-4.6	0.33	0-4.4
Short-tailed Albatross	0.53	0-4.7	0.41	0-4.5	0.36	0-4.4	0.2	0-4.1	0.34	0-4.4	0.28	0-4.3	0.21	0-4.1
Pink-footed Shearwater	7.8	3.3-15.5	4.16	1.2-10.5	4.21	1.2-10.5	4.36	1.3-10.8	4.42	1.3-10.9	4.57	1.4-11.1	4.43	1.3-10.9
Sooty Shearwater	13.77	7.5-23.2	15.15	8.5-24.9	8.51	3.8-16.4	4.99	1.6-11.7	6.69	2.6-14	7.71	3.3-15.4	24.59	15.8-36.4
Shearwater Unid	38.94	27.7-53.2	29.85	20.1-42.7	28.11	18.7-40.6	29.46	19.8-42.2	15.72	8.9-25.6	25.32	16.4-37.3	18.26	10.9-28.8
Northern Fulmar	10.48	5.1-19	2.45	0.4-7.9	4.5	1.4-11	2.34	0.4-7.8	2.2	0.3-7.5	5.15	1.7-11.9	1.68	0.2-6.7
Common Murre	5.47	1.9-12.3	7.55	3.2-15.2	6.79	2.7-14.1	8.44	3.7-16.3	6.41	2.4-13.6	5.89	2.1-12.9	6.47	2.5-13.7
Alcid Unid	0.76	0-5.1	0.58	0-4.8	0.55	0-4.8	0.3	0-4.3	0.51	0-4.7	0.4	0-4.5	0.32	0-4.3
Brandts Cormorant	3.14	0.7-9	3.28	0.7-9.2	3.7	0.9-9.8	3.97	1.1-10.2	3.11	0.7-8.9	2.82	0.5-8.5	2.77	0.5-8.4
Double-crested Cormorant	5.12	1.7-11.8	3.26	0.7-9.2	3.45	0.8-9.4	2	0.2-7.2	2.39	0.4-7.8	2.67	0.5-8.3	2.54	0.4-8.1
Cormorant Unid	4.48	1.3-10.9	3.69	0.9-9.8	3.45	0.8-9.4	2.1	0.3-7.4	2.49	0.4-8	2.85	0.6-8.5	2.5	0.4-8
California Gull	1.57	0.1-6.5	0.47	0-4.6	0.38	0-4.4	0.2	0-4.1	0.35	0-4.4	0.31	0-4.3	0.21	0-4.1
Glaucous-winged Gull	3.37	0.8-9.3	1	0-5.6	0.82	0-5.3	0.5	0-4.7	0.83	0-5.3	0.79	0-5.2	0.61	0-4.9
Arctic Herring Gull	10.35	5-18.8	1.68	0.2-6.7	1.41	0.1-6.3	0.89	0-5.4	1.5	0.1-6.4	1.44	0.1-6.3	1.11	0-5.8
Mew Gull	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ring-billed Gull	1.56	0.1-6.5	0.44	0-4.6	0.39	0-4.5	0.21	0-4.1	0.34	0-4.4	0.28	0-4.3	0.21	0-4.1
Western Gull	72.16	56.5-90.9	21.36	13.3-32.5	18.86	11.3-29.5	16.13	9.2-26.1	13.88	7.6-23.3	19.44	11.8-30.2	14.37	7.9-23.9
Gull Unid	27.34	18.1-39.7	16.99	9.9-27.2	15.44	8.7-25.3	12.93	6.9-22.1	11.02	5.5-19.7	14.98	8.4-24.7	11.72	6-20.6
Brown Pelican	14.47	8-24.1	12.56	6.6-21.7	12.68	6.7-21.8	11.32	5.7-20.1	11.6	5.9-20.4	13.27	7.1-22.6	11.15	5.6-19.9
Common Loon	2.94	0.6-8.7	3.1	0.7-8.9	3.57	0.9-9.6	2.86	0.6-8.6	2.91	0.6-8.6	3.03	0.6-8.8	2.57	0.4-8.1
Red-necked Phalarope	0	0	0	0	0	0	0	0	1	0-5.6	0	0	0	0
Bird Unid	3.29	0.7-9.2	3.2	0.7-9.1	3.72	1-9.8	3.44	0.8-9.4	2.25	0.3-7.6	2.44	0.4-7.9	2.68	0.5-8.3

Table 5: Estimated seabird mortality in U.S. west coast fisheries 2012-2018 for vessels fishing with hook-and-line gears. Estimates include both randomly and opportunistically sampled birds (see text for full explanation). Estimates for the entire time series can be found in the Supplemental Tables. LCL = lower 95% confidence limit, UCL = upper 95% confidence limit.

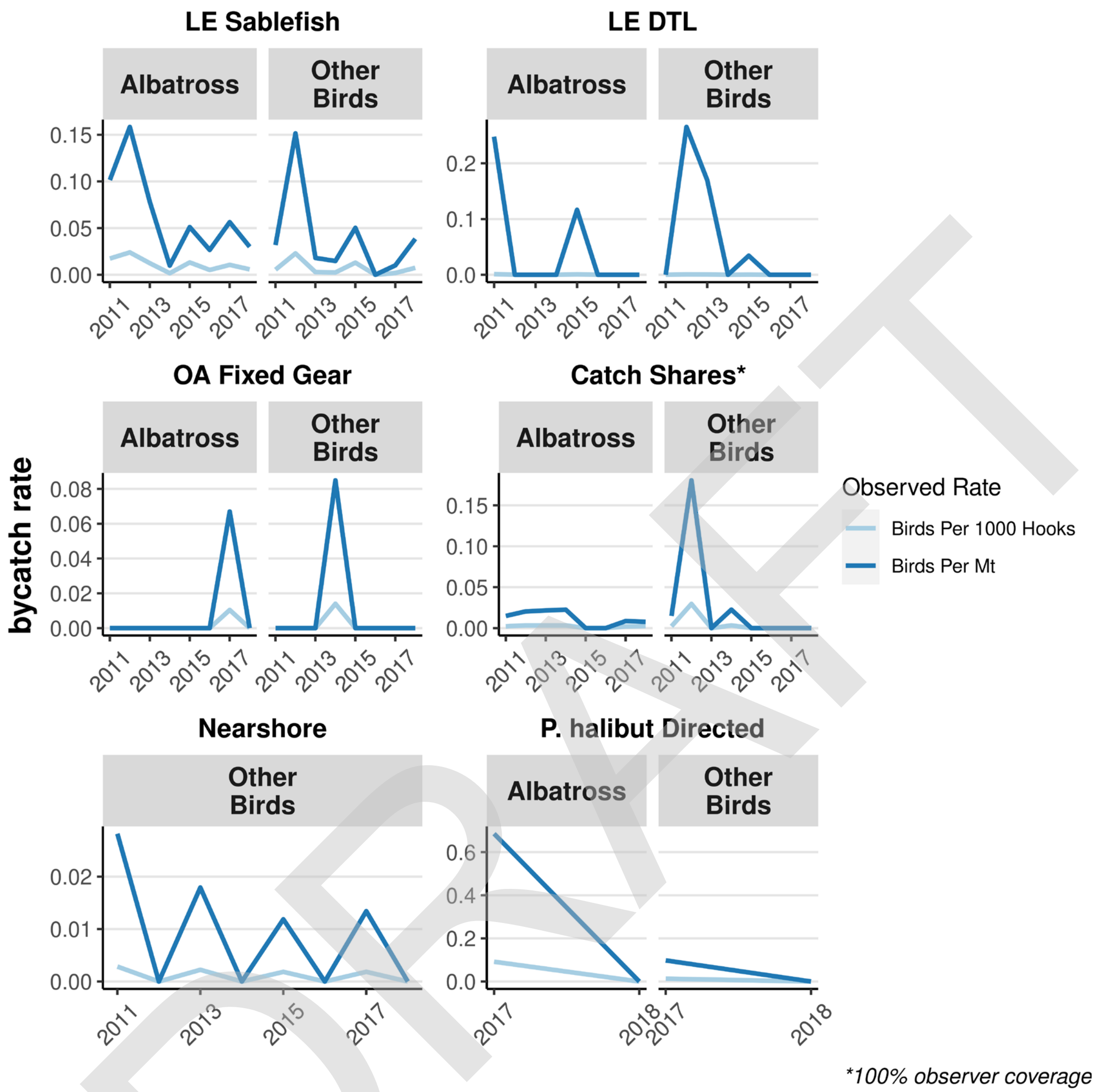

Figure 6: Albatross and other birds observed bycatch rates, as either number of observed birds per 1000 hooks or per metric ton of landed targeted fish, from hook-and-line fisheries observed by the NWFSC Groundfish Observer Program. Birds per 1000 hooks is the international standard for reporting seabird bycatch. LE = Limited Entry, OA = Open Access, DTL = Daily Trip Limits.

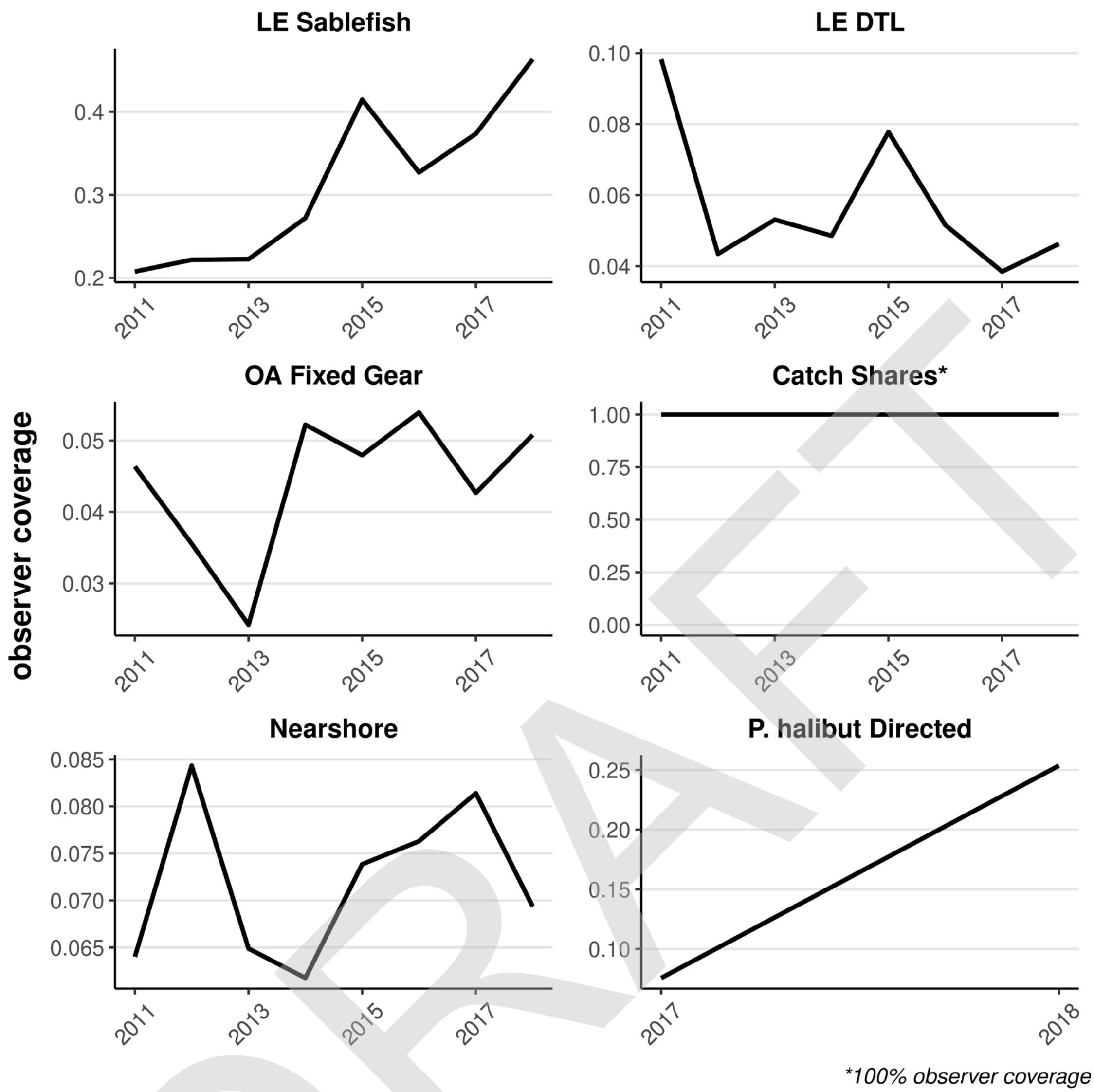

Figure 7: Observer coverage (observed retained fish [mt] / total landed target catch [mt]) in hook-and-line fisheries monitored by the NWFSC Observer Program. LE = Limited Entry, OA = Open Access, DTL = Daily Trip Limits.

Limited Entry Sablefish

The Limited Entry Sablefish Endorsed vessels use longlines to target sablefish and deliver their catch to shore-based processors managed by a tiered-quota system. The fishing season is open between April and October.

Black-footed albatross were the main seabird bycatch species caught in the Limited Entry Sablefish fishery. Mean annual bycatch in this fishery over the last 6 year period was 56 BFAL (Table 6). A single ESA-endangered short-tailed albatross was taken in the Limited Entry Sablefish Endorsed fishery in 2011 (Supplemental Table 3), this was the only such take of this species observed in any of the fisheries in this report. During the 2012 LE Sablefish season, a single dead Laysan albatross was observed in a random species composition sample which expanded to 1.88 birds in that set (Table 6), resulting in an estimated total of 2.83 individuals in 2012 in this fishery (Table 6).

Non-albatross species comprise a small amount of seabird bycatch in the LE sablefish fishery. A total of 17 taxa have been observed as bycatch in the LE Sablefish fishery over the 17-year period, primarily western gulls, shearwaters and northern fulmars (Table 6).

Limited Entry Daily Trip Limits (LE DTL)

Limited Entry DTL longline vessels target groundfish, primarily sablefish and thornyheads. These vessels have attained their annual sablefish quota limit and fish outside the normal LE sablefish season. Catch is delivered to shore-based processors or sold alive.

Shearwaters top the list of species caught in this fishery followed by black-footed albatross, brown pelicans, and gulls (Table 7, Supplemental Table 4. Three to four pink-footed shearwaters are estimated caught each year, on average, in this fishery (Table 7).

Open Access Fixed Gears

OA fixed gear vessels use a variety of fixed gear with hooks, including longlines, fishing poles, and stick gear. These vessels target non-nearshore groundfish and deliver their catch to shore-based processors.

Only two bird taxa have been reported from the OA fixed gear fishery: black-footed albatross and unidentified gulls (Table 8, Supplemental Table 5).

Catch Share Hook-and-Line Fisheries

Hook-and-line longline vessels that hold individual fishing quotas (IFQs) primarily target groundfish species, mainly sablefish, and deliver to shore-based processors. This fishery has 100% observer coverage; therefore, the observed bycatch is a complete census of these vessels.

Black-footed albatross, northern fulmars, mew gulls, western gulls, and unidentified gulls were observed as bycatch in this fishery (Table 9).

Nearshore

Nearshore fixed gear vessels use a variety of hook-and-line gear, including longline, fishing poles, stick gear, etc. to target nearshore rockfish and other nearshore species managed by state permits in Oregon and California. A subset of vessels also use pot gear to mainly target California sheephead (*Semicossyphus pulcher*). Data from Nearshore pot vessels are combined with data from other pot fisheries and presented in the section on pot gear (below). Catch is delivered to shore-based processors or sold live. Washington does not allow nearshore commercial fixed gear fishing.

Historically, the WCGOP has split the nearshore fishery by state but combined hook-and-line with pot gears within states (Jannot et al. 2011, Somers et al. 2018). However, our work here shows that seabird bycatch on hook-and-line gear is much greater than with pot gear (Table 5 & Table 19. Therefore, we estimate seabird mortality separately for hook-and-line and pot gear types by state.

Overall bycatch in the state-managed nearshore fisheries is low. The Oregon nearshore hook-and-line fishery has only caught common murres, western gulls, unidentified gulls, and unidentified birds (Table 10, Supplemental Table 7. In the California nearshore hook-and-line fishery, in addition to common murres and western gulls, observers have also recorded takes of Brandt's cormorant, brown pelican, and common loon (Table 10, Supplemental Table 7).

Pacific halibut fishery

Vessels with an International Pacific Halibut Commission issued Pacific halibut permit use longline gear to fish for Pacific halibut (*Hippoglossus stenolepis*) during the annual openers. The WCGOP began observing this fishery in 2017. In 2017, seven black-footed albatross and one shearwater were observed as takes, resulting in an estimated to 48 BFAL and 10 shearwaters in 2017. No bird bycatch was observed in 2018, so the fleet-wide estimates for these two species dropped in 2018 to 13 BFAL and three shearwaters.

Seabird Bycatch in Trawl Fisheries

Estimates indicate that potentially up to 45% of the global seabird bycatch occurs in trawl fisheries (Baker et al., 2007). The causes of seabird mortality in trawl fisheries can be broadly categorized into fatalities resulting from collisions with net transponder cable, warp cables or paravanes; and those being entangled in the net, in particular, diving birds interacting with pelagic trawlers (Sullivan et al., 2006a & b). Seabird collisions with trawl transponder or warp cables often go unwitnessed. Birds colliding with cables are not typically captured by the gear which can result in unreported cryptic mortality not often accounted for in fisheries management (Bartle, 1991; Melvin et al., 2011; Tamini et al., 2015). Seabirds in the air or on the water that strike a cable are rarely observed or recorded.

Of the fisheries reported here, only the at-sea hake catcher-processor midwater trawl vessels use transponder cables, which pose the highest risk to seabirds. To better understand cryptic mortality on these at-sea hake catcher-processor vessels, A-SHOP fisheries observers conducted a study of seabird cable strikes on these vessels from 2016-2019. Seabird cable strikes have been documented on mid-water trawl nets fishing for hake in the U.S. west coast (WA, OR) at-sea hake catcher-processor fleet (J. Jannot, unpublished data) as well as similar trawl fisheries around the globe (Williams & Capdeville 1996, Melvin et al. 2011, Parker et al. 2013, Tamini et al. 2015). For the first time, the A-SHOP study allows us to estimate mortality from cable strikes in the at-sea hake catcher-processor fleet. We have added estimates of bycatch from cable strikes to our other estimates of seabird mortality in this report. A brief description of the special study is provided in the Methods section of this report.

Because at least some portion of seabird bycatch in trawl fisheries is likely to go unreported, our estimates of seabird bycatch in trawl fisheries are biased to the low end and estimates of seabird bycatch in trawl fisheries reported here should be considered an underestimate of the true numbers.

Sooty shearwaters are the most frequently observed species in trawl bycatch, followed by Brandt's comorant, unidentified shearwaters, northern fulmars, unidentified gulls, and common murres (Table 12). A few black-footed albatross are observed each year, along with pink-footed shearwaters. Laysan albatross have been taken in the past in trawl fisheries (Supplemental Table 9). A smaller number of individuals, from 16 other species or taxa, were observed in these trawl fisheries over the 17-year period (Table 12). In contrast to hook-and-line fisheries, trawl fisheries kill fewer albatross, only between two and seven black-footed albatross annually, which includes estimates from cable-strikes on at-sea hake catcher processor vessels (Figure 8, Table 12, Supplemental Table 9). In 2013, the only observed mortality of a Laysan albatross in trawl fisheries was recorded (Table 12).

Species	Estimate	LCL.UCL	Estimate	LCL.UCL	Estimate	LCL.UCL	Estimate	LCL.UCL	Estimate	LCL.UCL
Year	2012	2012	2013	2013	2014	2014	2015	2015	2016	201
Black-footed Albatross	3	0.6-8.8	4	1.1-10.2	3	0.6-8.8	5	1.6-11.7	6	2.2-13.1
Laysan Albatross	0	0	1	0-5.6	0	0	0	0	0	
Leach's Storm-Petrel	0	0-3.7	2	0.2-7.2	0	0-3.7	2	0.2-7.2	5	1.6-11.7
Storm-Petrel Unid	0	0	1.04	0-5.6	0	0	0	0	0	
Pink-footed Shearwater	1.08	0-5.7	1.64	0.1-6.7	1.22	0.1-5.9	2.09	0.3-7.4	0.81	0-5.2
Sooty Shearwater	28.36	18.9-40.9	32.48	22.3-45.7	22.77	14.4-34.2	38.22	27.1-52.4	21.16	13.1-32.3
Shearwater Unid	19.63	11.9-30.4	22.66	14.3-34.1	22.23	14-33.6	20.58	12.7-31.6	22.05	13.8-33.4
Northern Fulmar	10.03	4.8-18.4	57	43.2-73.9	7	2.8-14.4	17	9.9-27.2	14.01	7.7-23.5
Tubenoses Unid	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7
Common Murre	6.46	2.5-13.7	9.41	4.4-17.6	4.52	1.4-11	9.9	4.7-18.3	8.13	3.5-15.9
Murre Unid	1.07	0-5.7	0	0	0	0	0	0	0	
Cassin's Auklet	0	0-3.7	2	0.2-7.2	2	0.2-7.2	0	0-3.7	1	0-5.6
Alcid Unid	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7
Brandts Cormorant	5.71	2-12.7	9.24	4.3-17.4	4.26	1.2-10.6	4.92	1.6-11.5	5.51	1.9-12.4
Cormorant Unid	3.32	0.8-9.2	3.1	0.7-8.9	1	0-5.6	1.06	0-5.7	2.82	0.5-8.5
California Gull	0	0	0	0	1.02	0-5.6	0	0	0	
Arctic Herring Gull	0	0	4	1.1-10.2	0	0	0	0	0	
Western Gull	1.59	0.1-6.6	1.71	0.2-6.8	0.38	0-4.4	0.37	0-4.4	1.54	0.1-6.5
Gull Unid	11.09	5.6-19.8	12.73	6.7-21.9	14.33	7.9-23.9	17.6	10.4-28	15.34	8.6-25.2
Green-winged Teal	0	0	0	0	0	0	0	0	0	
White-winged Scoter	0	0	0	0	0	0	0	0	0	
Seabird Unid	8	3.5-15.8	8	3.5-15.8	8	3.5-15.8	8	3.5-15.8	8	3.5-15.8
Warbler Unid	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7	0	0-3.7
Bird Unid	1.59	0.1-6.6	2.65	0.5-8.2	1.44	0.1-6.3	1.38	0.1-6.2	0.57	0-4.8

Table 12: Estimated seabird mortality in U.S. west coast fishery 2012-2018, for vessels fishing with trawl gears. Estimates include both randomly and opportunistically sampled birds (see text for full explanation). Estimates for the entire time series can be found in the Supplemental Tables. LCL = lower 95% confidence limit, UCL = upper 95% confidence limit

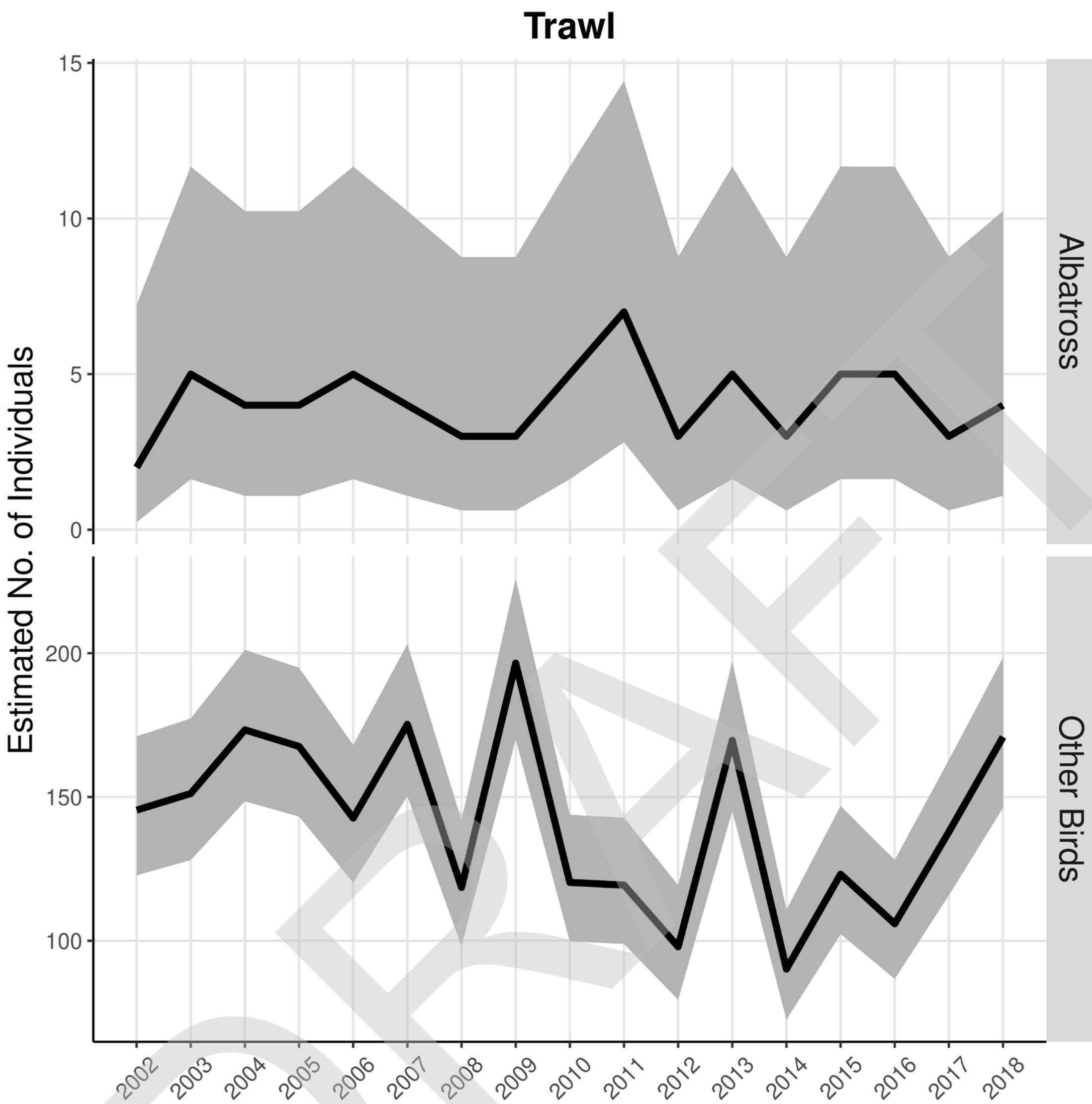

Figure 8: Total estimated seabird mortality from vessels using bottom, midwater, or shrimp trawl gear observed by the NWFSC Groundfish Observer Program. Solid black lines represent mortality from trawl gears. Gray band is the 95% confidence interval. Values are reported in Table 12.

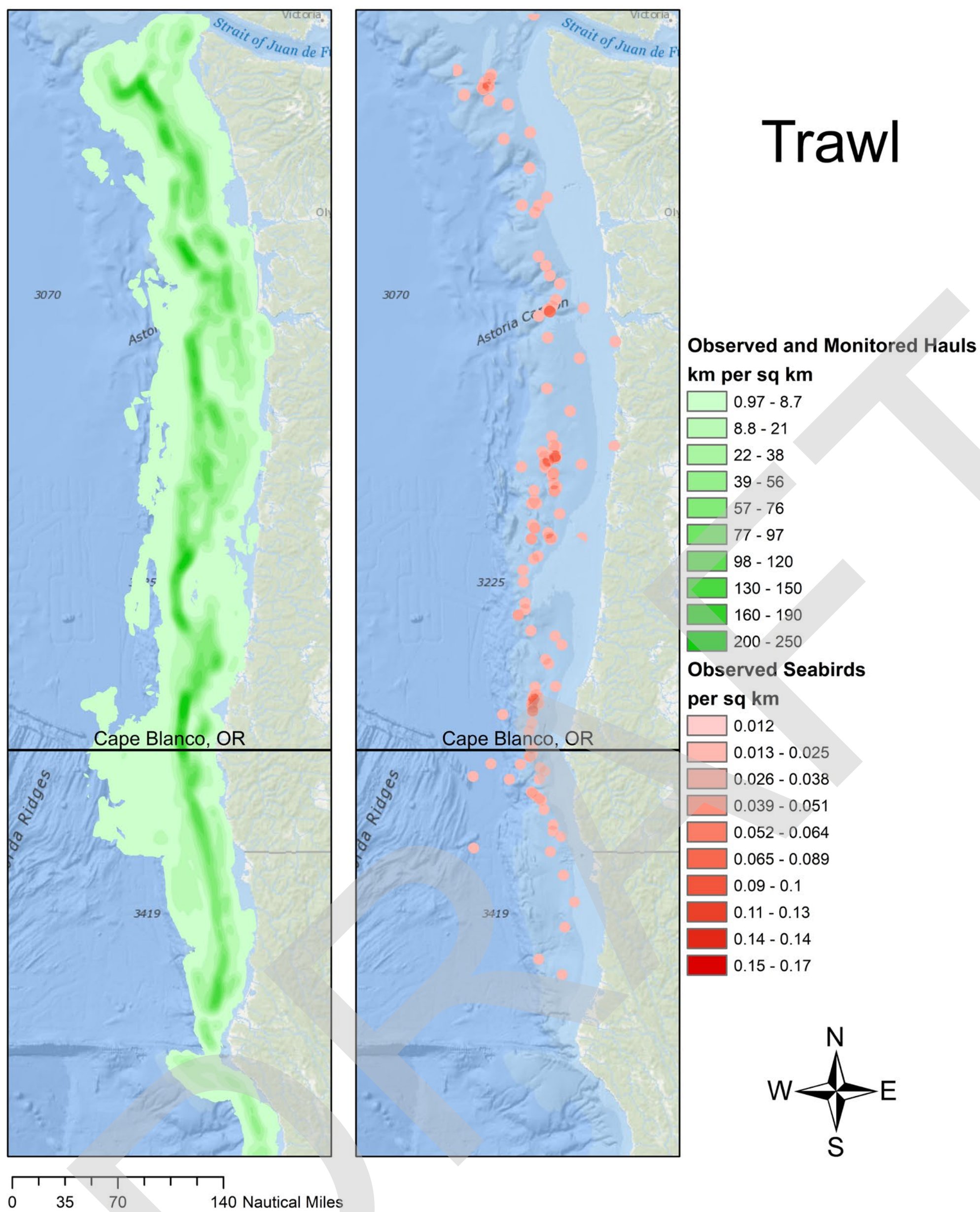

Figure 9: Spatial distribution of observed seabird bycatch (mt/km2) and monitored fishing sets on bottom, midwater, and shrimp trawl vessels along the Washington, Oregon, and Northern California coasts observed by the NWFSC Observer Program (2002–18) and the PSMFC Electronic Monitoring Program (2015–18). The nine catch classifications were defined by excluding any zero values and then applying the Jenks natural breaks classification method. Cells (200 km2) with less than three vessels were omitted from the map to maintain confidentiality.

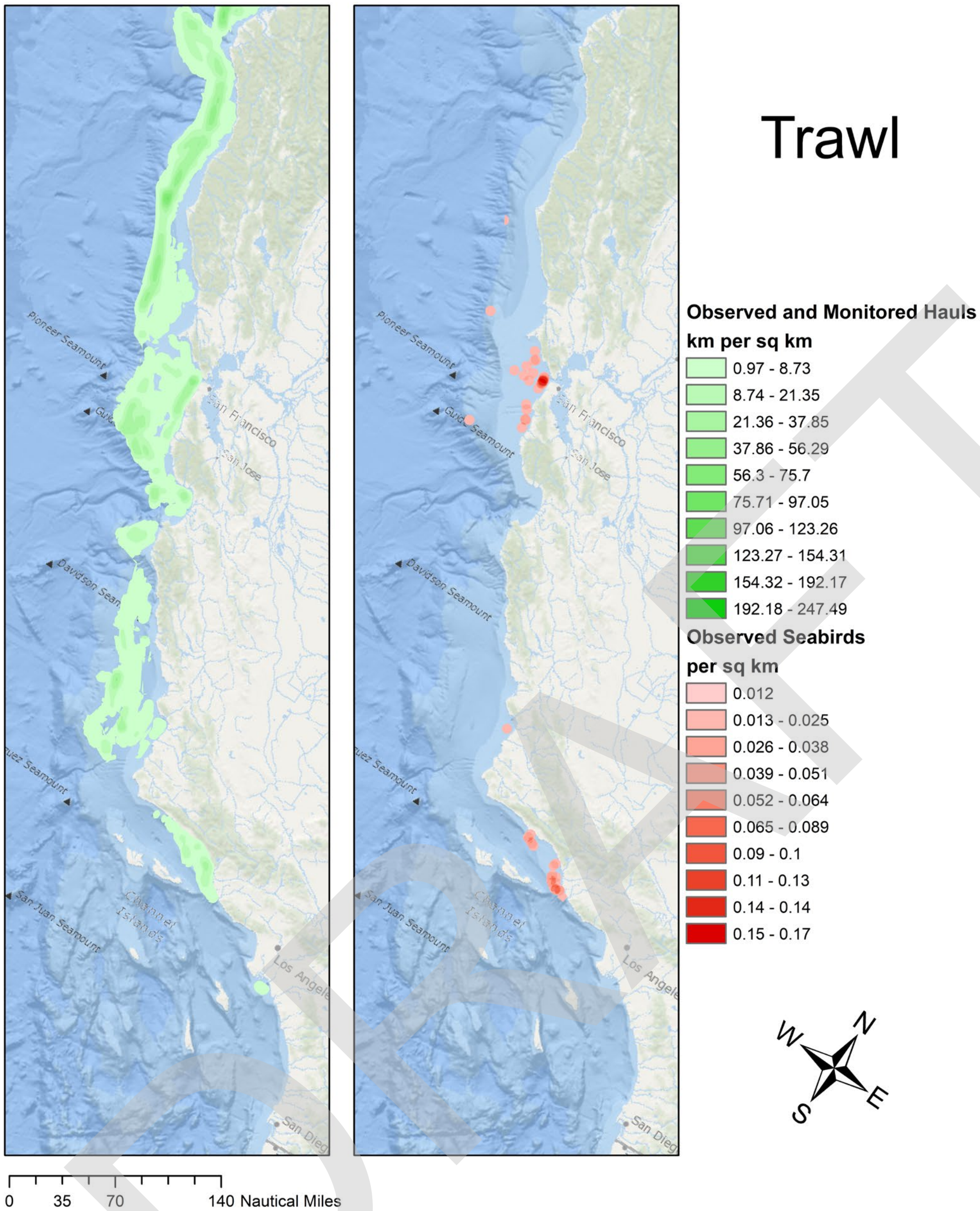

Figure 10: Spatial distribution of observed seabird bycatch (mt/km2) and monitored fishing sets on bottom, midwater, and shrimp trawl vessels along the Southern California coast observed by the NWFSC Observer Program (2002–18) and the PSMFC Electronic Monitoring Program (2015–18). The nine catch classifications were defined by excluding any zero values and then applying the Jenks natural breaks classification method. Cells (200 km2) with less than three vessels were omitted from the map to maintain confidentiality.

At-sea Hake Fisheries

The at-sea hake fishery is comprised of three separate sectors. At-sea catcher-processors use midwater trawl nets to catch and process Pacific hake at sea. Catcher vessels use midwater trawl nets to catch P. hake and deliver unsorted catch to mothership processors at-sea, where it is sorted and processed. At-sea tribal vessels use midwater trawl nets to catch and process Pacific hake at sea by Native American tribes. The tribes must operate within defined boundaries in waters off northwest Washington. Seabird bycatch from at-sea tribal fisheries are *not included* in this report.

The mortality of black-footed albatross was estimated to be three to four birds annually during 2012-2018 (Table 13). The most frequently caught non-albatross species on these vessels were shearwaters and northern fulmars, followed by gulls and common murres (Table 13). One to a few individuals of eight other taxa were observed taken annually on at-sea catcher processor vessels (Table 13, Supplemental Table 10).

Albatross have not been observed taken on hake catcher vessels delivering to motherships at-sea (Table 14, Supplemental Table 11). Seabird bycatch on these vessels is rarely observed, with only one to a few northern fulmars, common murres, Cassin's auklets, and unidentified birds observed taken on catcher vessels delivering to motherships at-sea in some, but not all, years (Table 14).

Catch Share Trawl Fisheries

Catch Share bottom trawl vessels use nets to catch a variety of non-hake groundfish species. Catch is delivered to shore-based processors. From 2002-2010, the LE bottom trawl vessels were managed under trip-limits and annual catch limits, and observer coverage rate varied from 10 to 25% of landings. Since 2011, the Catch Share program requires bottom trawl vessels to possess individual fishing quota (IFQ) for all IFQ species landed and discarded at sea. The Catch Share program also requires 100% observer coverage on all trips, unless vessels are participating in the Exempted Fishing Permit program that allows vessels to carry electronic monitoring (EM) equipment in lieu of an observer.

Some Catch Share vessels use midwater trawl nets to target mid-water non-hake species, typically rockfish. Vessels must possess quota for all landed and discarded IFQ species. Landings of Pacific hake from these vessels are less than 50% (by weight) of total trip landings. Catch is delivered to shore-based processors.

Because the Limited Entry Trawl program was converted to Catch Share in 2011, any seabird bycatch observed on vessels fishing in the Limited Entry California halibut fishery (see below) since 2011 were included with the Catch Share trawl estimates shown here. Very little effort occurred in this fishery from 2011-2013 and no activity in this fishery since 2013.

In 2017, a single unidentified seabird was recorded as bycatch by the electronic monitoring (EM) equipment on a Catch Share vessel fishing midwater trawl gear delivering Pacific hake shoreside. Because crew are required to present all seabirds to the camera for documentation on EM vessels, these vessels are considered to have a complete census of seabird bycatch.

Both black-footed and Laysan albatross mortalities have been observed on Catch Share trawl vessels: one black-footed albatross was taken in 2004 under the Limited Entry program (Supplemental Table 12). Two black-footed albatross were killed in 2015 and one in 2016 under the Catch Share program. One Laysan albatross was killed in 2013 under Catch Sharerh management (Table 15)). The most frequently caught non-albatross taxa on these vessels were Leach's and unidentified storm-petrels, followed by, in decreasing numbers, sooty shearwaters, unidentified murres, northern fulmars, and gulls (Table 15), Supplemental Table 12).

California Halibut Fisheries

Limited Entry (LE) California halibut trawl vessels use bottom trawl nets to target California halibut. Fishers must possess a state California halibut permit and an LE federal trawl groundfish permit. The LE Trawl program was converted to Catch Share in 2011, and thus LE California halibut bycatch estimates since 2011 are included with Catch Share trawl estimates (Table 15), see Supplemental Table 13 for historical estimates of LE California halibut seabird bycatch). California halibut trawl participants that do not hold an LE federal groundfish trawl permit can still operate under open access (OA) privileges if they possess a state California halibut permit. In both cases, catch is delivered to shore-based processors. The 2010 LE California halibut estimates are included with the 2010 OA values to maintain confidentiality (Supplemental Table 13).

Albatross have not been observed as bycatch in California halibut fisheries (Table 16, Supplemental Tables 13 & 13). Bycatch of Brandt's cormorant has increased in recent years in the OA California halibut fishery from about 5 in 2014, 2015, and 2016 to 11 in 2017, and 22 in 2018. Common murres are also a frequently caught species in the OA California halibut fishery, followed by unidentified cormorants, western gulls, and unidentified birds (Table 16).

Open Access WA, OR and CA Pink Shrimp Fisheries

Each of the three U.S. west coast states operates and manages pink shrimp trawl fisheries in their state waters by issuing state-specific pink shrimp permits. Pink shrimp vessels use shrimp trawl nets to target pink shrimp. Catch is delivered to shore-based processors.

The only species observed caught in the California pink shrimp fishery has been pink-footed shearwaters (Table 17). Sooty shearwaters is the main species recorded in Washington and Oregon pink shrimp fisheries (Table 17, Supplemental Table 14).

CA Ridgeback Prawn Fishery

The CA ridgeback prawn trawl fishery is managed by prawn permit issued by the state of California. Vessels catch a variety of prawn and shrimp species for shoreside delivery. The WCGOP began observing this fishery in 2017.

In 2018, five Brant's cormorants were recorded as bycatch in this fishery. Given the low observer coverage in this fishery, the mortality estimate for Brandt's cormorant is quite high: 35 in 2017 (LCI = 12, UCI = 70) and 61 in 2018 (LCI = 23, UCI = 125, Table 18).

CA Sea Cucumber Fishery

The CA sea cucumber fishery is managed by sea cucumber permit issued by the state of California. Vessels use trawl gears to catch sea cucumbers off the coast of California. The WCGOP began observing this fishery in 2017. No bird mortalities were observed in the sea cucumber fishery during in 2017. In 2018, we observed less than three vessels, and therefore bycatch data are not reported to maintain confidentiality.

Seabird Bycatch in Pot Gear Fisheries

The vessels using pot gear to catch groundfish are active in the same fisheries described above for hook-and-line vessels. To protect confidentiality, we cannot report seabird bycatch with pot gears stratified by fishery. To date, seabird mortalities have been observed on vessels fishing with pot gear in Catch Share (including vessels using electronic monitoring), Limited Entry Sablefish, and OR and CA Nearshore fisheries.

Most of the pot gear bycatch is cormorants, although a single black-footed albatross was taken in these fisheries in 2014 (Table 19, Supplemental Table 16).

Seabird Bycatch Mitigation and Avoidance

In response to the 2012 U.S. Fish and Wildlife Service Biological Opinion regarding short-tailed albatross interactions with U.S. west coast fisheries, the PFMC and NOAA implemented a regulation requiring the use of streamer lines on non-tribal longline vessels 55 feet or longer in December 2015 (NOAA, 2015). This rule requires:

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* Commercial, non-tribal, longline vessels 16.76 m (55 feet) and larger to de
ploy one or two streamer lines during fishing, depending on gear configuratio
n

* Streamer lines must meet technical specifications and be available for insp
ection

* Rough weather exemption is permitted for Gale Warning or more severe warnin
gs issued by the National Weather Service.
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In January 2020, the PFMC and NOAA implemented regulations that extended the use of streamer lines on non-tribal longline vessels to those 26 feet or longer for vessels fishing north of 36° N. latitude in Federal waters (NOAA 2019). This rule also provided an exemption to streamer line use for vessels setting and fishing at night, defined as 1 hour after sunset to 1 hour before sunrise (NOAA 2019).

As a result of these regulations, the NMFS West Coast Regional Office has asked the WCGOP to collect data that may be used to characterize and evaluate the effectiveness of seabird avoidance gear or measures used by longline vessels. Prior to these regulations, some vessels voluntarily used a number of seabird avoidance and mitigation measures and the WCGOP opportunistically collected data regarding these voluntary measures. Here we present data from all vessels regardless of size and from all years for which the WCGOP has collected data.

Figure 11 presents the percentage of hook-and-line gear deployments by year that used specific seabird mitigation for vessels across all fisheries. Noise is often used to scare birds away from setting hooks and includes the use of firecrackers, flash-bangs, whistlers and other types of loud noises. Figure 12 shows the same data as Figure 11, broken down by each fishery.

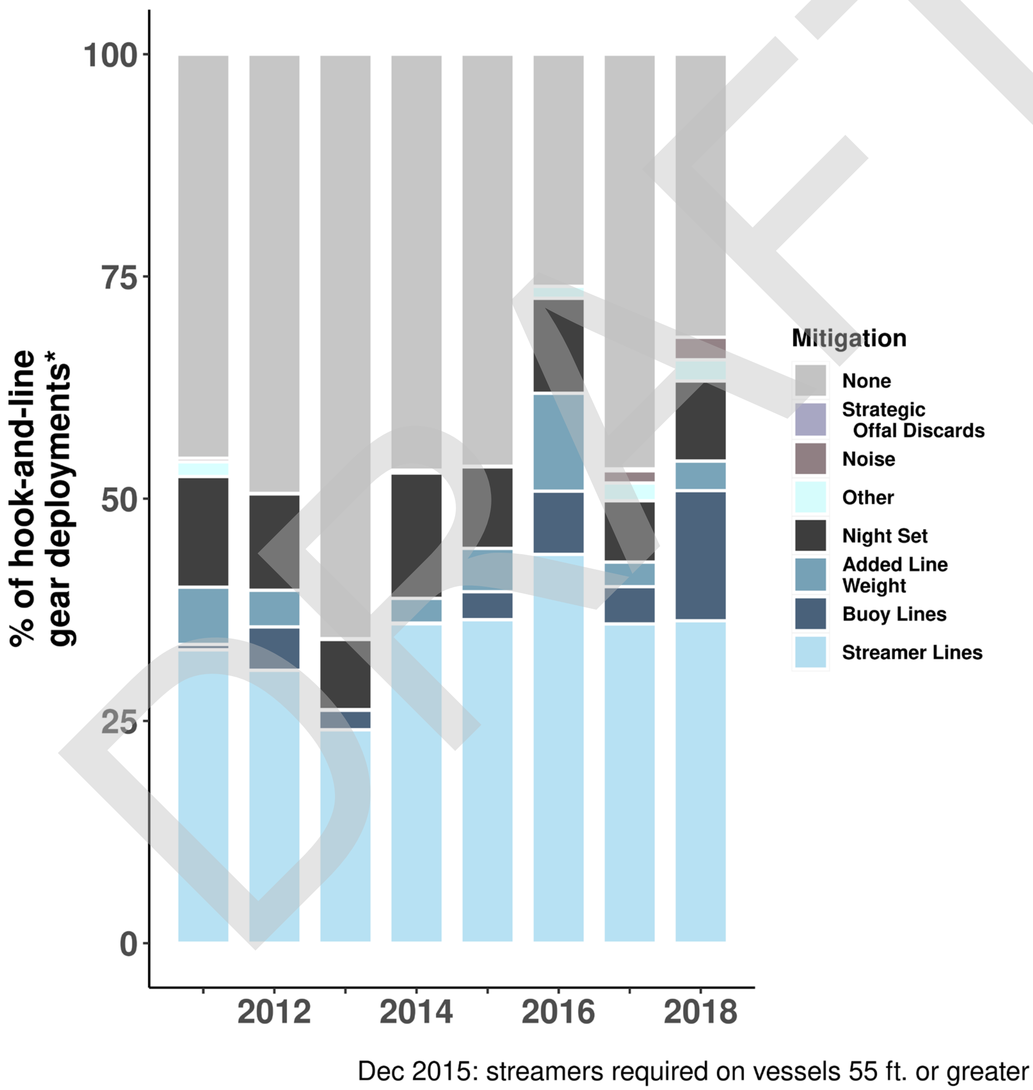

Figure 11: Percentage of observed hauls with seabird mitigation type by year for the 2011-2018 period. More than one type could be used on a single haul. Data on seabird mitigation type was not collected prior to 2009. Only vessels using hook-and-line gears are shown.

Vessels over 55 feet in length using hook-and-line gear were required to use streamer lines starting in December 2015.

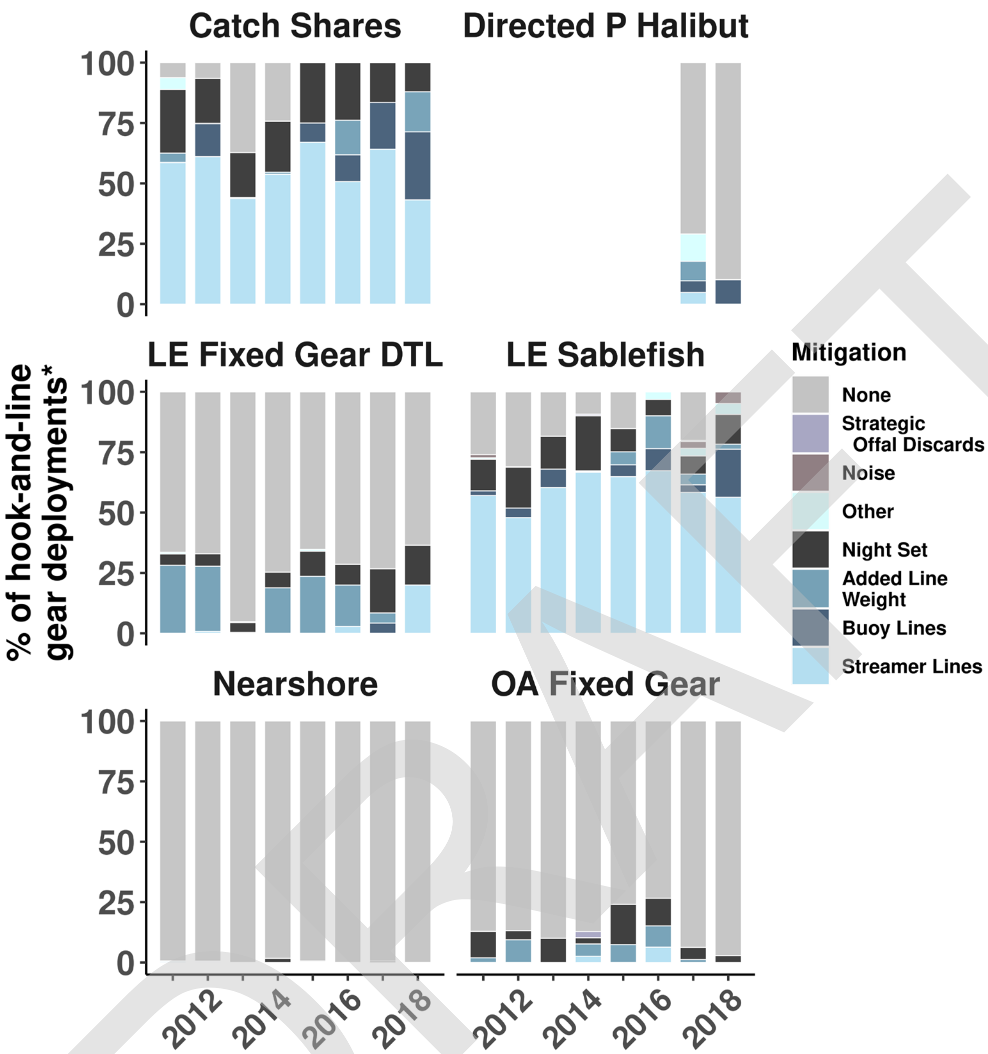

Figure 12: Percentage of observed hauls with seabird mitigation for each fishery by year for the 2011-2018 period. More than one type of mitigation could be used on a single haul. Data on seabird mitigation type was not collected prior to 2009. Only vessels using hook-and-line gears are shown. Vessels over 55 feet in length using hook-and-line gear were required to use streamer lines starting in December 2015.

Seabird Non-Lethal Interactions and Sightings

In addition to lethal interactions, both A-SHOP and WCGOP collect information regarding seabird interactions that are not lethal nor are likely to cause injury. Interactions are defined here as any bird that comes into contact with the vessel, gear, catch, or vessel discharge (e.g., offal, discards, vessel trash, etc.). Sightings of seabirds that do not interact with the vessel in any manner are also recorded. Collection of data on ESA-listed species is a high priority for observers who are instructed to document all non-lethal interactions and sightings of ESA-listed seabird species. However, because observers are not required to set aside time during every day to record sightings, these observations are opportunistic and rarely collected for non-ESA species. Furthermore, non-lethal and sighting observations reported here are limited in scope to vessel location which is driven by fishing activity. See Table 2 for the number of recorded sightings for each species for all years combined.

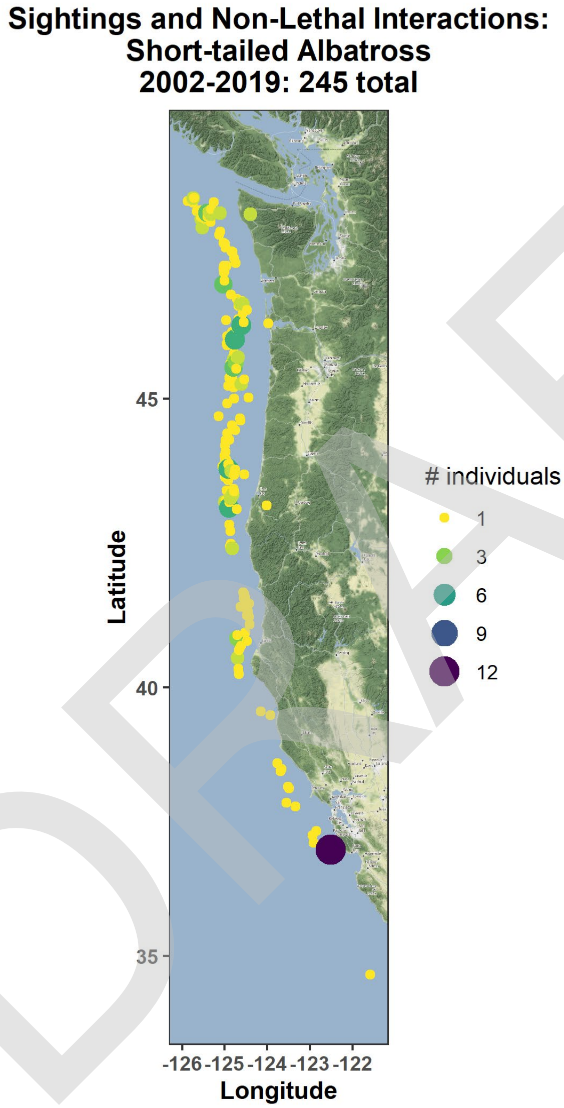

Figure 13: Spatial distribution of observed non-lethal interactions and sightings of short-tailed albatross from observers on fishing vessels along the U.S. Pacific coast (WA, OR, CA; 2002-2018). Data are not considered to be randomly sampled.

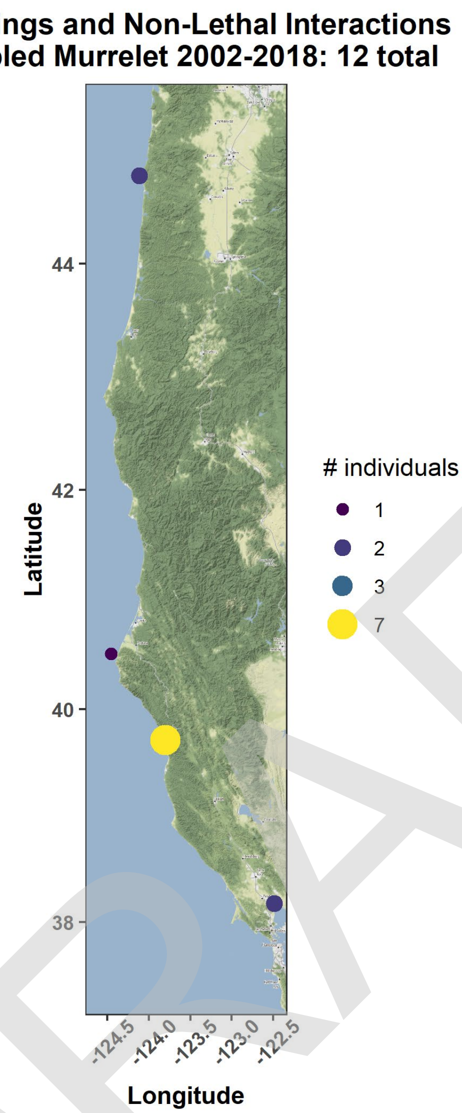

Figure 14: Spatial distribution of observed non-lethal interactions and sightings of marbled murrelets from observers on fishing vessels along the U.S. Pacific coast (WA, OR, CA; 2002-2018). Data are not considered to be randomly sampled.

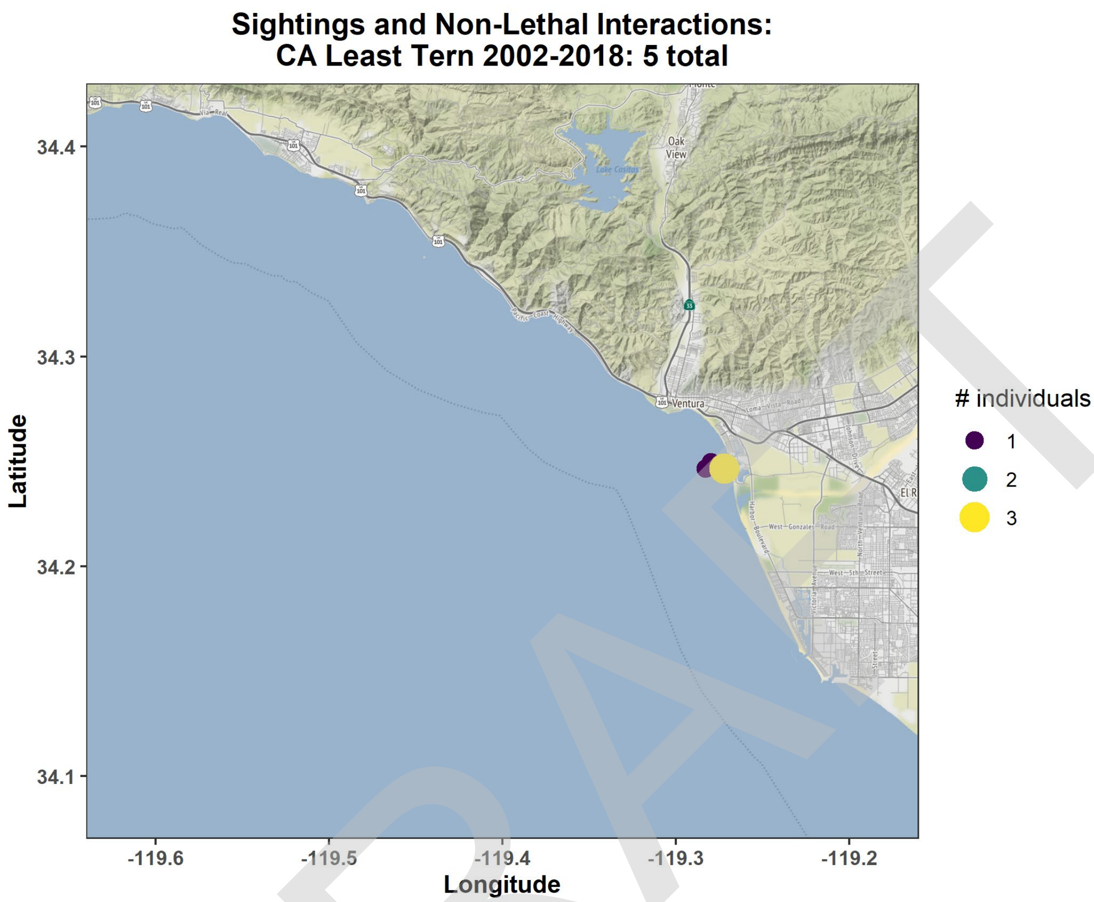

Figure 15: Spatial distribution of observed non-lethal interactions and sightings of California least tern from observers on fishing vessels along the U.S. Pacific coast (WA, OR, CA; 2002-2018). Data are not considered to be randomly sampled.

In total, there have been 245 short-tailed albatross non-lethal interactions and sightings recorded by observers for the period 2002–2018 (Figure 13, Tables 20 & 21). These short-tailed albatross non-lethal and sightings data update the map presented in Guy et al. (2013) which only included FOS data through 2010. The largest number of observed short-tailed albatross was just south of San Francisco Bay, California; however, significant numbers have occurred off Cape Flattery and Aberdeen Washington, the mouth of the Columbia River, and Coos Bay, Oregon (Figure 13). The majority of observations appear to be associated with the continental shelf/slope break, consistent with the findings of Guy et al. (2013).

Observers recorded 12 marbled murrelet non-lethal interactions and sightings along the U.S. west coast during the 2002-2018 period (Figure 14, Tables 20 & 21). The largest number of individuals (7) was observed in northern California. Observations range from south of San Francisco Bay to central Oregon coast, mainly in the nearshore environment (Figure 14).

Observers recorded five California least tern sightings during the 2002-2018 period, all within Pierpoint Bay, Ventura, CA (Figure 15, Table 21). No non-lethal interactions of California least tern have been observed (Table 20).

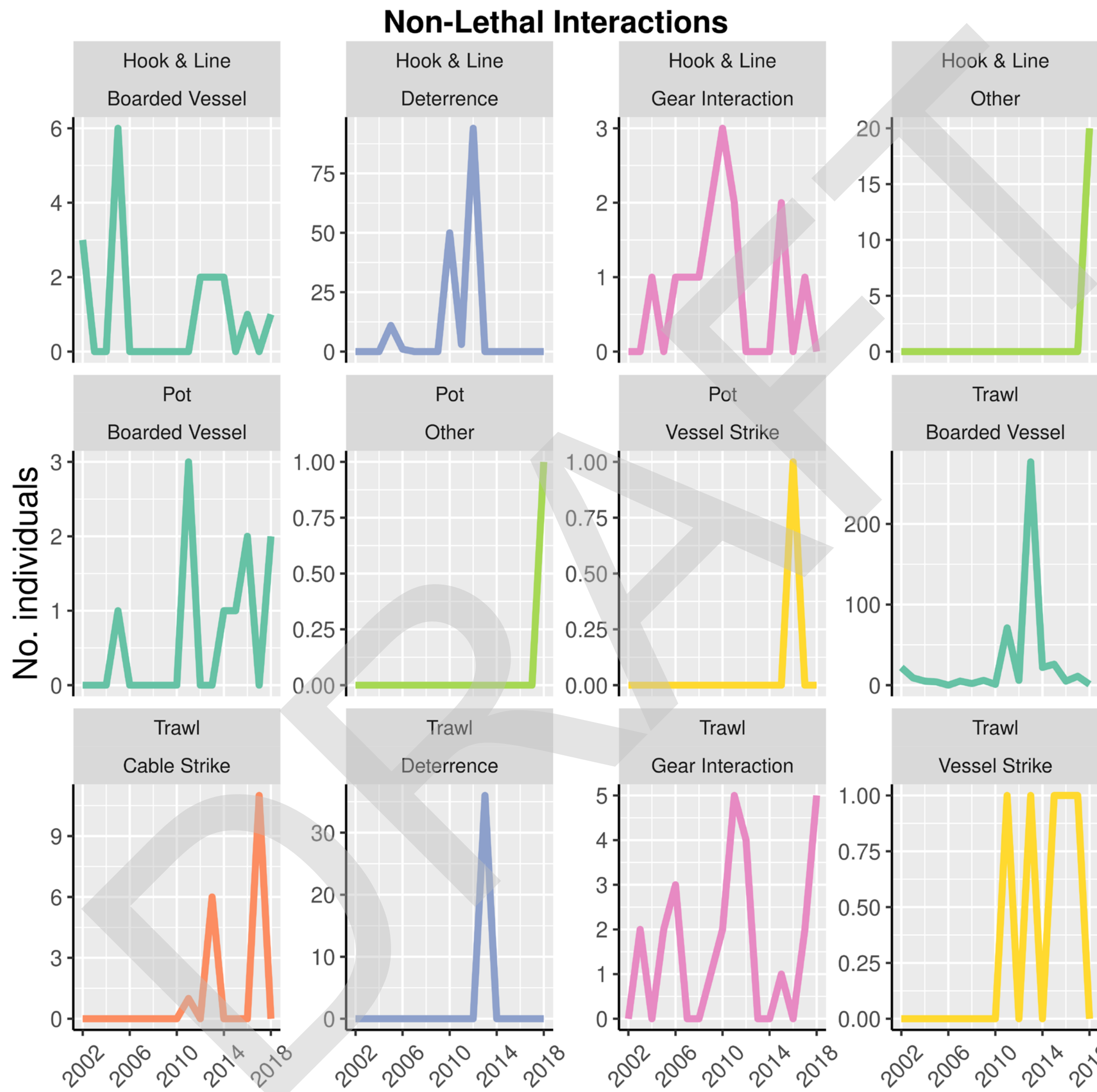

Figure 16: Observed number of nonlethal, non-feeding seabird interactions by year, gear type, and nonlethal interaction type, 2002-2018. Feeding interactions are shown in Figure 16.

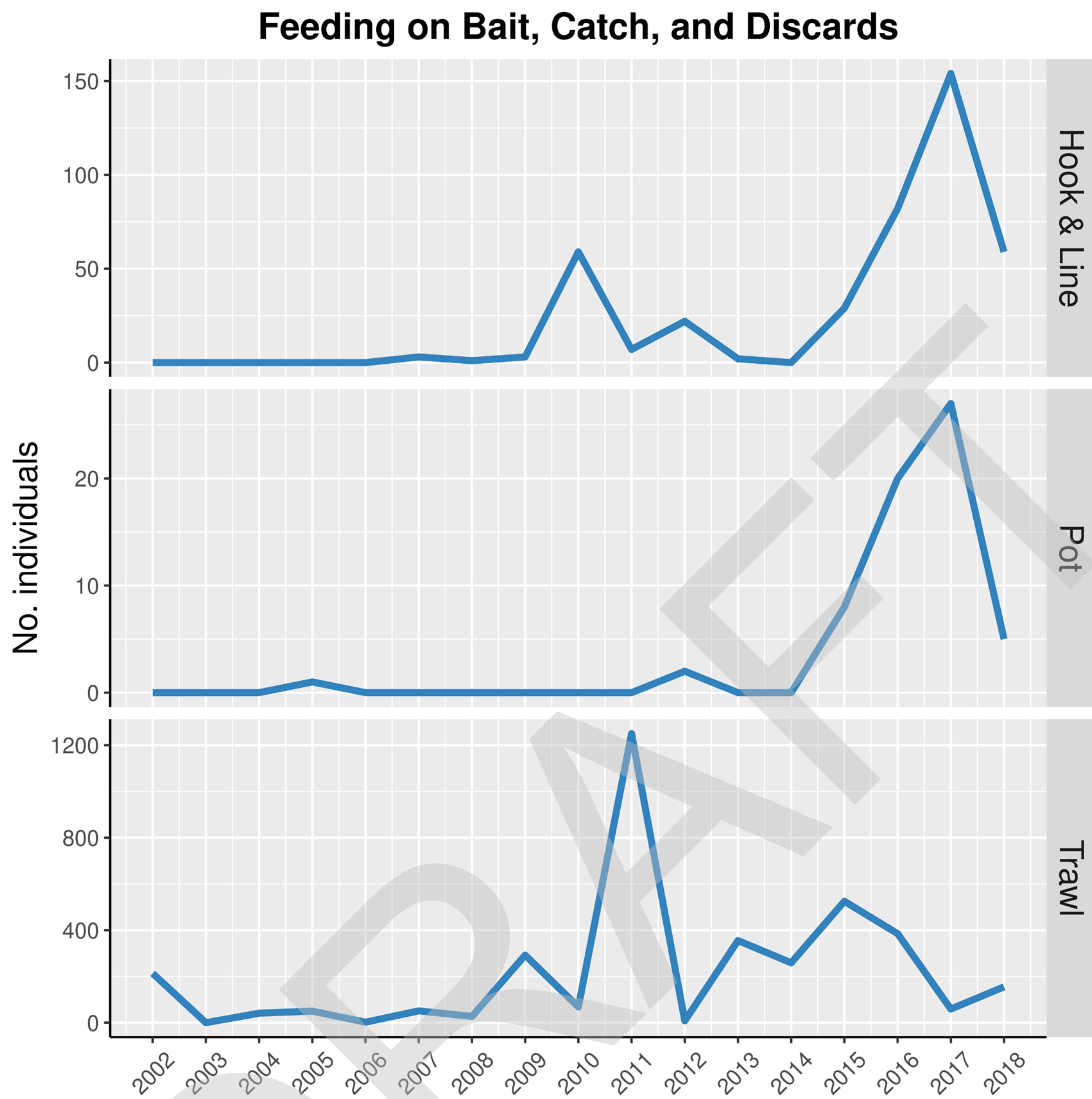

Figure 17: Observed number of seabirds feeding on bait, catch, or discards, by year and gear type, 2002-2018.

Methods

Data Sources

Data sources for this analysis include on-board observer data (from the WCGOP and A-SHOP), landing receipt data (referred to as fish tickets, obtained from PacFIN) and data generated from vessels carrying electronic monitoring (a.k.a. EM) equipment. Currently only vessels in the IFQ program fishing on an exempted fishing permit (EFP) carry EM equipment (see Somers et al. 2019 for observer and electronic monitoring coverage rates). Pacific States Marine Fisheries Commission houses and delivers EM data to the NWFSC Observer Program. Handling rules for vessels under the current EM EFP require vessel personnel to clearly display any protected species bycatch, including seabirds, to the EM camera system for identification and documentation. WCGOP also places observers on a randomly selected subset of EM vessels for protected species sampling (see Somers et al. 2019). A list of fisheries, coverage priorities and data collection methods employed by WCGOP in each observed fishery can be found in the WCGOP manuals (NWFSC, 2020). A-SHOP program information, documentation and data collection methods can be found in the A-SHOP observer manual (NWFSC, 2019). Both WCGOP and A-SHOP observer coverage and effort are reported by fishery and year in Somers et al. (2019).

WCGOP observers mainly sample the discarded portion of the catch of each haul. Trip-level fish landing receipts (aka fish tickets) are used to adjust observer estimates of retained catch, to ensure estimates of the retained catch are accurate. This process is described on the WCGOP Data Processing webpage and was conducted prior to the analyses presented in this report.

For data processing purposes, species and species groups were defined based on management. A complete listing of groundfish species is defined in the Pacific Coast Groundfish Fishery Management Plan (PFMC 2019).

Fish ticket landing receipts are completed by fish-buyers in each port for each delivery of fish by a vessel. Fish tickets are trip-aggregated sales receipts for market categories that may represent single or multiple species. Fish tickets are issued to fish-buyers by a state agency and must be returned to the agency for processing. Fish ticket and species-composition data are submitted by state agencies to the PacFIN regional database. Annual fish ticket landings data were retrieved from the PacFIN database (April 2020) and subsequently divided into various fisheries of the groundfish fishery as detailed in Somers et al. (2019).

For all PacFIN, WCGOP, and A-SHOP data, we maintain confidentiality of persons and businesses, as required by the Magnuson-Stevens Fishery Conservation and Management Act (often referred to as Magnuson-Stevens Act or MSA), which was most recently reauthorized in 2007. NOAA Fisheries guidance recommends, and NWFSC Fisheries Observation Science Program follows the "rule of three," which states that, "Information from at least three participants in the fishery must be aggregated/summarized at a temporal and spatial level to protect not only the identity of a person or a business, but also any business information."

Bycatch Estimation

For some fisheries, there is 100% observer coverage or electronic monitoring (EM) required on every trip. In these cases, we assume a complete census of seabirds on every haul. Seabird mortality is one of the highest priorities of observers, and crew are required to hold all seabirds up to the camera on EM vessels. However, a small portion of the catch can be unobserved on 100% coverage vessels, e.g., when hauls are subsampled or if an observer is ill. In these cases we do simple extrapolations to estimate unobserved seabird mortality (see Section below). For fisheries where there is less than 100% monitoring, we use a model based approach employing Bayesian methods.

Fisheries with less than 100% Observer Coverage

Fisheries observers monitor and record catch data on commercial fishing vessels by following protocols in the WCGOP manual (NWFSC 2020). Observer sampling focuses on discarded catch and supplements existing fish ticket landing receipt data to inform weights of retained catch. Observers generally sample 100% of tows or sets made during a trip. On trawlers, the total weight of discarded catch is estimated, and the discarded catch is then sampled for species composition. The species composition sample could represent either a census or a subsample of all discarded catch. On fixed gear vessels (hook-and-line and pot gears), observers sample total catch (similar to at-sea hake observer sampling methodology) and sample anywhere from 30 to 100% of the catch from each set.

Seabirds are often encountered while the observer is conducting species composition sampling, and thus might not be fully accounted for in the sampled portion of the catch alone. Prior to computing bycatch rates, the number of seabirds in the sample must be expanded to the tow/set level, as explained on the WCGOP Data Processing webpage.

Bycatch for the sampled portion of each fleet must be expanded to the unsampled portion of the fleet in fisheries where there is less than 100% observer monitoring. Historically, we have used ratio estimators to estimate seabird mortality in these fisheries (Jannot et al., 2011). Ratio estimators have been widely used in discard estimation (Stratoudakis et al., 1999; Borges et al., 2005; Walmsley et al., 2007). This method relies heavily on the assumption that bycatch is proportional to some metric or proxy of fishing effort, such as fishery landings (Rochet and Trenkel, 2005). Rochet and Trenkel (2005) note that this assumption is often not supported by data and that in some cases, bycatch might vary nonlinearly or even be unrelated to the ratio denominator. Most seabird species are encountered so rarely by these fisheries that it is difficult to assess whether the number of bycatch events is indeed linked to levels of fishing effort. Furthermore, bycatch estimates produced using ratio estimators have been shown to be biased, particularly when observer coverage is low (Carretta and Moore 2014, Martin et al. 2015).

To overcome the limitations of ratio estimators for estimating seabird bycatch, we applied a Bayesian modeling approach. Jannot et al. (2018) examined the differences between estimates calculated with a ratio estimator and those calculated with the Bayesian method. There are significant differences in annual bycatch estimates between the Bayesian approach and the ratio estimator method, as was expected (Jannot et al. 2018, Carretta and Moore 2014, Martin et al. 2015). We did not post-stratify the data, as has been done in previous reports (Jannot et al. 2011). We tested for the impact of dropping post-stratification by comparing annual Bayesian estimates generated with the strata used previously to those generated without stratification. The largest difference between annual estimates calculated with and without stratification was less than 1%. Thus, it is unlikely that removal of the stratification accounts for the large differences between Bayesian and ratio estimates. Here we report the Bayesian estimates generated without post-stratification. In the future, we will incorporate covariates, such as season, into our estimates.

Bayesian Estimation

We used Bayesian time-series models to estimate annual means and variability of seabird bycatch for each taxon within each fishery and gear type. These methods have been used with other rare bycatch species, including cetaceans, delphinids, pinnipeds, sea turtles, and sharks (Martin et al. 2015). For each species-fishery-gear type model, there are three parameterization choices to be made - the effort metric (# gear deployments, # gear units, mass of landed catch), the type of bycatch rate (constant or time-varying), and the type of bycatch-generating process (Poisson or negative binomial). In this report, we formally compare different effort metrics, time-varying to constant bycatch rates, and bycatch-generating model (Poisson vs. negative binomial). We use methods from the `loo` package as implemented in the `bycatch` package (Vehtari et al. 2019, Ward 2017) to compare among models within each fishery-species-gear type. Final estimates are presented from the single model that best fits the data.

Modeling Bycatch For each taxa-fishery-gear combination, the base model assumed bycatch rate was constant and inferred annual expected mortality, given a specified level of effort, using a simple Poisson process model, where the total number of bycatch events were assumed to follow a Poisson distribution,

$$n_{take,y} \sim \left(\lambda_y = \theta \cdot E_y\right)$$

where:

$n_{take,y}$ = number of observed bycatch events (or take events) in year y
λ_y = mean expected bycatch
θ = estimated bycatch rate
E_y = effort in year y

The estimated bycatch rate θ is assumed constant through time, but the quantity $\theta \cdot E_y$ includes uncertainty, as θ is estimated. Thus, a time series of the mean bycatch can be generated for a given species, with a given metric of effort. All uncertainty in the time series originates from fluctuating levels of effort through time (percent observer coverage only affects the expansion). We used a Bayesian model (Martin et al. 2015) to generate mean and 95% CIs of the bycatch rate parameter, θ, as well as for the expected bycatch, $\theta \cdot E_y$.

In this report, we built upon the simplified model above with the goal of finding the model that most accurately estimates bycatch and variance. To do that, we compared models to: (a) find the most suitable effort metric; (b) test the assumption that θ is constant through time; and (c) compare distributions (Poisson to negative binomial). For each species-fishery-gear there are a total of 12 possible models (three effort metrics, two rates, two distributions). To compare among these models, we used two model diagnostic tools (`Pareto-K` & `p-LOO`) and a model comparison method (`LOOIC`) from the `loo` package (Vehtari et al. 2019a) as implemented in the `bycatch` package (Ward 2017).

The `loo` package (Vehtari et al. 2019a) implements Leave One Out (LOO) sampling, a form of cross validation, which tests the efficacy of the model based on how well it approximates new data. LOO is based on Pareto smooth importance sampling (PSIS). Importance sampling is typically used when multiple distributions may be used, or when the density of the distribution is only partially known.

Before comparing among models, each model must be tested for efficacy using the `Pareto-K` values. Theoretically, the PSIS should converge to a mean and variance for the distribution, however, due to the use of random variables, convergence does not always emerge. LOO generates a `Pareto-K` value that reflects its convergence properties. A 'low' `Pareto-K` value (less than 0.5) indicates that both the mean and variance converge, reflecting an effective model. A 'slightly high' `Pareto-K` value ($0.5 \leq K < 1$) indicates a model whose mean converges, but variance either does not converge at all, or converges slowly. Finally, a 'high' `Pareto-K` value ($1 < K$) indicates neither the mean nor the variance converges. These values are simple heuristics to be used as guidelines, rather than hard rules (Vehtari et al. 2019b).

In addition to `Pareto-K` values, LOO can be used to test for overparameterization by generating a `p-LOO` value which is compared to the number of parameters used in the model. The parameters for the model includes all the incorporated covariates, as well as time, effort, and distribution. All models tested here have no covariates, and thus have three parameters (time, effort, distribution). A `p-LOO` less than the number of parameters denotes an appropriately parameterized model.

Once a model is considered suitable, the optimal model can be chosen by comparing among `LOOIC`'s, or 'Leave One Out Information Criterion'. The `LOOIC` is based on an expected log predictive density (ELPD). Generally, the preferred model is the model with the lowest `LOOIC`.

The 12 models within a species-fishery-gear were tested in the following order and excluded if any of the following cases were met:

```
1. Pareto-K > 0.7, as suggested by (Vehtari et al. 2019b)
2. p-LOO > 3 (the number of parameters)
3. LOOIC is not the minimum
```

In some cases, all 12 models failed both the `Pareto-K` and `p-LOO` tests. To reduce the model complexity in these cases, we reverted to a constant bycatch rate and Poisson distribution (see above), then compared among effort metrics and chose the single model that minimized all three model diagnostics, even if those diagnostics were larger than recommended.

Expanding Bycatch to Unobserved Portion of Fleet Because observer coverage is less than 100% in some fleets, and variable through time, we need to expand the estimated bycatch, $\theta \cdot E_y$, to the fleet-wide level. One approach for expansion would be to divide $\theta \cdot E_y$ by the percent observer coverage; however, this ignores uncertainty in the expansion. We accounted for uncertainty in the expansion by treating the observer coverage and estimated bycatch ($\theta \cdot E_y$) as known ('p', 'x', respectively) and sampling from the distribution of total bycatch (N) in proportion to the binomial density function. This process was repeated for each Markov Chain Monte Carlo (MCMC) draw, to propagate uncertainty in the estimates through the uncertainty in the expansion. Details on the implementation of this in R can be found in the `bycatch` package (Ward 2019). Fleet-wide bycatch of each seabird taxon was estimated for each fishery and gear type using observer coverage data (Somers et al. 2019).

One limitation of this method is that the time-series must be complete (i.e., no gaps). The Open Access California halibut fishery was observed from 2003-2005, and 2007-present, but not in 2006. To create a complete series (2003-present) we used the average across 2004-2008 to fill in the missing 2006 data. Averaging across years was only employed to create a complete series; therefore, we do not report bycatch estimates for 2006 for the OA California halibut fishery.

Fisheries with 100% Observer Coverage

There are two fisheries with 100% observer coverage: the at-sea Hake fishery and the Shoreside IFQ fisheries. For these fisheries, we assume a complete census of seabirds on every haul since seabird mortality is one of the highest priorities of observers and crew are required to hold all seabirds up to the camera on EM vessels. However, a portion of the catch can be unobserved on 100% coverage vessels, e.g., when hauls are subsampled or if an observer is ill. In these cases we do simple extrapolations to estimate unobserved seabird mortality.

At-sea Hake Fishery - The at-sea hake fishery, which is observed by the A-SHOP and the Catch Shares, or IFQ, fishery which is observed by the WCGOP both require 100% observer coverage. Currently in the Catch Shares fishery, vessels that participate in the electronic monitoring (EM) program can forgo 100% observer coverage provided that:

```
* They hold an Exempted Fishing Permit for the EM program;

* Electronic monitoring equipment is installed, used and working properly on
every trip;

* They take observers for scientific data collection on trips when selected t
o do so by the NWFSC Observer Program.
```

A-SHOP observers monitor for seabirds in two distinct ways. First, if a seabird was caught and is present in the observer’s species composition sample, the appropriate information (including weight, length, etc.) is documented. Secondly, observers monitor the dumping of catch from the net into the sorting tank for about 50-70% of the hauls. This is done to detect the presence of marine mammals; however, observers would also collect any seabirds at this time if any were observed, e.g., caught in the warps, cables, or wings of the net. These observations are considered opportunistic and are not used to extrapolate seabird mortality to the unsampled portion of the catch. Observers also record information on non-lethal interactions seen between fishing operations and seabirds and document sightings of ESA-listed species, as time allows.

Bycatch data for seabirds is primarily recorded during species composition sampling. Seabirds are small enough to make it below deck where the observer samples the catch and are recorded only if they happen to be included in the observer’s random species composition sample of a particular tow. Any bycatch of seabirds recorded in a species composition sample must be expanded to the haul level. Often, this results in the observation of one seabird expanding to two seabirds, depending on the observed sample size for that haul. However, since every vessel is observed and almost 100% of the fleet's tows are sampled, the bycatch expansion to the entire at-sea fishery is quite small.

To estimate total seabird bycatch in the at-sea hake fishery, all of the sampled tows were used in our analysis. Once the bycatch estimate of seabirds was expanded within each sampled tow. In rare instances, for example a tow goes unsampled, the estimate is then used to expanded to the unobserved portion of the fleet. This method for calculating seabird bycatch is the same as the method used to calculate fish bycatch in the at-sea hake fishery.

For each seabird species, the total number of takes during each tow was calculated using the following formula:

$$Y_t = y_t \times \frac{W_t}{w_t}$$

where:

Y_t = total number of takes in tow t
y_t = number of observed takes in the species composition of tow t
W_t = weight of the total catch in tow t
w_t = weight of the sampled catch in tow t

The total number of takes of each seabird species in the at-sea hake fleet was then calculated using the following formula: $B = \sum_t Y_t \times \left(\frac{C_{total}}{c_{obs}}\right)$

where:
B = total estimated bycatch for the species
C_{total} = total catch from all tows in the at-sea hake sector
c_{obs} = catch from the observed tows in the at-sea hake sector
w_t = weight of the sampled catch in tow t

Seabird bycatch data do not contain the necessary replicates for calculating within tow variation. The only source of uncertainty that could have been evaluated for fleet-wide seabird bycatch estimates was that associated with the variance between tows. Since nearly 100% of tows were sampled, this variation was quite small and not useful for estimating uncertainty.

Seabird Cable-strikes on At-sea Catcher Processors - On at-sea hake catcher processor vessels, some incidental seabird mortality could occur when birds collide with the trawl door warp wires or trawl net data cables during gear deployment or fishing. In the past, these interactions went unobserved, as fisheries observers do not normally monitor the setting or fishing of the gear. However, from 2016-2019, we trained fisheries observers to sample seabird cable strikes during daylight trawling activities twice per day, at randomly selected 15-minute intervals. We used a modified version of Melvin et al. (2011) data collection protocols. Fisheries observers recorded the species and number of birds colliding with cables, the date and time, the type of strikes (hard or soft), weather conditions, the configuration of cables, and characteristics of the offal discharge—the main attraction for seabirds. Hard strikes are defined as those that result in the bird changing course, falling into the water, or being dragged underwater, whereas soft strikes are defined as those that result from the bird being lightly touched by cables and/or moving away from them in a controlled manner. Differentiating hard strikes from soft is important, as hard strikes are more likely to result in mortality (Sullivan et al. 2006a & b, Melvin et al. 2011). Additional fishing activity information was recorded by observers, including net deployment/retrieval location, date and time; these were used to expand observed times to total minutes of daylight trawling activity for the entire at-sea catcher-processor fleet. Observations of cable strikes by species recorded during this special project are presented in Supplemental Table 28.

We used a Bayesian time series model (see above), with fishing season (Spring = May - June; Fall = August - October) as a covariate and the total hours of trawling activity as the metric of effort to estimate the total number of hard strikes by species, season, and year. Preliminary data analyses suggested that season might play an important role in determining seabird risk for cable strikes (data not shown). We took the average number of hard strikes across seasons and years, with mortality rate applied (Table 21) as an estimate of annual mortalities due to cable strikes. This number was then added to the estimated mortality (see above) for each year for the catcher-processor fleet only.

Cable-strike Mortality Rate Calculation - Not all hard strikes will result in mortality, thus a species-specific mortality rate must be applied to the total number of cable-strikes to obtain estimates of a hard cable-strike mortality (Table 21).

In addition to fisheries observer cable-strike data collection (above, see also Supplemental Table 28), during 2019 the NWFSC collaborated with Oregon Sea Grant (OSG) and the at-sea hake industry to place dedicated seabird monitors on at-sea hake catcher-processor vessels to conduct a more focused study of seabird interactions with cables on these midwater trawl vessels (A. Gladics, Oregon Sea Grant, pers. comm.). The at-sea hake fleet operates from May 15 –December 31 from the U.S-Canadian border to the Oregon-California border. There are distinct 'spring' (May–June) and 'fall' (September–November) fishing seasons. Methods were modified from Melvin et al. (2011) and similar to the fisheries observer cable-strike data collection (described above; A. Gladics, Oregon Sea Grant 2020, pers. comm.). One major difference was that seabird monitors spent more time watching cables for strike interactions, observing the fate of struck birds, and determining the likely outcome (e.g., no harm, injured, dead) of each cable strike — data that fisheries observers could not obtain because of time constraints and other duties. Thus, the OSG seabird monitors were able to develop species-specific mortality rates for cable-strikes on these vessels (Table 21). We applied these mortality rates to our Bayesian estimates of hard strikes and then added this number to the observed mortalities for each species in each year to obtain final mortality estimates for this fleet.

Species	mortality rate
Northern Fulmar	0.0235
Shearwaters, Sooty & Short-tailed combined	0.1505
Black-footed Albatross	0.0100
Gull spp. Unidentified	0.0450
Pink-footed Shearwaters	0.1000
Leach's Storm-petrel	1.0000

Table 22: Species-specific mortality rates due to cable-strikes as determined by Oregon Sea Grant seabird monitors on at-sea hake catcher processors during the 2019 spring and fall fishing seasons (A. Gladics, Oregon Sea Grant 2020, pers. comm.).

Shore-based IFQ Fisheries - Fleet-wide seabird bycatch estimates for the shore-based IFQ fisheries were derived from WCGOP observer data and fish ticket landings data. Fish tickets associated with the IFQ fishery were defined by analysts through an extensive quality control and review process of all available data sources, including those utilized for in-season management (see online documentation).

IFQ bottom trawl vessels can hold a California halibut bottom trawl permit and participate in the state-permitted California halibut fishery. Limited entry California halibut tows can occur on the same trip as tows targeting IFQ groundfish and were identified at the tow-level based on the use of bottom trawl gear and the following criteria:

1. The target was California halibut and more than 150 lbs. of California halibut was landed, or

2. The target was nearshore mix, sand sole, or other flatfish, and the tow took place in less than 30 fathoms and south of 40° 10′ N. latitude.

All IFQ bottom trawl tows that met at least one of the above requirements were analyzed using methods for IFQ discard estimation to reflect the sampling protocol performed by observers on the boat. Tow targets are typically determined by the vessel captain. Since 2013, no limited entry California halibut tows occurred.

Since 2011, all (100%) IFQ trips are required to carry an observer or EM equipment. Therefore, observed counts of seabird bycatch in these fisheries represent a near complete census. However, on rare occasions, sets or portions thereof, are unsampled. The unsampled portion of catch is typically less than 1% in any given year. We used ratio estimators to apportion any unsampled bycatch to specific species, based on observed numbers of individuals in the sampled catch. In most cases, this adds only a small amount (less than a whole bird) to our estimates of seabird bycatch. In the spirit of transparency, we provide the methods below for expanding this very small amount.

Infrequently, entire hauls, including species that would have normally been retained, are discarded at-sea either because of gear malfunctions (e.g., net rips before landed) or operational considerations (e.g., deliberate release of catch from net before landing because of safety or other concerns). In these instances, the observer records a visual estimate of unsorted catch weight, including both discarded and retained species. Very infrequently, haul data fail quality control measures. In all of these cases, bycatch was estimated based on retained weight from fish tickets. To obtain the estimated number of discarded individuals of a species (B) when the entire haul or set was unsampled, the unsampled weight was multiplied by the ratio of the bycatch number of individuals of the species divided by either the (a) weight of all species (discarded + would-have-been-retained) discarded at-sea or (b) retained weight of all species in all sampled hauls, depending on if the haul was unsampled because of complete discard at sea (a) or failed data (b):

$$\hat{B} = \sum_p x_p \times \frac{\sum_f b_f}{\sum_f x_f}$$

where:
$\hat{B}$ = estimated number of unsampled individuals of a given species
p = unsampled haul
x_p = weight of the unsampled discarded at-sea
f = sampled haul
x_f = weight of all retained species from fish tickets on sampled hauls b = sampled number of individuals of a given species

We used discard weight as the denominator in the ratio because we only have an estimated weight of unsampled hauls; counts of individuals are not available for unsampled hauls.

For partially unsampled hauls, observers are instructed to sample such that species in the sample are not also included in the unsampled portion of the catch to avoid double counting. To obtain the estimated number of bycatch individuals (B) included in partially sampled hauls, the unsampled discard weight (visually estimated) was multiplied by the ratio of the sampled number of individuals of the species divided by the sampled weight of all species .

The estimated number of unsampled individuals of a particular species were then added to the sampled number of individuals of that species to obtain the total bycatch estimate.

Statistical Software

The statistical software `R` (R Core Team, 2019) was used to produce the analyses, tables, figures in this report. Specifically, we relied heavily on the R packages:

```
* bycatch (Ward, 2017) for modeling and simulation,
* ggplot2 (Wickham, 2016) for plotting figures,
* loo (Vehtari et al. 2019) as implemented in `bycatch` for model comparisons
,
* knitr (Xie, 2020) for tables and dynamic reporting, and
* tidyverse (Wickham et al. 2019) & dplyr (Wickham et al. 2020) for data wran
gling.
```

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Appendix A: Fishery Descriptions

Table A-1: A description of permits, gears used, target groups, vessel length range, fishing depth range, and management of fisheries, sectors and subsectors in federally managed U.S. west coast groundfish catch share fisheries. For brevity, management descriptors are generalized for the given time period and are not meant to be complete or comprehensive.

Table A-2: A description of permits, gears used, target groups, vessel length range, fishing depth range, and management of fisheries, sectors and subsectors in federally managed, non-catch shares, U.S. west coast groundfish fisheries. For brevity, management descriptors are generalized for the given time period and are not meant to be complete or comprehensive.

Table A-3: A description of permits, gears used, target groups, vessel length range, fishing depth range, and management of fisheries, sectors and subsectors in state-managed U.S. west coast fisheries. For brevity, management descriptors are generalized for the given time period and are not meant to be complete or comprehensive.

Appendix B: Observed Mortalities - Random and Opportunistic

Table B-1: Observed random and opportunistic seabird mortalities by year, fishery, gear type and species for 2002-2018. Randomly sampled mortalities are used in estimating total mortality across observed and unobserved vessels within each fleet. Opportunistically sampled mortalities that occurred outside the fisheries observer's random samples and are simply added to the total mortality. The proportion of random to opportunistic samples are presented in Figure B-1.

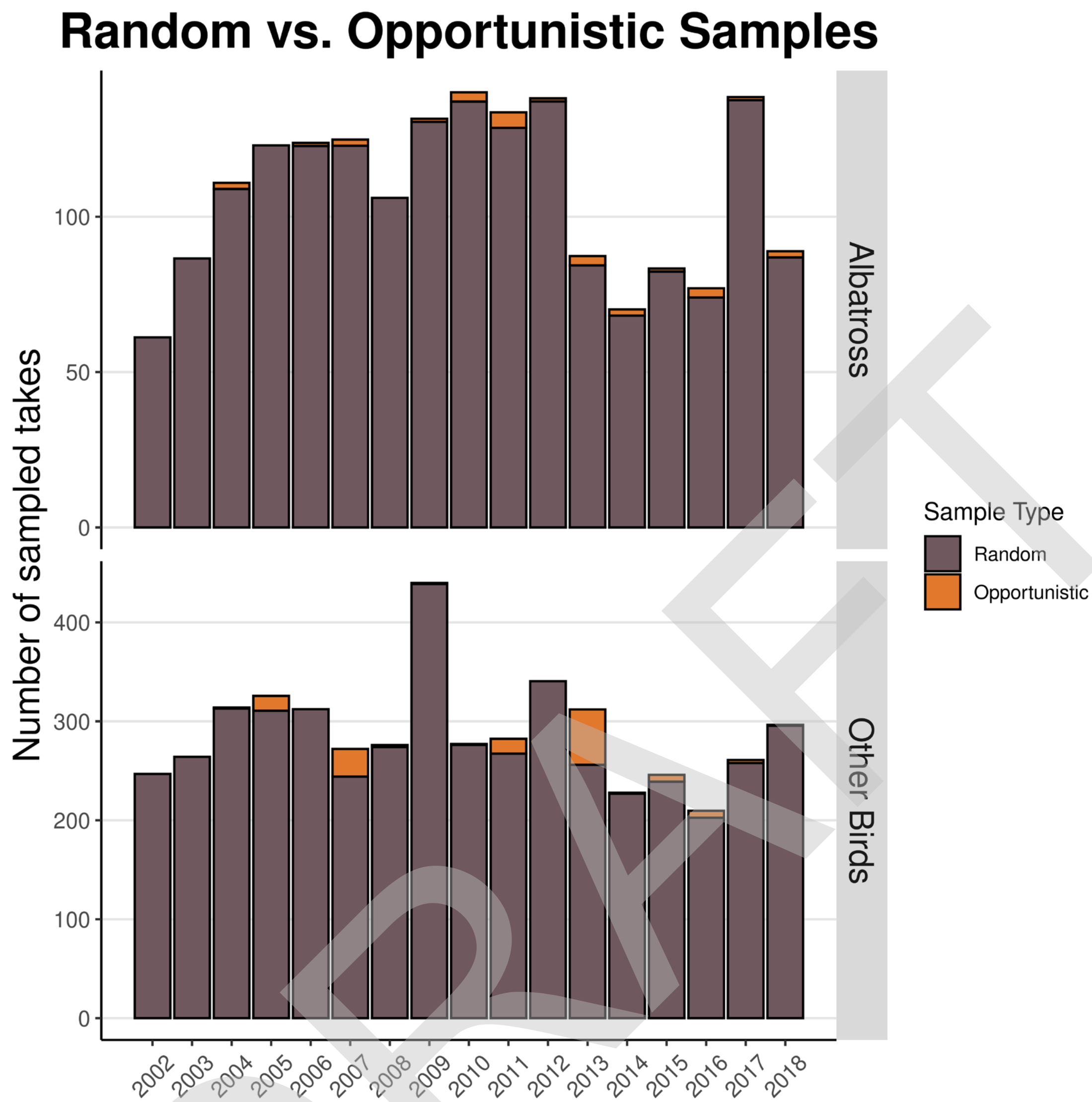

Figure B-1: Randomly sampled and opportunistic samples as a fraction of total samples, by year.