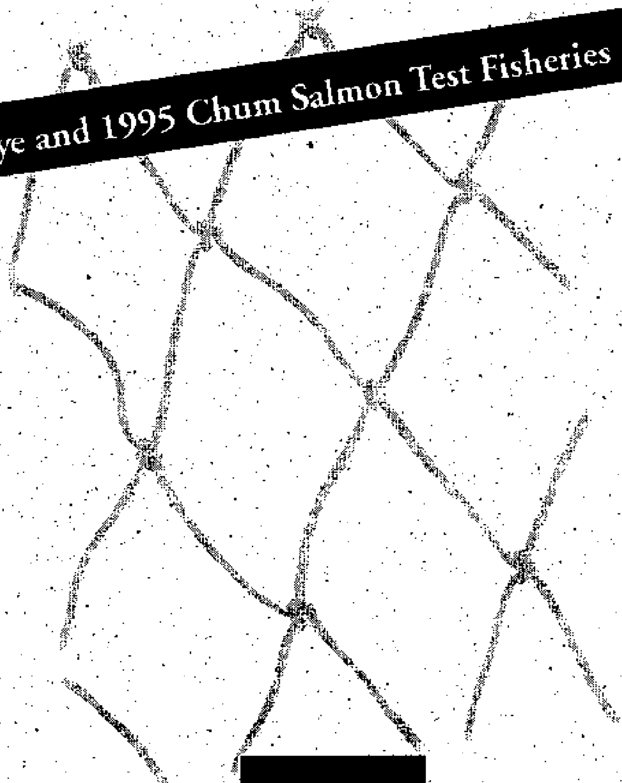
Seabird Bycatch Reduction:

New Tools for Puget Sound Drift Gillnet Salmon Fisheries

1996 Sockeye and 1995 Chum Salmon Test Fisheries - Final Report



WASHINGTON SEA GRANT PROGRAM
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By Edward F. Melvin, Loveday L. Conquest and Julia K. Parrish

Seabird Bycatch Reduction: New Tools for Puget Sound Drift Gillnet Salmon Fisheries

1996 Sockeye and 1995 Chum Salmon Test Fisheries Final Report

By
Edward F. Melvin
Marine Fisheries Specialist
Washington Sea Grant Program
University of Washington

Loveday L. Conquest
Professor, School of Fisheries/Center for Quantitative Science
Associate Dean, College of Ocean and Fishery Sciences
University of Washington

and
Julia K. Parrish
Research Assistant Professor
Zoology Department
University of Washington

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Washington Sea Grant Program
University of Washington
3716 Brooklyn Avenue N.E.
Seattle, WA 98105-6716

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 Contact Washington Sea Grant Program, 3716 Brooklyn Avenue N.E., Seattle, WA 98105-6716, (206) 543-6600, or fax (206) 685-0380.

Email: seagrant@u.washington.edu

Home page: http://www.wsg.washington.edu

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EXECUTIVE SUMMARY

This study compared entanglement rates of seabirds and marine mammals and catch rates of salmon among up to three experimental gear treatments and a control (nylon monofilament netting) and among three time-of-day categories in two Washington non-treaty salmon fisheries: the 1996 sockeye fishery in Management Area 7, the San Juan Islands vicinity of north Puget Sound; and the 1995 fall chum fishery in Management Area 10, south Puget Sound. Because the scope of activities and seabird interactions were greater in the sockeye fishery than in the chum fishery, research in the sockeye fishery is emphasized.

This research continued a university-industry research program begun in the 1994 non-treaty sockeye fishery and continued in a 1995 sockeye test fishery. Our goal was to develop methods that eliminate or significantly reduce the incidental capture of seabirds in salmon gillnet fisheries without significantly reducing the fishing efficiency of the nets. This work was funded by a grant from the National Marine Fisheries Service Saltonstall-Kennedy Grant Program and by Washington Sea Grant Program.

Experimental nets incorporated either visual or acoustic alerts into traditional nylon monofilament gear. Visual barrier nets were monofilament nets with highly visible netting replacing the upper quarter (50 Mesh) or upper eighth (20 Mesh) of the net. Acoustic alert nets were monofilament nets with low frequency sound-emitting devices (pingers) attached to the corkline. Pingers were tested in the 1996 sockeye test fishery only. Fishing time was divided into three categories: morning change of light (AM COL), daytime, and evening change of light (PM COL). Puget Sound Gillnetters' Association fishing vessels were contracted by the Washington Department of Fish and Wildlife (WDFW) to fish experimental nets in a Washington State Test Fishery under our research protocol.

During the 1996 sockeye test fishery, we caught 13,151 sockeye salmon in 642 sets during seventeen fishing trips from 28 July to 29 August. This level of effort exceeded our minimum effort target of 600 sets by 7%. During the 1995 chum test fishery, we caught 6,822 chum salmon in 107 sets in eight fishing trips from 25 October to 11 November. This level of effort met our minimum effort target of 100 sets. Both test fisheries were highly selective for the target species relative to other salmon species: sockeye salmon accounted for 98.4% of the salmon caught in the 1996 sockeye test fishery and chum salmon accounted for 99.7% of the salmon catch in the 1995 chum fishery.

In the 1996 sockeye test fishery, common murres were the most abundant seabird in the study area (30.7 sightings/set)—a rate 59 times greater than what we observed in our earlier research in the 1995 test sockeye fishery. Rhinoceros auklets made up almost all other alcid sightings and were almost three times more abundant in 1996 (4.5 sightings/set) than in 1995. A total of 349 alcids were entangled: 260 common murres (75% of the total), 87 rhinoceros auklets, one pigeon guillemot, and one marbled murrelet. Murre entanglement rates were 15 times higher than in the 1995 sockeye test fishery (0.60 murres/set vs. 0.04 murres/set); rhinoceros auklet entanglement rates were 2.8 times higher than 1995 (0.20 auklets/set vs. 0.07 auklets/set in 1995). Seabird and sockeye abundance changed dramatically within the 1996 sockeye season but in opposing patterns. During the final weeks of the fishery, sockeye catch rates dropped off to trace levels (about two fish/set) and murre abundance peaked at near 100 sightings per set.

In the 1995 chum test fishery, there were fewer alcids present than in either the 1996 or 1995 sockeye fisheries in Area 7 and abundance patterns were most similar to the sockeye fishery in 1995. Rhinoceros auklets were the most abundant seabird (0.51 auklet sightings/set) but they were three times less abundant than in the 1995 sockeye and nine times less abundant than in 1996 sockeye test fisheries. Common murres were few (0.1 murre sightings/set)—five times fewer than the 1995 sockeye test fishery and dramatically fewer (over 300 times) than the 1996 sockeye test fishery. Eleven rhinoceros auklets and twelve common murres were entangled. Murre and auklet entanglement rates exceeded those of the 1995 sockeye test fishery by four times and 1.6 times, respectively.

In the 1996 sockeye test fishery, entanglement rates of common murres and rhinoceros auklets and catch rates of sockeye salmon varied significantly among the experimental gears, time-of-day categories, and locations tested; however, the patterns of variation among all these factors were species specific. Pinger, 20 Mesh and 50 Mesh gears entangled alcids at rates 58%, 55%, and 50% (respectively) of the monofilament control; sockeye catch rates were 85%, 88% and 39%, respectively. In the 1995 chum test fishery, chum salmon catch rates varied significantly among the three gear types tested; however, alcid entanglement rates did not.

In the 1996 sockeye test fishery, daytime and evening change-of-light sets (COL) entangled alcids at rates of 36% and 68% respectively of those made during the morning COL, whereas sockeye catch rates were 79% and 74% respectively. In the 1995 chum test fishery, neither alcid entanglement rates nor chum catch rates varied significantly by the three time-of-day categories tested; however, the pattern and magnitude of variation was similar to that observed in the 1996 sockeye fishery.

Results of this study identify three basic tools that can be used to reduce seabird bycatch in Puget Sound salmon drift gillnet fisheries: abundance-based or ecosystem management, alternative gear, and time-of-day. The dramatic inter-annual and in-season variation of seabird abundance in Puget Sound is the most important factor determining the rate of seabird entanglements in Area 7. Inter-year and intra-season sources of variation in seabird abundance provide great opportunity for improved management of the fishery based on an ecosystem management concept.

We confirmed that visual barriers are an effective seabird bycatch reduction tool. The 20 Mesh gear met our original goal of significantly reducing seabird bycatch without significantly reducing fishing efficiency. It was tested and proved in multiple fisheries, and was conceived by and endorsed by the Puget Sound Gillnetters' Association as an acceptable tool to reduce seabird bycatch in this fishery. 50 Mesh nets, those with the deeper of the two visual barriers tested, were eliminated as possible seabird reduction tools because they did not meet goals of the research program, were impractical to fish, and entangled porpoise. Although pingers have the greatest potential as tools to reduce seabird bycatch in a wide range of gillnet fisheries, we do not recommend these devices as alternatives for Puget Sound at this time because we believe that they can be improved, results need to be duplicated, and the prototype device is not commercially available. The time of day that gillnets are fished significantly affects seabird bycatch rates. Elimination of morning change-of-light fishing is likely to reduce most rhinoceros auklet entanglements and contribute significantly to reducing common murre entanglements.

Although seabird bycatch and sockeye catch varied significantly by location, areas of high salmon catch and high seabird bycatch tended to overlap, eliminating the possibility of significantly reducing seabird bycatch without significantly reducing salmon catch through zonal or area closures within Management Area 7. Data suggest that the number of birds in the vicinity of the net is probably the most important factor influencing the entanglement rates of seabirds, but that sea state and weather also might be important.

Employing all available tools, fishing 20 Mesh nets at times of high fish abundance during openings that include either daytime and dusk or daylight-only fishing, have the potential to reduce seabird bycatch by up to 70% to 75% in years similar to 1996.

Recommendations

Based on this research, we recommend several management actions that will reduce the bycatch of alcid seabirds in Puget Sound drift gillnet fisheries and enhance seabird conservation in the shared waters of Washington and Canada. Recommendations focus on institutional change for fishery and wildlife management agencies as well as fishery practices. We recommend the following:

- Make seabird conservation an objective of all fishery management agencies with jurisdiction over Puget Sound and its adjacent waters.
- Implement seabird bycatch reduction measures that are comprehensive, extending to all fishers regardless of country or treaty status.
- Link seabird data from existing on-colony, outer coast and Puget Sound survey programs with seabird abundance data collected on the fishing grounds.
- Prioritize the development of a comprehensive seabird abundance data set and incorporate it into the fishery management process via wildlife management agencies responsible for seabird conservation.
- Manage the fishery interactively using real time seabird and fish abundance data.
- Eliminate morning change-of-light sets in the gillnet fishery and restrict fishing to daylight hours in years of high murre abundance.
- Require 20 Mesh nets (upper 20 meshes replaced with white, highly visible seine twine) to replace traditional monofilament drift gillnets in the Area 7/7A Fraser River sockeye fishery, and allow time for full compliance. The effectiveness of the 20 Mesh gear in the fall chum fishery has not been proved, and therefore, is not recommended.

ACKNOWLEDGMENTS

A program of this scope and complexity can only be accomplished with the help and dedication of a number of organizations and individuals. We would like to thank the Puget Sound Gillnetters' Association and the Washington Department of Fish and Wildlife (WDFW) for their cooperation and support. Special thanks to Lanny Pillatos, president of the Puget Sound Gillnetters' Association, for his trust, for organizing and coordinating fishers to participate in test fisheries, and for conveying the innovative ideas of the fishers he represents. We are indebted to Stuart Erholm, F/V Emily April; and Harry Henderson, F/V Annie Kae; for sharing their skill and experience as vessel team leaders in the 1996 sockeye test fishery and to the individual fishermen who made their vessels available and worked long hours under difficult conditions: Bill Rouch, F/V Pacific Breeze; Lanny Pillatos, F/V Wendy Sue; Jim Piercey, F/V Nightstalker; Matt Marinkovich, F/V Nightmare; Lanny Carpenter, F/V Some Guy; Dan Crawford, F/V Michelle Evonne; Steve Milkas, F/V Last Chance; Red Larsen, F/V Dakota Maid; Larry Barcott, F/V Mystique; and Robin Fakkema, F/V Bonnie D.

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We were extremely fortunate to have recruited an excellent crew of experienced and reliable field technicians who worked difficult and long hours collecting high quality data. We are indebted to Monique Wilson for her essential and tireless work coordinating observer activities, necropsying birds and supervising data entry and ensuring its quality. Debbie Craig, Natalie Herner, and Dan Cunningham were observers in both test fisheries. Kim Dietrich, Brian McDonald, Reisa LaTorra, Reaves Morris, and Andrew Craig were observers in the 1996 sockeye test fishery. We are especially grateful to Debbie Craig and Kimberly Dietrich for coordinating observer activities within their respective teams in the 1996 sockeye fishery. Tim Brown, WSGP, provided computer and logistical support and Nicolle Rutherford entered and helped edit data. Thanks to Mary Carlson and Laura Wymore, Seattle Aquarium, for their help training observers.

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INTRODUCTION

In 1993 and 1994 the Washington Department of Fish and Wildlife (WDFW) carried out observer programs in Puget Sound non-treaty drift gillnet fisheries to determine the extent to which marine mammals and marbled murrelets (*Brachyramphus marmoratus*), a species listed as threatened under the Endangered Species Act in 1992, are entangled in these fisheries. Results showed that marbled murrelet and harbor porpoise (*Phocoena phocoena*) entanglements were extremely rare (Pierce et al., 1996), but that other seabirds were entangled at rates ranging from one bird every five sets in the south Puget Sound chum (*Oncorhynchus keta*) fishery (Erstad et al., 1996) to one bird every two sets in the north Puget Sound sockeye (*O. nerka*) fishery (Erstad et al., 1994). Based on observer data WDFW estimated that more than 3,500 seabirds were entangled in drift gillnets in the 1994 non-treaty sockeye fishery in north Puget Sound (WDFW, unpublished data).

Most birds entangled during these observer programs were diving seabirds of the family Alcidae, mainly common murres (*Uria aalge*) and rhinoceros auklets (*Cerorhinca monocerata*). Mahaffy et al. (1994) suggested that seabird mortalities from net entanglements may contribute to declines of local breeding populations. In general, alcids are long-lived, low-fecundity animals with delayed maturity (Tuck, 1960). Up to half the population may consist of pre-breeders (Hudson, 1985). These life history characteristics make alcid populations highly sensitive to small increases in mortality rates from both natural and human sources (Hudson, 1985; Ford et al., 1982). Seabird mortalities in gillnet fisheries are a violation of the Migratory Bird Treaty Act (MBTA), a misdemeanor offense. Unlike the Marine Mammal Protection Act (MMPA), the MBTA has no provision for the incidental capture of protected species. These biological and legal concerns have heightened scrutiny of seabird bycatch in Puget Sound gillnet fisheries.

Common murres breed on uninhabited, mostly rocky islands along the coast of North America from central California to the Gulf of Alaska and Bering Sea. Exclusive of the Bering Sea, West Coast common murres number approximately 3 million to 3.5 million (J. Parrish, unpublished data). Along the Washington coast, murres aggregate during the breeding season (May through September) on a variety of islands within the U.S. Fish and Wildlife Service (USFWS) Outer Coast Refuge and on Tatoosh Island (Figure 1), but are known to breed only on Tatoosh Island (Parrish, 1996). Common murre chicks fledge from California and Oregon colonies in late June to early July (Boeklheide et al., 1990). Fledging is four to six weeks later on Washington colonies (mid-August to late September; Parrish, 1996).

Although the status of common murre populations attending Washington colonies is poorly understood, the trend appears to be decline. Within the Outer Coast Refuge murre colony attendance declined sharply from about 30,000 birds (1979 to 1982) to a mean of less than 5,000 birds beginning with the El Niño event in 1983 (Wilson, 1991). From 1991 to 1996 colony attendance in the refuge has ranged from 565 to 6,600 and averaged about 4,000 birds (Wilson, 1996). There are no data on the breeding status of these colonies, leaving their biological significance uncertain. On Tatoosh Island, murre attendance has ranged from 3,400 to 4,200 and averaged 3,700 since 1991 (Parrish, 1996). Although murre attendance at Tatoosh Island has been relatively stable in this time, direct and indirect pressure from bald eagles (*Haliaeetus leucocephalus*) has led to chronically depressed reproductive success and shifts in breeding habitat selection (Parrish, 1996). If trends continue, the Tatoosh colony could be in serious decline. Based in part on declining population size and depressed reproductive success, Washington common murres were recently listed as a species of concern by WDFW (Warheit, 1997). Common murres migrate into Puget Sound from coastal colonies beginning as soon as July (Manuwal et al., 1979). Whether they are from Oregon, California or Washington colonies is unknown.

Rhinoceros auklets breed on vegetated islands along the coast of North America from California to the Aleutian Islands (Gaston and Dechesne, 1996). Thirteen percent of the total North American population breeds in Washington (Gaston and Dechesne, 1996) on Protection and Smith Islands within Puget Sound (2 to 14 nautical miles from the fishing grounds), and on the coast at Destruction Island and several smaller islands including Tatoosh (Speich and Wahl, 1989; Figure 1). As with common murres, there is concern that some rhinoceros auklet populations are in decline. On Protection Island, estimates of the number of rhinoceros auklet breeders have declined from more than 34,000 birds in the mid 1970s (Wilson, 1977) to 25,000 birds in 1993 (U. Wilson, 1997, pers. comm.),

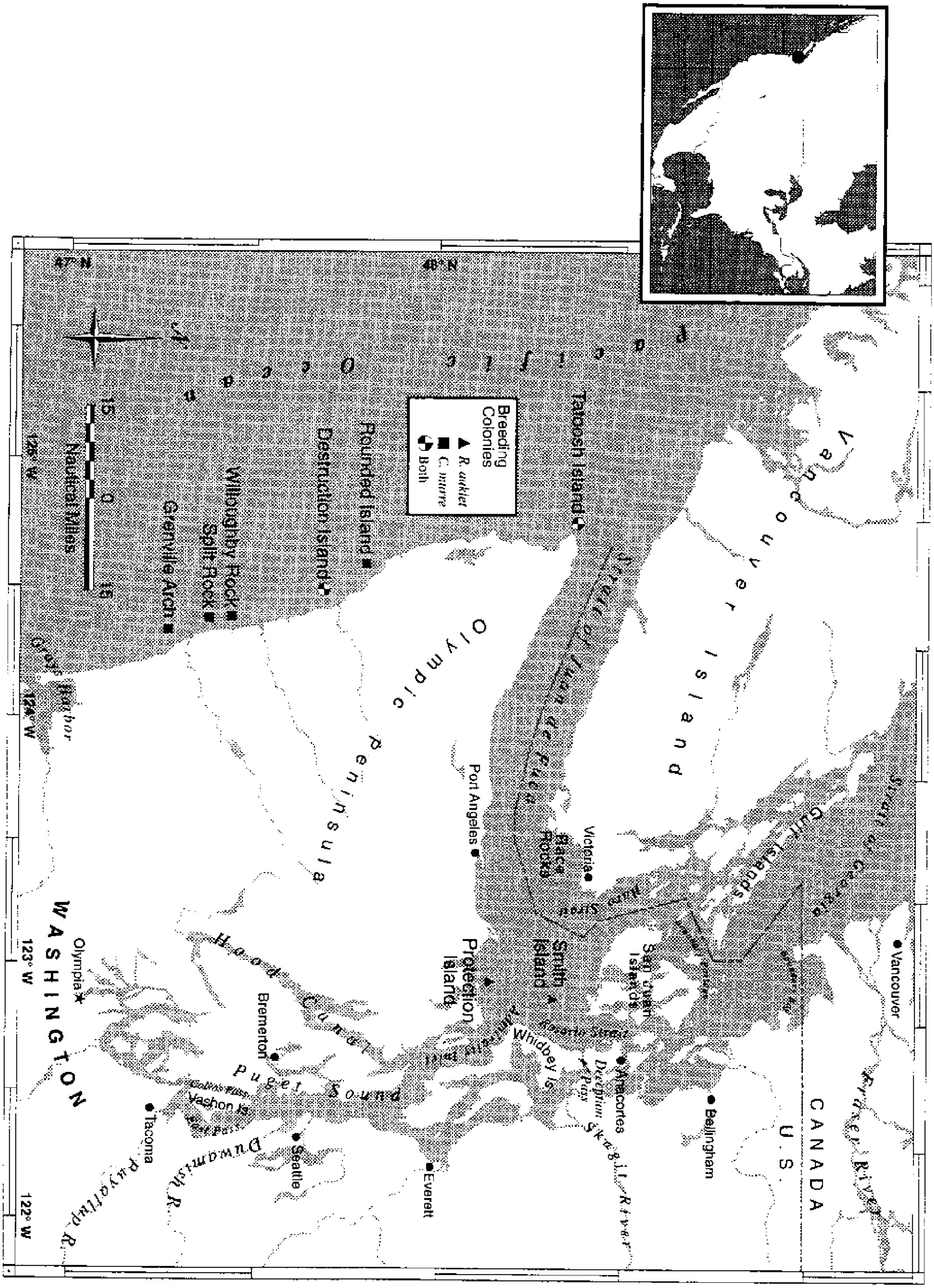

Figure 1. Seabird Breeding Colonies. Common murre and rhinoceros auklet breeding colony locations in Washington.

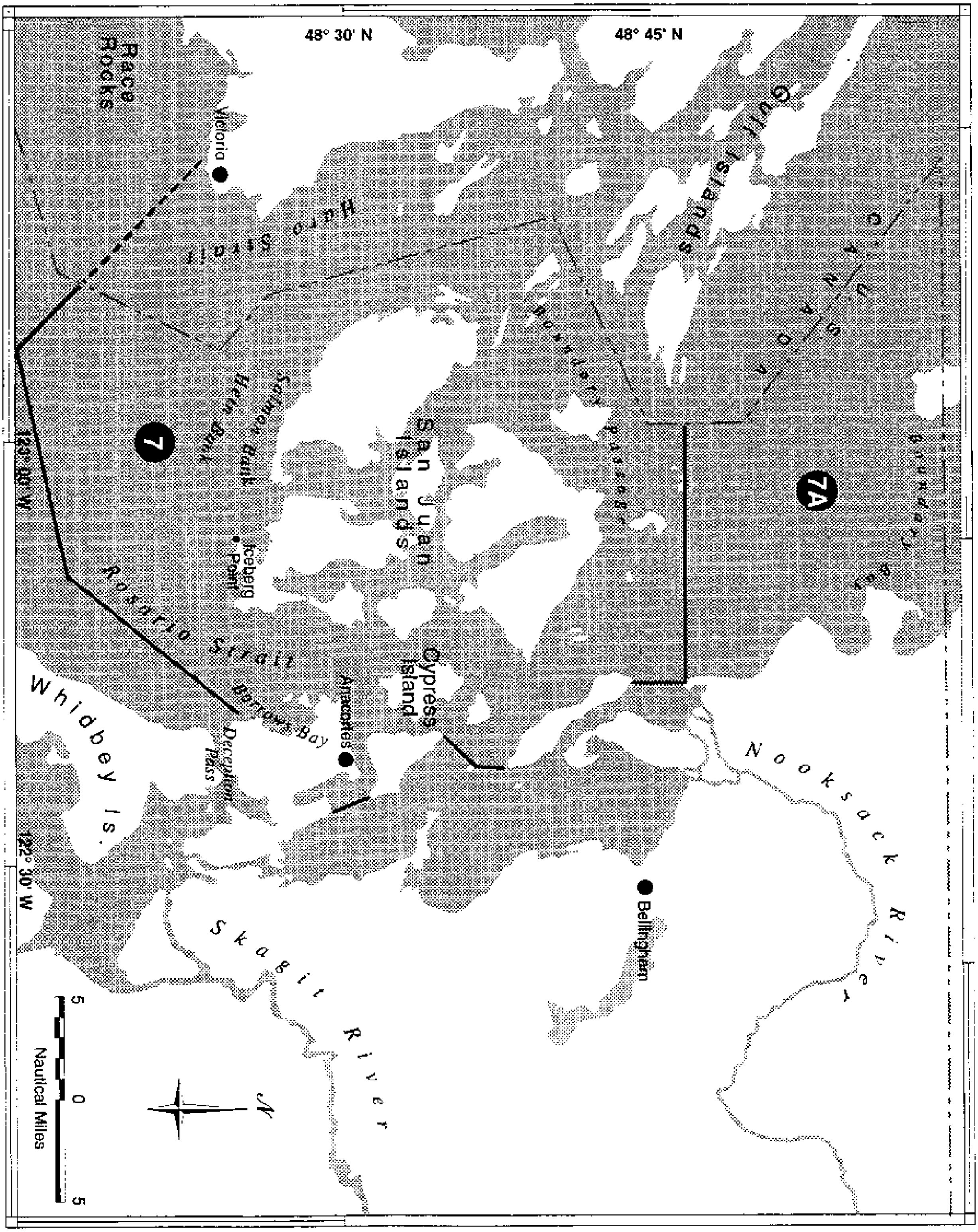

Figure 2. Fraser River Sockeye Study Area. Management Areas 7 and 7A, north Puget Sound, Wash.

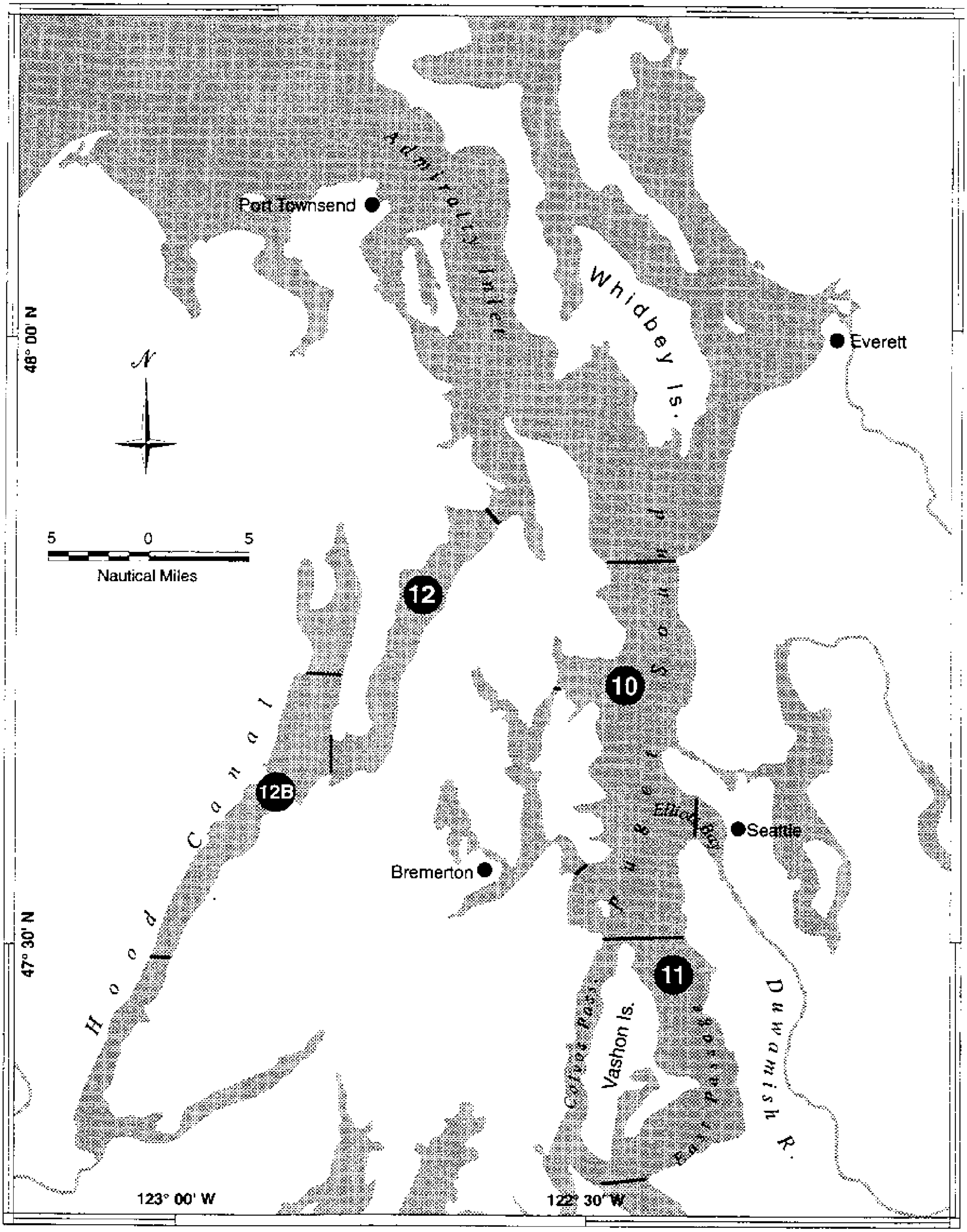

Figure 3. Fall Chum Study Area. Management Areas 10 and 12, south Puget Sound, Wash.

whereas Smith Island (1,200 birds) and Destruction Island (26,000 birds) populations appear relatively stable (Manuwal et al., 1979, and U. Wilson, 1997, pers. comm.). Protection and Smith Island auklet chicks fledge from late July to early September with 75% fledged in most years by mid-August (U. Wilson, 1997, pers. comm.). This peak fledging period overlaps peak sockeye fishing activity in the north Puget Sound sockeye gillnet fisheries in most years. The effect of Puget Sound gillnet fisheries on rhinoceros auklet breeding populations is poorly understood.

Puget Sound commercial salmon resources are allocated among treaty and non-treaty sectors by gear type (purse seine, gillnet and reef net) and are managed by a complex mix of agreements and treaties. The Area 7/7A sockeye and the Area 10/12 chum fisheries (Figures 2 and 3) are the largest and most important commercial salmon drift gillnet fisheries in Puget Sound

The Fraser River sockeye salmon fishery occurs in Puget Sound from early July to early September, but exact timing varies annually depending on the strength of more than twenty individual runs of sockeye salmon and, in odd-numbered years, sockeye and pink salmon (*O. gorbuscha*). The number of fish available to Puget Sound fisheries varies based on the size of the total run, the size of individual runs, allocations, and the diversion rate—the ratio of fish returning to the Fraser River via the Juan De Fuca Strait and Puget Sound versus Johnstone Strait. In most years, the Fraser River sockeye fishery is managed by the United States and Canada under the Pacific Salmon Treaty (PSC, 1996). In some years, such as 1994, 1995 and possibly 1997, negotiations between the two countries are contentious and management of the fishery can default to the individual countries. In this case, management relies on escapement data from Pacific Salmon Commission staff. Under the Treaty, the Fraser River Panel is responsible for in-season management of Fraser River sockeye and pink fisheries from Vancouver Island south. Panel decision priorities are to achieve gross salmon escapement, international and domestic allocations, and to address concerns for other salmon species and stocks (PSC, 1996). The panel modifies the fishing times stated in the management plan based on real time data from commercial and test fisheries and Fraser River escapement monitoring programs to allow for unexpected developments. At present, seabird bycatch reduction is not a priority in these decisions.

The chum salmon fishery is managed by the WDFW and individual treaty tribes under a co-management system. The chum season occurs typically from mid to late October through late November. The bulk of fishing occurs in south Puget Sound in Areas 10 and 12 (Figure 3) and targets wild and hatchery fish produced within Puget Sound watersheds. Non-treaty gillnet openings in both the sockeye and chum fisheries have been traditionally scheduled from dusk to dawn to reduce gear conflicts with the daylight-dependent purse seine fleet. WDFW has taken a number of actions in its management of the non-treaty gillnet fleet to reduce the bycatch of marbled murrelets and alcids in general, beginning in 1994. These actions included implementing area closures to protect marbled murrelets, restricting gillnet fishing to primarily daylight hours, and requiring gear research (T. Scott, 1997, pers. comm.). "Treaty Indian fisheries managers implemented seabird surveys to identify high risk areas and subarea closures beginning in 1995 to protect marbled murrelets in waters adjacent to the San Juan Islands. However, because the jurisdiction of the Migratory Bird Treaty Act with regard to treaty rights is not established and no specific conservation need has been demonstrated for other alcid species in northwest Washington, the tribes have not yet implemented measures to reduce gillnet bycatch of other species" (W. Beattie, NWIFC, 1997, pers. comm.).

Drift gillnets used in Washington commercial salmon fisheries are made from single or multi-strand monofilament nylon (approximately 0.5 mm in diameter). Monofilament is effective at catching fish because it is virtually invisible underwater. Mesh size is regulated by state law and varies with the species being targeted: sockeye drift nets use 5 to 6 in. (127 to 152 mm) mesh; chum nets use a minimum mesh size of 6.25 in. (159 mm). In both fisheries, non-treaty nets are limited to a maximum length of 1,800 feet (549 m). Most sockeye nets are 200 meshes deep (60 ft or 18.3 m) and chum nets are about 180 meshes deep (66 ft or 20 m). When deployed or "set" the net remains attached to the vessel throughout the set, about two hours.

In 1994 under the MBTA, the U.S. Attorney for the Western District of Washington required the non-treaty fishing industry as represented by the Puget Sound Gillnetters' Association (PSGA) to establish a five-year plan to reduce seabird entanglements in Puget Sound gillnet fisheries (T. Zimmerman, 1996, pers. comm.). The principal component of the plan was to initiate research on gear modifications that might reduce seabird bycatch. Without gear research, the most productive fishing area (Area 7) would have been closed to non-treaty gillnets beginning in 1994. Although seabird bycatch has been documented in coastal gillnet fisheries in California (Takekawa et al., 1990, Wild, 1990), British Columbia (Carter and Sealy, 1984), and Alaska (Wynne et al., 1991 and 1992), as well as many coastal gillnet fisheries in locations throughout the world (Christensen and Lear, 1977, Piatt et al., 1984, Oldén et al., 1985, Strann et al., 1991, Dunn, 1994, Stempniewicz, 1994), no research specifically aimed at reducing seabird bycatch by modifying fishing gear has been published.

In the Japanese high seas drift gillnet fishery for flying squid *(Ommastrephes bartrami)*, Hayase and Yatsu (1993) found that seabird entanglements were significantly lower in nets submerged two meters below the surface as compared to surface nets. However, fishing efficiency of subsurface nets was greatly compromised. Acoustic alerts (pingers) have been used successfully to reduce bycatch of harbor porpoise in set gillnets (Kraus et al., 1995, Gearin et al., 1996) and humpback whales in fish traps (Lien et al., 1992) without reducing the catch rate of the targeted fish species. These devices emit a low-frequency, low-intensity sound designed to alert marine mammals to the presence of a gillnet, rather than harassing them. The actual mechanism by which pingers reduce bycatch is poorly understood. The potential use of pinger technology to reduce seabird bycatch is unknown.

For gillnet modifications to be successful they must specifically address alcid biology. Both common murres and rhinoceros auklets are aggressive diving birds with great underwater agility and speed (Harrison, 1983). Both species, especially murres, aggregate in large flocks on the surface of the water. Common murres can dive to 180 meters (or eight times the depth of Puget Sound drift gillnets) and routinely dive for periods exceeding one minute (Piatt and Nettleship, 1985; Nettleship and Birkhead, 1985). Rhinoceros auklets tend to forage in the upper ten meters of the water column, but are capable of diving to 60 meters (Burger et al., 1993). Evidence from demersal cod fisheries in Newfoundland (Piatt and Nettleship, 1985) and demersal California halibut fisheries in California (Wild, 1990) indicates that common murre entanglements occur in nets 8 to 180 meters (26 to 590 ft) below the surface. Given these abilities and existing evidence, subsurface nets are an unlikely solution for reducing the bycatch of deep-diving alcids. Subsurface nets also are difficult and dangerous to handle due to the potential for suspension lines (connecting the surface floats to the top of the net) to tangle on the hydraulic drum as the net is re-deployed (backlash).

In 1994, in response to the required five-year seabird bycatch reduction plan and threats by WDFW to restrict the fishery to less productive areas, a cooperative research program was initiated under the auspices of Washington Sea Grant Program (WSGP) to develop and test gear modifications designed to reduce seabird bycatch. Strategies to reduce seabird bycatch were developed using the combined observations of PSGA fishers, fishing gear retailers, WSGP and WDFW. Participants agreed that gillnet corklines can form a barrier to surface swimming alcids—the birds tend to hesitate at the corkline, are reluctant to pass over or around it and sometimes become entangled as they attempt to dive below it. Several fishers indicated that they are least able to avoid aggregations of birds when they deployed the net in the dark and sometimes found at sunrise that they were surrounded by birds leading to increased entanglements. They also suggested that seabird numbers and perhaps activity levels were greatest near sunrise.

Based on previous research and input from individual fishermen, research to reduce seabird bycatch focused on modifying nets using visual barriers and fishing the nets at different times of day. Assuming that alcids rely on vision, fishers suggested modifying nets with visual barriers which incorporate highly visible netting into the upper portions of a traditional monofilament net. We hypothesized that birds could readily sense the visual barrier below the corkline and that most would opt not to dive beneath. We also assumed salmon would follow horizontally or vertically along the visual barrier and most would dive into the relatively invisible monofilament netting below, thus visual barriers would have little effect on fishing efficiency. Based on these ideas, two assumptions were key to our subsequent approach: (1) most alcids became entangled in drift gillnets when diving to pass under the corkline or while foraging and (2) more birds are entangled near sunrise than at other times of day.

Beginning with a pilot study in the 1994 sockeye fishery, Melvin (1995) compared several gear alternatives, including multifilament nets and monofilament nets with visual barriers, to a monofilament control. Results indicated that monofilament nets with visual barriers had the greatest potential as an alternative gear; however, results were not conclusive because of the limited scope and resources of the research. In 1995, Melvin and Conquest (1996) tested visual barriers at two depths, 20 and 50 meshes, and found that seabird bycatch rates and salmon catch rates decreased significantly as the depth of the visual barrier increased from the surface. Alcid entanglement rates were 43% to 93% less respectively, and sockeye salmon catch rates 8% to 36% less than with traditional nets. They also found that alcid entanglement rates were greatest near sunrise and that salmon catch rates varied little by time-of-day, but neither of these differences was statistically significant.

This report summarizes the results of our final year of research developing fishing gear modifications and fishery practices to reduce seabird bycatch in the Puget Sound drift gillnet fisheries. Specifically, our goal was to develop methods that eliminate or significantly reduce the incidental capture of seabirds in salmon gillnet fisheries without significantly reducing the fishing efficiency of the nets. Our objective was to compare seabird bycatch rates and salmon catch rates among experimental gillnets and traditional monofilament drift gillnets, and among three time-of-day categories.

This report provides a detailed data summary of (1) observations of seabirds and marine mammals near nets during fishing activities and from seabird transects on the fishing grounds; (2) comparisons of catch rates of salmon and entanglement rates of seabirds and marine mammal by gear type, time of day, and location; (3) comparisons of several management scenarios and their effect on seabird bycatch in these fisheries; and (4) recommendations for management. This work was funded by a grant from the Saltonstall - Kennedy Fisheries Development Program of the National Marine Fisheries Service and by Washington Sea Grant Program.

METHODS

We compared entanglement rates of seabirds and marine mammals and catch rates of salmon among up to three experimental gear treatments and a control (nylon monofilament netting) and among three time-of-day categories in two Washington non-treaty salmon fisheries: the 1996 sockeye fishery in Management Area 7, the San Juan Islands vicinity of north Puget Sound, and the 1995 fall chum fishery in Management Area 10, south Puget Sound (Figures 2 and 3). We have emphasized research in the sockeye fishery because the scope of activities and seabird interactions were greater than in the chum fishery.

Experimental Gear Treatments

Experimental nets incorporated either visual or acoustic alerts into traditional nylon monofilament gear. In early 1996, we developed specifications for a seabird pinger using the generic audiogram of avian species (Dooling, 1980) and behavioral observations. We speculated that a pinger-generated acoustic field might serve to alert birds of a possible hazard and provoke a cautionary or avoidance response. The frequency selected was above the hearing frequency of salmonids (500 Hz, A. Popper, 1996, pers comm.).

The following are the specifications for the control and experimental nets compared in the 1996 sockeye and 1995 chum fisheries. Specifications differ between the two fisheries because sockeye nets use smaller netting than chum nets (5-inch mesh vs. 6.25-inch mesh) and because experimental chum nets were a composite of two treatments and a control in a single 1,800 foot net.

1996 Sockeye Fishery: Each experimental gillnet was made of 5-inch (127 mm) mesh netting hung even and was 200 meshes deep (approximately 60 ft or 18.3 m) by 1,800 feet (549 m) long. All monofilament netting was high strength #8, triple knot, shade green (shade M4 Momoi or matched equivalent) netting. Two each of the following four experimental gillnet types were built and compared (Figure 4):

- Mono (Control): a 5-inch (127 mm) mesh nylon monofilament net typically used in the sockeye fishery.
- 20 Mesh: a 200 mesh nylon monofilament net with the upper 20 meshes replaced with 20 meshes of 5-inch mesh, white #18 multifilament nylon seine twine (210d/48) type netting (leaving 180 meshes of monofilament in the lower portion of the net). This configuration makes the upper six feet (1.8 m) of the net highly visible.
- 50 Mesh: a 200 mesh nylon monofilament net with the upper 50 meshes replaced with 50 meshes of 5-inch mesh, white #18 multifilament nylon seine twine (210d/48) type netting (leaving 150 meshes of monofilament in the lower portion of the net). This configuration makes the upper 15 feet (4.6 m) of the net highly visible.
- Pinger: a nylon monofilament control net with acoustic pingers clipped to the corkline every 150 feet (50 m), including each end of the net, for a total of 13 pingers per net. Pingers were designed to emit a 1.5 kHz (+/- 1 kHz) frequency signal with a pulse width of 300 ms (+/- 10%) every four seconds (+/- 10%) at a minimum intensity of 120 dB re. 1 micro Pascal or 35 to 40 dB above background noise levels. Field measurements confirmed that pingers produced a 2.2 kHz signal at 37 dB re 1 micro Pascal at the source and 9 dB 1 micro Pascal at 75 ft (23 m) from the source (Ken Neltmore, pers. comm.).

1995 Chum Fishery: Two gillnet modifications were compared to a control of traditional monofilament netting. Three experimental gillnets were constructed with all three gear treatments included in each net. Each gear treatment unit within each net, referred to as a shackle, was 600 feet (183 m) long, making each experimental net 1,800 feet (549 m) long (Figure 4). Nets were 180 meshes deep. The shackles in each net were sequenced randomly. All nylon monofilament netting was high strength, #12, double knot, shade green (shade M4 Momoi or matched equivalent) netting. The three gear treatments tested consisted of the following:

- Mono (control): a 6.25-inch (159 mm) nylon monofilament net typically used in the chum fishery.
- 20 Mesh: a 180 mesh nylon monofilament net with the upper 20 meshes replaced with 20 meshes of 6.25-inch (159 mm) mesh, white #18 multifilament seine twine (210d/48) type netting (leaving 160 meshes of 6.25-inch monofilament in the lower portion of the net). This configuration makes the upper 7 feet (2.1 m) of the net highly visible.
- 40 Mesh: a 180 mesh nylon monofilament net with the upper 40 meshes replaced with 40 meshes of 6.25-inch (159 mm) mesh, white #18 multifilament seine twine (210d/48) type netting (the lower 140 meshes of 6.25-inch monofilament). This configuration makes the upper 15 feet (4.6 m) of the net highly visible.

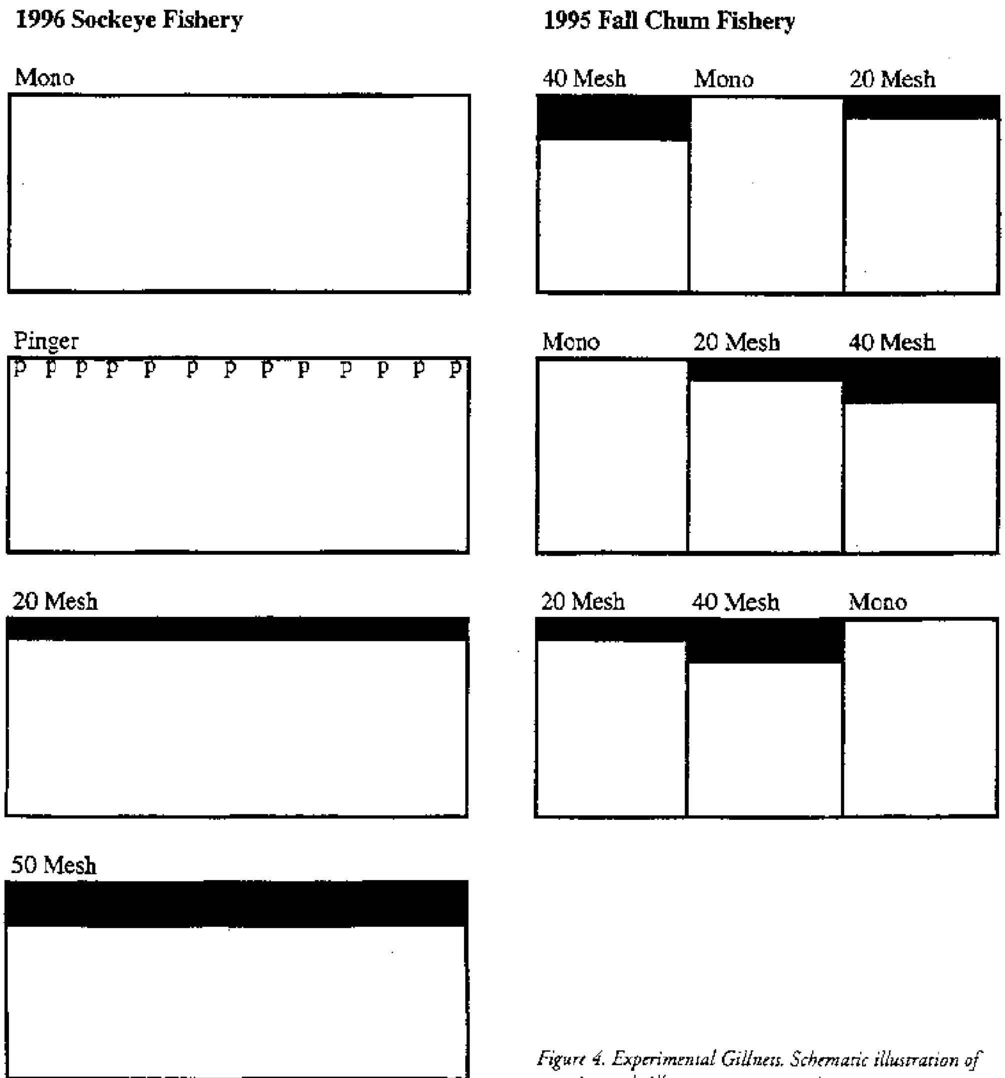

Figure 4. Experimental Gillnets. Schematic illustration of experimental gillnets.

Time of Day Categories

In both fisheries, fishing time was divided into three categories: morning change of light (AM COL), daytime, and evening change of light (PM COL). Change of light was arbitrarily defined as a three-hour period 1.5 hours before and after sunrise or sunset. Daytime was defined as the daylight period from the morning change of light to the evening change of light. Nets were not fished at night.

Fishing Protocol

Fishing vessels were contracted by the Washington Department of Fish and Wildlife (WDFW) through the Puget Sound Gillnetters' Association (PSGA) to fish experimental nets in a Washington State Test Fishery under our research protocol. The Test Fishery arrangement provided two critical elements that allowed this study to occur: (1) fishers were compensated for their fishing time with revenue derived from the sale of their fish, and (2) the experimental net research program was given the flexibility to fish outside very unpredictable commercial fishery openings.

1996 Sockeye Fishery: Eight fishing vessels were contracted and assigned to one of two teams of four. One fisher in each team was designated as team leader and coordinated the fishing activities of his team. Each vessel within a team fished one of the four experimental net types listed above. To minimize the possible effect of individual fishing skill on specific gear catch and entanglement rates, every week each vessel within a team switched nets with another team member and fished that net for the entire week. To minimize location effects, team members fished within sight of each other (in general, within a two-mile radius) in a location selected by the team leader. Fishers were asked to fish aggressively near birds. They were asked not to harass birds away from the net or chase fish into the net with the vessel (run the net).

The experimental nets were fished from 28 July to 29 August 1996. All vessels were based in the Port of Anacortes and fished exclusively in Management Area 7 (Figure 2) where high concentrations of seabirds and sockeye salmon overlap. Each team of four vessels made seventeen trips of approximately five two-hour sets per vessel per trip. All trips included one PM COL, one AM COL, and three daytime sets. Vessels anchored up after the evening change-of-light set and were back on the grounds for the morning change-of-light set. Team departures were offset so that vessels were on the water through all daylight conditions with minimum bias toward early or late day and, with the exception of four of the thirty-three days of the study, a team was on the water at all times.

1995 Chum Fishery: Three vessels were contracted as above and fished experimental nets two to three times per week, twelve to fourteen hours per day, over a three-week period from 25 October to 11 November. All vessels were based at Shilshole Marina in Seattle, and experimental nets were fished in WDFW management Area 10, from Colvos Pass to Kingston (Figure 3). Vessel operators targeted five two-hour sets per fishing trip.

Observations

Trained observers were aboard each fishing vessel during experimental fishing. They recorded seabird and marine mammal entanglements and fish catch by species and gear type for each set, as well as seabird and marine mammal abundance by species near the net throughout the set. The location of seabirds and marine mammals entangled in the net was recorded to the nearest 10 meshes. Entangled seabirds were labeled with a unique number and information on date, time, vessel, gear, location and species, and immediately stored on ice for later necropsy.

The location at which fish were caught in the net was recorded as being in the upper or lower net. In the sockeye fishery, the upper net was the upper 50 meshes for all but the 20 Mesh nets, which were the upper 20 meshes. In the chum fishery, the upper net was the upper 40 meshes of the Mono and 40 Mesh shackles, and the upper 20 meshes of the 20 Mesh shackles. Lower net was the remaining area of the net. Areas in the 20 Mesh nets were defined differently because of the difficulty of reliably estimating fish catch in the 30 meshes that lie between the visual barrier and the imaginary 50 mesh line. Salmon damaged by seals and not acceptable by a commercial fish buyer were enumerated and recorded separately. Physical and logistic variables (time, tide, depth, date, visibility, cloud cover, weather, sea state, distance from shore, current speed, and location) were recorded for each set.The number of alcids and marine mammals observed by species was recorded in two zones around the net during each set (Figure 5). Encounters were defined as the total number of alcids and marine mammals by species in an area 10 meters on either side of the corkline. Sightings were defined as the maximum number of alcids and marine mammals in an area between 10 and 100 meters on either side of the corkline (outside the encounter zone) of the net. Seabird sightings per set is a rigorous estimate of seabird abundance in the areas we fished. To investigate environ-

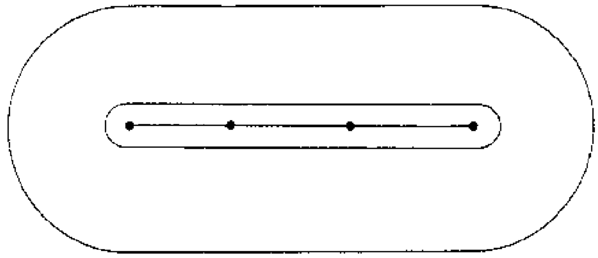

Figure 5. Seabird Observation Zones. Schematic illustration of seabird observation zones around gillnets. Encounter zone is within 10 m of the net; sighting zone is from 10 to 100 m around the net.

mental conditions that might influence seabird entanglements, observers recorded whether individual birds were on the leeward or windward side of the corkline or on the up or down side of the prevailing tidal current for both sightings and encounters. They also recorded fisher behaviors which may have influenced entanglement rates, such as running the vessel along the net to harass fish into the net. Observers were debriefed and data sheets reviewed and edited by project coordinators immediately after each trip.

Seabird Transects (Sockeye Test Fishery only)

In addition to enumerating and recording seabird and marine mammal abundance during each set, each vessel team ran a ten- to twenty-minute, fixed-speed (8 to 10 knots) seabird transect at one of five established locations to and from the fishing grounds each trip. Transects varied from 2.5 to 5 nm in length. Transect locations were as follows: Salmon Bank-Hein Bank area, southwest San Juan Island (a triangle beginning at Eagle Point, San Juan Island, on a line to the Salmon Banks navigational buoy, from the Salmon Banks navigation buoy to a point 5 nm along a line to the Hein Bank navigational buoy, and from that point to Eagle Point); Iceberg area, south Lopez Island (along a 3.5 nm line running from the Point Colville navigational buoy due west to off Iceberg Point); lower west Rosario Strait (a 3.5 nm line from the navigational buoy off Cape St. Mary, Lopez Island to Bird Rocks); Boundary Bay-Deception Pass Area or the Bluffs (a 4 nm line due north from off Deception Pass inside of Lawson Reef to 0.25 nm off Biz Point, Fidalgo Island, to the northern tip of Young Island in Burrows Bay); and west Cypress Island (a 2.5 nm line running from the navigational buoy south of Reef Point, Cypress Island to Tide Point, Cypress Island). The number of alcids was recorded by species in an area within 100 meters of the vessel in a 90 degree arc from a line straight off the bow to a line perpendicular to the side of the vessel. Observations were made on the side of the vessel with the most favorable viewing conditions. Observers recorded date, vessel speed, visibility, Beaufort sea state, start time and location, and end time and location for each transect.

Statistical Analyses

The distributions of entanglement rates of seabirds per set and catch rates of sockeye and chum salmon per set do not follow the normal distribution, even after transformation. Chum salmon was the exception; a square root transform was used to conform data to a normal distribution. All data sets were analyzed using GLIM software for general linear models (Crawley, 1993).

General linear models allow the user to run standard analyses of variance and regression analyses using normal and non-normal errors. The Poisson error term and log-linear model we used allow for the large number of zeros characteristic of this data set. The log linear model allows partitioning the variation in the outcome (response) variable (sockeye catch or bird entanglements per set) into systematic or known (gear treatment, time of day, location, sea state, trip; etc.) and random or unknown (the error term) sources of variation. This method yields a more realistic characterization of the error term. The log-linear model is then used to predict the natural log of the outcome variable. The actual value of the outcome variable used in comparative analyses was obtained by exponentiating back from the log-linear predicted value. The estimated variance term was obtained in a similar way using the delta-method (Seber, 1982). (The log-linear model yields the variance for the log of the fitted outcome variable.) Using the delta method, the variance of the exponentiated fitted value is: (variance for the log of the predicted value) x (fitted value ^{2}).

Comparisons of sockeye catch and bird entanglement rates per set were made among gear treatments, time of day and location factors using a factorial multiple comparison technique similar to analysis of variance (ANOVA) with covariates, but with a Bonferroni correction (Miller, 1966). These are approximate Z-tests with Bonferroni-adjusted alpha levels obtained by taking the alpha level (0.05) divided by the number of comparisons made in that particular set of comparisons. The null hypotheses (Ho's) tested in these comparisons were:

Entanglement rates of common murres and rhinoceros auklets per set and catch rates of sockeye or chum salmon per set are equal in all gear types, at all times of day, and in all locations.

The number of sets required to compare seabird entanglements and fish catches among factors was determined based on our 1995 work (Melvin and Conquest, 1996), power analyses, and financial and logistical constraints. In the sockeye fishery we estimated that a minimum of 150 sets would be required per gear treatment, or 600 sets total to detect significant differences in rates of bird entanglements among factors. In the chum fishery where measuring fish catch rates among gear types was the primary objective, we estimated that a minimum of 100 total sets would be necessary to detect significant differences. Sets that did not conform to study protocols (net not fully deployed, less than one hour in duration, or not made within change-of-light categories) were eliminated prior to statistical analyses. In the sockeye test fishery 44 sets were deleted from a total of 686 sets yielding 642 for analyses; in the chum test fishery 4 sets were eliminated from a total of 107 .

Seabird Age and Necropsies

Each seabird killed was examined for molt stage, measured for weight (g) and culmen length (cm), and dissected to determine sex, bursa size and condition, and gonad condition. Birds were sexed by visual inspection of the gonad.

We aged birds using a combination of characters: cloacal bursa condition, plumage characteristics, female gonad condition, and culmen length. Cloacal bursa condition was classified into one of three categories adapted from Broughton (1994): as either large and fleshy, thin-walled, or membranous/absent. Plumage was classified into one of four categories, adapted from Baker (1993): winter (juvenile/first basic plumage), pre-molt breeding plumage (all old feathers), molting breeding plumage, or post-molt (all new winter plumage). Female gonad condition was classified into four categories: translucent, with numerous follicles, enlarged follicles/non-dilated oviduct, and enlarged follicles/dilated oviduct.

Common murres and rhinoceros auklets were aged into three categories: young of the year (YOY), pre-breeders, and breeders. Common murres were aged by combining bursa-based criteria (Gaston and Bradstreet, 1993), and plumage- and culmen-length-based criteria (Baker, 1993). In the sockeye fishery when YOY murres were a maximum of 1.5 to 2 months old, YOY birds were those that had a large fleshy bursa, juvenile/first basic plumage, and a culmen shorter than 4.1 cm. Pre-breeders were those with a fleshy or thin-walled bursa, and breeding plumage. Breeders were those with a membranous or absent bursa and breeding plumage. Only one female pre-breeder had a gonad without follicular development (translucent gonad), which is typical of YOY birds, and all but five breeders had enlarged follicles, typical of breeder females. In each of these cases, these animals were in the upper ranges of weight and culmen length for their categories.

Rhinoceros auklets were aged by combining bursa-based criteria (Gaston and Bradstreet, 1993), culmen-length-based criteria (primarily for males), and female gonad condition. Because YOY birds fledge from breeding sites within 4 to 17 nm of the fishing grounds (Protection and Smith Islands, Wash.) and can be no more than 3 months old when entangled, culmen length is useful to separate them from pre-breeders (external characteristics such as bill and iris color and presence or absence of head plumes were not recorded). Given a mean culmen length of 2.6 cm (range of 2.3 to 2.8 cm; U. Wilson, 1997, pers. comm.) for fledgling rhinoceros auklets (approximately 7 weeks old) at Protection Island, Wash., we defined YOY auklets as those with a large fleshy bursa and a culmen less than 3.0 cm. Pre-breeders were those with a fleshy or thin-walled bursa, with old or pre-molt breeding plumage or a culmen longer than 3.0 cm (in one case a male with old breeding plumage had a culmen 2.9 cm long and was aged as a pre-breeder). Breeders were those with a membranous bursa or no bursa. Only one female pre-breeder was devoid of follicular development (translucent gonad), and all female breeders had enlarged follicles. As with the common murre females, this one atypical pre-breeder with a translucent gonad was in the upper range of weight and culmen length for female pre-breeders.

During the fall chum fishery when YOY murres can be 4.5 to 6.5 months old and rhinoceros auklets YOY can be 5 months old, we were unable to distinguish YOY birds from pre-breeders. Entangled birds with fleshy bursae and new winter plumage were categorized as YOY/pre-breeders.

RESULTS

GENERAL TRENDS

1996 Sockeye Fishery

Fishing Effort/Catch

We caught 13,151 sockeye salmon in 642 sets in seventeen fishing trips from 28 July to 29 August (Appendix 1). This level of effort exceeded our minimum effort target of 600 sets by 7%. The fishery was highly selective for sockeye salmon relative to other salmon species with sockeye accounting for 98.4% of the salmon catch. Relatively few king salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), Atlantic salmon (*Salmo salar*) or steelhead (*O. mykiss*) were caught—collectively they accounted for 1.2% of the catch; however, 8,852 dogfish (*Squalus acanthias*) were captured and discarded. Salmon were caught in 71.2% of the sets made. Salmon catch/set was relatively high in trips within the first three weeks of the season (through trip 10) ranging from 8.4 to 93.3 sockeye/set, and relatively low the last two weeks of the season, ranging from 2.0 to 5.0 sockeye/set (Figure 6).

Seabird Interactions

Alcids were observed within 100 meters of the net (sightings) during most sets (75%), and within 10 meters of the net (encounters) during slightly fewer sets (59%; Appendix 2). Common murres were the most

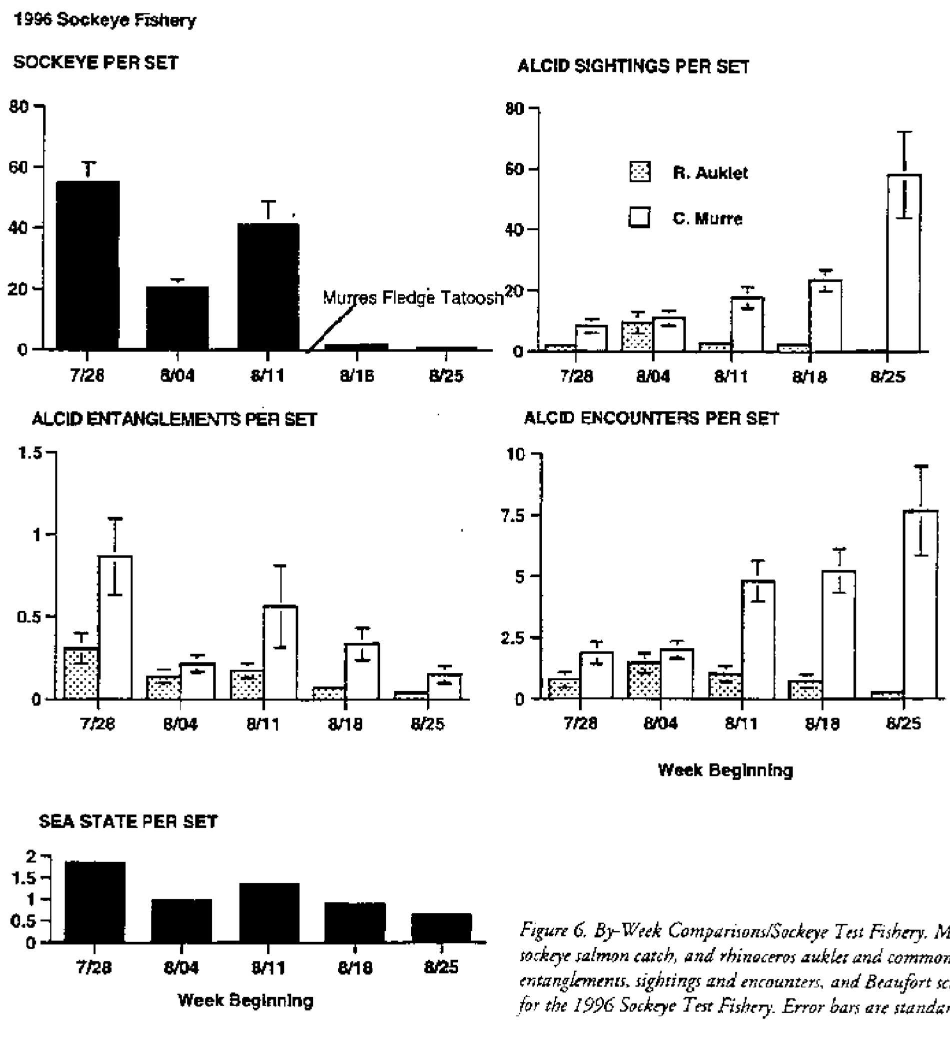

Figure 6. By-Week Comparisons/Sockeye Test Fishery. Mean rates per set of sockeye salmon catch, and rhinoceros auklet and common murre entanglements, sightings and encounters, and Beaufort scale sea state by week for the 1996 Sockeye Test Fishery. Error bars are standard errors.

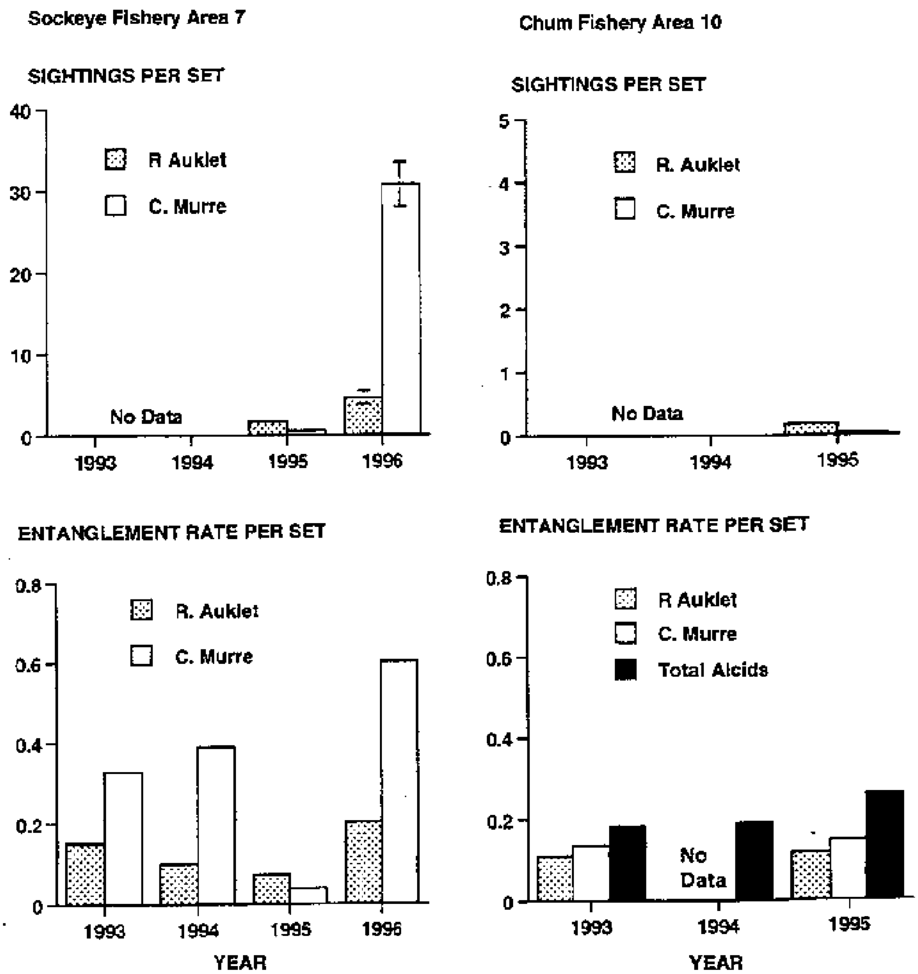

Figure 7. Inter-Year Comparisons. Mean rate per set of rhinoceros auklet and common murre sightings and entanglements by year for the 1996 Area 7 Sockeye and the 1995 Area 10 Chum Non-Treaty Fisheries. 1995 and 1996 sockeye entanglement rates and 1995 chum entanglement rates are for monofilament nets only. (Data from Pierce et. al., 1994, Erstad et. al., 1994, Erstad et. al., 1996, Melvin and Conquest, 1996). Error bars are standard errors.

Year	Sightings (rates per set)		Encounters		Entanglements (monofilament)		Sea State	Weather
	Murre	Auklet	Murre	Auklet	Murre	Auklet		
1996 Sockeye	30.70	4.50	4.40	0.85	0.601	0.202	1.10	1.06
1995 Chum	0.10	0.51	0.16	0.79	0.147	0.117	2.12	1.75
1995 Sockeye	0.53	1.64	0.36*	0.411*	0.039	0.072	1.48	1.63

* 3 times birds per shackle set (overestimate)

Table 1. Inter-Year Comparisons. Mean rate per set of common murre and rhinoceros auklet sightings, encounters and entanglements and mean Beaufort sea state and weather for the 1996 Sockeye, the 1995 Chum and the 1995 Sockeye Test Fisheries (Melvin and Conquest, 1996).

abundant bird in the study area, accounting for 83% of the alcids sighted at an average of 30.7 sightings/set, a rate 59 times greater than what we observed in 1995 test sockeye fishery (0.53 sightings/set; Table 1 and Figure 7). Rhinoceros auklets made up almost all other alcid sightings and were almost three times more abundant in 1996 (4.5 sightings/set) than 1995 (1.6 sightings/set).

Murres made up 81% of alcid encounters at an average rate of 4.4 murres/set (Table 1 and Appendix 2). rhinoceros auklets made up most other alcid encounters at a rate of 0.9 auklets/set. Pigeon guillemots were rare, averaging 0.12 sightings/set and 0.04 encounters/set. Marbled murrelets were extremely rare, averaging 0.03

1996 Sockeye Fishery								
Age/Measurements	Common Murre				Rhinoceros Auklet			
	Female	Male	Total	Percent	Female	Male	Total	Percent
Young of the Year	0	0	0		19	17	36	44%
Pre-Breeders	36	35	71	29%	9	16	25	30%
Breeders	75	102	177	71%	14	7	21	26%
Unknown			3	1%			0	
Released Alive			9	3%			5	
Total	111	137	260		42	40	87	

Table 2. Alcids Entangled: Numbers and Ages/Sockeye Test Fishery. The number of common murres and rhinoceros auklets entangled in gillnets by species, age, and sex for the 1996 Sockeye Test Fishery in Area 7.

sightings/set and 0.01 encounters/set.

Common murre sightings and encounters steadily increased throughout the study period and peaked during the final week (Figure 6 and Appendix 2), approaching 100 murre sightings/set on 27 August and 12.6 murre encounters/set on 25 August. Rhinoceros auklet sightings and encounters peaked in week two (22.6 auklet sightings/set and 2.5 auklet encounters/set on 7 August) when fledging began at Protection and Smith Islands (U. Wilson, 1996, pers. comm.). Auklet sighting and encounter rates then decreased steadily through the final week of the study.

In general, entanglement rates by species reflect the pattern of sightings and encounters. A total of 349 alcids were entangled during the study: 260 common murres (75% of the total), 87 rhinoceros auklets, one pigeon guillemot, and one marbled murrelet (Table 2 and Appendix 3). Nine common murres and five rhinoceros auklets were released alive with no apparent injury. Most (71%) of the common murres entangled were breeders (58% male) and the rest were pre-breeders (1:1 sex ratio). None were YOY birds hatched in 1996 (Table 2 and Appendix 4). Almost all other alcid entanglements were rhinoceros auklets. In contrast to murres, most rhinoceros auklets entangled were YOY birds (44%); 26% were adults and 30% were pre-breeders. The sex ratio of entangled rhinoceros auklets was 1:1 overall. That a greater percentage of auklets compared to other alcids were entangled (25%) than observed in the sighting or encounter zone (12% and 16% respectively) might be explained by the predominance of recently fledged, inexperienced birds. The single pigeon guillemot (*Cepphus columba*) and marbled murrelet entanglement reflect the rarity of both species near the nets.

Both the number of sets with alcid entanglements (entanglement events) and the magnitude of alcid entanglement rates were much greater in 1996 than 1995. Alcid entanglements occurred in 25% of sets made in 1996 versus less than 2% of the sets in 1995. Murre entanglement rates in 1996 were 15 times greater than those of 1995 (0.60 murres/set vs. 0.04 murres/set); Rhinoceros auklet entanglement rates were 2.8 times higher in 1996 (0.20 auklets/set vs. 0.07 auklets/set, Table 1 and Figure 7). Because fishers were asked to fish aggressively around birds in the 1995 and 1996 experimental gear programs, possible comparisons of these entanglement rates and those of the fishery observer programs of 1993 and 1994 (Pierce et al., 1994 and Erstad et al., 1994) are limited. However, the fact that common murre and rhinoceros auklet entanglement rates from the 1993 and 1994 WDFW observer programs were intermediate relative to the 1995 and 1996 experimental gear programs (Figure 7), suggests that 1995 and 1996 represented extremes in alcid abundance in Management Area 7.

Murre entanglement rates by week showed no identifiable pattern and did not reflect the pattern of murre sightings and encounters by week; however, they correlate well with Beaufort sea state condition by week (Figure 6 and Appendix 10), suggesting that sea state may influence alcid entanglement rates. In contrast, rhinoceros auklet entanglement rates decreased as the season progressed, reflecting their decreasing abundance in the study area.

Marine Mammal Interactions

Harbor seals accounted for most marine mammal interactions with experimental gillnets. Marine mammals were in the sighting zone during more than half the sets and most (85%; Appendix 5) were harbor seals (*Phoca vitulina*) Killer whales (*Orcinus orca*), Dall's porpoise (*Phocoenoides dalli*), and harbor porpoise accounted for 9%, 4%, and 1% respectively, of the marine mammals observed in the sighting zone. Of marine mammals observed in the encounter zone of the net (62% of the sets), almost all (97%) were harbor seals feeding on salmon caught in the gillnets (Appendix 5). Killer whales and Dall's porpoise accounted for about 2% and 1% respectively, of marine

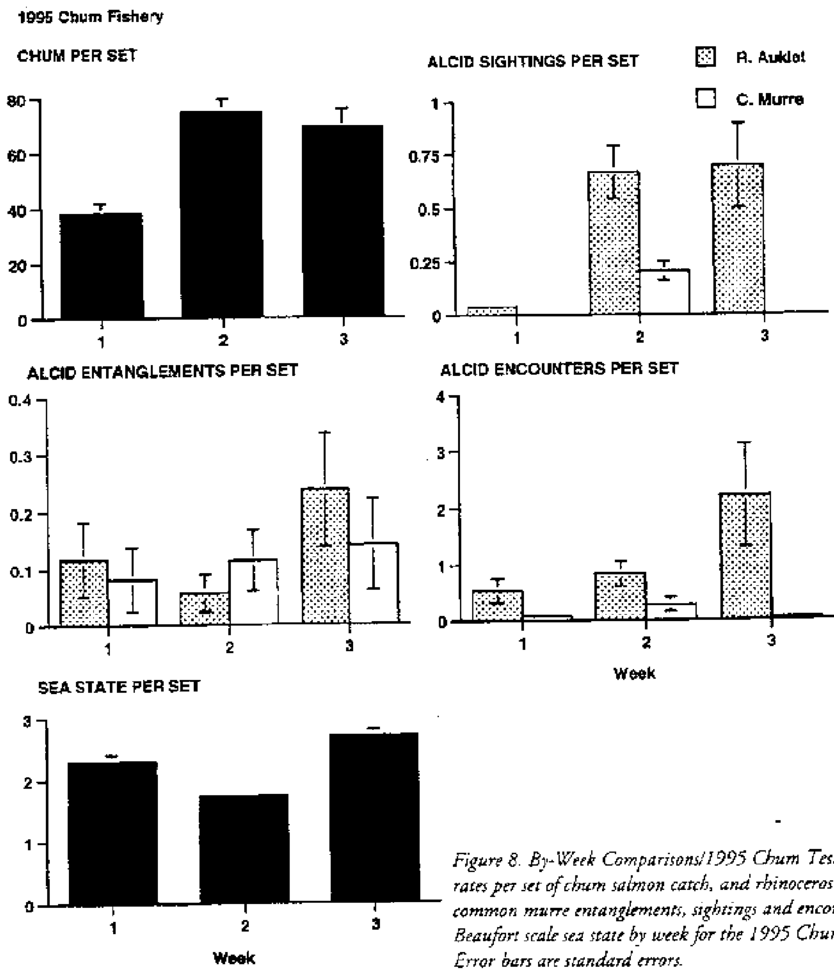

Figure 8. By-Week Comparisons/1995 Chum Test Fishery. Mean rates per set of chum salmon catch, and rhinoceros auklet and common murre entanglements, sightings and encounters, and Beaufort scale sea state by week for the 1995 Chum Test Fishery. Error bars are standard errors.

mammal encounters. Eight marine mammals were entangled in the experimental nets: three harbor seals (one was released alive with no apparent injury), three Dall's porpoise and two Harbor porpoise. All porpoise were entangled in the 50 Mesh gear treatment.

1995 Chum Fishery

Fishing Effort/Catch

We caught 6,822 chum salmon in 107 sets in eight fishing trips from 25 October to 11 November 1995 (Appendix 1). This level of effort met our minimum effort target of 100 sets. Similar to the 1996 sockeye fishery, the chum salmon fishery was highly selective for the target species with chum accounting for 99.7% of the salmon catch. Relatively few king or coho salmon were caught—collectively they accounted for 0.3% of the salmon catch; 95 dogfish were captured and discarded. Salmon were caught in all the sets we made. Salmon catch/set was relatively high for all trips, ranging from 25 to 100 chum per set and averaging 64 chum/set overall (Appendix 1, Figure 8).

Seabird Interactions

In general there were fewer alcids in the 1995 Area 10 chum fishery than in either the 1996 or 1995 sockeye fisheries in Area 7 and abundance patterns were more similar to the sockeye fishery in 1995. Few chum sets had alcids within the sighting zone (25% of sets) or encounter zone (31% of sets) of the nets (Figure 5 and Appendix 6). This result was similar to the 1995 sockeye fishery where 29% and 14% of the sets had alcid sightings and encounters, respectively (Melvin and Conquest, 1996). Rhinoceros auklets were the most abundant bird in the sighting zone, accounting for over half (53%) of the alcids sighted at an average of 0.51 auklets/set; a rate 3 times less than 1995 sockeye and 9 times less than 1996 sockeye test fisheries (Figure 7, Table 1 and Appendix 6). Unidentified murrelets, ancient murrelets and marbled murrelets collectively made up the second most abundant alcid grouping accounting for 33% of the alcids sighted in the 1995 chum test fishery (Appendix 6); murrelet species were rare in both the 1996 and 1995 sockeye test fisheries. Common murres represented only 11% of the alcids sighted and averaged 0.1 murres/set—5 times fewer than the 1995 sockeye test fishery and dramatically fewer (more than 300 times) than the 1996 sockeye test fishery. A variety of non-alcid bird species were observed in the sighting zone of the net (grebes, scoters, cormorants, and loons, Appendix 6).

More rhinoceros auklets and more common murres were observed in the encounter zone of the net (0.79 auklets/set and 0.16 murres/set) than in the sighting zone (Table 1 and Appendix 6). This result contrasts with the 1995 and 1996 sockeye fisheries which showed the opposite trend; auklet and murre sighting rates were 4 to 11 times that of encounter rates (Figure 6 and Appendix 2; Melvin and Conquest, 1996). Rhinoceros auklet encounter rates exceeded those in the 1995 sockeye fishery (0.41 auklets/set), but were similar to those the 1996 sockeye fishery (0.85 auklets/set). Murre encounter rates were less in the 1995 chum fishery than both the 1995 and 1996 sockeye fisheries, but greater than sighting rates might suggest. These data strongly suggest that aspects of the physical environment in Area 10 force increased alcid interaction with gillnets despite the relatively low abundance of alcids in the area.

Despite the variety of bird species being observed in the vicinity of experimental nets, only rhinoceros auklets (11) and common murres (12) were entangled (Table 3 and Appendix 6). Murres and auklets were entangled at rates exceeding those of the 1995 sockeye fishery by 4 times (0.15 murres/set) and 1.6 times (0.12 auklets/set; Figure 7 and Table 1). These increases may be due to a number of factors: higher encounter rates, rougher sea conditions, increased water turbidity, and dense boat traffic characteristic of this urban waterway in the fall, but actual causes are uncertain. As might be expected, murre and auklet entanglement rates were less (4 and 2 times) than those in the 1996 Area 7 sockeye fishery, reflecting the lower sighting and encounter rates of both species in the chum fishery (Figure 7 and Table 1). The weekly pattern of seabird entanglements poorly reflects encounter or sighting rates, but appear to mirror sea state conditions with entanglement rates increasing as sea state increases (Figure 8).

All birds were classified as YOY /pre-breeders (Table 3) because of limitations of the aging methodology (see methods). Females and males of both species were equally represented. Although rhinoceros auklets were about 6 times more abundant than murres in the study area, similar numbers of auklets and murres were entangled.

1995 Chum Fishery

Age/Measurements	Common Murre				Rhinoceros Auklet			
	Female	Male	Total	Percent	Female	Male	Total	Percent
YOY/Pre-Breeders	6	5	11	100%	6	6	12	100%
Breeders	0	0	0		0	0	0	
Released Alive			0				0	
Total	6	5	11		6	6	12	

Table 3. Alcids Entangled: Numbers and Ages/Chum Test Fishery. The number of common murres and rhinoceros auklets entangled in gillnets by species, age, and sex for the 1995 Chum Test Fishery in Area 10.

Marine Mammal Interactions

Sea lions accounted for most marine mammal interactions with experimental gillnets. Marine mammals were observed in the sighting zone in only 15% of sets and most were California sea lions, *Zalophus californianus*, (57%; Appendix 5); harbor seals and Dall's porpoise accounted for 33% and 10% respectively. Marine mammals were observed in the encounter zone of the net in over half the sets (50%); most were sea lions (86%) or harbor seals (13%) feeding on salmon caught in the gillnets; harbor porpoise and Dall's porpoise (1%) also were observed in the encounter zone (Appendix 5). No marine mammals were entangled in the experimental nets.

Gear Comparisons

1996 Sockeye Fishery: The entanglement rates of common murres, rhinoceros auklets and sockeye salmon varied significantly among the three experimental gears and the monofilament control ($P<0.05$); however, the

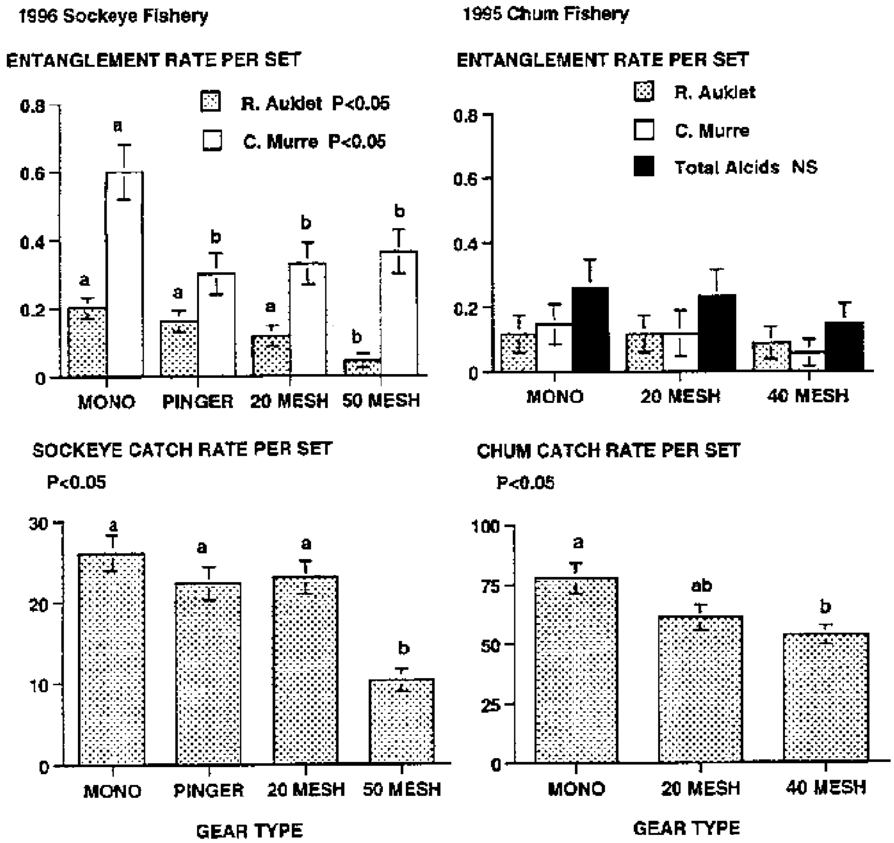

Figure 9. Gear Comparisons/Rates. Mean rate per set of rhinoceros auklet and common murre entanglements and mean salmon catch by gear type for the 1996 Sockeye and the 1995 Chum Test Fisheries. Error bars are standard errors. P values are for factorial multiple comparisons. Significant groupings from post-hoc comparisons are shown as "a" or "b".

pattern of variation among gear types was species specific (Figure 9 and Appendix 7). Significantly fewer common murres were entangled in all three experimental gears (0.30 to 0.36 murres/set) than in the monofilament control (0.60 murres/set). Rhinoceros auklets entanglement rates, though less in all experimental gears (0.04 to 0.16 auklets per set) compared to the control (0.20 auklets/set), were significantly less only in 50 Mesh nets. Pinger, 20 Mesh and 50 Mesh gears entangled all alcids at 58%, 55%, and 50% (respectively) of the monofilament control (Figure 10).

The percent of sets with entanglements was similar for Mono, Pinger and 20 Mesh nets (27% to 29%; Table 4). However, the percentage of large entanglement events (sets with greater than two birds/event) in all experimental gears was half (17% to 19%) that of the monofilament control (37%). These data suggest that the significantly reduced entanglement rates observed in the experimental nets do not result from reducing the number of entanglement events, but rather from reducing the number of birds entangled per event.

Variable	Mono	Pinger	20 Mesh	50 Mesh
No. of Sets	168	153	161	160
Total Birds	136	72	72	65
Entanglement Rate/Set	0.81	0.471	0.447	0.406
% Sets w/ Entanglements	29.2%	27.5%	26.7%	15.0%
% Entanglement Sets >2 Bird	36.7%	19.1%	18.6%	16.6%
Mean # birds/Entanglement Event	2.8	1.7	1.7	2.7
Depth Entangled (Meshes)				
Median	30	30	50	70
Mean	49	49	70	85

Table 4. Gear Comparisons/Sockeye Test Fishery. Total number of sets and birds entangled, and mean rate per set of bird entanglements, percent of sets with entanglements, percent of sets with more than two birds entangled, mean number of birds per entanglement event (set), and median and mean depth of bird entanglements by gear type for the 1996 Sockeye Test Fishery.

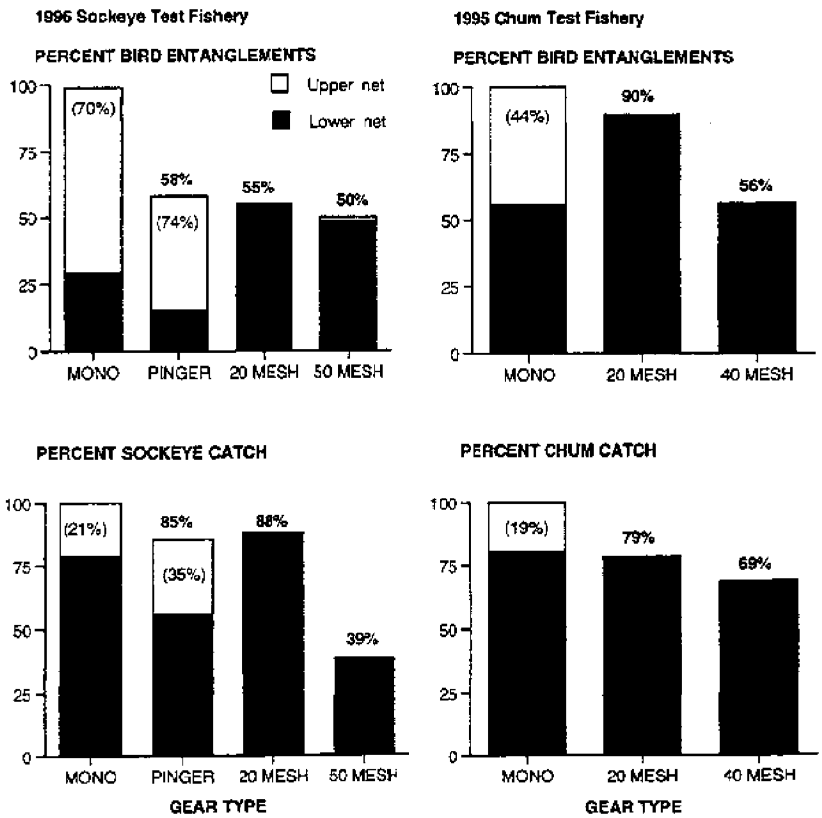

Figure 10. Gear Comparisons/Percent. Percent rate per set—relative to the monofilament control (control = 100%)—of alcid entanglements and sockeye and chum salmon catch by gear type and percent () caught in the upper net for the 1996 Sockeye and the 1995 Chum Test Fisheries. Upper net is upper 50 meshes for the Mono, Pinger and 50 Mesh sockeye treatments, upper 40 meshes for the Mono and 40 Mesh chum salmon treatments, and the upper 20 meshes of the 20 Mesh treatments.

Most seabirds were entangled within the upper 50 meshes of the mono and pinger nets (70% and 74%, respectively; Figure 10), at a median depth of 30 meshes in both gears (Table 4). Seabirds were entangled progressively deeper in 20 Mesh and 50 Mesh nets at median depths of 50 and 70 meshes respectively. No seabirds were caught in the white meshes of the 20 Mesh gear, and only two birds were entangled in the white meshes of the 50 Mesh gear. These data strongly suggest that seabirds were able to recognize the visual barriers and avoided them, in some cases by diving beneath them.

Fewer sockeye salmon were caught in all three experimental gears (10.3 to 22.3 sockeye/set) compared to controls (26.1 sockeye/set) but only the 50 Mesh gear caught significantly fewer sockeye than the other nets (Figure 9 and Appendix 7). Pinger, 20 Mesh and 50 Mesh gears caught salmon at rates 85%, 88% and 39%, respectively, of the monofilament control (Figure 10 and Appendix 7). Few sockeye were caught in the white meshes of the 20 Mesh and 50 Mesh gears, (1% and 2% respectively), whereas 21% and 35% of the sockeye were caught in the upper 50 meshes of the Mono and the Pinger nets.

More harbor seals and more seal-damaged fish (not salable) were found near or in Pinger nets (Figure 11), suggesting that harbor seals are attracted to and damage more fish in nets with pingers. Two harbor porpoise and three Dall's porpoise were entangled dead in 50 Mesh nets, two harbor seals were entangled dead in the 20 Mesh nets and one harbor seal was entangled in the Pinger nets and released alive. No marine mammals were caught in monofilament nets.

1995 Chum Fishery: Alcid entanglement rates did not vary significantly among the three gear types tested, despite a pattern of decreasing entanglement rates with increasing depth of opaque mesh from the surface ($P>0.05$; Figure 9 and Appendix 7). This result was expected because few birds were caught and the total number of sets was designed to detect differences in fish catch rates only. Entanglement rates were highest in the monofilament control (0.26 alcids/set), intermediate in the 20 Mesh gear (0.23 alcids/set), and lowest in the 40 Mesh gear (0.15 alcids/set).

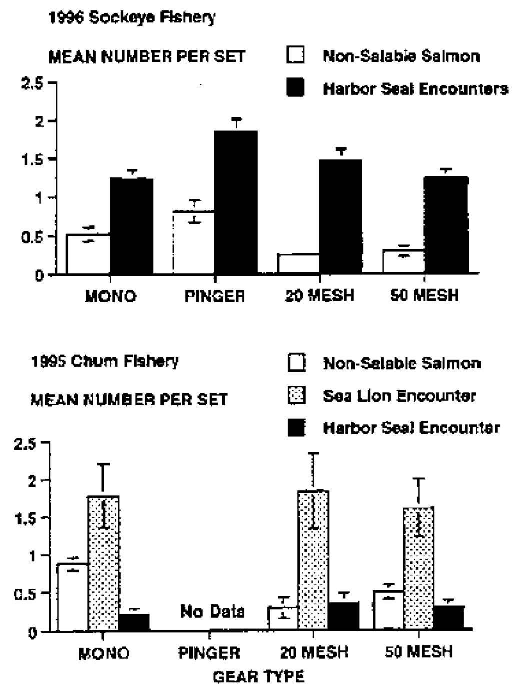

Figure 11. Pinniped Interactions by Gear Type. Mean rate per set of non-salable (pinniped damaged) salmon and mean harbor seal and/or sea lion encounters by gear type for the 1996 Sockeye and the 1995 Chum Test Fisheries. Error bars are standard errors.

The proportion of murres and auklets caught was similar in all gear types. Entanglement rates were 90% and 56% of the monofilament control for the 20 Mesh and 40 Mesh gears, respectively (Figure 10). Almost half (44%) of the birds caught in the monofilament net were caught in the upper 40 meshes; no birds were caught in the opaque seine twine of the two experimental gears (Figure 10).

Chum catch rates varied significantly among the two modified gears and the monofilament control ($P<0.05$) and illustrated a pattern similar to that of alcids—decreasing catch rates with increasing depth of the opaque mesh from the surface (Figure 9). Catch rates were greatest in the monofilament control (77.8/set), intermediate in the 20 Mesh gear (61.1/set), and least in the 40 Mesh gear (53.4/set). In post hoc comparisons, we found two overlapping groupings: monofilament and the 20 Mesh gear, and the 20 Mesh and 40 Mesh gears. This indicates that significantly fewer fish were caught in the 40 Mesh gear than in the monofilament control, but neither were significantly different than the 20 Mesh gear. Catch rates were 79% and 69% of the monofilament control for the 20 Mesh and 40 Mesh gears, respectively (Figure 10). Almost 20% of the chum caught in the monofilament control were caught in the upper 40 meshes of the net (519 fish); few (12) fish were caught in the opaque meshes of the 20 Mesh and 40 Mesh gears.

The number of fish damaged as a result of pinniped predation was greatest in the monofilament control despite similar numbers of California sea lions and harbor seals interacting with individual gear shackles within the nets (Figure 11).

Time of Day Comparisons

1996 Sockeye Fishery: Entanglement rates of common murres and rhinoceros auklets and catch rates of sockeye salmon varied significantly among the three time-of-day categories ($P<0.05$) and the pattern of variation among gear types was species specific (Figure 12 and Appendix 8). Rhinoceros auklet entanglement rates were significantly (4 times) greater in morning change-of-light (COL) sets, than in daytime or evening COL sets ($P<0.05$). In contrast, common murres were entangled at significantly greater rates in both morning and evening COL sets, than during the daylight hours ($P<0.05$).

The percentage of sets with entanglements was similar in the morning and evening COL sets (36% and 32%) and least during the day (19%) reflecting entanglement rates per set (Table 5). The percentage of large (greater than two birds) entanglement events and the number of birds entangled per event were greatest in morning COL sets (33% of sets and 2.7 birds/event); both measures were similar for daytime (23% and 1.9 birds/event) and evening COL sets (17% and 2.1 birds/event). These data suggest that although both COL categories have similar entanglement frequencies, morning COL sets tended to catch more birds per entanglement event.

Like those of rhinoceros auklets, the catch rates of sockeye salmon were significantly greater during morning COL sets, than either daylight or evening COL sets (Figure 12 and Appendix 8). In general, time-of-day had a much greater effect on alcid entanglement rates than on sockeye catch rates. Overall, daytime and evening COL entanglement rates were 36% and 68% respectively, of morning COL rates; whereas sockeye catch rates were 79% and 74% respectively, of morning COL rates (Figure 13).

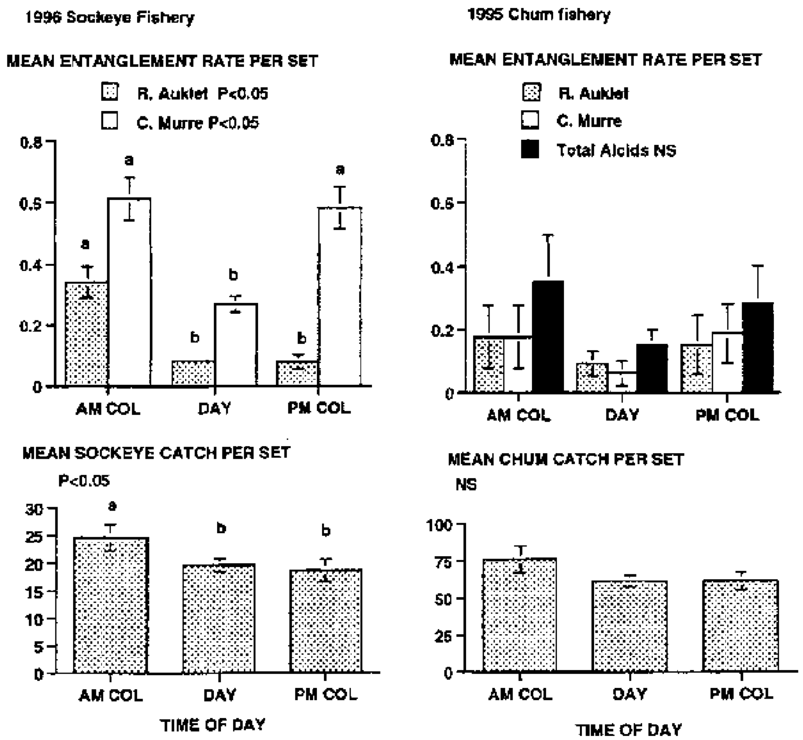

Figure 12. Time of Day Comparisons/Rate. Mean rate per set of rhinoceros auklet and common murre entanglements and mean salmon catch by time of day category for the 1996 Sockeye and the 1995 Chum Test Fisheries. Error bars are standard errors. P values are for factorial multiple comparisons. Significant groupings from post-hoc comparisons are shown as "a" or "b".

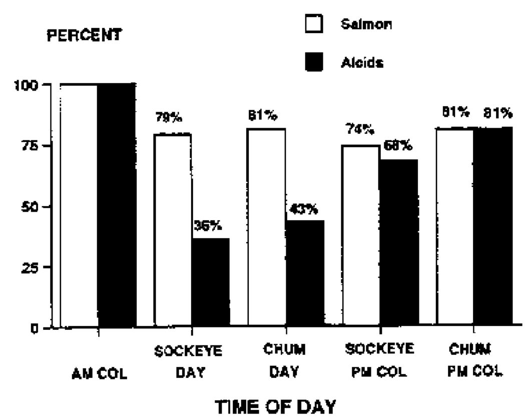

Figure 13. Time of Day Comparisons/Percent. Percent rate per set — relative to the morning change-of-light (AM COL = 100%) — of alcid entanglements and sockeye salmon and chum salmon catch by time of day category for the 1996 Sockeye and the 1995 Chum Test Fisheries.

Variable	AM COL	DAY	PM COL
No. of Sets	129	384	129
Total Birds	126	134	85
Entanglement Rate/Set	0.97	0.35	0.66
% Sets w/ Entanglements	36%	18%	32%
% Entanglement Sets >2 Bird	33%	23%	17%
Mean # birds/Entanglement Event	2.7	1.9	2.1
Depth Entangled (Meshes)			
Median			
C. Murre	70	35	40
R. Auklet	40	30	35

Table 5. Time of Day Comparisons/Sockeye Test Fishery. Total number of sets and birds entangled, mean rate per set of bird entanglements, percent of sets with entanglements, percent of sets with more than two birds entangled, mean number of birds per entanglement event (set), and median and mean depth of bird entanglements by time of day category for the 1996 Sockeye Test Fishery. COL is change of light.

Although murres were entangled at similar rates per set in morning and evening COL sets, the median depth at which murres were entangled during morning COL sets was almost twice (70 meshes) that of either daytime of evening COL entanglement depths (35 and 40 meshes, respectively; Table 5), presumably due to increased feeding and therefore diving behavior in the early morning. Rhinoceros auklets showed little variation in median entanglement depth by time of day, despite morning COL entanglement rates being 4 times that of either daytime or evening COL sets.

All but one of the eight marine mammals entangled in the course of the study were entangled during daylight fishing; one porpoise was caught during an evening COL set.

1995 Chum Fishery: Neither alcid entanglement rates nor chum catch rates varied significantly ($P>0.05$) by the three time-of-day categories tested; however, the pattern and magnitude of variation was similar to that observed in the 1996 sockeye fishery (Figure 12 and Appendix 8). Alcid entanglement rates were greatest in morning COL sets (0.35 birds/set), least during day sets (0.15 birds/set), and intermediate during evening COL sets (0.29 birds/set). Daytime and evening COL sets entangled birds at rates 43% and 81%, respectively, of sets made during the morning COL; whereas chum salmon were caught at 81% of morning COL sets for sets made during the daytime and evening COL periods (Figure 13 and Appendix 8).

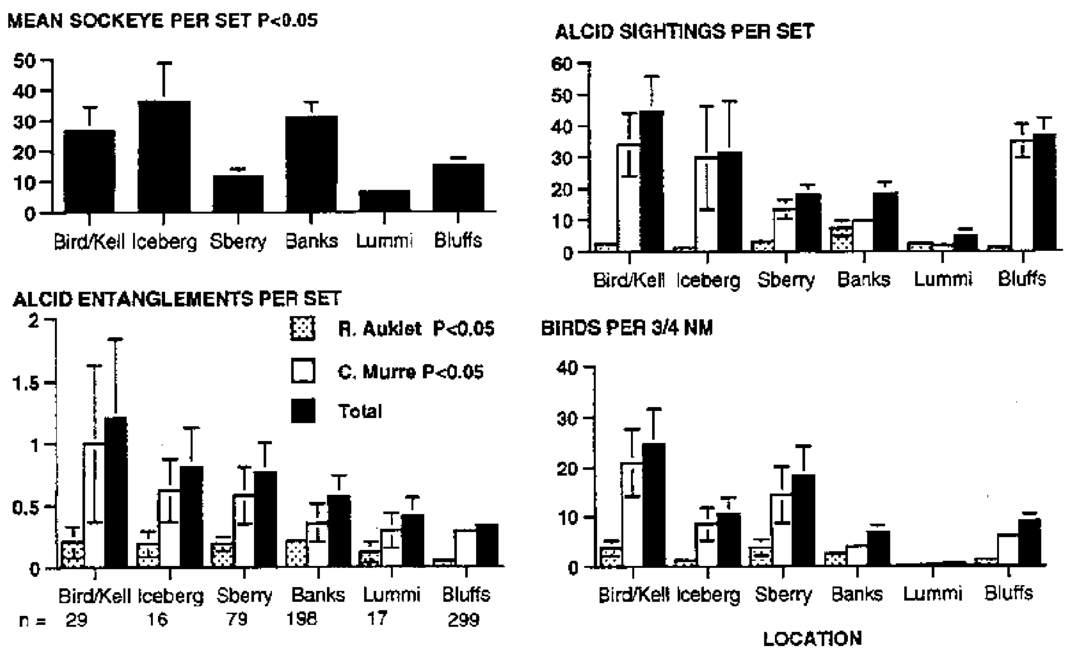

Figure 14. Area 7 Sockeye Test Fishery Location Comparisons. Mean rate per set of sockeye salmon catch, and rhinoceros auklet, common murre, and total alcid entanglements and sightings by location; and seabird abundance per 3/4 nm vessel transect by location in Area 7 for the 1996 Sockeye Test Fishery. Error bars are standard errors.

Location Comparisons

The areas fished in Management Area 7 were divided into seven categories: the Banks (west of San Juan Island around the Salmon and Hein Banks), Iceberg (Iceberg Point to Colville Point including McArthur Bank, South Lopez Island), Bluffs (Williamson Rocks to Deception Pass, Fidalgo Island), Strawberry (west side of Cypress Island), Lummi Island (Village Point, Lummi Island to Sinclair Island), San Juan Channel (south of Pear Point, San Juan Island), and Bird Rocks-Kellett Ledge (Colville Point, Lopez Island to James Island (see Appendix 9).

Common murre and rhinoceros auklet entanglement rates and sockeye catch rates varied significantly among the location categories ($P<0.05$, Figure 14 and Appendix 9), but as with other comparisons, the pattern of variation was species specific. The number of sets made per location category varied greatly (4 to 299 sets), making comparisons difficult. For example, entanglement rates in San Juan Channel were relatively high for both common murres (2.8/set) and rhinoceros auklets (0.5/set), but are not discussed here because only 4 sets were made there and these were during extreme weather conditions (Appendix 9).

Common murre entanglement rates were greatest from the Banks to mid-Rosario Strait along Lopez Island (Bird Rocks-Kellett Ledge (1.0/set), Iceberg (0.6/set), Strawberry (0.6/set) and the Banks (0.4/set). Rhinoceros auklet entanglement rates were greatest in these same areas and did not vary (0.2/set). The fewest birds of both species were entangled at the Bluffs and Lummi Island. Sockeye salmon catch rates were generally greatest in the areas where seabird entanglements were greatest, 31.1/set at the Banks, 26.7/set at Bird Rocks to Kellett Ledge and 36.3/set at Iceberg. Strawberry, where catch rates were 11.5/set, was the exception.

Alcid sightings followed the same pattern as alcid entanglements (Figure 14 and Appendix 9) with one exception; murres were almost as abundant at the Bluffs as at Bird Rocks-Kellett Ledge and Iceberg areas, where entanglement rates were two to three times higher. Rhinoceros auklets were about twice as abundant at the Banks as other locations, though entanglement rates were similar to other locations. Bird transect data (Figure 14 and Appendix 9) approximated the same general patterns of alcid abundance in the study area as sightings data, but showed fewer alcids at the Iceberg and Bluff locations. This suggests that vessel surveys along the transects we chose in this study can be used to reliably estimate relative alcid abundance by location and throughout the study area.

Sightings, encounters and survey data indicated that marbled murrelet abundance was greatest at the Bluffs near Burrows Bay, a quiet water location closed to commercial salmon fishing to protect marbled murrelets; one marbled murrelet was entangled there during this study. Although marbled murrelets were observed in the sighting zone of the net at Iceberg (two birds) and the Bluffs (three birds), none were observed in the encounter zone of the net in these locations.

Environmental Factors

In the 1996 sockeye fishery, most sets with entanglements had alcids in the sighting zone (84%) and the encounter zone (78%) of the net (Table 6 and Appendix 10). This was also true for encounters (53%) in the 1995 chum fishery, but not for sightings, which were rare overall. In both fisheries, bird entanglements do not appear to be linked to the position of birds in the encounter or sighting zones of the net relative to the prevailing wind and tide direction and the corkline (Table 6). These data agree with those from the 1995 sockeye test fishery (Melvin and Conquest, 1996). Collectively they strongly suggest that wind and tidal currents are not important factors influencing seabird entanglements in drift gillnets.

	1996 Sockeye Fishery		1995 Chum Fishery	
Bird Location Relative to Corkline	**Encounters**	**Sightings**	**Encounters**	**Sightings**
Sets	**123**	**132**	**10**	**5**
Up Wind/Up Tide	24	23	2	2
Up Wind/Down Tide	10	17	0	0
Down Wind/Up Tide	11	10	0	0
Down Wind/Down Tide	40	36	2	1
Both Sides	18	29	4	2
Other	20	17	2	0

Table 6. Alcid Position Relative to Nets/Sockeye Test Fishery. The number of sets with seabird entanglements where alcids were observed in the encounter zone or sighting zone of the net and the position of alcids relative to the corkline of the net and the prevailing wind and tide for the 1996 Sockeye Test Fishery.

Comparing sets with and without bird entanglements in both fisheries, sets with entanglements tended to be longer, to have larger numbers of birds near the net, and catch more salmon (Appendix 10). Entanglement sets in the 1996 sockeye fishery occurred in rougher sea conditions. This was not true in the 1995 chum fishery where sea conditions were rougher overall, but less variable than in the sockeye fishery. Entanglement sets in the 1995 chum fishery tended to occur in more inclement weather conditions. Tidal state, current speed and water depth were similar for sets with and without entanglements. Although we have documented cases where a fishing vessel running the length of the net has caused individual entanglements, the percentage of sets with and without entanglements were similar in sets with and without this behavior. These data suggest that, with the possible exception of sea state and weather, physical factors have little influence on entanglement rates. The number of birds in the vicinity of the net is likely the most important factor influencing the entanglement rates of seabirds.

In both the 1996 and the 1995 sockeye fisheries, sets that entangled seabirds tended to catch almost twice as many salmon as those that did not entangle seabirds; and in the 1995 chum fishery, 25% more. This phenomenon reinforces the suggestion that entanglements may be more likely when alcid prey (bait fishes) co-occur with sockeye and chum salmon prey (euphausiids; Melvin and Conquest, 1996).

DISCUSSION

The Ecosystem

The extreme inter-annual variation of seabird abundance in Puget Sound is the single most important factor determining the rate of seabird entanglement in Area 7. Between 1995 and 1996, common murre abundance varied by a factor of almost 60 and murre entanglement rate by a factor of 15. This variation in murre abundance in the Area 7 gillnet fishery is probably due to variation in the timing of the post-breeding migration of Oregon breeders (over 700,000 birds; R. Lowe, 1997, pers. comm.) and perhaps California breeders (360,000; Takekawa et al., 1990) to Puget Sound. In most years these large populations leave their coastal breeding colonies in late June to early July (Boekleheide et al., 1990) and intermingle with the much smaller population of Washington breeders (about 5,000 murres, J. Parrish, unpub. data) which begin leaving Tatoosh Island four to six weeks later in mid-August. Typically, male-chick pairs leave the colonies first and swim to their wintering grounds while females leave later and fly. In 1996, Oregon murre breeding colonies failed (R. Lowe, 1997, pers. comm.). The earlier post-breeding migration and the breeding failure of California and Oregon murres, together with higher entanglement rates and the absence of YOY birds entangled in the fishery, strongly suggest that murres entangled in the Puget Sound fishery originated from southern colonies in 1996. In 1995 the opposite occurred—Oregon murre breeding activity was near normal and their migration to Puget Sound was later, and murre entanglements in the sockeye fishery were dramatically lower.

Rhinoceros auklet abundance and entanglement rates were three times greater in 1996 than in 1995 (Melvin and Conquest, 1996). Auklets are much less variable in their year-to-year interaction with Area 7 gillnet fisheries, because their colonies at Protection and Smith Islands are close to the fishing grounds and their annual breeding success is relatively constant (U. Wilson, 1997, pers. comm.). The variability that we saw in auklet interactions between 1995 and 1996 was likely a function of where in Puget Sound these birds chose to forage and minor variation in the number of breeders on an annual basis.

Our understanding of the seabird-gillnet interaction in the Area 10 chum fishery is incomplete. Although there were fewer alcid sightings in the Area 10 chum fishery, the alcid entanglement rate and the rhinoceros auklet encounter rate exceeded those of the 1995 sockeye fishery in Area 7. This and other observations suggest that aspects of physical environment in Area 10, such as rougher sea conditions and/or increased boat traffic, increase the intensity of the interaction between alcids and gillnets in this location. The lack of inter-annual data on seabird abundance for the Area 10 chum fishery limits our understanding of the importance of this area for seabirds and the relationship between abundance and entanglement rates.

Seabird and sockeye abundance changed dramatically within the 1996 sockeye season but in opposing patterns. During the final weeks of the fishery, sockeye catch rates dropped off to trace levels (about 2 fish/set) and murre abundance peaked at near 100 sightings per set (Figure 6). It was during this same period that the only two non-treaty fishery openings for gillnets were scheduled (16 and 19-20 August). Clearly it is not in the best interest of fishers or murres to schedule openings when the likelihood of catching salmon is extremely low and entangling murres is high. It was also during this period that murres from the stressed Tatoosh Island population began to fledge (15 August, J. Parrish, unpublished data) and possibly recruit to the aggregation of post-breeding birds in Puget Sound. Although the 1996 schedule of non-treaty gillnet openings was atypical because of allocation shifts to protect Washington coho salmon stocks (D. Austin, 1997, pers. comm.), it demonstrated that without an ecosystem management approach to the fishery management and seabird conservation, objectives can conflict. Scheduling fishery openings when fish are scarce, birds are abundant, and murres from a stressed population might begin recruiting to post-breeding aggregations in Puget Sound is not the best approach to fisheries management, if reducing seabird bycatch is a resource management priority.

At present seabird abundance is not measured on the fishing grounds nor are seabird data from existing research programs considered in fishery management decisions. Data are collected annually at seabird breeding colonies in Oregon (R. Lowe, USFWS) and Washington (U. Wilson, USFWS and J. Parrish, University of Washington). Seabird survey data are collected along the outer coast of Washington throughout the summer (C. Thompson, WDFW) and in Puget Sound during July (Puget Sound Ambient Monitoring Program (PSAMP, D. Nysewander, WDFW). It may be possible to adapt both WDFW survey programs to enhance the data required for improved management of the fishery. We have demonstrated that the vessel transects used in this study reliably measure seabird abundance on the fishing grounds in Area 7. We urge that seabird abundance be measured on the fishing grounds in areas 7 and 7A before, during and after the sockeye fishery using vessel transects, and that these data be merged with those from existing seabird monitoring programs to form a comprehensive data set. These data and real time fish data could be incorporated into an interactive management system to manage the fishery.

Inter-year and intra-season sources of variation in seabird abundance provide great opportunity for improved management of the fishery based on an ecosystem management concept. We recommend the following:

- Make seabird conservation an objective of all fishery management agencies with jurisdiction over Puget Sound and its adjacent waters.
- Implement seabird bycatch reduction measures that are comprehensive, extending to all fishers regardless of country or treaty status.
- Link seabird data from existing on-colony, outer coast and Puget Sound survey programs with seabird abundance data collected on the fishing grounds.
- Prioritize the development of a comprehensive seabird abundance data set and incorporate it into the fishery management process via wildlife management agencies responsible for seabird conservation.
- Manage the fishery interactively using real time seabird and fish abundance data.
- Eliminate morning change-of-light sets in the gillnet fishery and restrict fishing to daylight hours in years of high murre abundance.
- Require 20 Mesh nets (upper 20 meshes replaced with white, highly visible seine twine) to replace traditional monofilament drift gillnets in the Area 7/7A Fraser River sockeye fishery, and allow time for full compliance. The effectiveness of the 20 Mesh gear in the fall chum fishery has not been proved, and therefore, is not recommended.

These data also argue strongly that studies designed to measure seabird interactions in fisheries need to be multi-year programs in order to accomplish their goals.

The Fishery

The different entanglement patterns for common murres and rhinoceros auklets by time of day reflect their general activity patterns. Rhinoceros auklets leave their breeding colonies at Smith and Protection Islands before sunrise and return prior to sunset each day (Wilson and Manuwal, 1986). This behavior explains the rare entanglement of auklets during evening change-of-light sets and their common entanglement (over half) during morning change-of-light sets. Murres, on the other hand, are on the water constantly but were entangled most during change-of-light sets (60%). **We recommend that morning change-of-light sets be eliminated in the gillnet fishery and that, where possible, fishing be restricted to daylight hours in years of high murre abundance.**

We found that common murre entanglement rates were significantly less in all three gear treatments tested, but that rhinoceros auklet entanglement rates, though less in the experimental gears, were significantly less only in nets with the deeper visual barrier (50 Mesh). Statistical comparisons were less robust for rhinoceros auklets because fewer auklets were entangled (3 times less than murres), thus reducing the effective sample size. It is likely that fewer rhinoceros auklets were entangled because they were 7 times less abundant than murres, and seldom entangled after early morning. Results from this study and our earlier work (Melvin and Conquest, 1996) confirm that visual barriers are an effective seabird bycatch reduction tool.

The 50 Mesh nets were the only net type tested that caught significantly fewer salmon (over 60% less than the control) as well as significantly fewer murres and auklets. These nets were difficult to fish because of their weight and bulk and that they entangled the only porpoise (five animals) in the 1996 sockeye test fishery, suggesting that they may be a hazard to these echo-locating species. For these reasons, the 50 Mesh gear is not a practical seabird bycatch reduction alternative in Puget Sound drift gillnet fisheries.

Nets with pingers and 20 Mesh visual barriers caught fewer rhinoceros auklets and significantly fewer common murres than controls, but only slightly fewer salmon. Evidence suggests that these gears do not reduce the number of entanglement events, but rather reduce the number of birds entangled per event. We speculate that visual barriers reduce aggregate behavior/decision making (follow the leader) and force individuals to decide how to avoid the obstacle that the corkline /visual barrier array presents. Although pingers have the greatest potential as a tool to reduce seabird bycatch in a wide range of gillnet fisheries because one array of pingers can be easily applied to other nets and fisheries, we believe that we need to refine the pinger design as we learn more about seabird hearing, especially hearing capabilities underwater, to make them more effective. Ideally, pinger research should be directed at developing a device that is effective at reducing the bycatch of porpoise and perhaps other species as well as seabirds. Secondly, pinger tests should be repeated and results reproduced before they are required by law as a bycatch reduction tool. On a more practical level, the prototype we developed is not commercially available at this time.

Of the three gears tested, only the 20 Mesh gear (upper 20 meshes replaced with white, highly visible seine twine) is recommended as a seabird reduction management tool in the Area 7/7A drift gillnet fishery. The 20 Mesh gear met our original goals, was tested and proved in multiple fisheries, and was conceived by and endorsed by the Puget Sound Gillnetters' Association as an acceptable tool to reduce seabird bycatch in this fishery (L. Pillatos, PSGA, 1997, pers. comm.). The cost of incorporating the 20 mesh strip of white, #18 seine twine into existing nets is estimated at $1,800 to $2,000 per net including a week or more of labor (T. Crump, LFSI, Inc., 1997, pers. comm. and J. Armstrong, Redden Net Co., 1997, pers. comm.). Its usable life is estimated at six to nine years depending on use patterns, yielding an annual cost of approximately $223 to $333 for each fisher. The time necessary to order and ship the seine twine netting and incorporate it into an existing net is estimated at three to six months, depending on the time of year. **The effectiveness of the 20 Mesh gear in the fall chum fishery has not been proved, and therefore, is not recommended.**

Although seabird bycatch and sockeye catch varied significantly by location, areas of high salmon catch and high seabird bycatch tended to overlap, eliminating the possibility of significantly reducing seabird bycatch without significantly reducing salmon catch through zonal or area closures within Management Area 7. However, the significant variation in both seabird abundance and bycatch by location demonstrated in this study and our earlier work (Melvin and Conquest, 1996) underscores the importance of accounting for geographic variation in experimental comparisons.

Management Tools

The Fraser River sockeye salmon fishery is carefully managed to allocate the sockeye resource among United States and Canadian user groups by gear and by treaty status. Seabird bycatch reduction measures that decrease the fishing efficiency of gillnets can thus cause a de facto reduction in allocation unless gillnetters are given more sets to catch their allocation. Results of this study identify three basic tools that can be used to reduce seabird bycatch: alternative gear, time of day, and abundance-based or ecosystem management. We use a simple model to demonstrate the percentage of seabirds that might be entangled under a range of management scenarios relative to the monofilament control fished at all times of day (Appendix 11). The fishing effort (the number of sets) required to catch a hypothetical allocation of sockeye salmon (272,000 sockeye) is determined based on the catch rates we measured in this study for the four gears under the three time-of-day scenarios and two fish-abundance scenarios. For each gear type and scenario combination, we project the number of seabirds that might be entangled based on the entanglement rate estimates for that scenario. This model cannot forecast the range of seabirds that are likely to be caught in this fishery because fish abundance and quotas, run timing, fishing effort and bird abundance vary tremendously from year to year. In addition, entanglement rates used here are likely to be higher than those from an actual fishery, because fishers participating in this study were instructed to fish aggressively near birds, and are useful only for comparisons.

Focusing on gear alone (fishing at all times of day at mean fish abundance), results indicate that seabird bycatch can be reduced by 32% to 37% by fishing nets with pingers or 20 Mesh barriers respectively, and that seabird bycatch would actually increase 28% using 50 mesh nets (Table 7 and Appendix 11). Using the same approach, we compared the projected seabird bycatch of monofilament nets fished at three time-of-day combinations. Results indicate that seabird bycatch in monofilament nets could be reduced 13% by fishing daylight and evening change-of-light hours, and 25% by fishing during only daylight hours. The greatest reduction in seabird bycatch from any single activity can be achieved (43%) by limiting fishery openings to periods when fish are in high abundance (monofilament nets fished all times of day) simply because this approach reduces effort. Clearly, there are significant conservation consequences to fishery management practices. Fishing 20 Mesh nets at times of high fish abundance, and during openings that include either daytime and dusk or daylight-only fishing, have the potential to reduce seabird bycatch by 70% to 75% in years similar to 1996.

GEAR	TIME OF DAY		
	ALL	NO AM	DAYTIME
Monofilament	*0%	13%	25%
Abundance Based	**43%**	**50%**	**57%**
Mono + Pinger	32%	45%	57%
Abundance Based	**64%**	**70%**	**77%**
20 Mesh	37%	28%	55%
Abundance Based	**66%**	**70%**	**75%**
50 Mesh	-28%	40%	41%
Abundance Based	**29%**	**66%**	**65%**

* control

Table 7. Management Scenario Matrix/Sockeye Test Fishery. Matrix of estimated percent reduction in seabird entanglement rates by gear type and time of day for periods of mean fish abundance (all weeks) and high fish abundance (first three weeks) for the 1996 Sockeye Test Fishery. For details, see Appendix 11.

CONCLUSIONS

Results of this study identify three basic tools that can be used to reduce seabird bycatch in Puget Sound salmon drift gillnet fisheries: abundance-based or ecosystem management, alternative gear, and time of day. The dramatic inter-annual and in-season variation of seabird abundance in Puget Sound is the most important factor determining the rate of seabird entanglements in Area 7. Inter-year and intra-season sources of variation in seabird abundance provide great opportunity for improved management of the fishery based on an ecosystem management concept.

We confirmed that visual barriers are an effective seabird bycatch reduction tool. The 20 Mesh gear met our original goal of significantly reducing seabird bycatch without significantly reducing fishing efficiency. It was tested and proved in multiple fisheries, and was conceived by and endorsed by the Puget Sound Gillnetters' Association as an acceptable tool to reduce seabird bycatch in this fishery. The 50 Mesh nets (with the deeper of the two visual barriers tested) were eliminated as a possible seabird reduction tool because they did not meet goals of the research program, were impractical to fish, and entangled porpoise. Although pingers have the greatest potential as a tool to reduce seabird bycatch in a wide range of gillnet fisheries because of their versatility, we do not recommend these devices as an alternative for Puget Sound at this time because we believe that they can be improved, results need to be duplicated, and the prototype device is not commercially available. The time of day that gillnets are fished significantly affects seabird bycatch rates. Elimination of morning change-of-light fishing is likely to reduce most rhinoceros auklet entanglements and contribute significantly to reducing common murre entanglements.

Although seabird bycatch and sockeye catch varied significantly by location, areas of high salmon catch and high seabird bycatch tended to overlap, eliminating the possibility of significantly reducing seabird bycatch without significantly reducing salmon catch through zonal or area closures within Management Area 7. Data suggest that the number of birds in the vicinity of the net is probably the most important factor influencing the entanglement rates of seabirds, but that sea state and weather might also be important.

By employing all available tools, fishing 20 Mesh nets at times of high fish abundance during openings that include either daytime and dusk or daylight-only fishing, managers have the potential to reduce seabird bycatch by up to 70% to 75% in years similar to 1996.

Recommendations

We recommend several management actions based on this research that will reduce the bycatch of alcid seabirds in Puget Sound drift gillnet fisheries and enhance seabird conservation in the shared waters of the Washington and Canada. Recommendations focus on institutional change for fishery and wildlife management agencies as well as fishery practices. We recommend the following:

- Make seabird conservation an objective of all fishery management agencies with jurisdiction over Puget Sound and its adjacent waters.
- Implement seabird bycatch reduction measures that are comprehensive, extending to all fishers regardless of country or treaty status.
- Link seabird data from existing on-colony, outer coast and Puget Sound survey programs with seabird abundance data collected on the fishing grounds.
- Prioritize the development of a comprehensive seabird abundance data set and incorporate it into the fishery management process via wildlife management agencies responsible for seabird conservation.
- Manage the fishery interactively using real time seabird and fish abundance data.
- Eliminate morning change-of-light sets in the gillnet fishery and restrict fishing to daylight hours in years of high murre abundance.
- Require 20 Mesh nets (upper 20 meshes replaced with white, highly visible seine twine) to replace traditional monofilament drift gillnets in the Area 7/7A Fraser River sockeye fishery, and allow time for full compliance. The effectiveness of the 20 Mesh gear in the fall chum fishery has not been proved, and therefore, is not recommended.

EPILOGUE

On 30 May 1997 the Washington Fish and Wildlife Commission acted to reduce seabird bycatch in non-treaty Puget Sound drift gillnet fisheries based on the results of this study[1]. They acted to require use of the 20 Mesh gear modification in Management Areas 7/7A beginning in 1998. The minimum twine size of the white opaque netting or "bird strip" was set at #12 (as opposed to #18) in response to fisher concerns over safety, weight and cost. Action came too late to require the 20 Mesh gear in 1997. They will also restrict fishing to a period from 1.5 hours after sunrise to 11:59 p.m. This action precludes morning change-of-light and most night fishing.

In preference to a proposed WDFW regulation to restrict fishing to a projected period of high fish abundance, 1 to 23 August, they delegated to the WDFW director "the authority to take emergency action to ensure fishing in areas 7 and 7A is beneficial to the protection of birds based on abundance of salmon." This alternative action was in response to uncertainty regarding the timing and abundance of both fish and birds and the potential for unnecessary lost fishing opportunity. The commission indicated that this action serves the fishing industry and seabird conservation objectives better by scheduling fishery openings based on actual salmon abundance and the relative abundance of seabirds. No action was taken on monitoring seabird abundance.

[1] *Source: Bern Shanks, Ph.D, Director of the Department of Fish and Wildlife in a 24 June 1997 letter to Mr. Kurt Smitch, Assistant Regional Director, US Fish and Wildlife Service, North Pacific Coast Ecoregion.*

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APPENDICES

1996 Sockeye Fishery

DATE	EFFORT		SALMON CATCH PER SET									
	Trip	Sets Total	Sets with salmon	Percent	Sockeye	King	Coho	Atlantic	Steelhead	Unid.	Total	Dogfish
28-Jul	1	28	28	100%	54.3	0.2	0.0	0.3	0.0	0.0	54.8	24.7
29-Jul	2	34	34	100%	58.9	0.3	0.0	0.1	0.0	0.0	59.4	24.1
31-Jul	3	29	29	100%	51.0	0.3	0.0	0.1	0.0	0.1	51.6	15.0
4-Aug	4	49	45	92%	33.4	0.2	0.1	0.1	0.0	0.0	31.0	21.2
6-Aug	5	39	34	87%	17.4	0.1	0.1	0.0	0.0	0.0	15.5	15.2
7-Aug	6	41	34	83%	16.1	0.1	0.1	0.0	0.0	0.3	13.7	10.2
11-Aug	7	36	32	89%	93.3	0.2	0.0	0.0	0.0	0.3	83.4	12.6
12-Aug	8	38	34	89%	30.6	0.1	0.0	0.1	0.0	0.4	27.9	6.2
14-Aug	9	36	35	97%	25.6	0.3	0.0	0.0	0.0	0.1	25.2	12.3
15-Aug	10	33	13	39%	8.4	0.0	0.0	0.1	0.1	0.0	3.4	13.8
18-Aug	11	42	30	71%	3.7	0.8	0.0	0.0	0.0	0.0	3.2	26.5
20-Aug	12	40	26	65%	3.0	0.2	0.0	0.0	0.0	0.0	2.2	13.5
21-Aug	13	39	21	54%	5.0	0.1	0.2	0.0	0.0	0.0	2.9	5.6
22-Aug	14	41	15	37%	3.1	0.0	0.1	0.0	0.0	1.1	1.6	4.5
25-Aug	15	36	20	56%	3.0	0.1	0.1	0.0	0.0	0.2	1.9	12.9
27-Aug	16	41	12	29%	3.3	0.0	0.1	0.0	0.1	0.3	1.1	10.3
28-Aug	17	40	15	38%	2.0	0.1	0.3	0.0	0.0	0.1	1.0	8.1
Totals	17	642	457		13,151	94	27	25	8	62	13,367	8,852
Mean					20.5	0.1	0.0	0.0	0.0	0.1	20.8	13.8
SE					1.999	0.024	0.009	0.009	0.004	0.027	2.005	1.142
Percent				71.2%	98.4%	0.7%	0.2%	0.2%	0.1%	0.5%	100.0%	*

1995 Chum Fishery

DATE	EFFORT		SALMON CATCH PER SET				
	Trip	Sets	Chum	Coho	King	Total	Dogfish
25-Oct	1	12	25.2	0.1	0.1	25.5	0.5
26-Oct	2	14	48.9	0.1	0.1	49.5	0.7
1-Nov	3	14	63.9	0.1	0.1	64.2	0.4
2-Nov	4	14	79.5	0.0	0.0	79.8	0.9
3-Nov	5	12	100.2	0.1	0.2	100.5	0.4
9-Nov	6	14	59.1	0.6	0.0	64.7	2.5
10-Nov	7	13	66.3	0.2	0.0	60.0	0.5
11-Nov	8	14	66.6	0.1	0.0	66.9	0.9
Totals	12	107	6,822	19	5.0	6,866	95.0
Mean			63.75	0.18	0.06	64.17	0.90
SE			3.110	0.045	0.021	3.111	3.120
Percent			99.7%	0.3%	0.0	100%	*

* includes four partial net sets due to gear damage

Appendix 1. Fish Catch. Mean rate per set of salmon and dogfish catch and total catch by species for the 1996 Sockeye and the 1995 Chum Test Fisheries.

1996 Sockeye Fishery

Date	Trip	Sets	SIGHTINGS Sets	Percent	Common Murre	Rhinoceros Auklet	Marbled Murrelet	Pigeon Guillemot	Unid. Alcid	Other Alcid	Total Alcids	ENCOUNTERS Sets	Percent	Common Murre	Rhinoceros Auklet	Unid. Alcid	*Other Alcid	Marbled Murrelet	Total
28-Jul	1	28	23	82%	13.82	3.86	0	0	0.32	0	18.00	20	71%	3.04	0.57	0.14	0.07	0	3.82
29-Jul	2	34	15	44%	6.94	1.00	0	0.03	0.47	0	8.44	15	44%	1.97	1.50	0.06	0	0	3.53
31-Jul	3	29	19	66%	4.52	0.76	0	0.10	1.00	0	6.38	11	38%	0.59	0.10	0.14	0.03	0	0.86
4-Aug	4	49	36	73%	4.57	4.69	0.02	0.12	1.73	0	11.14	32	65%	1.73	1.39	0.37	0	0	3.49
6-Aug	5	39	28	72%	15.59	1.56	0.10	0	0.85	0	18.10	20	51%	1.23	0.41	0.08	0	0	1.72
7-Aug	6	41	35	85%	14.17	22.59	0	0.02	6.51	0	43.29	29	71%	3.02	2.49	0.05	0.02	0	5.59
11-Aug	7	36	29	81%	25.28	3.25	0.03	0.17	1.72	0	30.44	26	72%	6.58	1.58	0.56	0	0.03	8.75
12-Aug	8	38	29	76%	5.97	0.97	0	0.05	0.53	1.31	7.55	19	50%	3.03	0.47	0.03	0.05	0	3.58
14-Aug	9	36	24	67%	10.17	4.06	0	0	0.33	0	14.56	21	58%	3.11	1.22	0.08	0	0	4.42
15-Aug	10	33	27	82%	40.88	1.21	0.06	0.06	0.21	1.22	42.46	23	70%	6.48	0.55	0.06	0.03	0.06	7.18
18-Aug	11	42	37	88%	26.05	0.57	0	0.31	0.19	1.14	27.14	32	76%	4.64	0.31	0.24	0.29	0	5.48
20-Aug	12	40	33	83%	25.80	2.08	0	0.15	4.58	0	32.60	25	63%	4.88	0.75	0.10	0.03	0	5.75
21-Aug	13	39	31	79%	23.56	6.51	0	0	0.77	0	30.85	31	79%	10.87	1.97	0.05	0	0	12.90
22-Aug	14	41	31	76%	15.54	1.51	0	0.22	0.39	0	17.66	20	49%	1.85	0.17	0	0.15	0	2.17
25-Aug	15	36	30	83%	28.72	0.42	0	0	0.22	0	29.36	24	67%	12.64	0.19	0.14	0	0	12.97
27-Aug	16	41	31	76%	93.73	0.41	0.10	0.02	0.24	0	94.51	21	51%	7.61	0.37	0.05	0	0.10	8.12
28-Aug	17	40	25	63%	31.68	0.25	0	0.15	0.08	0	32.15	10	25%	1.85	0.15	0	0	0	2.00
Totals	17	642	483		14,845	2,186	12	56	798	3	17,900	379		2,835	548	82	26	7	3,498
Mean/set					30.735	4.526	0.025	0.116	1.652	0.006	37.060			4.416	0.854	0.128	0.040	0.011	5.449
SE					2.724	0.784	0.007	0.028	0.390	0.028	2.903			0.446	0.141	0.025	0.021	0.006	0.477
Percent				75%	82.9%	12.2%	0.1%	0.3%	4.5%	0.0%	100.0%		59.0%	81.0%	15.7%	2.3%	0.7%	0.2%	100.0%

* 24 Pigeon Guillemots, one Tufted Puffin and one Cassin's Auklet

Appendix 2. Alcid Abundance/Sockeye Test Fishery. Mean rate per set of alcid sightings (maximum number within 10 to 100 meters of the corkline) and encounters (within 10 meters of the corkline) by date and species and total sightings and encounters by species for the 1996 Sockeye Test Fishery.

Date	Trip	Sets (total)	ENTANGLEMENTS Sets	Percent	Common Murre	Rhinoceros Auklet	Marbled Murrelet	Pigeon Guillemot	Total Alcids
28-Jul	1	28	10	36%	0.57	0.14	0	0	0.71
29-Jul	2	34	15	44%	1.32	0.50	0	0	1.82
31-Jul	3	29	13	45%	0.62	0.24	0	0	0.86
4-Aug	4	49	16	33%	0.27	0.31	0	0	0.57
6-Aug	5	39	5	13%	0.15	0	0	0	0.15
7-Aug	6	41	8	20%	0.22	0.07	0	0.02	0.32
11-Aug	7	36	14	39%	1.17	0.22	0	0	1.39
12-Aug	8	38	5	13%	0.13	0.03	0	0	0.16
14-Aug	9	36	14	39%	0.28	0.28	0	0	0.56
15-Aug	10	33	11	33%	0.61	0.06	0	0	0.67
18-Aug	11	42	13	31%	0.31	0.17	0	0	0.48
20-Aug	12	40	2	5%	0.08	0	0	0	0.08
21-Aug	13	39	14	36%	0.85	0.10	0	0	0.95
22-Aug	14	41	3	7%	0.10	0.07	0	0	0.17
25-Aug	15	36	9	25%	0.50	0	0.03	0	0.53
27-Aug	16	41	6	15%	0.07	0.10	0	0	0.17
28-Aug	17	40	0	0%	0.00	0	0	0	0.00
Totals	17	642	158		258	85	1	1	345
Dead					249	80	1	1	331
Alive					9	5	0	0	14
Non-analyses					2	2	0	0	4
Total - all sets					260	87	1	1	349
Percent				25%	75%	25%	0%	0%	100%
Mean/set					0.402	0.132	0.002	0.002	0.537
SE					0.067	0.020	0.002	0.002	0.071

* birds entangled in sets deleted from analyses (see methods)

Appendix 3. Alcid Entanglements/Sockeye Test Fishery. Mean rate per set of alcid entanglements by date and species and total alcid entanglements by species for the 1996 Sockeye Test Fishery.

1996 Sockeye Fishery

Age/Measurements	Common Murre Female Mean	Range	Male Mean	Range	Total	Rhinoceros Auklet Female Mean	Range	Male Mean	Range	Total
										44%
Young of the Year (no.)	0		0		0	19		17		36
Culmen Length (cm)						2.7	2.5 to 2.9	2.8	2.6 to 3.0	
Body Weight (g)						372.2	241.4 to 455.4	383.6	327.5 to 492.5	
					29%					30%
Pre-Breeders (no.)	36		35		71	9		16		25
Culmen Length (cm)	4.7	4.2 to 5.1	5.0	4.5 to 5.4		3.2	3.1 to 3.3	3.3	2.9 to 3.8	
Body Weight (g)	1,004.4	840.7 to 1,152.3	1,042.1	528.3 to 1,208.4		554.7	473.2 to 602.6	578.7	496.2 to 655.1	
					71%					26%
Breeders (no.)	75		102		177	14		7		21
Culmen Length (cm)	4.8	4.3 to 5.4	4.9	4.3 to 5.5		3.2	2.8 to 3.5	3.3	2.8 to 3.6	
Body Weight (g)	1,047.8	876.5 to 1,344.8	1,070.3	899.1 to 1,320.2		565.6	484.2 to 659.4	621.3	567.2 to 671.4	
Unknown					3					0
Released Alive					9					5
Total	111		137		260	42		40	0	87

1995 Chum Fishery

Age/Measurements	Common Murre Female Mean	Range	Male Mean	Range	Total	Rhinoceros Auklet Female Mean	Range	Male Mean	Range	Total
YOY/Pre-Breeders (no.)	6		5		11	6		6		12
Culmen Length (cm)	4.4	3.9 to 4.8	4.6	4.2 to 5.2		3.1	2.9 to 3.3	3.1	2.8 to 3.2	
Body Weight (g)	1,024.0	902.8 to 1,074.6	1,000.5	956.7 to 1,067.4		580.0	534.2 to 634.4	599.0	531.6 to 666.7	
Breeders (no.)	0		0		0	0		0		0
Released Alive (no.)					0					0
Total (no.)	6		5		11	6		6		12

Appendix 4. Ages of Entangled Seabirds. The number, mean and range culmen length (mm), and mean and range total weight (grams) of entangled seabirds by species, age and sex for the 1996 Sockeye and the 1995 Chum Test Fisheries.

1996 Sockeye Fishery

Date	Trip	Sets (Total)	SIGHTINGS Sets	Percent	Harbor Seal	Harbor Porpoise	Dall's Porpoise	Killer Whale	Other*	Unid.	ENCOUNTERS Sets	Percent	Harbor Seal	Dall's Porpoise	Killer Whale	ENTANGLEMENTS Sets	Percent	Harbor Seal	Harbor Porpoise	Dall's Porpoise
28-Jul	1	28	7	25%	0.39	0	0	0	0	0.04	11	39%	0.57	0	0	0	0.0%	0.00	0.00	0.00
29-Jul	2	34	5	15%	0.29	0	0	0	0	0	15	44%	0.65	0	0	0	0.0%	0.00	0.00	0.00
31-Jul	3	29	7	24%	0.45	0	0	0	0	0	14	48%	0.97	0	0	0	0.0%	0.00	0.00	0.00
4-Aug	4	49	17	35%	0.33	0	0	0.24	0	0	19	39%	0.49	0	0.12	0	0.0%	0.00	0.00	0.00
6-Aug	5	39	18	46%	1.44	0	0	0.26	0	0	21	54%	1.72	0	0.26	0	0.0%	0.00	0.00	0.00
7-Aug	6	41	23	56%	0.98	0.05	0.05	0.20	0.02	0.05	23	56%	1.07	0	0	1	2.4%	0.00	0.00	0.02
11-Aug	7	36	14	39%	0.83	0	0	0	0	0	20	56%	1.22	0	0	0	0.0%	0.00	0.00	0.00
12-Aug	8	38	14	37%	0.45	0	0.11	0.13	0	0.03	14	37%	0.50	0.08	0	0	0.0%	0.00	0.00	0.00
14-Aug	9	36	14	39%	0.72	0	0	0	0	0	21	58%	0.97	0	0	0	0.0%	0.00	0.00	0.00
15-Aug	10	33	23	70%	1.76	0	0	0	0	0	26	79%	1.79	0	0	1	3.0%	0.03**	0.00	0.00
18-Aug	11	42	23	55%	1.07	0.05	0	0.17	0	0	24	57%	1.10	0	0	1	2.4%	0.00	0.02	0.00
20-Aug	12	40	21	53%	1.40	0	0	0	0	0	26	65%	1.60	0	0	0	0.0%	0.00	0.00	0.00
21-Aug	13	39	26	67%	1.31	0.10	0.26	0.72	0.03	0.10	26	67%	1.56	0	0.08	1	2.6%	0.00	0.00	0.03
22-Aug	14	41	31	76%	2.66	0	0.44	0.12	0.02	0	37	90%	3.29	0.15	0.02	1	2.4%	0.00	0.00	0.02
25-Aug	15	36	31	86%	2.14	0	0	0.03	0	0	32	89%	2.47	0	0	1	2.8%	0.03	0.00	0.00
27-Aug	16	41	33	80%	1.80	0	0	0	0	0.05	35	85%	2.24	0	0	2	4.9%	0.02	0.02	0.00
28-Aug	17	40	30	75%	1.83	0.05	0	0	0	0.05	35	88%	1.95	0	0	0	0.0%	0.00	0.00	0.00
Total	17	642	337		762	10	34	76	3	12	399		923	9	20	8		3	2	3
Rate/Set					1.19	0.02	0.05	0.12	0.005	0.02			1.44	0.01	0.03			0.005	0.003	0.005
SE					0.07	0.01	0.02	0.03	0.003	0.01			0.07	0.01	0.02			0.003	0.002	0.003
Percent				52.5%	84.9%	1.1%	3.8%	8.5%	0.3%	1.3%		62.1%	97.0%	0.9%	2.1%		1.2%	37.5%	25.0%	37.5%

* other marine mammals: trips 6 and 14, Minke Whale; trip 13, Elephant Seal ** released alive

1995 Chum Fishery

Date	Trip	Sets (Total)	SIGHTINGS Sets	Percent	Harbor Seal	CA Sea Lion	Dall's Porpoise	ENCOUNTERS Sets	Percent	CA Sea Lion	Harbor Seal	Porpoise
25-Oct	1	12	2	17%	0.08	0.00	0.17	6	50%	0.58	0.08	0.078**
26-Oct	2	14	4	29%	0.07	0.43	0.00	10	71%	3.36	0.86	0.072***
1-Nov	3	14	1	7%	0.07	0.00	0.00	6	43%	1.29	0.50	0.00
2-Nov	4	14	4	29%	0.28	0.14	0.00	7	50%	2.07	0.14	0.00
3-Nov	5	12	0	0%	0.00	0.00	0.00	5	42%	2.25	0.25	0.00
9-Nov	6	14	2	14%	0.07	0.07	0.07	6	43%	0.93	0.21	0.00
10-Nov	7	13	2	15%	0.00	0.00	0.00	9	69%	2.54	0.08	0.00
11-Nov	8	14*	1	7%	0.00	0.00	0.00	6	43%	1.43	0.00	0.00
Totals	8	107	16		8	12	2			194	29	3
Mean					0.08	0.11	0.02			1.81	0.27	0.03
SE					0.017	0.025	0.011	55		0.261	0.060	0.021
Percent:				15.0%	33.3%	57.1%	9.5%		51.4%	85.8%	12.8%	0.9%

* includes four partial net sets ** Dall's Porpoise *** Harbor Porpoise

Appendix 5. Marine Mammal Abundance. Mean rate per set of marine mammal sightings, encounters and entanglements by date and species for the 1996 Sockeye and the 1995 Chum Test Fisheries. No marine mammals were entangled in the chum test fishery.

1995 Chum Fishery

Date	Trip	Sets (Total)	SIGHTINGS Sets	Percent	Rhino. Auklet	Unid. Murrelet	Common Murre	Ancient Murrelet	Marbled Murrelet	Unid. Alcid	Grebe Spp.	Scoter Spp.	Cormorant Spp.	Loon Spp.
25-Oct	1	12	1	8%	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26-Oct	2	14	0	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.07	0.00
1-Nov	3	14	7	50%	0.57	0.00	0.57	0.00	0.00	0.14	1.07	1.14	0.14	0.07
2-Nov	4	14	4	29%	0.14	0.00	0.07	0.00	0.07	0.00	1.00	0.43	0.07	0.07
3-Nov	5	12	2	17%	0.50	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00
9-Nov	6	14	6	43%	1.43	1.50	0.14	0.00	0.21	0.00	0.14	0.00	0.00	0.00
10-Nov	7	13	4	31%	1.23	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00
11-Nov	8	14	3	21%	0.14	0.00	0.00	0.21	0.00	0.07	0.00	0.00	0.00	0.00
Totals	8	107	27		55	21	11	9	4	3	35	22	4	2
Mean/set					0.51	0.20	0.10	0.08	0.04	0.03	0.33	0.21	0.04	0.02
SE					0.135		0.04		0.029	0.021				
Percent				25%	55%	20%	11%	9%	4%	3%				

1995 Chum Fishery

Date	Trip	Sets (Total)	ENCOUNTERS Sets	Percent	Rhino. Auklet	Grebe Spp.	Common Murre	Unid. Murrelet	Unid. Alcid	Loon Spp.	ENTANGLEMENTS Sets	Percent	Rhino. Auklet	Common Murre	Total
25-Oct	1	12	3	25%	0.42	0.00	0.00	0.00	0.00	0.00	1	8%	0.00	0.08	0.08
26-Oct	2	14	4	29%	0.50	0.43	0.14	0.00	0.14	0.00	3	21%	0.21	0.07	0.29
1-Nov	3	14	6	43%	0.43	1.00	0.29	0.00	0.00	0.07	2	14%	0.07	0.14	0.21
2-Nov	4	14	3	21%	0.21	0.14	0.00	0.00	0.00	0.00	1	7%	0.00	0.07	0.07
3-Nov	5	12	3	25%	0.67	0.33	0.00	0.00	0.00	0.00	1	8%	0.08	0.00	0.08
9-Nov	6	14	6	43%	1.64	0.29	0.71	0.14	0.00	0.00	3	21%	0.07	0.21	0.29
10-Nov	7	13	6	46%	2.08	0.08	0.08	0.00	0.00	0.00	3	23%	0.23	0.08	0.31
11-Nov	8	14	2	14%	0.43	0.00	0.00	0.00	0.00	0.00	5	36%	0.21	0.14	0.36
Totals	8	107	33		85	31	17	2	2	1	19		12	11	23
Mean/set					0.79	0.29	0.16	0.02	0.02	0.01			0.11	0.10	0.22
SE					0.181		0.068						0.033	0.033	0.045
Percent				31%	62%	22%	12%	1%	1%	1%		18%	52%	48%	100%

Appendix 6. Seabird Abundance and Entanglements/Chum Test Fishery. Mean rate per set of seabird sightings, encounters and entanglements by date and species for the 1995 Chum Test Fishery.

1996 Sockeye Fishery

SPECIES (caught/ entangled)	MONO n=168				PINGER n=153				20 MESH n=161				50 MESH n=160			
	Total	%*	Rate	SE	Total	%	Rate	SE	Total	%	Rate	SE	Total	%	Rate	SE
Sockeye																
Total	4391	100%	25.137	2.136	3415	85%	22.320	2.067	3669	89%	22.994	2.035	1643	39%	10.269	1.374
Alcids																
C. Murre	101		0.601	0.060	46		0.301	0.060	53		0.329	0.061	58		0.363	0.064
R. Auklet	34		0.202	0.053	25		0.163	0.041	19		0.118	0.032	7		0.044	0.024
M. Murrelet	1		0.006	0.006	0		0	0	0		0	0	0		0	0
P. Guillemot	0		0	0	1		0.007	0.007	0		0	0	0		0	0
Total	136	100%	0.810	0.173	72	58%	0.471	0.074	72	55%	0.447	0.080	65	50%	0.406	0.193
Marine Mammals																
Harbor Seals	0	*	0	0	1		0.007	0.007	2		0.012	0.009	0		0	0
Porpoise	0	*	0	0	0		0	0	0		0	0	5**		0.031	0.014
Total	0	*	0	0	1	-	0.007	0.007	2	*	0.012	0.009	5	*	0.031	0.014

* percent is catch rate divided by Mono catch rate
** includes 2 Harbor Porpoise and 3 Dall's Porpoise

95 Chum Fishery

SPECIES (caught/ entangled)	MONO n=103				20 MESH n=103				40 MESH n=103			
	Total	%*	Rate**	SE	Total	%	Rate	SE	Total	%	Rate	SE
Chum												
Total	2,671	100.0%	77.800	6.504	2,098	79%	61.107	5.301	1,833	69%	53.388	4.056
Alcids												
C. Murre	5		0.147	0.063	4		0.117	0.072	2		0.057	0.042
R. Auklet	4		0.117	0.057	4		0.117	0.019	3		0.087	0.051
Total	9	100%	0.261	0.067	8	90%	0.234	0.081	5***	56%	0.147	0.063

* percent is catch rate divided by Mono catch rate
** rate is catch or entanglement rate per full net set (3 x shackle set).
*** excludes one seabird caught in a partial net set (only two shackles deployed)

Appendix 7. Gear Comparisons. Total number, percent, mean rate per set and standard error for salmon, alcid, and marine mammal species entangled in gillnets by gear type for 1996 Sockeye and the 1995 Chum Test Fisheries.

1996 Sockeye

SPECIES (caught/ entangled)	AM COL n=129			DAYTIME n=384			PM COL n=129		
	Total	Rate*	SE	Total	Rate	SE	Total	Rate	SE
Sockeye	3,219	24.953	2.636	7,535	19.622	1.223	2,397	18.581	2.048
Percent				79%			74%		
Alcids									
C. Murres	80	0.612	0.093	103	0.268	0.036	75	0.581	0.091
R. Auklets	44	0.341	0.076	31	0.081	0.017	10	0.078	0.032
Total	126	0.969	0.254	134	0.349	0.062	85	0.659	0.160
Percent	100%			36%			68%		
Harbor Seal	1	0.008	0.008	2	0.005	0.004	0	0	0
Porpoise	0	0	0	4	0.101	0.005	1	0.008	0.008

* rate is catch or entanglement rate per set

1995 Chum Fishery

SPECIES (caught/ entangled)	AM COL n=51			DAYTIME n=195			PM COL n=63		
	Total	Rate*	SE	Total	Rate	SE	Total	Rate	SE
Chum	1,295	76.176	8.991	4,010	61.692	3.933	1,297	61.761	6.126
Percent	100%			81%			81%		
Alcids									
C. Murres	3	0.177	0.099	4	0.063	0.039	4	0.189	0.093
R. Auklets	3	0.177	0.099	6	0.093	0.036	2	0.096	0.066
Total	6	0.354	0.144	10**	0.153	0.048	6	0.285	0.117
Percent				43%			81%		

* rate is catch or entanglement rate per full net set (3 x rate per shackle set)
** excludes seabird caught in partial net set

Appendix 8. Time of Day Comparisons. Total number, percent, mean rate per set and standard error for salmon, alcid and marine mammal species entangled in gillnets by time of day category for the 1996 Sockeye and the 1995 Chum Test Fisheries.

1996 Sockeye Fishery

Variable/ Species	Salmon-Hein Banks n=198 Total	Mean	SE	Iceberg/ McArthur Bank n=16 Total	Mean	SE	Bluffs n=299 Total	Mean	SE	Strawberry Island n=79 Total	Mean	SE
Sightings												
C. Murre	1,886	9.525	1.297	475	29.688	16.470	10.406	34.803	5.486	1,066	13.364	3.018
R. Auklet	1,426	7.202	2.413	22	1.375	0.857	346	1.157	0.345	259	3.278	1.176
M. Murrelet	0	0.000	0.000	2	0.125	0.125	7	0.023	0.012	3	0.038	0.028
Other Alcid	4	0.020	0.012	0	0.000	0.000	46	0.154	0.066	7	0.089	0.077
Unid. Alcid	320	1.616	0.943	4	0.250	0.194	146	0.488	0.172	87	1.101	0.562
Total Alcids	3.636	18.364	3.472	503	31.438	16.351	10.951	36.625	5.503	1,411	17.861	3.171
Encounters												
C. Murre	486	2.455	0.426	31	1.938	0.868	1.659	5.548	0.741	417	5.278	1.603
R. Auklet	267	1.348	0.378	1	0.063	0.063	162	0.542	0.134	71	0.899	0.240
M. Murrelet	0	0.000	0.000	0	0.000	0.000	7	0.023	0.012	0	0.000	0.000
Other Alcid	3	0.015	0.009	0	0.000	0.000	22	0.074	0.045	0	0.000	0.000
Unid. Alcid	14	0.071	0.029	1	0.063	0.063	43	0.144	0.037	22	0.278	0.125
Total Alcids	770	3.889	0.630	33	2.063	0.704	1.893	6.331	0.761	510	6.456	1.616
Seals	284	1.434	0.136	52	3.250	0.955	500	1.672	0.089	49	0.620	0.087
Entanglements												
C. Murre	71	0.359	0.156	10	0.625	0.256	86	0.288	0.044	46	0.582	0.230
R. Auklet	42	0.212	0.050	3	0.188	0.101	15	0.050	0.015	15	0.190	0.057
M. Murrelet	0	0.000	0.000	0	0.000	0.000	1	0.003	0.003	0	0.000	0.000
P. Guillemot	1	0.005	0.005	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000
Total Alcids	114	0.571	0.165	13	0.813	0.319	102	0.341	0.050	61	0.772	0.236
Seals	0	0.000	0.000	0	0.000	0.000	3	0.010	0.006	0	0.000	0.000
Porpoise	3	0.015	0.009	0	0.000	0.000	1	0.003	0.003	1	0.013	0.013
Catch												
Sockeye	6,150	31.061	6.064	580	36.250	12.531	4.538	15.177	2.285	912	11.544	2.858

Variable/ Species	Lummi Island n=17 Total	Mean	SE	San Juan Channel n=4 Total	Mean	SE	Bird Rocks/ Kellett Ledge n=29 Total	Mean	SE	Total n=642 Total	Mean	SE
Sightings												
C. Murre	30	1.765	0.838	7	1.750	1.031	986	34.000	10.039	14,845	23.123	2.724
R. Auklet	42	2.471	1.984	21	5.250	5.250	70	2.414	0.849	2,186	3.405	0.784
M. Murrelet	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	12	0.019	0.007
Other Alcid	0	0.000	0.000	1	0.250	0.250	1	0.034	0.034	59	0.092	0.028
Unid. Alcid	6	0.353	0.266	0	0.000	0.000	235	8.103	5.176	798	1.243	0.39
Total Alcids	78	4.588	2.342	29	7.250	5.648	1,292	44.552	11.228	17,900	27.882	2.903
Encounters												
C. Murre	10	0.588	0.272	23	5.750	5.422	209	7.207	3.114	2,835	4.416	0.446
R. Auklet	7	0.412	0.193	8	2.000	2.000	32	1.103	0.765	548	0.854	0.141
M. Murrelet	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	7	0.011	0.006
Other Alcid	0	0.000	0.000	0	0.000	0.000	1	0.034	0.034	26	0.040	0.021
Unid. Alcid	1	0.059	0.059	0	0.000	0.000	1	0.034	0.034	82	0.128	0.025
Total Alcids	18	1.059	0.348	31	7.750	7,420	243	8.379	3.124	3,498	5.449	0.477
Seals	13	0.765	0.235	2	0.500	0.289	23	0.793	0.175	923	1.438	0.068
Entanglements												
C. Murre	5	0.294	0.143	11	2.750	1.601	29	1.000	0.630	258	0.402	0.067
R. Auklet	2	0.118	0.081	2	0.500	0.500	6	0.207	0.125	85	0.132	0.020
M. Murrelet	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	1	0.002	0.002
P. Guillemot	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	1	0.002	0.002
Total Alcids	7	0.412	0.150	13	3.250	1.974	35	1.207	0.634	345	0.537	0.071
Seals	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	3	0.005	0.003
Porpoise	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	5	0.008	0.003
Catch												
Sockeye	115	6.765	1.545	81	20.250	8.864	775	26.724	7.912	13,151	20.484	1.999

1996 Sockeye Fishery Survey Summary

Species	Salmon-Hein Banks n=16 Total	Rate*	SE	Iceberg n=23 Total	Rate	SE	Bluffs n=59 Total	Rate	SE	Strawberry Island n=10 Total	Rate	SE	Lummi Island n=7 Total	Rate	SE	Bird Rocks/ Kellett Ledge n=31 Total	Rate	SE	Total n=146 Total	Rate	SE
C. Murre	236	3.88	0.98	839	8.50	3.30	1517	6.04	1.26	364	14.37	5.77	9	0.35	0.18	2314	20.66	6.82	5279	9.63	1.73
R. Auklet	175	2.62	0.61	120	1.19	0.24	290	1.22	0.24	113	3.75	1.81	3	0.11	0.05	490	3.81	1.42	1191	1.99	0.35
M. Murrelet	0	0.00	0.00	18	0.17	0.08	267	1.25	0.38	1	0.03	0.03	2	0.07	0.07	2	0.02	0.02	290	0.55	0.16
P. Guillemot	9	0.13	0.07	59	0.60	0.30	101	0.44	0.10	1	0.03	0.03	0	0.00	0.00	9	0.08	0.04	176	0.31	0.05
Unid. Alcid	6	0.13	0.07	6	0.07	0.03	26	0.12	0.04	0	0.00	0.00	0	0.00	0.00	1	0.01	0.01	41	0.08	0.02
Total Alcid	426	6.76	1.40	1039	10.53	3.31	2203	9.06	1.32	479	18.17	5.96	14	0.53	0.23	2816	24.59	7.04	5977	12.55	1.80
Grebe	2	0.03	0.03	0	0.00	0.00	3	0.02	0.01	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	5	0.01	0.00
Cormorant	64	1.02	0.72	3	0.03	0.02	9	0.03	0.02	0	0.00	0.00	0	0.00	0.00	99	0.90	0.51	175	0.32	0.14
Phalarope	1	0.02	0.02	0	0.00	0.00	10	0.35	0.04	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	11	0.02	0.01

* rates are per 5 minute transect unit or approximately 3/4 nm.

Appendix 9. Location Comparisons/Sockeye Test Fishery. Total number and mean rate per set of alcid and marine mammal sightings, encounters and entanglements by species and sockeye salmon catch by location; and total number and mean number of seabirds per five minute transect unit (approximately 3/4 nm) by transect location for the 1996 Sockeye Test Fishery.

	1996 Sockeye			1995 Chum fishery		
Variables	**Sets Without Entanglements**	**Sets With Entanglements**		**Sets Without Entanglements**	**Sets With Entanglements**	
Physical	No. of Sets	No. of Sets	Percent	No. of Sets	No. of Sets	Percent
Total	484	158	25%	88	19	18%
Tidal State						
Flood Tide (sets)	149	40	21%	22	4	15%
High Slack	25	6	19%	0	0	0%
Ebb Tide (sets)	114	38	25%	29	7	19%
Low Slack	21	9	30%	1	0	0%
Mixed	175	65	27%	36	6	18%
Operational						
Not Run Net	310	108	26%	no data	no data	
Run Net	174	50	22%	no data	no data	
	Mean	**Mean**	**Difference**			**Difference**
Set Duration (min.)	116	125	9	137	157	20
Weather (index)	1.07	1.01	(0.06)	1.67	2.13	0.46
Seas (Beaufort scale)	0.99	1.43	0.44	2.15	2.07	(0.08)
Max-current (knots)	1.17	1.09	(0.08)	0.50	0.55	0.05
Depth (fathoms)	54	49	(4)	61	74	13
Biological						
Total Alcid Sightings	25.50	35.20	9.7	0.98	0.80	(0.2)
Total Alcid Encounters	3.80	10.50	6.7	0.82	1.47	0.6
Sockeye Catch	17.05	31.02	14	60.30	79.20	19

Appendix 10. Environmental Effects/Sockeye Test Fishery. Mean values contrasting physical and biological variables for sets with and without seabird entanglements for the 1996 Sockeye Test Fishery. See appendix 12 for sea state and weather units.

1996 Sockeye Fishery

Times of Day	All				Day and PM COL				Day Only			
	Mono	Pingers	20Mesh	50Mesh	Mono	Pingers	20Mesh	50Mesh	Mono	Pingers	20Mesh	50Mesh
Variables												
Sockeye												
(catch/set)												
Mean Fish Abundance	26.14	22.32	22.99	10.27	26.32	21.58	19.36	10.00	27.69	22.37	18.92	9.43
High Fish Abundance	45.48	41.73	42.12	18.37	45.84	39.52	35.33	17.67	48.09	41.57	34.46	16.00
Effort												
(272,000 fish)												
Mean Fish Abundance	10,406	12,186	11,831	26,485	10,334	12,604	14,052	27,200	9,822	12,157	14,380	28,847
High Fish Abundance	5,981	6,517	6,458	14,811	5,934	6,882	7,699	15,396	5,656	6,543	7,893	17,000
Seabirds												
(Entang./set)												
R. Auklet	0.202	0.163	0.118	0.044	0.097	0.105	0.095	0.023	0.119	0.121	0.053	0.031
C. Murre	0.601	0.301	0.329	0.363	0.612	0.266	0.333	0.163	0.525	0.176	0.213	0.143
Total Alcids	0.810	0.471	0.447	0.406	0.709	0.371	0.429	0.186	0.644	0.297	0.266	0.173
Alcids												
(Entanglements/set)												
R. Auklet	2,102	1,986	1,396	1,165	1,002	1,323	1,335	626	1,169	1,471	762	894
C. Murre	6,254	3,668	3,892	9,614	6,324	3,353	4,679	4,434	5,157	2,140	3,063	4,125
Alcids Entangled												
(Projected)												
Mean Fish Abundance												
Total Alcids	8,428	5,740	5,289	10,753	7,327	4,676	6,028	5,059	6,325	3,611	3,825	4,991
Percent	100%	68%	63%	128%	87%	55%	72%	60%	75%	43%	45%	59%
High Fish Abundance												
Total Alcids	4,845	3,070	2,887	6,013	4,207	2,553	3,303	2,864	3,642	1,943	2,100	2,941
Percent	57%	36%	34%	71%	50%	30%	39%	34%	43%	23%	25%	35%

Appendix 11. Management Model/Sockeye Test Fishery. Model of study results by gear type and time-of-day category for the 1996 Sockeye Test Fishery. Model estimates the total number of birds that might be entangled under a variety of management scenarios for periods of high fish abundance (weeks 1 to 3) and low fish abundance (weeks 4 and 5). It assumes a gillnet quota of 272,000 sockeye.

Beaufort Scale Sea State Codes

Code	Wind Speed	Effects
0	<1	Sea like mirror
1	1-3	Ripples with appearance of scales; no foam crests
2	4-6	Small wavelets; crests glassy, not breaking
3	7-10	Large wavelets; crests beginning to break; scattered whitecaps
4	11-16	Small waves becoming longer; numerous whitecaps
5	17-21	Moderate waves becoming longer; many whitecaps; some spray
6	22-27	Larger waves forming; whitecaps everywhere; more spray
7	28-33	Sea heaps up; white foam from breaking waves blown in streaks
8	34-40	Moderate high waves; waves breaking into spindrift; blowing foam

Weather Codes

0 = Clear (<10% cloud cover)
1 = Partly Cloudy (10-50% cloud cover)
2 = Cloudy (60-90% cloud cover)
3 = Overcast (>90% cloud cover)
4 = Drizzle
5 = Rain
6 = Fog
7 = Intermittent fog
8 = Other

Appendix 12. Codes. Sea state and weather codes.

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