Seabird Bycatch

Trends, Roadblocks, and Solutions

Edited by
> Edward F. Melvin
> Washington Sea Grant Program
> University of Washington
> > and
> Julia K. Parrish
> Zoology Department
> University of Washington

Acknowledgments

University of Alaska Sea Grant
P.O. Box 755040
203 O'Neill Bldg.
Fairbanks, Alaska 99775-5040
(907) 474-6707 Fax (907) 474-6285
http://www.uaf.edu/seagrant/

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Preface

Edward F. Melvin and Julia K. Parrish

Seabirds are incidentally killed in the course of fishing operations throughout the world's oceans. Seabird bycatch occurs both in coastal areas and on the high seas in almost all gear types. Although bycatch is often rare relative to target catch, by virtue of their life history, seabirds are vulnerable to population decline from subtle and chronic mortality. Because seabirds are long-lived, have delayed maturity, and may produce only one egg annually or biannually, populations can decline when adult survival drops by as little as 3 to 5% annually. For the same reason, seabird populations recover very slowly from significant mortality, whether it is episodic, as in oil spills or El Niño events, or chronic as in direct harvesting, introduced predators on seabird colonies, plastics ingestion, and fishing mortality. Many populations suffer mortality from some or all of these sources.

Seabird bycatch emerged as an important marine conservation issue in 1972 when C. Eric Tull and his colleagues (1972) published a paper in *Nature* estimating the fishing mortality of Thick-billed Murres *(Uria lomvia)* in the drift gillnet fishery targeting Atlantic salmon *(Salmo salar)* in the offshore waters of West Greenland at 500,000 per year. An additional 250,000 murres were taken annually by hunters. Although Christensen and Lear (1977) fine-tuned the estimate of annual murre bycatch down to 207,000 annually, these numbers triggered scrutiny of seabird bycatch in other drift gillnet fisheries throughout the world's oceans. Twenty years later, after much documentation of both seabird and marine mammal mortality in these fisheries, high seas drift gillnets were banned through international agreement in 1990.

Attention to seabird bycatch spread from high seas to coastal gillnet fisheries in the late 1970s with particular focus on bycatch of diving seabirds, the Alcidae. Studies have characterized seabird bycatch in the coastal gillnet fisheries in the Atlantic (Newfoundland, Canada, and throughout Europe) and in the Pacific (California to Alaska). Seabird mortality remains a serious conservation issue in most of these fisheries today.

With the demise of high seas drift nets came a proliferation of high seas longlines, mostly for pelagic fishes like tuna and billfishes, and high rates of incidental mortality of albatrosses and other procellariids. Longline bycatch was eventually linked to dramatic population declines of these species in the Southern Oceans. In a landmark paper, Nigel Brothers (1991) estimated the mortality of albatrosses in the Japanese tuna longline fishery in the Southern Oceans at 44,000 birds per year, focusing serious attention on characterizing the extent of seabird bycatch in longline fisheries worldwide and an international push for solutions.

The emergence of seabird bycatch as a fisheries conservation and management issue also galvanized the environmental community and helped spark the formation of campaigns by non-governmental organizations (NGOs) such as the Audubon Society's Living Oceans Program in the United States and BirdLife International's Seabird Conservation Program in South Africa. The political actions of NGOs continue to bring seabird conservation in marine fisheries to the attention of scientists, resource managers, and the public at local, national, and international levels. An example of their reach and effectiveness, as well as the prominence of seabird bycatch in global marine conservation, is the adoption of an international Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries in 1999 by the Food and Agriculture Organization of the United Nations (see the paper by Cooper et al., this volume).

Recognizing the escalation of seabird bycatch as a marine conservation and fisheries management issue, the Pacific Seabird Group (PSG) invited us to convene a symposium on seabird bycatch at their 26th Annual Meeting in Blaine, Washington. Although several symposia have been held in North America on fisheries bycatch, none have addressed the incidental mortality of seabirds. The PSG symposium was titled "Seabird Bycatch: Trends, Roadblocks and Solutions." Our purpose was to bring people together who have worked on seabird bycatch in various fisheries around the world and share information on (1) techniques to quantify this bycatch and its effect on populations, (2) obstacles to finding and implementing solutions, and (3) solutions to bycatch-specific technologies as well as the process by which they were developed and implemented. Ultimately, it was and is our hope that a sharing of experiences in this unique area would serve to identify successful processes and technologies that reduce bycatch in the long term as well as to trigger synergies and partnerships of those working in this important field.

The symposium featured fifteen presentations: three from the Southern Oceans, two from the Atlantic Ocean, and the balance from throughout the North Pacific. Presenters were of a diversity of disciplines including avian, marine mammal, fishery, and ecological sciences, marine policy and resource management, and the fishing industry. The symposium addressed two fundamental gear types used widely throughout the world's oceans: longlines targeting both pelagic and demersal species, and coastal drift and set gillnets targeting a variety of pelagic species.

This volume includes nine peer-reviewed papers and seven abstracts. One paper (Boggs) was not presented at the symposium, but is important work that was in progress at the time of the symposium. Also included is a synthesis of themes and issues relevant to seabird bycatch, which proposes a set of guidelines that should be followed in efforts to "solve" bycatch for seabirds and all other taxa. We thank all the authors for their hard work and contributions to this volume and the host of scientists who provided anonymous reviews. We wish to thank the Portland Migratory Bird office of the U.S. Fish and Wildlife Service for financial support. The

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The **Pacific Seabird Group** (PSG) is a volunteer society of professional seabird researchers and managers dedicated to the study and conservation of seabirds throughout the Pacific. PSG strives to increase the quality and quantity of seabird research through facilitating information exchange via annual meetings, symposia, standing committee work, and publications. PSG is committed to identification and assessment of significant threats to seabird populations in order to provide government agencies and other interested parties with expert advice on long-term conservation and management.

Symposium Synthesis

Edward F. Melvin and Julia K. Parrish

As additional pressures are put on marine resources, and additional responsibilities are placed on marine natural resource managers to create sustainable, ecosystem-level plans for fisheries management, decreasing seabird bycatch and bycatch in general is crucial. From this volume and other publications, it becomes obvious that seabird bycatch is a worldwide marine conservation issue. It is equally obvious that solutions to bycatch will not be easy. As with many conservation controversies, the stakeholders represent different value sets. In the case of fishery-related seabird mortality, bycatch is seen as everything from a nuisance causing loss of fishing time and occasionally gear, to a cause célèbre for shutting down the fishing industry. Thus, solutions must involve not only proactive gear modification and time-area regulation, but a serious commitment to conversation and education about the value systems of the players.

Based on this volume; literature on seabird and other nontarget, noncommercial bycatch; and our personal experience working to find solutions to seabird bycatch in both gillnet and demersal longline fisheries, we have synthesized the following characteristics or trends common to many seabird bycatch issues and the roadblocks that tend to hinder their solutions. Finally, we offer a set of guidelines for effectively solving bycatch problems regardless of taxa (Table 1). Our hope is that this volume will provide useful insight into the incidental mortality of seabirds in commercial fisheries and lead those confronting bycatch issues to recognize their complexity and solve them comprehensively.

Problem Statement (Trends)

Life History Bottleneck

Seabirds are long-lived and have delayed maturity and low fecundity. Whereas many finfish target species produce hundreds to hundreds of thousands of eggs per spawning season, many seabirds place their energies in rearing rather than egg production, laying only a single egg annually or biannually. Thus, populations can decline even at low levels of breeder mortality (3 to 5% annually) and recover very slowly. Seabirds are subject to multiple sources of mortality—both anthropogenic and natural—some of which are episodic (e.g., El Niño and oil spills) and some of which

Table 1. Set of guidelines for effectively solving bycatch problems.

Trends	Roadblocks	Solutions

• Life history bottleneck
• Conservation uncertainty
 	
• Rarity paradox
 	
• Mixed stock conundrum
• Forbidden species effect
  Reactive vs. proactive
• Alarm-solutions paradox
	• Lack of protection
	• Not threatened/not
	  important
	• Not commercial/not
	  important
	• Institutional inertia
	• Rush for regulations
	• No trust/no rewards
		• Cross-cultural teamwork
		  Two levels of proof
		• Forest for the trees
		  No reduction in target
		    catch
		  Significant decline in
		    affected species bycatch
		  No increase in other
		    species bycatch
		  Community level rather
		    than species du jour
		• Keep it simple
		• No silver bullet—toolbox
		  approach

are chronic (e.g., global warming). Thus, subtle increases in any chronic factor, or in the frequency of any episodic factor, can change population growth from positive to negative.

Conservation Uncertainty

Except in rare, well-studied cases, detailed colony-level information on seabird population size and trends is largely unknown. Information on seabird distribution, especially during the nonbreeding season, is even more sparse. The highly migratory nature of seabirds and the fact that distribution, abundance, and demography of pre-breeding seabirds are nearly impossible to know further complicates the picture. Thus, where nontrivial seabird bycatch has been established, it is often difficult to link that mortality to population declines at any single seabird colony.

Similarly, seabird and other nontarget bycatch has rarely been rigorously quantified in commercial or recreational fisheries. Observer coverage, when present, is often limited to a small percentage of the total fishing effort. Observer programs are often targeted toward bycatch of commercially important species, rather than at quantifying the totality of bycatch biodiversity. Even in the very few fisheries where seabird bycatch rates are known, almost never do we know how bycatch varies in space and time, or as a function of a myriad of physical (e.g., weather, oceanographic phenomena) or biological (e.g., seabird density, breeding status, or hunger) conditions. Thus, where population declines of seabirds have been clearly established, it is often difficult to link that mortality to specific fisheries, even when anecdotal observation of seabird bycatch indicates a potential conservation problem.

Rarity Paradox

In most fisheries, seabird bycatch is uncommon. Thousands to millions of target organisms may be captured for every seabird hauled in. Occasionally, a nontrivial number of seabirds may be captured in a single haul, but these mass events are vanishingly rare. At the same time, fishers are typically surrounded by hundreds to thousands of seabirds during fishing operations. Conservation problems arise when the effort across a fishery is much larger than for any individual vessel, such that seabird bycatch at the level of the fleet becomes a significant mortality source.

The rarity paradox has two major consequences. First, it is not intuitive—to fishers or fishery managers—that fisheries-related seabird mortality can have a negative effect on seabird populations. Second, research to either characterize bycatch rates or to test solution strategies requires huge sample sizes and is therefore expensive and logistically challenging. The rarity issue speaks to a great need to educate fishers and fishery managers about the life history characteristics of seabirds.

Mixed Stock Conundrum

Relatively healthy seabird stocks that can sustain some harvest without population level effects are frequently found in association with a highly endangered species where the capture of only a very few individuals can have severe consequences for the sustainability of the species. This may be especially true when fishery vessels are fishing in areas frequented by seabirds, and/or are attracting seabirds via offal discharge such that hundreds to thousands of birds surround the vessel (thus increasing the chances of finding a rare species). In these cases, the bycatch of even one bird can have a disproportional and crippling effect on an otherwise healthy fishery, which may or may not have been the cause of the seabird's endangered status. At the same time, bycatch of more common species may go relatively unnoticed as fishery managers react with crisis management rather than ecosystem consideration.

Forbidden Species Effect

The incidental capture of some species such as marine mammals, sea turtles, and seabirds are socially taboo in many first world nations, whether the populations are at risk or not. Bycatch of these charismatic animals can create a strong emotional response in some individuals and social sectors, unlinked to ecological reality. At a fundamental level, this is the difference between animal rights (concern for each individual) and conservation (concern for populations). Confusion between emotional concern and ecological concern can divert attention and resources away from genuine conservation problems and may generate ecologically inappropriate solutions.

Reactive vs. Proactive

Proactive attempts to reduce seabird bycatch are rare. In most cases, the approach is reactive; money to address and correct seabird bycatch problems result from "gun-to-the-head" scenarios where a severely endangered species interacts with fisheries and litigation is threatened or brought against the managing agency for redress. In these situations, the time needed to quantify the magnitude of the problem adequately, let alone design and test gear-based bycatch solutions, is limited to lacking. At the same time, money and commitment to address seabird bycatch more comprehensively (the proactive approach) are not forthcoming.

Alarm-Solutions Paradox

Conservation biology has been primarily concerned with sounding the alarm—establishing a pattern of decline and likely causality. Seabird bycatch is no different. With the exception of recent activity in longline fisheries, few attempts have been made to develop technologies or methods to reduce seabird mortality. Most of the energy created by the situation goes into proving that a problem exists, at the expense of finding a workable solution. Sounding the alarm often serves to vilify and alienate the fishing industry, stymieing the establishment of the partnerships necessary to find solutions.

Roadblocks

Lack of Protection

Even in first world nations, there is a distinct lack of conservation law to protect seabirds in fisheries. Where a legal framework does exist, it is rarely enforced (e.g., Migratory Bird Treaty Act in the United States). Furthermore, existing laws in one country are rarely matched by neighboring nations (e.g., Endangered Species Act in the United States). Given that many seabirds are highly migratory species, the geographical imbalance in conservation law stifles opportunities for scientists or mangers to effectively conserve seabirds.

Not Threatened/Not Important

A sidebar to the "Mixed Stock Conundrum" is the notion that if a species is not endangered, it is not important. All attention is focused on one species, but the fact that thousands of individuals of other species are taken in the same fishery can be completely ignored in characterizing the issues, or worse, in the quest for solutions.

Not Commercial/Not Important

It is rare that fishery management agencies employ scientists with expertise in anything other than fish, usually with a narrow focus on fish spe-

cies with a commercial value. Bycatch of noncommercial species (finfish or otherwise) is frequently ignored. Because seabird biologists in fishery agencies are rare to nonexistent, when issues arise involving seabirds, the capacity and will to address the problem effectively does not exist.

Institutional Inertia

Even when tools are available to reduce seabird bycatch, they may not be applied. Agencies and the fisheries they manage can be slow to accept change that is not seen as directly economically beneficial (and may even be portrayed by some as detrimental) and/or required by law. Once new regulations are established, there is often no adaptive management mechanism to monitor their effectiveness or allow for improvements.

Rush for Regulations

Once a clear conservation concern has been established, the reaction is often a mad dash for regulations. Unfortunately, proactive solution-oriented research is usually lacking. Operating in crisis mode, agencies are strongly tempted and even encouraged by environmentalists to import regulations or solutions developed outside of their fisheries just so that "something" is done. The result is that ineffective and occasionally inappropriate "solutions" can become codified into regulations (e.g., fishing at night in high latitude summer fisheries) or regulations can become so watered down as to be useless (e.g., voluntary measures). The greatest conservation "wrong" is to require untested solutions that are in fact ineffective at reducing bycatch in order to satisfy a political imperative. If fishers are asked to modify fishing gear or practices, the conservation benefit should be certain and clear.

No Trust/No Rewards

Fishers, scientists, and natural resource managers exist in distinctly different cultures, each with its own value sets, methods for evaluating problems, and communication pathways. However, all three must become bedfellows to solve bycatch issues effectively. Management agency personnel are rarely trusted by the fishing industry and vice versa. Both come with the baggage of previous battles lost and won. Fishers are seen as inherently biased and unable to regulate their own effort or conform to conservation regulations in the absence of outside oversight. When individual agency personnel are trusted by the industry, it is because these individuals have spent the time and effort building lines of communication with fishers. As such, they are rarely encouraged or rewarded by the agency for their efforts. Non-agency scientists have a greater probability of establishing trust within the industry, but many are not rewarded academically for working on applied science issues. Many academics discount fisher knowledge as anecdotal even though direct experience of commercial fishing by scientists is limited to nonexistent. Professionals able to

straddle these cultures and work under the rigorous conditions of commercial fishing are rare and perhaps the greatest limiting resource to finding bycatch solutions.

Solution Guidelines

Cross Cultural Teamwork

In order to find effective solutions, scientists, the fishing industry, and fishery resource managers must work together. Scientists must be willing to accept the role of partner in, rather than leader of, a solution-oriented process. The knowledge of experienced fishers must be brought to bear in developing bycatch strategies so that solutions are practical and do-able, and ultimately, accepted. Research testing bycatch reduction strategies must be done on fishing vessels so that testing conditions are authentic to commercial fisheries and outcomes of the research process are accepted without debate. Resource managers must be involved in the process as well, to learn the realities and constraints of fishing practices and gear and to shape resource management needs based on that understanding. Once all three communities are working together, interactive mechanisms for regulation implementation and adaptive management must be created. Cross-cultural teamwork results in proof at two levels: solution strategies are defensible at the scientific level and accepted by the management community, and solution strategies are practical and acceptable by industry standards.

Forest for the Trees

To be effective, bycatch solutions must significantly reduce the bycatch of the affected species, without significant reductions in target catch. Lost income from applying conservation solutions is a no-win situation for fishers and is strong incentive to circumvent conservation practices where possible. Equally important is the requirement that the bycatch solution for the species of today's crisis concern not increase the bycatch of other species in the system. Ideally, the search for bycatch solutions—as well as sustainable target species management—should happen at the ecosystem level rather than species by species as sequential crises come to the fore. In mixed stock cases, new markets for and products from non-endangered nontarget catch should be considered alongside technological fixes to reduce bycatch.

Keep It Simple

Solutions must be simple and straightforward. Ideally, technological fixes should be inexpensive. Financing expensive gear changes which reduce the bycatch of individual species of concern is not likely to be accepted by the fishing industry. At the same time, solutions must be relatively imper-

vious to misapplication and nonconformity. Establishing new observer programs to police bycatch solutions is not likely to be accepted by either the fishery or the regulatory agencies.

No Silver Bullet–Toolbox Approach

It is extremely rare that a single technology or practice will effectively solve all present and future bycatch issues in a single fishery. Instead the search should acknowledge from the outset that there are likely be multiple solutions which may be deployed concurrently and/or which change in effectiveness as a function of time of season and area. A "toolbox" of solutions provides flexibility and is more likely to address the complexity inherent in ecological systems.

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Off the Hook? Initiatives to Reduce Seabird Bycatch in Longline Fisheries

John Cooper
University of Cape Town
Rondebosch, South Africa

John P. Croxall
Natural Environment Research Council
Cambridge, U.K.

Kim S. Rivera
National Marine Fisheries Service
Juneau, Alaska

Abstract

The recent history of global initiatives to reduce seabird bycatch in longline fisheries is reviewed, highlighting in turn the activities of environmental and industry non-governmental organizations (NGOs), national governments, and inter-governmental bodies. At least 40 species of seabirds, especially albatrosses and petrels, are affected, with mortality rates in perhaps half of them leading to population decreases. An International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries, adopted by the Food and Agriculture Organization of the United Nations in June 1999, has much promise for effectively addressing the problem, if nations are willing to develop and implement it. Environmental NGOs and scientists should collaborate with the fishing industry to assist governments (and inter-governmental bodies where appropriate) to implement national plans of action in a way that would solve the problem and thereby keep the world's seabirds off the hook.

Introduction

Interactions between seabirds and fisheries are well known and described in the literature and have led to conservation concern in many seas around the world. They include direct effects (such as birds drowning in nets) and indirect effects, primarily via changes to the birds' food supply, either by enhancement (e.g., disposal of offal at sea) or by reduction due to high fishing levels (see Tasker et al. 2000 for a recent review). During the 1980s, seabird bycatch in longline fisheries was recognized as an additional conservation problem. Commencing with the first published observations of unsustainable catches of albatrosses in the Southern Ocean (Croxall 1990, Brothers 1991), seabird mortality of at least 40 species has been reported in many longline fisheries, in practically all of the world's oceans (reviewed by Brothers et al. 1999). The first sign of problems came from recoveries of banded seabirds from fishing vessels, coupled with observations of population decreases at breeding islands, such as of the Wandering Albatross *Diomedea exulans* (e.g., Weimerskirch and Jouventin 1987, Croxall and Prince 1990). However, it required direct observations aboard fishing vessels (Brothers 1991, Murray et al. 1993) before the magnitude of seabird bycatch in fisheries began to be realized. Seabirds are long lived and, depending on the relative impact of incidental mortality on adults and juveniles, some important effects may take years to be detected, even where long-term population studies exist. Distribution of longline fishing effort is, in many cases, poorly or unevenly known. The at-sea distribution of seabirds is also poorly known at relevant scales. Relating the two is difficult, but where good long-term population data (with appropriate overlap) exist, significant correlations have been detected (e.g., Weimerskirch et al. 1997)

Although longlining, which offers greater selectivity for target fish than do nets and trawls, has been presented as a relatively "environmentally friendly" fishing technique (e.g., Bjordal and Løkkeborg 1996), seabirds, especially albatrosses and petrels, swallow baited hooks and are subsequently drowned as the line being set pulls them below the sea surface. Birds can also be hooked during line-hauling and injured or killed, but mortality occurs much less frequently than during setting. In addition to seabirds, longlining is a cause of mortality of marine turtles, leading to concern being expressed for the survival of some species (e.g., Spotila et al. 1996) and of non-target species of fish, such as sharks (FAO 1999a). Interactions have also been reported with marine mammals (e.g., Ashford et al. 1996).

The concerns engendered by drowned seabirds being brought aboard fishing vessels and by decreasing populations at some breeding sites have led to a variety of activities nationally, regionally, and worldwide to combat the problem. In this review, rather than attempt a strict chronology, we highlight the relevant activities of both environmental and industry non-governmental organizations (NGOs), national governments, and inter-

governmental bodies, although we realize there has been, and continues to be, much interaction between all of these. We do not review the actual numbers of seabirds of the various species killed in the different longline fisheries of the world, nor the mitigation measures that have been proposed or adopted. For details of both of these, readers are referred to Brothers et al. (1999) and to Appendix 1.

A History of Concern

Non-governmental Organizations: Pressure for Action

In October 1996 an international group of approximately 20 environmental NGOs, loosely led by the United States-based Defenders of Wildlife and with the support of at least one governmental delegation (New Zealand), cosponsored a resolution "Incidental Mortality of Seabirds in Longline Fisheries" at the First World Conservation Congress of the World Conservation Union (IUCN) in Montréal, Canada. The resolution, adopted by a show of hands, called upon nations to reduce seabird mortality caused by longlining to "insignificant levels for affected species" (IUCN 1997a,b). The resolution has subsequently been furthered by IUCN through its Antarctic Advisory Committee, which has sent observers to various inter-governmental fora where seabirds and longlining have been discussed in the last few years.

Internationally, the Antarctic and Southern Coalition (ASOC; a linkage of ca. 250 NGOs in 50 countries) launched its Southern Ocean Fisheries Campaign in 1998, which includes the aim of monitoring and reducing seabird mortality from longlining. ASOC continues to pay special attention to the problem in the Southern Ocean by attending regional meetings and presenting information papers (B. Clark, The Antarctica Project, USA, pers. comm.). In Australia, ISOFISH (the International Southern Oceans Longline Fisheries Information Clearing House) has been active since late 1997 in unravelling trade in illegally caught Patagonian toothfish *(Dissostichus eleginoides)* in the Southern Ocean—a fishery known to kill many albatrosses and petrels, especially the White-chinned Petrel *(Procellaria aequinoctialis)* (ISOFISH 1998 a,b; 1999; CCAMLR 1998a). In 1998 and again in 1999 ASOC and the Humane Society International have called for Patagonian toothfish to be listed within either Appendix I or II of CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora), in an endeavor to bring unregulated trade under control (B. Clark, pers. comm.; N. Beynon, Humane Society International, Australia, pers. comm.). Further, some NGOs (including the United States–based Antarctica Project and Greenpeace International) are calling for cessation of fishing for toothfish, to protect both the fish and seabirds (G. Leape, Greenpeace, USA, pers. comm.). Greenpeace has also called for a "global suspension" of the southern bluefin tuna *(Thunnus maccoyii)* longline fishery, until it stops killing albatrosses (Greenpeace New Zealand 1998).

The Royal Society for the Protection of Birds (U.K.) working with the Norsk Ornitologisk Forening and the U.K. Joint Nature Conservation Committee (JNCC), have been testing mitigation measures (especially underwater setting tubes) in the Norwegian Sea (E. Dunn, RSPB, U.K., pers. comm.). A number of United States–based NGOs continue to press for improved regulations in domestic longline fisheries in Alaskan and Hawaiian waters, in order to protect the Short-tailed *(Phoebastria albatrus)* and Black-footed *(P. nigripes)* Albatrosses (both with a IUCN Vulnerable status, Croxall and Gales 1998) and the Laysan Albatross *(P. immutabilis)* (E.L. Gilman, Living Oceans Program Pacific representative, National Audubon Society, and G. Winegrad, American Bird Conservancy, pers. comm.). In a number of other countries, concerned NGOs are addressing the problem. However, there is much scope for increased activity in many others, including those most involved in longline fishing.

In 1997 BirdLife International established its Seabird Conservation Programme, with an investigation of seabirds and longlining as its first project (Cooper 1999). The programme, based in South Africa, works closely with BirdLife national partners in many countries to research the severity of the problem, encourage the adoption of mitigation measures, and to increase awareness. Earlier, BirdLife International had contributed to a process of evaluating the conservation status of the world's albatrosses, assigning IUCN threatened status to many of them, due primarily to the effects of longline-induced mortality on their populations (Croxall and Gales 1998). BirdLife International is currently reviewing the conservation status of all threatened seabirds, including those species affected by longlining (A. Stattersfield, BirdLife International, U.K., pers. comm.).

The role of the fishing industry in reducing seabird bycatch is also very important and should not be overlooked. Most mitigation measures (which include both the use of new equipment and better ways of using existing equipment) and regulations that have been adopted by various fisheries or nations originated from work undertaken in the Japanese tuna longlining fishery in the Australian sector of the Southern Ocean. The Japanese tuna longline industry has been involved in the development of mitigation measures that are progressively being adopted worldwide (Brothers et al. 1999). Longline industry associations in Japan (Japan Tuna Fisheries Cooperative Associations) and the United States (North Pacific Longline Association), as well as in other countries, have distributed educational material to fishers, highlighting methods that can be used effectively to reduce seabird bycatch and bait loss. In New Zealand the fishing industry has funded enhanced observer programs, monitoring of affected species, and mitigation research through a Conservation Services Levy program (West et al. 1999). There is a general recognition by most longline industry groups that a need exists to employ seabird bycatch reduction methods and devices in their respective fisheries, both for the sake of seabirds and for the sake of their fishing livelihoods. Of significance here is that reducing

bird bycatch in longline fisheries can result in operational benefits to the industry. Examples are the increased opportunities to catch more fish through avoiding or reducing bait loss to birds (Brothers 1991, Løkkeborg 1998) and preferential access by vessels with good mitigation records to scarce licenses to fish. Gear technology companies in several countries (such as Australia, New Zealand, and Norway) have been active of late in developing new equipment that will lead to bycatch reduction (Brothers et al. 1999; G. Robertson, Australian Antarctic Division, pers. comm.). Such developments are ultimately driven by market need, so fishing companies need to demand improvements for them to become commercially available.

Research into aspects of longline mortality of seabirds is now being undertaken by numerous scientists in many countries, including identifying factors causing bycatch, thereby providing new avenues for mitigation. In August 1998 about 50 concerned scientists came together in a roundtable discussion at the 22nd International Ornithological Congress held in Durban, South Africa, and adopted a statement of concern (Cooper and Wanless 1999). Scientists will continue to have a role, for example, in the development and testing of mitigation measures and the collecting and analyzing of mortality data from observer programs.

National Governments: Starting to Act

The Australian government continues to play a significant leadership role in efforts to take actions to reduce seabird bycatch. In 1992, soon after the alarming findings presented by Brothers (1991), the Australian Nature Conservation Agency sponsored a global review of threats to albatrosses (Gales 1993). Following the findings of a workshop associated with the First International Albatross Conference in Hobart, Tasmania, in 1995 (Alexander at al. 1997, Robertson and Gales 1998), the Australian Government in 1997 successfully nominated 11 albatross species at risk from longlining for inclusion in the Appendices of the Bonn Convention on the Conservation of Migratory Species of Wild Animals (CMS 1997, see below). Other activities include the production of a Threat Abatement Plan to reduce seabird mortality from longlines in terms of the Endangered Species Protection Act of 1992 (Environment Australia 1998), public release for comment in late 1999 of a draft recovery plan for albatrosses and giant petrels (Environment Australia 1999), research into mitigation measures (by the Australian Antarctic Division and Tasmanian Parks and Wildlife Service), and the publication of a mitigation booklet (Brothers 1996), now translated into several languages. Gales et al. (1999) provide a detailed review of Australian actions to date.

The United States government has also been active, in part due to the encouragement of NGOs such as the American Bird Conservancy and the Pacific Seabird Group. Most important, the fishing industry itself had applied pressure for action (especially via the North Pacific Longline

Association, which was highly concerned that Alaskan longline fisheries could be shut down via the U.S. Endangered Species Act of 1973 if the lack of mitigation measures led to mortality of the Short-tailed Albatross (T. Smith, North Pacific Longlining Association, pers. comm.). The regional fishery councils and the National Marine Fisheries Service, which manage fisheries in EEZ waters off Alaska and Hawaii, and the U.S. Fish and Wildlife Service have responded to the severity of the problem via seabird data collection by onboard observers, testing and adopting mitigation measures, producing biological opinions as required by the Endangered Species Act, and by holding workshops (Garcia and Associates 1998; McNamara et al. 1999; USFWS 1999a,b; Cousins 2001; Stehn et al. 2001; Cousins and Cooper 2000). A number of other major longlining countries (including Brazil, Canada, Chile, France, Japan, New Zealand, Norway, South Africa, Spain, United Kingdom, and Uruguay) have introduced regulations into their domestic and/or high-seas longline fisheries to reduce seabird mortality and/or are undertaking or facilitating studies of the problem. However, many other nations with known or potentially serious bird bycatch mortality in their longline fisheries still need to act.

Inter-governmental Bodies: The Way to Solution

Conservation of marine species lends itself to an inter-governmental approach: seabirds, for example, regularly cross international boundaries, and many species affected by longlining occur in international waters, out of the reach of national legislation. Action commenced within regional fishery organizations in the Southern Hemisphere, where seabird bycatch is severe (Brothers et al. 1999). In 1994 both the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and Commission for the Conservation of Southern Bluefin Tuna (CCSBT) set up working groups to investigate and report on seabird mortality (Haward et al. 1998). The CCAMLR Working Group on Incidental Mortality Arising from Longline Fishing (WG-IMALF), which includes in its membership scientists active in research on the affected seabirds, has been especially influential, resulting in longlining fishing in the Southern Ocean being well regulated by the Commission, save for that conducted by illegal, unregulated and unreported (IUU) "pirate" fishing vessels (CCAMLR 1998a,b; ISOFISH 1998a,b; ISOFISH 1999). Further, CCAMLR adopted a catch documentation scheme for toothfish in an endeavor to reduce IUU fishing at its October 1999 meeting, after holding an inter-sessional meeting on the subject in Brussels, Belgium, earlier in the year. Support for this initiative by way of a resolution has come from the XXIII Antarctic Treaty Consultative Meeting, held in Lima, Peru, in May-June 1999 (ATCM 1999). Regulations developed by CCAMLR are now being adapted and adopted in longline fisheries elsewhere in the world.

Another example of activity by a regional fishery body is that of the International Pacific Halibut Commission of the North Pacific (Canada and

the United States) which has undertaken some preliminary studies on bycatch levels and mitigation measures (Trumble 1999, Trumble and Geernaert 1999). Several other inter-governmental fishery bodies, however, have yet to investigate properly the scale of problem in their areas, including those regulating tropical tuna fisheries (Brothers et al. 1999).

In March 1997 the 22nd Session of the Committee on Fisheries (COFI) of the Food and Agriculture Organization of the United Nations (FAO) proposed that an "expert consultation" be undertaken into the problem of seabird mortality from longlining in order to develop a plan of action (FAO 1997). The governments of Japan and the United States agreed to fund the process. Accordingly, a Technical Working Group met in Tokyo, Japan, in March 1998 to produce a draft plan of action and to discuss solicited reviews (published after revision as Brothers et al. 1999). During the course of the rest of the year, two consultations were held in Rome, Italy, leading to the unanimous adoption of the "International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries" (IPOA-Seabirds) at the 23rd Session of COFI in February 1999. The plan was commended by the FAO Fisheries Ministerial in March and endorsed by the FAO Council in June and the FAO Conference in November 1999 (FAO 1998; FAO 1999a,b; J.W. Valdemarsen, FAO, Italy, pers. comm.). Because of its potential importance, the full text of the IPOA-Seabirds is included below (Appendix 1, see also FAO 1999c). Briefly, the IPOA-Seabirds, which is a voluntary measure, encourages longlining nations to investigate the scale of the problem, conduct mitigation research, and introduce measures by way of National Plans of Action, reporting back to the FAO's COFI at its 24th Session in 2001. To facilitate this, the IPOA-Seabirds summarizes recommended mitigation measures (FAO 1999c, Appendix 1), which have been described in detail by Brothers et al. (1999). This FAO initiative may be regarded as the most important international action to date, and it carries much promise as an important step toward the solution of the longlining and seabird bycatch problem. The United States released its draft National Plan of Action in December 1999 for public comment (Federal Register, Vol. 64, No. 249, 29 December 1999 pp. 73017-73018; D. Kerstetter, National Marine Fisheries Service, USA, pers. comm.), but progress in other countries that undertake longlining so far appears to be minimal.

The listing of threatened albatrosses in the Appendices of the Bonn Convention (CMS) in 1997 has opened the way for a Regional Agreement to further their conservation. Again, Australia has taken the lead, via the Group of Temperate Southern Hemisphere Countries on the Environment (the Valdivia Group, comprising Argentina, Australia, Brazil, Chile, New Zealand, South Africa, and Uruguay), by sponsoring the "Inaugural Meeting of the Valdivia Working Group on Albatross" in Canberra, Australia, in June 1999 (Humane Society International Tech. Bull. 1998; P. Botha, Department of Environmental Affairs and Tourism, South Africa, pers. comm.). A related development has been the successful nomination to Appendix II

of the CMS by South Africa of a further seven Southern Ocean seabird species of the petrel genera *Macronectes* and *Procellaria* that are at risk from longlining (Huyser et al. 1999). These species were accepted for listing by the CMS at its 6th Conference of Parties, held in South Africa in November 1999. This allows for their inclusion in a Regional Agreement. Further, at the CMS' 6th COP two resolutions, on the urgent need for an agreement on Southern Hemisphere albatrosses and on fishery bycatch, including of seabirds, were adopted.

Last, the problem of seabird bycatch in longline fisheries has now been discussed in the General Assembly of the United Nations, the world's most senior inter-governmental body, which adopted a resolution at its 53rd Session in 1998, noting its concern with "reports of the continued loss of sea birds" and its satisfaction with the FAO initiative (described above), urging States to reduce fishery bycatch (UN 1999). This followed the report by the UN Secretary General to the General Assembly on the subject of "Oceans and the Law of the Sea," which included information on the longlining problem and a call for a resolution by BirdLife International's Seabird Conservation Programme, via the Endangered Seas Campaign of the World Wide Fund for Nature (UN 1998).

The Future: What Actions Now?

Saving seabirds from drowning on longline hooks is a solvable problem. Reasonably effective (and inexpensive) mitigation measures already exist and their correct use has already resulted in substantial reductions in mortality in several fisheries (e.g., CCAMLR 1998a,b; Brothers et al. 1999). New mitigation measures, currently under test and development in several countries, offer significant potential improvements. However, as Croxall (1998) has noted, the adoption of effective mitigation measures and national agreements to minimize or eliminate seabird mortality are unlikely to be sufficient on their own. Necessary additional activities include:

1. Educating fishers to the benefit they can derive from no longer catching seabirds.

2. Creating and financing schemes to help fishers use devices to reduce seabird bycatch and to monitor their effectiveness.

3. Using the full range of international conventions and agreements to protect seabirds and to regulate longline fisheries so as to reduce (and ultimately eliminate) seabird mortality.

4. Inducing nations not signatory to these conventions and agreements to abide by their provisions—in particular addressing the problem of "pirate" fishing.

BirdLife International's Seabird Conservation Programme, working through the national partnership in over 80 countries, will run a global campaign to address these issues from 2000, commencing with persuading and facilitating the major longlining nations to "sign on" to the FAO's IPOA-Seabirds.

Two seabird bycatch workshops to be held in 2000, (1) in Canada in April, under the auspices of the Circumpolar Seabird Working Group of the inter-governmental Conservation of Arctic Flora and Fauna (CAFF) and (2) in Hawaii, USA, in May as part of the Second International Conference on Albatrosses and Petrels will act as opportunities for updates and solutions to the problem. A third workshop on seabird bycatch mitigation planned be held in New Zealand later in the year will actively involve the fishing industry (J. Molloy, Department of Conservation, New Zealand, pers. comm.).

It is considered that the best approach is one where the major players, environmental and industry NGOs, governments, and inter-governmental bodies, act in unison at both national and international levels: we do not recommend an adversarial approach to solving the problem. If we can make good progress in setting and reaching targets involving seabird research, fishing technology and management, public awareness and education, and national and international legislation, not only will we have improved the prospects for seabirds in the 21st century but we will have also laid a good foundation for improving the health of their ecosystem—the world ocean.

Acknowledgments

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Appendix 1

FAO International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries

Introduction

1. Seabirds are being incidentally caught in various commercial longline fisheries in the world, and concerns are arising about the impacts of this incidental catch. Incidental catch of seabirds may also have an adverse impact on fishing productivity and profitability. Governments, non-governmental organizations, and commercial fishery associations are petitioning for measures to reduce the mortality of seabirds in longline fisheries in which seabirds are incidentally taken.

2. Key longline fisheries in which incidental catch of seabirds are known to occur are: tuna, swordfish, and billfish in some particular parts of oceans; Patagonian toothfish in the Southern Ocean, and halibut, black cod, Pacific cod, Greenland halibut, cod, haddock, tusk, and ling in the northern oceans (Pacific and Atlantic). The species of seabirds most frequently taken are albatrosses and petrels in the Southern

Ocean, northern fulmars in the North Atlantic, and albatrosses, gulls, and fulmars in the North Pacific fisheries.

3. Responding to the need to reduce the incidental catch of seabirds in commercial fisheries in the Southern Ocean, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) adopted mitigation measures in 1992 for its 23 member countries to reduce incidental catch of seabirds.

4. Under the auspices of the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), Australia, Japan, and New Zealand have studied and taken seabird mitigation measures in their southern bluefin tuna longline fishery since 1994, and in 1995 CCSBT adopted a recommendation relating to ecologically related species, including the incidental mortality of seabirds by longline fishing. The recommendation stipulates a policy on data and information collection, mitigation measures, as well as education and information dissemination. All member nations of CCSBT have made the use of bird scaring lines (tori poles) mandatory in their fisheries.

5. The United States of America also adopted, by regulation, measures for reducing incidental catch of seabirds for its groundfish longline fisheries in the Bering Sea/Aleutian Islands and Gulf of Alaska in 1997, and for its halibut fishery in 1998. The United States is currently developing measures to mitigate the incidental catch of seabirds in the Hawaiian pelagic longline fisheries. Several other countries with longline fisheries have likewise adopted similar mitigation measures.

Origin

6. Noting an increased awareness about the incidental catch of seabirds in longline fisheries and its potential negative impacts on seabird populations, a proposal was made at the Twenty-second Session of the Committee on Fisheries (COFI) in March 1997 that FAO organize an expert consultation, using extra-budgetary funds, to develop Guidelines leading to a Plan of Action to be submitted at the next Session of COFI aiming at a reduction in such incidental catch.

7. The International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (IPOA-SEABIRDS) has been developed through the meeting of a Technical Working Group in Tokyo 25-27 March 1998, and the Consultation on the Management of Fishing Capacity, Shark Fisheries, and Incidental Catch of Seabirds in Longline Fisheries held 26-30 October 1998 and its preparatory meeting held in Rome 22-24 July 1998.

Nature and Scope

8. IPOA-Seabirds is voluntary. It has been elaborated within the framework of the Code of Conduct for Responsible Fisheries as envisaged by Article 2 (d). The provisions of Article 3 of the Code of Conduct apply to the interpretation and application of this document and its relationship with other international instruments. All concerned States are encouraged to implement it.

9. The IPOA-SEABIRDS applies to States in the waters of which longline fisheries are being conducted by their own or foreign vessels and to States that conduct longline fisheries on the high seas and in the exclusive economic zones (EEZ) of other States.

Objective

10. Taking into account in particular the objectives of articles 7.6.9 and 8.5 of the Code of Conduct, the objective of the IPOA-SEABIRDS is to reduce the incidental catch of seabirds in longline fisheries where this occurs.

Implementation

11. In implementing the IPOA-SEABIRDS States should carry out a set of activities. This should be done as appropriate in conjunction with relevant international organizations. The exact configuration of this set of activities will be based on an assessment of the incidental catch of seabirds in longline fisheries.

12. States with longline fisheries should conduct an assessment of these fisheries to determine if a problem exists with respect to incidental catch of seabirds. If a problem exists, States should adopt a National Plan of Action for reducing the incidental catch of seabirds in longline fisheries (NPOA-SEABIRDS). (See below the "Technical note on developing a National Plan of Action for reducing the incidental catch of seabirds in longline fisheries.") When developing the NPOA-SEABIRDS experience acquired in regional management organizations should be taken into account as appropriate. FAO should provide a list of experts and a mechanism of technical assistance to countries for use in connection with development of NPOA-SEABIRDS.

13. States which determine that an NPOA-SEABIRDS is not necessary should review that decision on a regular basis, particularly taking into account changes in their fisheries, such as the expansion of existing fisheries and/or the development of new longline fisheries. If, based on a subsequent assessment, States determine that a problem exists,

they should follow the procedures outlined in paragraph 12, and implement an NPOA-SEABIRDS within two years.

14. The assessment should be included as a part of each relevant State's NPOA-SEABIRDS.

15. Each State is responsible for the design, implementation, and monitoring of its NPOA-SEABIRDS.

16. States recognize that each longline fishery is unique and the identification of appropriate mitigation measures can only be achieved through on-the-spot assessment of the concerned fisheries. Technical and operational mitigation measures are presently in use or under development in some longline fisheries where incidental catch of seabirds occurs. Measures developed by different States are listed in a Technical Note at the end of this document. This list does not prejudice the right of States to decide to use any of these or other suitable measures that may be developed. A more comprehensive description and discussion of the mitigation measures currently used or under development can be found in FAO Fisheries Circular No. 937.

17. States should start the implementation of the NPOA-SEABIRDS no later than the COFI Session in 2001.

18. In implementing their NPOA-SEABIRDS States should regularly, at least every four years, assess their implementation for the purpose of identifying cost-effective strategies for increasing the effectiveness of the NPOA-SEABIRDS.

19. States, within the framework of their respective competencies and consistent with international law, should strive to cooperate through regional and subregional fisheries organizations or arrangements, and other forms of cooperation, to reduce the incidental catch of seabirds in longline fisheries.

20. In implementing the IPOA-SEABIRDS States recognize that cooperation among States which have important longline fisheries is essential to reduce the incidental catch of seabirds given the global nature of the issue. States should strive to collaborate through FAO and through bilateral and multilateral arrangements in research, training, and the production of information and promotional material.

21. States should report on the progress of the assessment, development and implementation of their NPOA-SEABIRDS as part of their biennial reporting to FAO on the Code of Conduct for Responsible Fisheries.

Role of FAO

22. FAO will, as and to the extent directed by its Conference, and as part of its Regular Programme activities, support States in the implementation of the IPOA-SEABIRDS.

23. FAO will, as and to the extent directed by its Conference, support development and implementation of NPOA-SEABIRDS through specific, in-country technical assistance projects with Regular Programme funds and by use of extra-budgetary funds made available to the Organization for this purpose.

24. FAO will, through COFI, report biennially on the state of progress in the implementation of the IPOA-SEABIRDS.

Technical note on developing a National Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries (NPOA-SEABIRDS)

This is not an exclusive or necessarily all-encompassing list but provides guidance for preparation of the NPOA-SEABIRDS.

The NPOA-SEABIRDS is a plan that a State designs, implements, and monitors to reduce the incidental catch of seabirds in longline fisheries where it occurs.

I. Assessment

1. The purpose of the assessment is to determine the extent and nature of a State's incidental catch of seabirds in longline fisheries where it occurs.

2. The assessment may include, but is not limited to, the collection and analysis of the:

   • Criteria used to evaluate the need for an NPOA-SEABIRDS.

   • Fishing fleet data (numbers of vessels by size).

   • Fishing techniques data (demersal, pelagic, methods).

   • Fishing areas.

   • Fishing effort by longline fishery (seasons, species, catch, number of hooks per year per fishery).

   • Status of seabird populations in the fishing areas, if known.

   • Total annual catch of seabirds (numbers per 1000 hooks set per species per longline fishery).

- Existing mitigation measures in use and their effectiveness in reducing incidental catch of seabirds.

- Incidental catch of seabird monitoring (observer program, etc.).

- Statement of conclusions and decision to develop and implement an NPOA-SEABIRDS.

II. NPOA-SEABIRDS

The NPOA-SEABIRDS may contain the following elements:

1. Prescription of mitigation measures

    The NPOA-SEABIRDS should prescribe appropriate mitigation methods. These should have a proven efficiency, and be cost-effective for the fishing industry. If effectiveness of mitigation measures can be improved by combining different mitigation measures or devices, it is likely that each State will find it advantageous to implement a number of different measures that reflect the need and particular circumstances of their specific longline fishery.

2. Research and development

    The NPOA-SEABIRDS should contain plans for research and development, including those aiming: (i) to develop the most practical and effective seabird deterrent device; (ii) to improve other technologies and practices which reduce the incidental capture of seabirds; and (iii) undertake specific research to evaluate the effectiveness of mitigation measures used in the longline fisheries, where this problem occurs.

3. Education, training and publicity

    The NPOA-SEABIRDS should prescribe means to raise awareness among fishers, fishing associations, and other relevant groups about the need to reduce the incidental catch of seabirds in longline fisheries where this occurs; National and International Plans of Action and other information on the incidental catch of seabirds in longline fisheries; and to promote the implementation of the NPOA-SEABIRDS among national industry, research, and its own administration.

    Provide information about technical or financial assistance for reducing the incidental catch of seabirds.

    Preferably design and implementation of outreach programs for fishers, fisheries managers, gear technologists, maritime architects, shipbuilders, and conservationists, and other interested members of the public should be described in the plan. These programs should aim at

improving the understanding of the problem resulting from incidental catch of seabirds and the use of mitigation measures. The outreach program may include educational curricula, and guidelines disseminated through videos, handbooks, brochures, and posters. The program should focus on both the conservation aspects of this issue and on the economic benefits of expected increased fishing efficiency inter alia by eliminating bait loss to seabirds.

4. Data Collection

Data collection programs should collect reliable data to determine the incidental catch of seabirds in longline fisheries and the effectiveness of mitigation measures. Such programs may make use of onboard observers.

Technical note on some optional technical and operational measures for reducing the incidental catch of seabirds in longline fisheries

I. Introduction

To reduce the incidental catch of seabirds, it is essential to reduce the number of encounters between seabirds and baited hooks. It should be noted that, if used in combination, the options could improve mitigation effectiveness.

For each of the measures, the effectiveness and the cost involved for fishers are briefly presented. In this presentation, "effectiveness" is defined as to what extent the measures reduce incidental catch of seabirds; "cost" is defined as the initial cost or investment and any ongoing operational costs.

Other technical options are currently under development and fishers and researchers in the field may develop new mitigation measures, so the list of measures is likely to increase over time.

If effectiveness of mitigation measures can be improved by combining different mitigation measures or devices, each State may find it advantageous to implement different measures that are more suitable for their conditions and reflect the needs of their specific longline fisheries.

The list below should not be considered mandatory or exhaustive and FAO shall maintain a database of measures that are in use or under development.

II. Technical Measures

1. Increase the sink rate of baits

    a. Weighting the longline gear

Concept: Increase the sinking speed of baited hooks and reduce their exposure time to seabirds.

Effectiveness: Studies have shown that appropriate line-weighting can be highly effective in avoiding bait loss to birds.

Cost: The cost is the initial purchase of the weighting material (either heavier gear or weights) and any ongoing replacement of weights lost during fishing.

b. Thawing bait

Concept: Overcome buoyancy problems in bait by thawing and/or puncturing swim bladders.

Effectiveness: Rate of incidental catch of seabirds is reduced when thawed baits are used. It has also been shown that bait fish with deflated swim bladders sink more quickly than those with inflated swim bladders did.

Cost: Possible costs include bait thawing rack, or extra weight to compensate flotation resulting from the air bladder.

c. Line-setting machine

Concept: Increase line sinking rate by removing line tension during gear deployment.

Effectiveness: Although no quantitative assessments have been done, this practice would result in the line sinking more rapidly thereby reducing availability of baited hooks to seabirds.

Cost: For some fisheries, initial costs may include purchase of a line-setting device.

2. Below-the-water setting chute, capsule, or funnel

Concept: Prevent access by seabirds to baited hooks by setting line under water.

Effectiveness: Underwater setting devices are still under development but could have high effectiveness.

Cost: Initial cost would include purchase of the underwater setting device.

3. Bird-scaring line positioned over or in the area where baited hooks enter the water

Concept: Prevent seabirds access to baited hooks where they enter the water. The bird scaring line is designed to discourage birds from

taking baited hooks by preventing their access to baited hooks. Design specifications may vary by vessel, fishing operation, and location and are critical to its effectiveness. Streamer lines and towing buoys are examples of these techniques.

Effectiveness: A number of studies and anecdotal observations have demonstrated significant effectiveness of these devices when properly designed and used.

Cost: Low initial cost for the purchase and installation of bird-scaring line.

4. Bait-casting machine

Concept: Places bait in area protected by a bird scaring line and outside the turbulence caused by the propeller and the ship's wake.

Effectiveness: Deployment of bait under the protection zone of the bird-scaring line reduces the availability of baited hooks to seabirds. The extent to which bait loss is reduced by the use of bait-casting machines, used either without a bird-scaring line or in such a manner that baits are not protected by a bird-scaring line, is yet to be determined.

Cost: High; initial costs may include purchase of a bait-casting device.

5. Bird-scaring curtain

Concept: To deter seabirds from taking baited hooks during the haul by using a bird scaring curtain.

Effectiveness: Anecdotal evidence indicates that the bird-scaring curtain can effectively discourage birds from seizing baits in the hauling area.

Cost: Low cost for materials.

6. Artificial baits or lures

Concept: Reduce palatability or availability of baits.

Effectiveness: New baits are still under development and effectiveness has yet to be resolved.

Cost: Currently unknown

7. Hook modification

Concept: Utilize hook types that reduce the probability of birds getting caught when they attack a baited hook.

Effectiveness: Hook size might affect the species composition of incidentally caught seabirds. The effect of modification of hooks is, however, poorly understood.

Cost: Unknown.

8. Acoustic deterrent

    Concept: Deterring birds from the longline using acoustic signals, such as high frequency, high volume, distress call, etc.

    Effectiveness: Low probability of being effective as background noises are loud and habituation to noises is common among seabirds.

    Cost: Unknown.

9. Water cannon

    Concept: Concealing baited hooks by using high pressure water.

    Effectiveness: There is no definite conclusion about the effectiveness of this method.

    Cost: Unknown.

10. Magnetic deterrent

    Concept: Perturbing the magnetic receptors of the birds by creating magnetic fields.

    Effectiveness: No indication of effect in practical experiments.

    Cost: Unknown.

III. *Operational Measures*

1. Reduce visibility of bait (Night setting)

    Concept: Set during hours of darkness and reduce illumination of baited hooks in the water.

    Effectiveness: This method is generally recognized as being highly effective. However, effectiveness can vary between fishing grounds and also seasonally according to the seabird species. Effectiveness of this measure may be reduced around the full moon.

    Cost: A restriction of line setting to the hours of darkness may affect fishing capacity, especially for smaller longliners. Small costs may be incurred to make vessel lighting appropriate. Such restriction can also entail investing in costly technology for maximizing fishing efficiency in a shorter period of time.

2. Reduce the attractiveness of the vessels to seabirds

   Concept: Reducing the attractiveness of vessels to seabirds will reduce the potential for seabirds being incidentally caught. Materials (e.g., fish discards, garbage) discharged from vessels should be at a time or in a way that makes them least available to birds or least likely to cause them harm. This includes avoidance of the dumping of discarded fish, offal, fish heads, etc. with embedded hooks. If dumping offal is unavoidable, it should be done on the opposite side of the vessel to where lines are being set or in such a manner that birds are not attracted to the vessel (e.g., at night).

   Effectiveness: The issue of offal discharge is a complex one, and there have been conflicting results regarding effects of various procedures in the studies done to date.

   Cost: Low; in some situations costs may be associated with providing for offal containment or reconfiguration of offal discharge systems on the vessel.

3. Area and seasonal closures

   Concept: Reduce incidental catch of seabirds when concentrations of breeding or foraging seabirds can be avoided.

   Effectiveness: Area and seasonal closures could be effective (such as in high density foraging areas or during the period of chick care when parental duties limit the distances adults can fly from breeding sites) although displacement of fishing fleet to other seabird areas needs to be considered.

   Cost: Unknown, but a restriction on fishing by area or season may affect fishing capacity.

4. Give preferential licensing to vessels that use mitigation measures that do not require compliance monitoring

   Concept: Incentive provided for effective use of mitigation measures that do not require compliance monitoring.

   Effectiveness: May be highly effective in stimulating the use of mitigation measures and development of fishing systems that reduce incidental catch of seabirds.

   Cost: Unknown.

5. Release live birds

   Concept: If despite the precautions seabirds are incidentally caught, every reasonable effort should be made to ensure that birds brought

onboard alive are released alive and when possible hooks should be removed without jeopardizing the life of the birds.

Effectiveness: Depends on the number of birds brought onboard alive and this is considered small by comparison to the numbers killed in line setting.

Cost: Unknown.

Reducing Seabird Bycatch in Longline Fisheries by Means of Bird-Scaring Lines and Underwater Setting

Svein Løkkeborg
Institute of Marine Research
Bergen, Norway

Abstract

Seabirds scavenge baits from the hooks of commercial longline gear resulting in bait loss and seabird mortality. This interaction may cause decline in seabird populations and seriously reduce efficiency of fishing gear. Various mitigation measures capable of reducing the likelihood of seabird incidental catches have been proposed and described, but only a few studies have been conducted to quantify their effectiveness. An experiment to quantify seabird bycatch and bait loss caused by seabirds was carried out in the course of commercial longlining. Data were obtained from longlines set using three different mitigation measures and compared with those of longlines set without such measures. Potential increases in catches of target fish by using such measures were also quantified. The three measures tested included two different types of bird-scaring line (lines with suspended streamers that are towed astern during setting) and an underwater setting funnel. In the course of 11 settings for each of these methods, zero and two seabirds respectively were caught using one or the other of the bird-scaring lines, and six with the setting funnel, compared with 74 birds when no device was used. The experiment demonstrated reduced bait loss and increased catch rates of target species in settings where either mitigation measure was employed. Increased catch rates were most pronounced for lines that were set using one of the bird-scaring lines.

Introduction

Seabird bycatch is a problem in some longline fisheries during certain seasons, and attraction of seabirds to longline baits may cause incidental mortality and bait loss (Weimerskirch and Jouventin 1987, Brothers 1991, Cherel et al. 1996, Kalmer et al. 1996, Weimerskirch et al. 1997, Løkkeborg 1998). This effect of longline fishing thus comprises a twofold problem as it may cause seabird populations to decline, while it also reduces gear efficiency. The most serious concerns regarding seabird population declines focus on albatross populations in the Southern Oceans and the north Pacific (Weimerskirch and Jouventin 1987, Croxall et al. 1990, Moloney et al. 1994, Prince et al. 1994, Woehler 1996), whereas in the north Atlantic, interactions between seabirds and longline fisheries are regarded merely as a problem for longlining efficiency and profitability (Løkkeborg 1998).

Various mitigation measures capable of reducing the likelihood of seabird bycatch have been described (Brothers et al. 1999a). Fishermen prefer modifying fishing operations and equipment to restrictions, such as confining line setting to the hours of night or restricting fishing areas or seasons, because such restrictions are more likely to affect profitability (see Discussion). The greatest potential for solution thus lies in modifications that either make the baited hooks less available to seabirds or devices that deter birds from taking baited hooks while maintaining or improving catch rates. However, few studies have been designed to quantify the effectiveness of such measures (Brothers et al. 1999b).

Longlining has a long tradition in Norway, and large proportions (15-90%) of several of the most important groundfish resources in Norwegian waters are taken by longlines (Bjordal and Løkkeborg 1996). The longline vessels used in these fisheries vary greatly in size (8-50 m) and operate both on coastal and high-sea fishing grounds. The Norwegian longline fleet was made up of 813 vessels in 1996, of which 79 were above 25 m and landed 60% of the total catch of 144,000 metric tons (Brothers et al. 1999a). The larger vessels that operate far offshore and on high-sea fishing grounds stay at sea for six to seven weeks and use the Mustad autoline system (61 vessels in 1996). Norwegian fishermen are aware that seabirds taking bait affects longline catchability. They therefore commonly use a line with floats attached to its end, and the line is towed during setting with the floats moving in the area where birds may take baits.

I compared three mitigation measures in the course of commercial longlining to determine if seabird bycatch and bait loss could be reduced in Norwegian longline fisheries. Mitigation measures included two different types of bird-scaring lines and an underwater setting funnel, and their effectiveness was compared to a control. Recognizing that increased fish catch and profit are important incentives for fishermen to employ mitigation measures, I also quantified fish catch to determine if mitigation measures increased catch rates of target fish species compared to the control. Bird-scaring lines and underwater setting funnels have both been shown

to reduce seabird bycatches (Løkkeborg 1998), but to the best of my knowledge increased catches of target fish species by the use of seabird mitigation measures have not been demonstrated.

Methods

The experiment was conducted during an 11-day period from 13 August 1998 on a commercial longliner (M/S *Søviknes*) operating on fishing grounds (57-359 m depth) off the coast of mid-Norway (63°02′-64°33′N). The vessel was equipped with the Mustad autoline system and an underwater setting funnel, and used 7 mm diameter longlines rigged with EZ-baiter hooks (size: 12/0, hook spacing: 1.4 m). The lines were baited with a combination of mackerel and squid. Each day, four fleets of experimental lines (about 6,500 hooks each) were set in randomized order using the three mitigation measures and a control. The lines were set in the morning and retrieved during the day and night, as is typical of this commercial fishery. Most of the lines were set in daylight, in that 75% of the fleets were set after sunrise.

Three of the four fleets were set using one of three types of seabird mitigation measures: two different types of bird-scaring line and an underwater setting funnel. The fourth fleet was set as a control without using any mitigation measure. The bird-scaring lines had floats attached to their after end and were deployed astern during line setting to deter birds from taking baits. One of the bird-scaring lines (termed "advanced bird-scaring line" in the Results) had four gillnet float rings at its after end and twelve 8 cm-wide streamers of yellow tarpaulin attached at intervals of 5 m and increasing in length from 0.5 m at the after end to 3.0 m at the end secured to the stern of the vessel (see Fig. 2 in Løkkeborg 1998). The other bird-scaring line (termed "simple bird-scaring line") was the one normally used by the vessel and had a punctured buoy at the after end and six 30 cm long streamers cut from red buoys, spaced at equal intervals along its length. The bird-scaring lines were about 80 m long, and when deployed, they were secured to the stern of the upper deck (7-8 m above sea level).

An underwater setting funnel is designed to set lines under water so that the baited hooks first emerge in the water out of sight of seabirds. The setting funnel tested guided the lines down to about 1 m beneath the surface, the exact depth being dependent on the pitch angle of the vessel. This 11-day experiment was conducted during the first part of a six week trip when the vessel was still lightly loaded. The vessel thus had the most favorable pitch angle at that time, with the setting funnel being at its maximum depth.

During line hauling, the catches of marketable species and the numbers of seabirds caught were recorded for each of the four fleets of experi-

Table 1. **Catches of seabirds (number) and target fish species (number and weight) for longlines set with no mitigation measure, advanced bird-scaring line (BSL), simple bird-scaring line, and setting funnel.**

	No measure	Fish		Advanced BSL	Fish		Simple BSL	Fish		Setting funnel	Fish	
Day	Seabird	No.	kg	Seabird	No.	kg	Seabird	No.	kg	Seabird	No.	kg
1	0	445	550	0	640	750	0	578	800	0	475	700
2	6	285	350	0	377	600	0	559	950	0	520	750
3	15	368	600	0	369	600	1	498	750	0	390	600
4	19	307	450	0	514	950	0	446	600	2	265	500
5	12	328	600	0	262	450	0	348	600	0	306	500
6	18	555	650	0	840	900	1	696	850	0	659	750
7	0	737	900	0	816	1,000	0	693	700	0	762	800
8	0	441	500	0	320	300	0	615	650	0	554	650
9	0	795	1,400	0	990	1,200	0	674	1,100	3	862	1,200
10	3	720	850	0	1,335	1,650	0	1,037	1,150	0	1,080	1,400
11	1	453	800	0	710	1,500	0	638	900	1	487	700
Total	74	5,434	7,650	0	7,173	9,900	2	6,782	9,050	6	6,360	8,550

Each day 6,500 hooks were set in each treatment, except day 11 when 5,200 hooks were set.

mental lines. Numbers of each marketable species were counted and their total weight was estimated to the nearest 50 kg.

Fish and scavengers as well as seabirds may take bait. The bait loss due only to seabirds was determined by setting lines without anchors and retrieving them immediately in order to prevent fish and scavengers at the seabed from taking baits. Lines baited with both mackerel and squid were set, and bait loss was determined on retrieval. This test was conducted for the three mitigation measures and the control. Three sets of about 1,300 hooks each were set for each of the setting methods. Most were baited with mackerel baits as this bait type is more easily taken by seabirds than squid. Because line setting with an autoline system results in a proportion of the hooks being set without bait, the recorded bait loss is only partly caused by seabirds (Løkkeborg 1998).

Results

There were significant differences between the setting methods in numbers of seabirds caught (Friedman's test: $X_r^2 = 13.8$, d.f. $= 3$, $P < 0.01$; Table 1). When no mitigation measure was used, 74 seabirds (1.06 birds per 1,000 hooks) were caught, compared with zero and two birds (0.00 and 0.03 birds per 1,000 hooks) respectively when either bird-scaring line was used and six birds (0.08 birds per 1,000 hooks) with the setting funnel
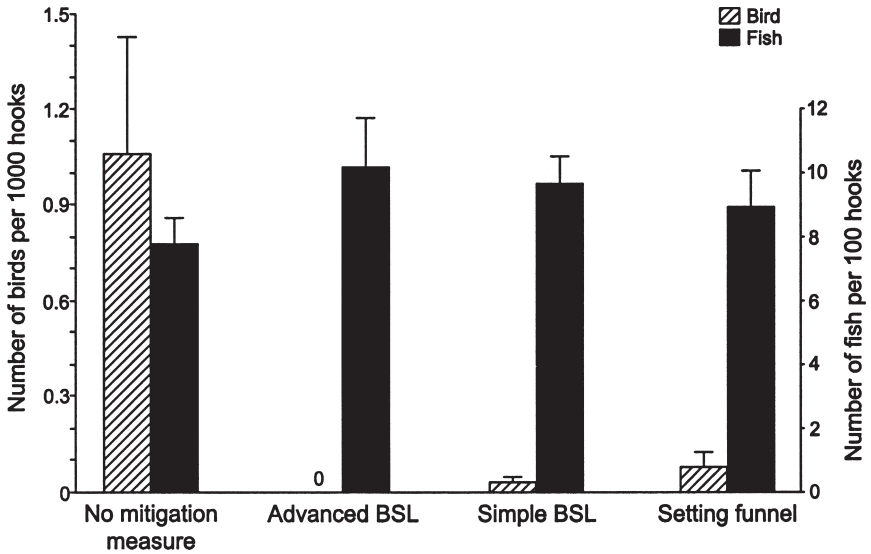
Figure 1. Catch rates of seabirds (per 1,000 hooks) and target fish species (per 100 hooks) for longlines set with no mitigation measure, advanced bird-scaring line (BSL), simple bird-scaring line, and setting funnel. Bars indicate standard error (n = 11).

(Fig. 1). The great majority of the birds caught were Northern Fulmars *(Fulmarus glacialis).*

The catch rates of target species were higher with lines that were set using one of the mitigation measures than with those set without any measure (Friedman's test: $X_r^2 = 9.4$, d.f. = 3, $P < 0.05$; Table 1 and Fig. 1). The differences in catch rates among the three mitigation measures were not significant. The highest catch rate was obtained by lines set with the most advanced bird-scaring line, which gave a 32% catch increase compared with the control. The catches consisted mainly of haddock *(Melanogrammus aeglefinus),* torsk *(Brosme brosme),* and ling *(Molva molva).*

The results also showed differences in bait loss between the four different setting methods tested (chi-square test: $X^2 = 271.2$, d.f. = 3, $P < 0.001$ for mackerel bait; $X^2 = 11.5$, d.f. = 3, $P < 0.01$ for squid bait; Table 2). Mackerel-baited lines that were set without a mitigation device or through the setting funnel had higher bait losses than lines set using the bird-scaring lines ($X^2 = 246.4$ and 134.3, respectively, d.f. = 2, $P < 0.001$). For lines baited with squid baits, the three mitigation measures resulted in similar rates of bait loss, but these lines lost fewer squid baits than lines set without using any measure. In this part of the experiment, nine sea-

Table 2.   Bait losses (percentage of hooks without bait) of mackerel and squid bait for longlines set with no mitigation measure, advanced bird-scaring line (BSL), simple bird-scaring line, and setting funnel.

Mitigation measure	Mackerel	Squid
No measure	30.9 (3,060)	22.5 (551)
Advanced BSL	15.2 (3,138)	15.6 (706)
Simple BSL	18.7 (3,164)	16.9 (655)
Setting funnel	26.6 (3,261)	16.7 (546)

Total numbers of hooks are given in parentheses.

birds were caught when no mitigation measure was used, one seabird with the setting funnel, and no birds with the bird-scaring lines.

Discussion

The results obtained in this experiment demonstrated that the three mitigation measures tested were all effective in reducing seabird incidental catch. The catch rate of seabirds was reduced from 1.06 bird per 1,000 hooks when no mitigation measures were used to 0-0.08 when one of the measures was employed. Thus, the two principles of either deterring birds from taking baits or underwater setting, where the baits first emerge in the water out of sight of seabirds, both seemed to be effective methods of reducing seabird incidental catch. This study was carried out in the course of commercial longlining in the north Atlantic, where non-diving species are the major problem, and conclusions cannot be drawn on the effectiveness of these mitigation measures in fisheries where other bird species are dominant. Several studies conducted in the Southern Oceans indicate that bird-scaring lines are effective in reducing seabird catch rates also in this area, but the results from most of these studies relied on data collected by fisheries observers incidentally to their main work and were not found to be statistically significant (Brothers et al. 1999b). Bird-scaring lines and underwater setting do not cause significant practical problems and are acceptable to fishermen. Traditionally, a bird-scaring line without streamers is used by Norwegian longline vessels, and the small difference in the results obtained for the two bird-scaring lines tested in this experiment indicates that the traditional bird-scaring line is also effective.

In a similar experiment where bird catch rate (1.75 per 1,000 hooks) in the control lines was greater than in this experiment, the use of an identical bird-scaring line was also shown to reduce the incidental catch of seabirds to an insignificant level (0.04 birds per 1,000 hooks, Løkkeborg 1998). In that experiment, however, lines set using a setting funnel gave a

bird catch rate of 0.49. The setting funnels tested in the two experiments were identical, but the experiments were conducted on different vessels, and this difference may have affected the performance of the funnel. However, different pitch angles due to the loading of the vessels is a more likely explanation. The present experiment was conducted during the early part of a trip when the vessel was unloaded and the funnel was at its maximum depth due to the pitch of the vessel. In the course of a trip, the pitch angle changes as the bait storage room (aft) empties and the main freezing room (midships/forward) fills up with the catch, and the depth of the setting funnel thus decreases. My earlier experiment (Løkkeborg 1998) was conducted during the last part of a trip when lines set through the funnel emerged closer to the surface, and wake and turbulence created by the propeller may have brought the baited hooks to the surface. Thus it is likely that this mitigation measure can be made more effective by using a funnel whose length can be increased as the trip proceeds.

Lines set when either mitigation measure was used produced higher catch rates of target species. This increased catch rate may be explained by the reduced bait loss to birds. Loss of mackerel bait was greater with the setting funnel than with the two bird-scaring lines. Baits may have been thrown off the hooks as they passed through the funnel, partially counteracting the effect of setting the lines under water and out of sight of the seabirds. However, baits could also have been taken by birds as the propeller wash may have brought the baited hooks to the surface. Although not significant, the results indicated lower catch rates for lines set through the setting funnel than for lines set with the bird-scaring lines. The difference in catch rates between lines that were set with and without mitigation measures was statistically significant. However, catch data often show large variations due to factors such as setting time and sites, and this should be considered when interpreting the magnitude of the catch differences.

Northern Fulmars comprise the great majority of seabirds caught in the longline fishery in the north Atlantic (Løkkeborg 1998). Northern Fulmar populations have undergone massive increases of range and number in this region over the past two or three centuries (Lloyd et al. 1991). The potential of increased catch and profit are therefore the most important incentive for fishermen to employ seabird mitigation measures and thereby reduce the environmental effects of longline fishing. This study has demonstrated that such potential exists, and indicated large increases in catch rates even under conditions of relatively low bait loss due to seabirds compared to the 70% bait loss documented by Løkkeborg and Bjordal (1992).

Interactions between seabirds and longline fishing may be reduced by means of various mitigation measures. However, limiting line setting to nighttime and fishing area or season closures, which have been proposed for longline fisheries in other regions, are less acceptable to Norwegian fishermen as such restrictions severely affect profitability. Line setting in darkness (at night) is impossible during the polar summer, and area

closure may exclude vessels from operating at attractive fishing grounds. Modifications to setting procedures, such as weighting the lines, using thawed bait, or discharging offal during setting are either not possible or are impractical in the autoline fishery in the north Atlantic (Løkkeborg 1998, but see Cherel et al. 1996). The mitigation measures tested in this study cause few such problems and proved to be effective in reducing seabird incidental catch.

Acknowledgments

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Effect of Line Sink Rate on Albatross Mortality in the Patagonian Toothfish Longline Fishery

Graham Robertson
Australian Antarctic Division
Kingston, Tasmania, Australia

Abstract

An experiment was conducted on an autoline longline vessel to derive a sink rate, and line weighting regime, that would minimize the capture of albatrosses based on knowledge of line sink rates and albatross diving abilities. Sink rates of lines deployed into propeller turbulence, which probably slowed sink rate, varied as a function of distance between line weights. Asymptotic sink rates (0.1-0.15 m/s) were achieved with 70 m between 6.5 kg weights. Sink rates to 4 m depth were greatest with 35 m (0.44 m/s) and 50 m (0.33 m/s) between weights. For vessels using bird scaring lines and setting lines in propeller turbulence, longline sink rates >0.3 m/s should greatly reduce the incidental take of albatrosses. For vessels with similar gear and line setting characteristics to the experimental vessel, this sink rate should be achievable with 4 kg weights distributed every 40 m on longlines.

Introduction

Longline fishing for Patagonian toothfish *(Dissostichus eleginoides)* commenced in waters under the jurisdiction of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) in the late 1980s. In the 1996-1997 fishing season there were 16 longline vessels fishing legally for toothfish in CCAMLR areas (CCAMLR waters fall, roughly, between the coast of the Antarctic continent and the outer limit of the Antarctic Polar Front). Toothfish is caught on the seabed (ca. 800-2,500 m depth) near sub-Antarctic islands and near the southern coasts of South America,

which are also areas of high seabird abundance. Longline vessels may deploy up to 20,000 baited hooks per day, and during line setting procedures seabirds scavenging baits may become hooked and drown. Seabirds may also become hooked during line hauling operations when baited hooks once again become available to birds in surface waters. Longlining for toothfish may take a heavy toll on seabirds, with annual estimates in some fisheries being in the order of tens-of-thousands of seabirds killed (CCAMLR 1997).

Two longline fishing methods are used in CCAMLR waters for the harvesting of Patagonian toothfish: the autoline, or single line, method and the Spanish, or double line, method. These two fishing methods differ greatly in line construction, the way lines are set, hauled, and managed on board, and in operational procedures that affect seabirds. For instance, autoline vessels deploy negatively buoyant longlines whereas Spanish system vessels deploy buoyant longlines that would not sink without added weight. Practical efforts to reduce seabird mortality in toothfish longline fisheries must take into account basic differences in equipment used and fishing methods if results of experiments are to be meaningful. This is particularly the case with experiments aimed at increasing line sink rates as a primary goal in attempts to reduce seabird deaths in toothfish longline fisheries.

This paper presents the results of an experiment conducted on autoline and Spanish system fishing vessels during December 1997 and January 1998 on the Patagonian shelf near the Falkland Islands/Islas Malvinas. Vessels were the Consolidated Fisheries Limited *Pioneer* and the Korean owned *In Sung 66.* The *Pioneer* is equipped with a Mustad autoline system and the *In Sung 66* uses the Spanish system of fishing. The objectives of the experiment were to:

1. Determine, based on time-depth recorder-derived measurements of longline sink rates and knowledge of albatross diving abilities, a longline weighting regime for the *Pioneer* that had the potential to eliminate bait taking by albatrosses and minimize bait taking by other seabird species; and

2. Determine the longline sink rate of the *In Sung 66,* a vessel with very low reported catch rates of albatrosses during line setting operations.

The paper also describes the autoline and Spanish system methods, as adopted by the *Pioneer* and *In Sung 66* respectively, so that results of sink rate trials can be placed in context with the fishing operations and gear used. The autoline and Spanish systems have also been described by Bjordal and Løkkeborg (1996).
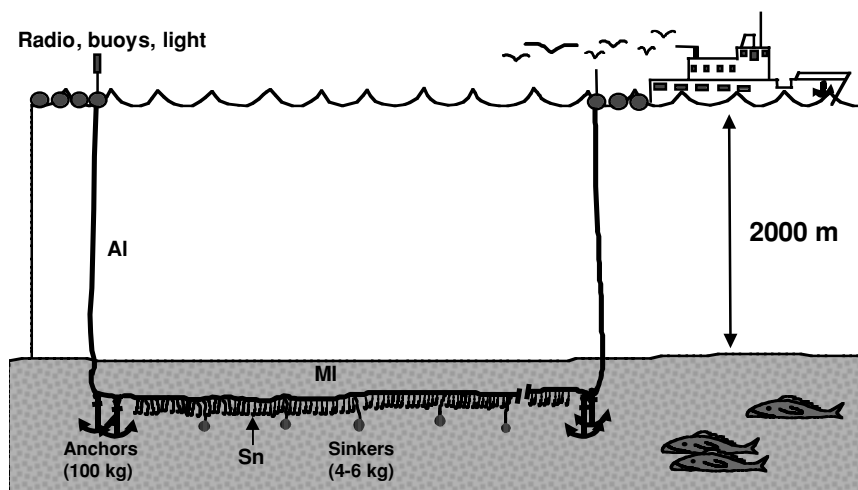
Figure 1. Longline configuration of the CFL Pioneer (Mustad autoline [single line] method) used for the capture of Patagonian toothfish. Anchor lines (Al), mother line (Ml), and snood line (Sn) are 18 mm, 11.5 mm, and 3 mm in diameter, respectively.

The CFL *Pioneer*

Longline Configuration

The *Pioneer* is a 47 m × 11.5 m Spanish built trawler converted for toothfish longlining. The autoline system (Fig. 1) deploys a single 11.5 mm line with 100 kg anchors at each end. About 50 m separated the end of the snoods (gangions) on the mother line from the anchors. Hook-bearing snood lines were attached via metal swivels and collars at 1.2 m intervals along the mother line. Snood lines were 3 mm in diameter and 50 cm in length.

Line Weight and Weights on the Line

The mother line on the *Pioneer* was a 11.5 mm Fiskevegn Swiveline made from a mix of polypropylene and polyester coated with tar to protect the line from abrasion on the seabed and to improve coiling ability. The specific gravity of the line was 1.10 and the line weighed 12.65 kg per 100 m including swivels (22.5 g in water) and tar (1.07 kg per 100 m land weight). Hooks weighed 5.18 g and bait weighed 50 g.

The weight of the longline during the set has an important bearing on line sink rate and whether seabirds will be caught. The crew of the *Pioneer*

attached 6.5 kg weights to the line, initially at 140 m spacings (i.e., 12 weights per magazine: racks from which coiled longline is suspended) and later (following the capture of birds) at 70 m spacings every second set of 140 m spacings (i.e., 16 weights per magazine). In a standard set of eight magazines (10,800 hooks) with 12 weights per magazine, the *Pioneer* deployed about 3,050 kg dry weight of gear. This comprised 728 kg of anchor lines, 1,640 kg of mother line and swivels, 55 kg of hooks, and 624 kg of line weights. With 16 weights per magazine the fishing gear would weigh 3,254 kg, line weights being 26% of this total. During a haul from 2,000 m depth the dry weight of the gear being hauled would be about 390 kg; line weights would be 33% of this weight.

Line Setting and Hauling

A typical set for the *Pioneer* was about eight magazines or 10,800 hooks, giving a line length on the seabed of about 13 km (depending on slack in the line). The line was set at any time of day or night, depending on events in the fishing operation. The *Pioneer* set the line at 5.5-6.5 knots, and bait shooting rate, which varies as a function of setting speed and snood spacings, averaged 2.72 hooks per second. At this rate the *Pioneer* set 10,800 hooks (eight magazines) in about 1 hour. Bait used was squid *(Illex* sp.), which was cut into 50 mm length blocks and deployed in a half-thawed state. Bait hooking success by the autobaiter was about 80%. During setting the line entered the water about 15 m behind the vessel. The line was hauled at 1-1.5 knots and hauling rate was about 1 magazine per hour.

The *In Sung 66*

Longline Configuration

The *In Sung 66* is a 47.7 m, Japanese pelagic longliner re-fitted for the capture and processing of Patagonian toothfish. The *In Sung 66* employed the Spanish (double line) system of fishing. In this system hooks and weights were attached to a relatively light line (hook line: 5 mm) which floats above the seabed suspended from a heavier (18 mm) floating motherline (Fig. 2). The two lines are connected every 76 m by branchlines (18 m long; 9 mm). Hooks are spaced every 1.5 m and weights (3.6 kg) every 38 m. Snoods connecting hooks to the hook line were 0.7 m long (3 mm). Anchors (50-100 kg) were attached to the floating mainline 600 m from the first and last branchline. Hook lines were stored on deck in plastic baskets containing 48 hooks each. Hook lines were deployed in batches of 20 baskets (960 hooks) extending 1.4 km, and between these 20 baskets of line a 20 kg weight was attached to the motherline (at 1.5 km intervals); this weight enabled the motherline and hook line to sink independently. In summary, the structure of the Spanish system longline involves multiple snood lines suspended from a single (but discontinuous)
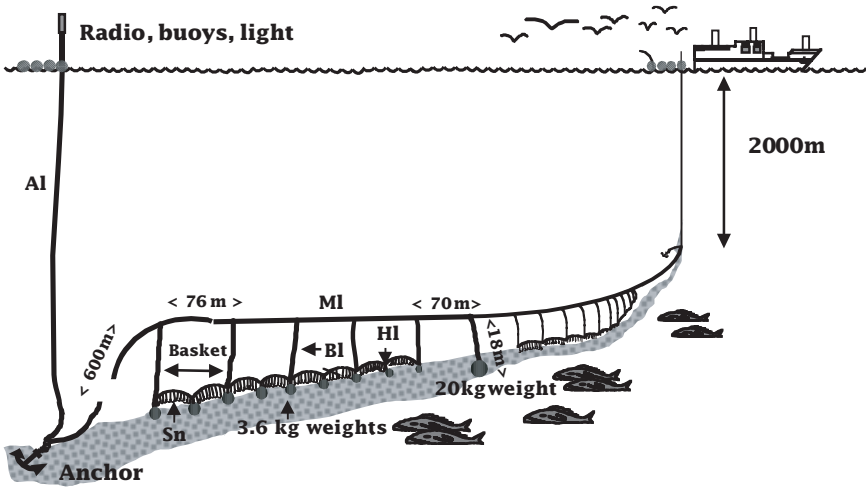
Figure 2. *Longline configuration of the In Sung 66 (Spanish system [double line method]) used for the capture of Patagonian toothfish. Anchor lines (Al), mother line (Ml), branch lines (Bl), hook line (Hl), and snood lines (Sn) are 20 mm, 18 mm, 9 mm, 5 mm, and 2.5-3 mm in diameter, respectively. Baited hooks are deployed in "baskets," with each basket containing 76 meters of hook line and 48 baited hooks.*

hook line suspended from multiple branch lines suspended from a single mother line.

Line Weight and Weights on the Line

The lines used by the *In Sung 66* were polypropylene. The anchor line, mother line, branch line, and hook line weighed 18.2 kg, 14.77 kg, 3.77 kg, and 1.1 kg per 100 m, respectively. Swivels used to attach snoods to the hook line weighed 5.5 g and had a specific gravity of 7.1. Hooks weighed 6.3 g and had a specific gravity of 7.8. Due to the complicated structure of the line for the *In Sung 66* to shoot the same number of hooks (10,800) as in a standard set for the *Pioneer,* about 5,430 kg dry weight of gear would be deployed, which was about 40% more than the *Pioneer*. This would comprise 728 kg of anchor ropes, 2,390 kg of mother line, 146 kg of branch line, 178 kg of hook line, 68 kg of hooks, 59 kg of swivels, 200 kg of mother line weights, and 1,440 kg of hook line weights. The dry weight of the non-rope components (weights, hooks, and swivels) amounted to about 1,770 kg, or about 32% of total gear weight (about the same as for the *Pioneer*). All ropes used by the *In Sung 66* were buoyant (specific gravity = 0.91) and would have floated without the attachment of weights. During a

haul from 2,000 m depth the dry weight of the line used by the *In Sung 66* would be about 540 kg but the non-buoyant components would be only about 205 kg (about half that of the *Pioneer).* The line weights would constitute about 90% of the weight of these non-buoyant components.

Line Setting and Hauling

The *In Sung 66* set the line at 10 knots. During line setting the line entered the water (about 8 m behind the vessel) as a heavy duty hauling (mother) line on the starboard side of the stern of the vessel and a light duty (hook and snood lines) fishing line on the port side of the stern of the vessel, with branch lines straddling the area in between. During line deployment hook lines (coiled in separate baskets) were joined, and weights were attached at both ends and at the center of each basket of hook lines. Branch lines (connected motherline and hook line) were attached to the ends of each basket of hook lines. Both mother line and hook or snood lines were paid out passively, line shooting speed being determined by setting speed, the pull of the line already deployed, and hooks jagging on ship's gear.

A single set for the *In Sung 66* involved the deployment of 100-360 baskets, or 8.3-30 km respectively, of longline gear. Hooks were set at 3.25 hooks per second. Bait used was squid *(Illex* sp.) cut into 50-70 mm blocks (three baits from one squid, bait weight: 60 g). Since the bait was attached to hooks manually, hooking success was 100%. The line was hauled at 1-1.5 knots, and hauling usually took about 8 hours.

Longline Sinking Experiment
Methods
CFL Pioneer

Recording Line Sink Rates. The effects of weight spacing on line sink rate of the *Pioneer* were determined by varying the distance between weights on the longline. Weight spacings were 35 m, 50 m, 70 m, 100 m, 140 m, and 200 m. Line sink rates were measured with Mk 7 time-depth recorders (TDRs; Wildlife Computers, USA), which were attached with cord and tape to the mainline midway between snoods. Three TDRs were used for each weight spacing and TDRs were attached separately in series midway between consecutive weights. TDRs were deployed in triplicate to derive average sink rates (TDRs occasionally give anomalous readings). Since it was not possible to manipulate the length of the entire longline, experimental weight spacings were maintained for three additional spacings either side of the line bearing the three TDRs. Thus nine weights were used in each treatment, with distances between weights, and TDRs, within each treatment being as described above. The intention with this approach was to minimize the effect of the unmanipulated sections of line on the manipulated sections of line.

   Line weights (6.5 kg) and setting speed (5.5-6.5 knots) were constant. Data from the TDRs were downloaded onto a portable computer at the end of every haul, and data from the three TDRs used on each set were averaged. All deployments of TDRs were made on the second magazine deployed in a set, a set usually involving eight magazines of longline. Time constraints did not permit replication of experimental weighting regimes; thus it was not possible to gain a measure of within-treatment variance due to effects of the tide, sea state, or other factors.

   Before deployment, the TDRs were hosed with seawater for about five minutes to minimize effects on TDR accuracy of temperature differences between air (8-13°C) and sea (about 9°C). The TDRs were programmed to commence recording the instant they entered the water. The TDRs sampled depth in 2 m increments and temperature every second. The start depth for the interpretation of sink rates was 4 m, the shallowest depth at which confidence exists in the accuracy of the TDRs; this depth was generally deeper than the rise and fall of the sea, the area in the water column in which TDRs may record inaccurately. The TDRs rounded depth readings downwards (i.e., 0-1.9 m depths were recorded as 0 m and 2-3.9 m depths were recorded as 2 m) meaning that longlines, and baited hooks, were nearly always deeper than indicated by the instruments. Rounding down should, therefore, have resulted in measurements being conservative in favor of seabirds.

Steamer Line and Bird Counts. At the beginning of the voyage the *Pioneer* used 40 m long paired bird scaring streamer lines slung 10 m apart from the deck hand rail with 1 m long streamers, made of raincoats, every 3-4 m. Seabird catching streamer lines were made 60 m in length, about 50 m of which was suspended in the air, and 3 m long streamers were placed 1.5 m apart. The streamer lines were suspended 5 m above the water. This streamer line was in constant use during the line sinking experiment.

   Each time the line was set, a single count of seabirds within a 300 m radius of the vessel was made. During line hauling operations dead seabirds hauled aboard were counted in 70% of the duration of the hauls.

Data Treatment. With the data gathered on the *Pioneer* three dependant variables—sink rate, sink time, and distance astern—were chosen for analysis because of their relevance to seabird conservation: sink rate and sink time-to-depth have implications for speed of bait spotting and dive velocity by seabirds, and distance astern pertains to the areas afforded "protection" by propeller wash and bird scaring streamer lines. Depths of 4 m, 8 m, and 12 m were chosen for interpretation because 4 m approximates the maximum recorded diving depth (4.5 m) of Black-browed Albatrosses *(Thalassarche melanophrys,* Prince et al. 1994), 8 m exceeds by one dive recorder increment the known maximum diving depth of Grey-headed Albatrosses *(T. chrysostoma)* (6.5 m; Huin and Prince 1997), and 12 m

approximates the known maximum diving depth (12.5 m) of Light-mantled
Sooty Albatrosses *(Phoebetria palpebrata)* (Prince et al. 1994) and White-
chinned Petrels *(Procellaria aequinoctialis)* (Huin and Prince 1997). Wan-
dering Albatrosses have been recorded to 0.6 m only (Prince et al. 1994).
These five species of seabirds exhaust published accounts of diving depths
of seabirds likely to attack baits in the Patagonian toothfish longline fishery.

The In Sung 66

The TDRs were deployed on two sets only to examine sink rates of nor-
mally configured longline gear used by the *In Sung 66.* TDRs were de-
ployed in threes as for the *Pioneer.* Setting speed (10-10.5 knots) and line
weights (3.6 kg) were constant during the experiment. The bird line on the
In Sung 66 consisted of a single 80 m long piece of rope, suspended from
5 m above the water, with three 1 m long pieces of scarf about halfway
down its length. About 60 m of the streamer line length was suspended in
the air. During line sets seabird numbers were counted as for the *Pioneer.*

Results

The *Pioneer*

The results of the line sinking experiment are presented as a family of
polynomial and logarithmic regressions expressing line sink rate (Fig. 3),
sink time (Fig. 4), and distance astern at certain depths in the water col-
umn (Fig. 5) as a function of distance between weights on longlines. All
relationships shown in Figs. 3, 4, and 5 are curvilinear, which is probably
a result of drag in the water, the downward pull of the anchor, and the
effect of propeller upwellings. Sink rates to 4 m depth ranged from 0.44-
0.1 m/s with weights at 35 m and 200 m intervals, respectively (Figs. 3 and
6). Sink rates to any depth did not vary greatly with weight spacings >70 m,
suggesting that at shallow depths (<12 m) there was either enough slack
in the longline to nullify the effect of additional weight, that the longline
had cleared the propeller wash (resulting in a more linear sink rate), or
elements of both. Fig. 3 infers that even to 4 m depth with >70 m weight
spacings the longline would have cleared the propeller wash (ranges, patch-
ily, to c. 40 m astern), after which a more linear sink rate might be ex-
pected. For 35 m and 50 m spacings sink rates to 8 m depth (0.37 m/s and
0.24 m/s, respectively) were similar to sink rates to 12 m depth (0.37 m/
s and 0.21 m/s, respectively). However, sink rates to 4 m depth for these
two weight spacings (0.44 m/s and 0.37 m/s, respectively) were apprecia-
bly greater than to the two deeper depths. Thus with weight spacings of
35 m and 50 m sink rates were greatest closest to the surface.

Sink time increased as weight spacing increased (Fig. 4). At 4 m the
functional relationship predicted that sink time increased by 2 seconds
for each 10 m between weights. The longline took 3-4 times longer to
reach all depths with weights every 200 m compared to 35 m. With 35 m

4 m depth

$$\text{Sink rate (m/s)} = 0.07 + \frac{3.4}{WS} + \frac{345}{WS^2}$$

$$(F_{2,5} = 23.8;\ p = 0.01;\ r^2 = 0.94)$$

8 m depth

$$\text{Sink rate (m/s)} = 0.11 - \frac{0.8}{WS} + \frac{338.5}{WS^2}$$

$$(F_{2,5} = 127.2;\ p = 0.001;\ r^2 = 0.98)$$

12 m depth

$$\text{Sink rate (m/s)} = 0.14 - \frac{5.6}{WS} + \frac{473.2}{WS^2}$$

$$(F_{2,5} = 44.4;\ p = 0.006;\ r^2 = 0.97)$$

Sink rate (m/s)
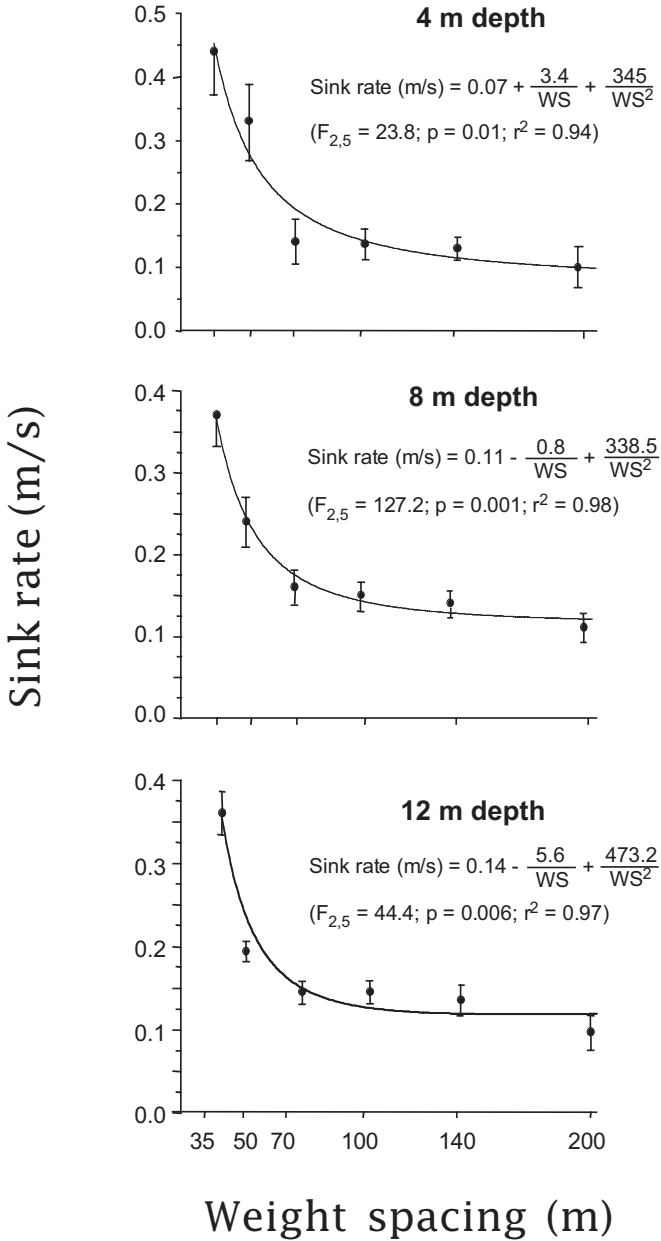
Weight spacing (m)

Figure 3.   *Longline sink rate to depths shown as a function of weight spacing (WS, in meters) on longline set by the CFL Pioneer. Note differences in increments on y axes. Closed circles indicate means ±1 standard deviation for three TDRs deployed simultaneously on longlines in experiments (there was no replication at the treatment level).*

4 m depth

Sink time (s) = -52.6 + 17.5 log$_e$ WS
($F_{1,5}$ = 40.6; p = 0.003; r^2 = 0.91)

8 m depth

Sink time (s) = -65.9 + 25.4 log$_e$ WS
($F_{1,5}$ = 62.7; p = 0.001; r^2 = 0.94)

12 m depth

Sink time (s) = -78.3 + 32.1 log$_e$ WS
($F_{1,5}$ = 43.7; p = 0.002; r^2 = 0.91)

Time (seconds)
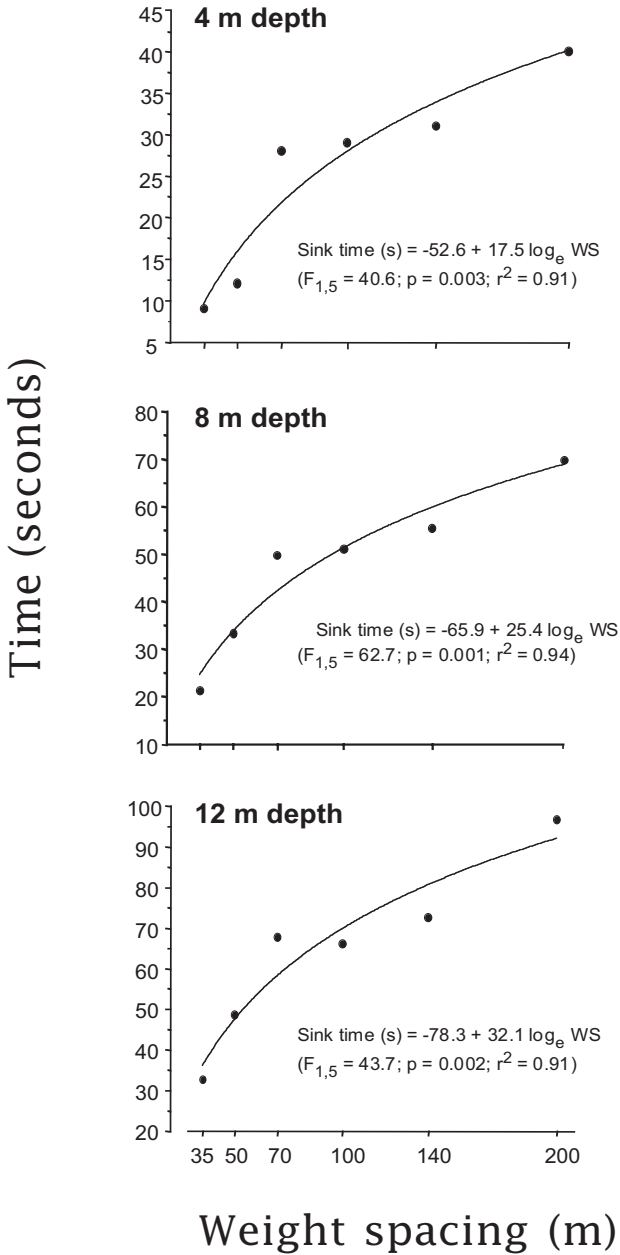
Weight spacing (m)

Figure 4.   *Longline sink time (seconds) to depth shown as a function of weight spacing (WS, in meters) on longline set by the CFL Pioneer. Note variation in increments on y axes. Closed circles represent means from three TDRs.*

4 m depth

Distance (m) = -135.6 + 45.0 $\log_e$ WS

($F_{1,5}$ = 40.6; p = 0.003; r^2 = 0.91)

8 m depth

Distance (m) = - 169.8 + 65.5 $\log_e$ WS

($F_{1,5}$ = 62.8; p = 0.001; r^2 = 0.94)

12 m depth

Distance (m) = - 202.1 + 82.8 $\log_e$ WS

($F_{1,5}$ = 43.6; p = 0.003; r^2 = 0.92)

Distance astern (m)
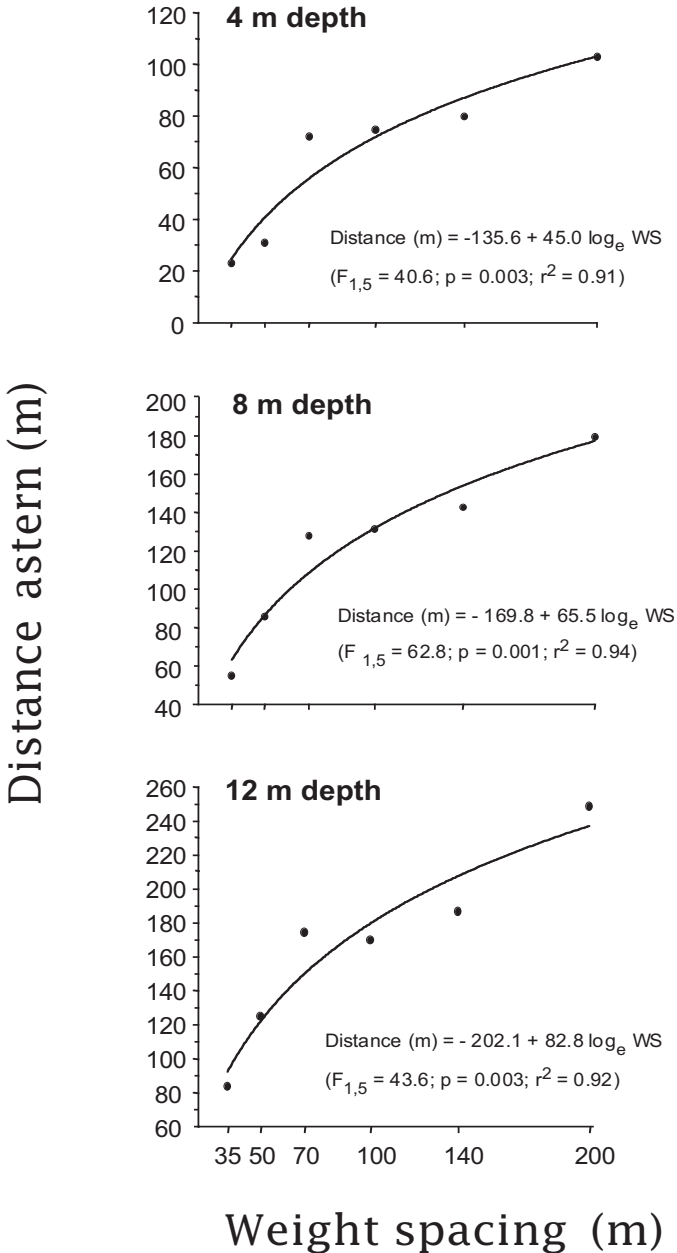
Weight spacing (m)

Figure 5.   Longline distance astern from water entry point (15 m behind vessel) at depths shown as a function of weight spacing (WS, in meters) on longline set by the CFL Pioneer. Ship setting speed was 2.572 m/s (5 knots). Closed circles represent means from three TDRs.

and 200 m between weights 21 seconds and 70 seconds, respectively, were required to reach 8 m depth, and 33 seconds and 97 seconds, respectively, were required to clear the bird strike zone at 12 m depth. Thus with weights every 35 m baits would be available, theoretically, to Grey-headed Albatrosses (and, most probably, Black-browed Albatrosses) and White-chinned Petrels for about 20 seconds and 33 seconds, respectively. At 200 m spacings these two species of bird would have about 70 seconds and nearly 100 seconds before the sinking baits exceeded their known maximum diving depths.

Figure 5 shows the relationships between the distance behind the *Pioneer* to particular depths by the longline and the distance between weights on the line (note that the distance between the stern of the vessel and the water entry point of the line—about 15 m—has not been included in the figure so that measured values, not "guesstimates," could be used to compile the equations). With 35 m weight spacing at 4 m depth the longline would be 38 m astern (i.e., 23 m + 15 m), at 8 m depth it would be 70 m astern, and at 12 m depth the line would be 98 m astern—48 m beyond the aerial portion of the bird line. With 200 m between weights 4 m depth would be reached 115 m behind the vessel, 8 m would be reached 195 m behind, and 12 m would be reached about 265 m. For all weight spacings tested, protection of the bird strike zone by the bird line would only have been achieved to 8 m depth for weights 35 m apart and to 4 m only for weights 50 m apart.

Data on line sink rates can be rearranged to show more clearly the effect of variation in line weight spacings on line sink rate, duration, and distance astern (Figs. 6, 7, and 8). These figures reveal the advantages of short distances between weights: weights at <50 m produce noticeable increases in line sink rates that reduce sink time and the distance astern that baited hooks are available to seabirds. In contrast, longlines with 70-200 m between weights sank at similar rates, all being appreciably slower than line with <50 m between weights.

The In Sung 66

The *In Sung 66* deployed 3.6 kg weights every 38 m on the hook line and 20 kg weights every 1,500 m on the mother line. The hook line sank at 0.28 m/s to 4 m depth, 0.33 m/s to 8 m depth, and 0.32 m/s to 12 m depth. Thus sink rates were fairly constant throughout the depth ranges recorded. Sink durations were 14 seconds to 4 m depth, 24 seconds to 8 m depth, and 37 seconds to 12 m depth. At a setting speed of 5.144 m/s (10 knots) at 4 m, 8 m, and 12 m depth the hook line would have been 72 m, 123 m, and 190 m astern, respectively. At all distances the hook line would have cleared the area "protected" by the propeller wash and bird line while still well within diving range of Grey-headed Albatrosses, Light-mantled Sooty Albatrosses, and White-chinned Petrels.
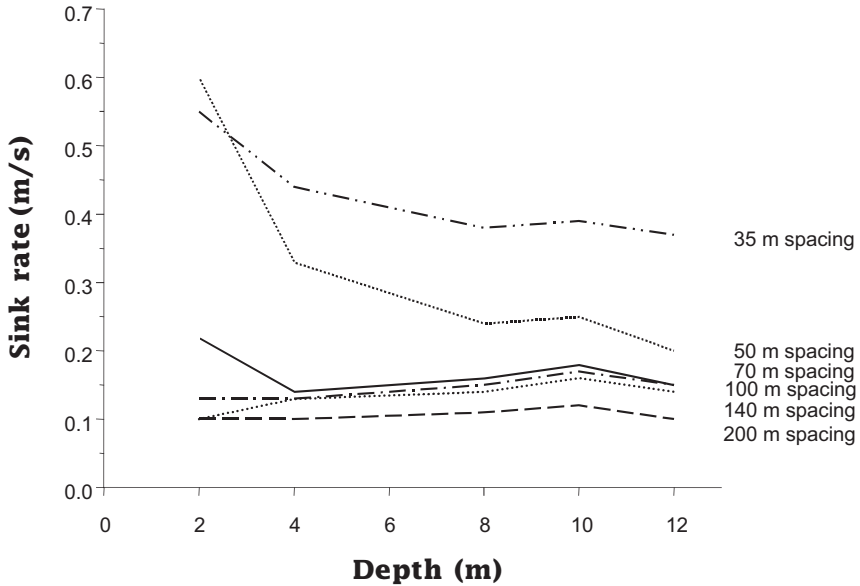
Figure 6. *Sink rate to depth shown as a function of weight spacing on longline. Linear interpolation between 4 m depth and y axis indicates sink rates to 2 m depth of about 0.5 m/s and 0.4 m/s for 35 m and 50 m weight spacings, respectively. Sink rates to this depth for all other weight spacings was 0.1-0.15 m/s.*

Seabird Numbers and Mortality

On all line sets 150-300 Black-browed Albatrosses hunted for bait behind the *Pioneer* and 50-100 Black-browed Albatrosses followed the *In Sung 66.* During line hauling about 250 Wandering Albatrosses *(Diomedea exulans)*, about 500 Giant Petrels *(Macronectes* spp.) and about 500 Black-browed Albatrosses frequented both the *Pioneer* and *In Sung 66.* Wandering Albatrosses and Giant Petrels generally did not follow vessels when lines were being set.

After four days fishing with 12 weights per magazine and the short version of the streamer line (see above) the *Pioneer* caught in one daytime set of eight magazines 19 Black-browed Albatrosses and one Giant Petrel; five Black-browed Albatrosses were caught the next day. After changing the line weighting regime to 16 weights per magazine and extending the streamer line (see above) no further seabirds were observed caught by the *Pioneer.* No seabirds were observed caught by the *In Sung 66* during line setting operations.
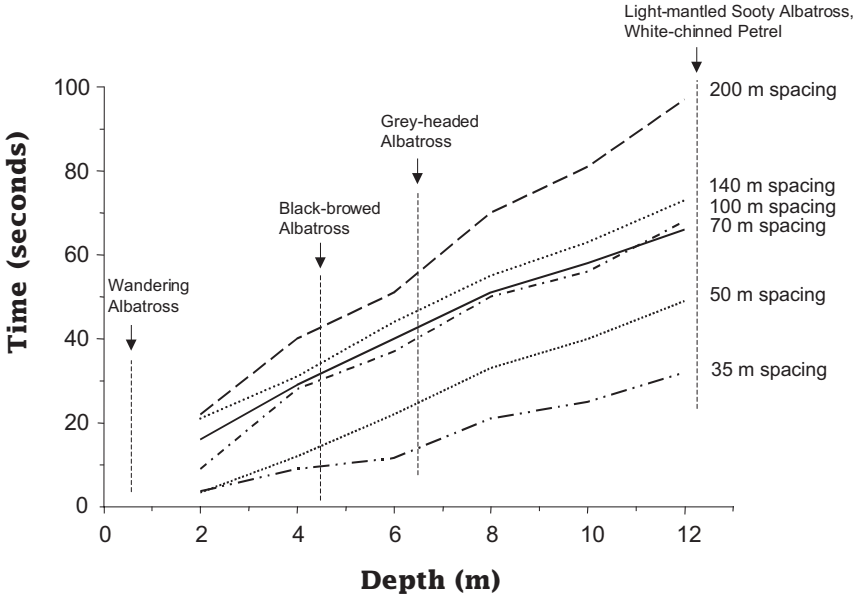
Figure 7. Time for longline to reach depths shown as a function of weight spacing on longline. Time at 2 m depth has been estimated by linear interpolation based on estimates to 4 m depth. Maximum recorded diving depths of the Grey-headed Albatross, Light-mantled Sooty Albatross, and White-chinned Petrel are indicated by dotted lines. For given weight spacings cross reference of seabird diving depth and y axis reveals time available for seabird strike to occur.

Discussion

Caveats

Weights were added to sections of longlines near the TDRs only, not to the entire length of longlines. The unweighted sections of longline would be expected to slow the sink rate of the weighted sections of line once the weighted sections reached a certain depth in the water column; this probably slowed the sink rate of the weighted sections of line by an unknown amount.

Line hookups (when hooks got stuck on ships' gear during line pay-out) and weight pullbacks (when line weights are pulled from the vessel by the drag of the line already deployed) may have affected the line sink rate measurements. Hookup rate for the *Pioneer* was 1 per 75 seconds (no weight pullbacks occurred because weights were deployed while the longline was slack) and that for the *In Sung 66* was 1 per 95 hooks, or 1 per 30 seconds; weight pullbacks occurred about every eight seconds. Hook-
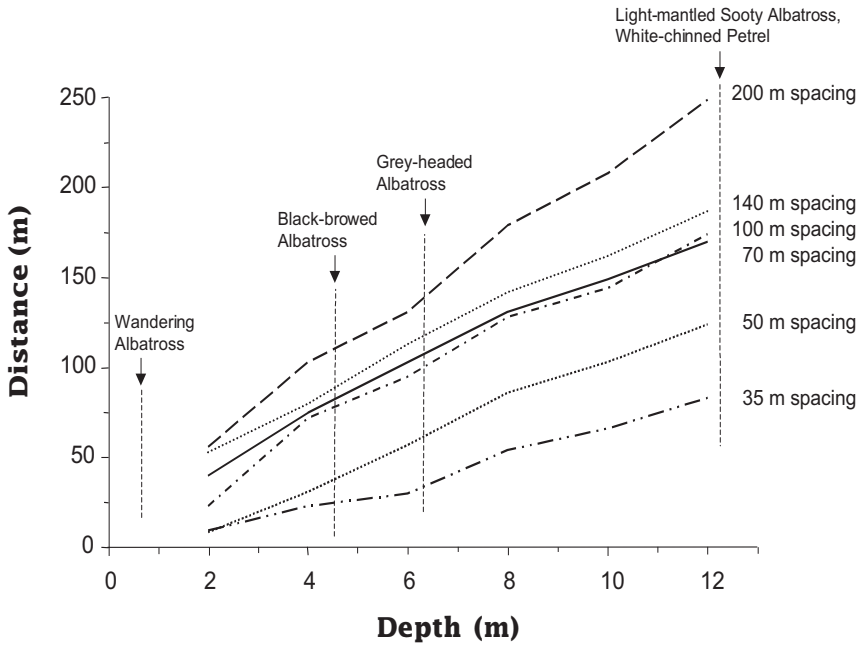
Figure 8.   *Distance astern at depths shown as a function of weight spacing on long-line. Distance at 2 m depth has been estimated by linear interpolation based on estimates to 4 m depth. Maximum recorded diving depths of Grey-headed Albatrosses, Light-mantled Albatrosses, and White-chinned Petrels are indicated by dotted lines. For given weight spacings cross reference of seabird diving depths and y axis reveals distance behind the CFL Pioneer baited hooks are "available" to birds.*

ups and pullbacks tended to yank longlines upward, theoretically slowing sink rates. The effect of this on the sink rate measurements is unclear because for all weighting regimes except 35 m and 50 m, propeller turbulence tended to keep longlines aloft anyway, irrespective of the line being yanked due to hookups and pullbacks. Lines with weights 35 m and 50 m apart sank quickly (as verified by eye) in spite of propeller turbulence and upward yanks on the line.

In summary, because of the concerns expressed above it would be prudent to consider the relationships between longline sink rates and line weighting regimes as being approximations only of actual sink rates induced by adding weights to longlines.

Sink Rates and Line Weighting

The regressions shown in Figs. 3, 4, and 5 allow predictions to be made of the effect of changes to weight distribution on longline sink rates. For

instance, with 35 m between weights line sink rate to 4 m depth is pre-
dicted as 0.45 m/s (as against 0.44 m/s measured) and sink rate with 200
m spacings is 0.09 m/s (as against 0.1 m/s). With the *Pioneer* asymptotic
longline sink rates (0.1-0.15 m/s) were achieved with weight spacings of
70 m; spacings greater than 70 m had no effect on line sink rates to any of
the depths over which measurements were made (Figs. 3 and 6). By con-
trast, longlines with weights at 35 m (0.44 m/s) and 50 m (0.33 m/s) inter-
vals sank almost immediately, providing limited opportunity for baited
hooks to be taken by seabirds. With weights spaced <50 m on longlines
and sink rates in aerated water of >0.3 m/s, very low seabird catch rates
by the *Pioneer* would be expected when fishing with a bird scaring line.
This was borne out, more or less, in practice. As mentioned above, the
Pioneer deployed weights every 140 m until birds were caught, then every
70 m. With the increase in weight no further albatrosses were observed to
be caught. With the extra weight albatrosses hunting behind the *Pioneer*
seemed to have difficulty finding the rapidly sinking bait in the propeller
wash. While this might suggest that 70 m weight spacing is suitable for
the *Pioneer,* line weight regimes should include a safety margin in favor of
seabirds because circumstances will sometimes arise where seabirds attack
baits with greater intensity than observed during this experiment. Hence
<50 m between weights is recommended for the *Pioneer,* with the exact
distances being influenced by the mass of each weight.

The 6.5 kg weights used on the *Pioneer* were too heavy and tended to
burden the crew during both setting and hauling. The *In Sung 66* used 3.6
kg weights every 38 m (on a buoyant line), and these were light enough to
remove from the mainline and flick across the deck one handed. Judging
by the ease of handling of weights by the crew of the *In Sung 66,* the line
weighting regime and low reported seabird catch rates of that vessel, and
the results of the sink rate experiments on the *Pioneer,* weights of 4 kg, or
thereabouts, might be more suitable for the *Pioneer.* Since weights of this
mass are less than those used in the experiment, weight spacings of 40 m,
or thereabouts, would seem appropriate to minimize the incidence of "bel-
lying up" of the longline between weights. This would result in 28 weights
per magazine (as against 16 for the 6.5 kg weights) and a total of 112 kg
per magazine (as against 104 with 6.5 kg per 70 m) of longline, and might
only be feasible, operationally, with a semi-automated system of weight
deployment.

With the *In Sung 66* it is to be expected that the different line configu-
ration, buoyant line, and different line weight regime would result in
different sink rates to the *Pioneer.* Sink rates of the hook line were 0.28 m/s
to 4 m depth and 0.32 m/s to 12 m depth. In *Pioneer* terms, these esti-
mates are equivalent to weights (6.5 kg) every 50-60 m to 4 m depth and
every 40 m to 12 m depth. Sink durations were 24 seconds to 8 m depth
and 37 seconds to 12 m depth. Due to the faster setting speed of the *In
Sung 66,* the sink rates would result in the line reaching 4 m depth 72 m
astern, 8 m depth 123 m astern, and 12 m depth 190 m astern; these

distances are roughly equivalent to weights every 100-140 m on the *Pioneer* and suggest that baits would still be vulnerable to attack by seabirds, in spite of the low catch rates reported for this vessel.

CCAMLR conservation measure 29/XVI seeks that to minimize seabird mortality Spanish system vessels deploy 6 kg weights every 20 m on longlines. At a hook deployment rate of, say, 3 per second (the equivalent, roughly, of the hook setting rate of both the *Pioneer* and *In Sung 66)* the conservation measure would require the deployment of one weight every 13 hooks, or one weight per 4 seconds (at 1.5 m between hooks). Operationally, this would be very difficult for fishermen to achieve. Adherence to the conservation measure would also create a problem regarding the total amount of weight on longlines. A set of, say, 10,000 hooks (15 km of line at 1.5 m between hooks) would require the deployment of 750 weights (15 km ÷ 20 m) or 4.5 metric tons of weight, which would have to be hauled in addition to the weight of the fish catch. To my knowledge no Spanish system vessel has adopted the CCAMLR-recommended line weighting regime. For fishing methods where hook lines must float off the seabed it is important to remember that changing the distance between weights (as against amount of weight at each point on lines) goes right to the heart of fishing strategy and is unlikely to be viewed sympathetically by fishermen seeking a profitable enterprise. Note that 6 kg per 20 m on longlines will sink longlines at about 0.9 m/s (see Brothers, 1995), three times that estimated in this study to minimize the take of albatrosses. Provided sink rates exceed 0.3 m/s and a properly configured streamer line is used this should be all that is necessary to reduce, to very low levels, albatross deaths in toothfish longline fisheries.

Conclusion

Toothfish longline vessels that deploy lines at about 5 knots in propeller turbulence and use streamer lines should achieve line sink rates >0.3 m/s to minimize the incidental mortality of albatrosses. For autoline system vessels with gear and line setting characteristics similar to the *Pioneer,* this will require weight spacings of <50 m on longlines. About 4 kg per 40 m on longlines would seem both appropriate and relatively practical for fishermen. If used with effective streamer lines, this line weighting regime should greatly reduce the capture of albatrosses during line setting operations.

Acknowledgments

etrate the Spanish fishing method and its nuances is solely due to James Elliott's (CFL observer) expert knowledge of that fishing practice and of the art of catching Patagonian toothfish. Comments by Ed Melvin, Barry Baker, Janice Molloy, and two anonymous referees improved a draft.

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Incidental Catch of Seabirds by Longline Fisheries in Alaska

Robert A. Stehn
U.S. Fish and Wildlife Service
Anchorage, Alaska

Kim S. Rivera
National Marine Fisheries Service
Juneau, Alaska

Shannon Fitzgerald
National Marine Fisheries Service
Seattle, Washington

Kenton D. Wohl
U.S. Fish and Wildlife Service
Anchorage, Alaska

Abstract

The incidental catch of seabirds by longline fisheries is a conservation issue in Alaska. National Marine Fisheries Service (NMFS) certified observers record seabirds and fish species caught by longline fisheries for Pacific cod *(Gadus macrocephalus)* and other groundfish in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA). Total estimated annual mortality of seabirds in the Alaskan longline groundfish fisheries was 14,000 birds between 1993 and 1997, ranging from 9,400 birds in 1993 to 20,200 birds in 1995. Approximately 83% of the take occurred in the BSAI region. The estimated annual bycatch rate was 0.090 birds per 1,000 hooks in the BSAI and 0.057 birds per 1,000 hooks in the GOA regions between 1993 and 1997. Northern Fulmars *(Fulmarus glacialis)* represented about 66% of the total estimated bycatch of all bird species, gulls *(Larus hyperboreus, L. glaucescens)* contributed 18%, while Laysan Albatrosses *(Phoebastria immutabilis)* accounted for 5% and Black-footed Albatrosses *(P. nigripes)* were about 4% of the total. During the period from 1993 to 1997, only one Short-tailed Albatross *(P. albatrus)* was recorded in the observer sample

and the estimated annual take averaged 1 for this species. NMFS implemented regulations in May 1997 requiring longline groundfish vessels to use seabird avoidance measures, and in 1998, similar regulations were enacted for the Pacific halibut *(Hippoglossus stenolepis)* fishery. Continued data collection by NMFS-certified observers and improved data analyses will allow the effectiveness of these bird avoidance measures to be monitored.

Introduction

Alaska's extensive estuaries and offshore waters provide breeding, foraging, and migrating habitat for approximately 100 million seabirds, one of the world's largest concentrations of seabirds. Forty species of seabirds breed in Alaska (USFWS 1999). Breeding populations are estimated to contain 36 million individuals in the Bering Sea (BS) and 12 million in the GOA; total seabird population size including subadults and nonbreeders is estimated approximately 30% higher. In addition, up to 50 million individual shearwaters *(Puffinus* spp.) and three albatross species *(Phoebastria* spp.) feed in Alaskan waters during the summer months but breed farther south (USFWS 1999).

Also operating in these highly productive waters are commercial trawl, pot, and longline fisheries. Longline as used here refers to "hook-and-line" gear as defined in NMFS regulations at 50 CFR 679.2 to mean "stationary, buoyed, and anchored line with hooks attached." In 1998, approximately 1.87 million metric tons (t) of groundfish were harvested from the BSAI and the GOA fishery regions by all gear types combined (Hiatt and Terry 1999). "Groundfish" refers to a NMFS fishery management complex that consists of species such as walleye pollock *(Theragra chalcogramma),* Pacific cod *(Gadus macrocephalus),* sablefish *(Anoplopoma fimbria),* Greenland turbot *(Reinhardtius hippoglossoides)* and other flatfish, and rockfish *(Sebastes* and *Sebastolobus* spp.). The groundfish complex does not include Pacific halibut *(Hippoglossus stenolepis),* which is managed cooperatively by NMFS and the International Pacific Halibut Commission.

Vessels used to prosecute these fisheries vary greatly in length overall (LOA), ranging from vessels of only several meters LOA operating in inshore waters (zero to three miles), to those that operate well offshore in the 3-200 mile Exclusive Economic Zone (EEZ) and are over 75 meters LOA. Longline vessels are either catcher-processors which catch and process fish onboard, or catcher vessels which deliver sorted catch to shoreside processing facilities. Catcher-processors tend to be relatively larger than the catcher vessels, although there is some overlap in LOA between the two processing modes.

From 8% to 10% of the annual groundfish harvest was from vessels using longline gear (Hiatt and Terry 1999, Fig. 1a). From 1996 to 1998, the average annual harvest from longline groundfish vessels was 133,000 metric tons (t) in the BSAI and 26,000 t in the GOA (Hiatt and Terry 1999,

(a) Gear Type

(b) Longline catch by target species
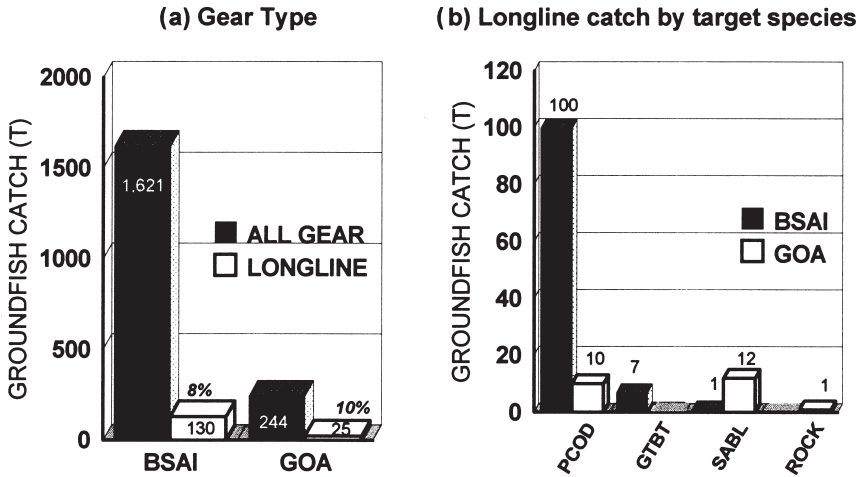
Figure 1. *1998 Groundfish catch effort off Alaska. (a) By gear type: 1,000 t and percent longline of all gear. (b) Longline catch by target species: 1,000 t. PCOD = Pacific cod; GTBT = Greenland turbot; SABL = sablefish; ROCK = rockfish spp.; BSAI = Bering Sea and Aleutian Islands Management Area; GOA = Gulf of Alaska.*

Fig. 1). Approximately 128 and 39 million hooks were deployed annually in the BSAI and GOA groundfish fisheries, respectively (NMFS 1999b).

Catcher-processors accounted for 98% of the BSAI harvest, and catcher vessels of various size classes accounted for 76% of the harvest in the GOA in 1998 (Hiatt and Terry 1999). Although the same fishing techniques are generally used, these vessel types and size classes differ in species targeted, fishing gear, bait used, hooks set per day, setting speed, and many other vessel and gear characteristics.

Fishery Description

Longline gear in Alaskan waters is demersal (fished on the bottom rather than midwater or pelagic) and consists of a groundline with hooks attached by short gangions (branchlines) of 0.5 to 2.0 m long, spaced out at intervals of one to several meters. Groundlines are anchored at each end and most often weighted at intervals. There are many variations in the specific gear deployed between vessels of different sizes or processing modes.

In the BSAI, the groundfish longline fishery harvest is predominantly Pacific cod as well as smaller amounts of Greenland turbot and sablefish (Fig. 1b). The Pacific cod fishery is generally open from January to May and September to December. Harvests are typically constrained by halibut bycatch limits. Sablefish has been managed under the Individual Fishing Quota (IFQ) system since 1995 and the season is from March 15 to Novem-

ber 15. Most fishing for Greenland turbot occurs in May. In the GOA, the groundfish longline fishery primarily harvests sablefish, Pacific cod, and rockfish (Fig. 1b). The IFQ sablefish harvest occurs March 15 through November 15, Pacific cod harvest generally occurs from January through March, and rockfish is typically harvested incidentally to other groundfish and halibut fisheries.

Fisheries Management

Groundfish fisheries in the EEZ off Alaska are managed using a system where total allowable catch (TAC) amounts are established for each gear-species complex, and catch is monitored inseason to determine fishery closure dates. TACs are established annually through North Pacific Fisheries Management Council processes where NMFS fishery scientists make recommendations on TAC using weight- or age-based modeling procedures. Inseason management occurs at the NMFS Alaska Region Offices, Sustainable Fisheries Division, Juneau, Alaska, where weekly processor reports from each processing facility are combined with weekly observer reports and run through a program that "blends" these data and determines total catches of established species groups or individual species (see Methods).

Role of NMFS-certified Observers

Current observer coverage requirements for vessels are based on vessel length, regardless of processing mode. Catcher-processors or catcher vessels 38.1 m LOA or longer must carry a NMFS-certified observer during 100% of its fishing days (100% coverage). Vessels equal to or longer than 18.3 m LOA, but less than 38.1 m LOA, that participate for more than three fishing days in a directed fishery for groundfish in a calendar quarter, must carry a NMFS-certified observer (1) during at least 30% of its fishing days in that calendar quarter, and (2) at all times during at least one fishing trip in that calendar quarter for each of the groundfish fishery categories (30% coverage). Directed fishing occurs when the amount retained of a species or species group exceeds the maximum retainable bycatch (NMFS regulations at 50 CFR 679.20). Vessels less than 18.3 m LOA are not required to carry observers.

NMFS-certified observers complete a suite of data collection duties in support of NMFS fisheries management objectives (NMFS 1999a). Specific methods used while monitoring longline fishing activity are described below. Since 1990, between 20,000 and 35,000 observer coverage days (fishing days) occur each year in the groundfish fisheries overall.

The collection of seabird bycatch data was integrated into an existing comprehensive data-gathering observer program designed to collect data for a wide variety of management and research purposes. Preliminary work was conducted in 1991-1992, and in 1993 seabird related duties were standardized as part of all observers' duties. All observers currently entering the North Pacific Groundfish Observer Program (NPGOP) receive seabird identification training during their initial three-week certification

course, and receive a briefing each year before their first deployment which focuses primarily on albatross identification.

Problem

Birds that forage in the same waters as commercial fishery operations are susceptible to interaction with fishing gear. Abundant food in the form of offal (discarded fish and fish processing waste) and bait attract many birds to fishing vessels. Most foraging by seabirds is for offal and bait that has come off hooks. However, while longline gear is being set, the baited hooks are attractive to seabirds until the weighted groundline and hooks sink far enough below the surface to no longer be available to birds. If a bird becomes hooked when feeding on baits at or near the surface, it is dragged underwater and drowned.

The first study to estimate seabird bycatch on longline gear was in the Japanese pelagic longline fishery for tuna in southern oceans near Australia (Brothers 1991). Bycatch estimated for other longline fisheries was summarized by Alexander et al. (1997) and Brothers et al. (1999). Rigorous estimates of seabird bycatch numbers and rates have not been previously made for the Alaska longline fisheries, thus the focus of the work we are reporting here.

Methods

This report used five years of commercial fishery catch and processing reports and groundfish observer data from 1993 to 1997 to calculate annual estimates of seabird bycatch for Alaska longline groundfish fisheries. Bycatch was not estimated for the halibut IFQ fisheries or for fisheries outside the EEZ since NMFS does not currently collect this information and there are no observer coverage requirements. An estimate of total seabird bycatch in longline groundfish fisheries was derived using two data components: (1) number of birds caught per unit of fishing effort and (2) a measure of total fishing effort.

Number of Birds Caught Per Unit of Fishing Effort—Observer Seabird Data

Observer data comprised the first data component. Observers determine the composition of species within a haul using a method known as tally sampling. The observer stands at a safe location near or above where the gear is being retrieved and where they have a clear view of the longline as it exits the water. The observer tallies each individual fish, invertebrate, mammal, and bird and makes the best species identification possible from their station. A subset of each fish species is set aside to confirm species identifications and to calculate an average weight for that species. Each species average weight is applied to the total number of individual fish of that species to determine the total catch sampled. The observer also records

the total number of hooks set (provided by the captain, but periodically verified) and tallies empty hooks that come up during the tally sampling period. This information is summarized and the total catch for the haul is calculated. During the sampling period, the crew is required to keep all birds when requested by the observer, but birds do sometimes drop off the longline or are knocked off by the crew (a standard practice for years to avoid fouling the retrieval gear). Observers are directed to tally sample for at least one-third of each retrieval monitored. Random sampling techniques are applied when observers select their multiple tally sample periods. Observers are able to monitor from 50 to 100% of the retrievals during a trip.

The observer calculated and recorded the official total catch weight of the entire haul based on the sum of species sample weights multiplied by total estimated number of hooks and divided by the number of observed hooks. For our analysis the number of observed hooks was calculated by multiplying the total hooks by the sum of species composition weights divided by official total catch weight. Data available thus included the number and weights of fish, birds, and invertebrates in the species composition sample, the observed haul data (total number of hooks per set), and accessory data files with species codes and area-year lists.

Observers are instructed to make the most reliable (to species or species group) identification possible. Observers generally have no background in ornithology or bird identification before coming to the NPGOP. They are provided with basic instruction and identification materials on how to identify dead birds in the hand and sightings of the albatross and several other species of interest. Codes were developed to capture different levels of confidence with an identification, from the species level up through several taxonomic codes ultimately to unidentified seabird. For example, an albatross might be identified to species, or noted as unidentified albatross, unidentified procellarid, or unidentified seabird.

Measure of Total Fishing Effort—Fishery Catch Data

The second data component used for bycatch estimation was the estimated total weight of fish caught by all vessels in the fishery, including those vessels without observers. Since 1993, NMFS has used a groundfish catch accounting system based on industry weekly production reports and observer reports of total estimated catch. This system combines data from industry and observer reports to estimate groundfish harvest in the BSAI and GOA groundfish fisheries. This provides NMFS managers with estimates of total commercial catch for each calendar week in various fishery zones and is the basis for quota monitoring and fishery closures when a seasonal quota for target or bycatch is reached. Blend data are also used for numerous regional and national reports, fishery stock assessments, and analysis of fishery management plans. Processors maintain detailed logbooks and report amounts of fish products and discards to NMFS each week. Product weights are converted to estimates of round

(whole) weight through application of standard product recovery rates. In longline fisheries, observers provide independent estimates of total catch using a tally method that was described in the previous section. The "blend program" uses the following sources for fish catch information: (1) shoreside processor weekly production reports, (2) catcher-processor weekly production reports, and (3) observer reports of total estimated catch.

Estimation of Total Seabird Bycatch

In order to match the estimated total fishery catch data, we tabulated the observer data from sampled hauls for all four-week periods in the five years from 1993 to 1997, for a total of 65 time periods for each area (130 strata). Each year the 13 periods were defined as (four) Saturday-to-Saturday calendar weeks with non–7 day weeks (partial weeks) included in the first or last period. The data were summed for all fishery zones of the BSAI or the GOA regions. For some strata the observed portion of hauls represented about $1/3$ of the total number of hooks set, whereas in other zones and times, the observed sample represented less than $1/50$ of the estimated total hooks.

All observed hauls within each stratum were used to calculate the mean and variance of birds per fish-kg and birds per hook as ratio estimates. A ratio estimate allowed for unequal size hauls but assumed the observed portion of each haul was an independent sample unit. In fact, each haul was not independent because hauls occurred in groups (cluster samples) for a vessel with a NMFS-certified observer onboard for a series of fishing days (a cruise). For simplicity, the vessel-cruise cluster sampling and the different observer sampling rates for various vessel size classes were ignored in this analysis.

Birds per fish-kg and birds per 1,000 hooks were not calculated separately for each species to avoid high variability due to sampling error, particularly for the less frequently caught species. Seasonal and regional patterns in catch and catch rate were determined for combined bird species, and then the estimated number of birds was subdivided (allocated) into species or species groups. This approach will work when there is a positive correlation in catch rate among various bird species, a reasonable but untested assumption. This estimation approach assumed that sampled hauls were representative of all vessels and hauls within that region and time period, and that each haul was independent. If fewer than 20 hauls were sampled in a region-year-period block, the mean ratios of birds per fish-kg and birds per hook were calculated with all five years of data combined for that region and period.

For each block, the catch of seabirds was calculated as the sum of (1) total identified birds from observed hauls; (2) the total of observed but unidentified birds apportioned into species or species groups; and (3) the estimated number of birds on unobserved hauls apportioned into species or species groups. The total number of unobserved birds was calculated

using the ratio of birds per fish-kg from the observed hauls in each block and an estimate of unobserved fish weight that was calculated from the estimate of total commercial catch weight of fish minus the fish weight from the observer sample. The total variance was the sum of the component variances. Variance in component (1), above, is 0.0 because this is the counted number of birds on observed portion of hauls with no sampling error. The variance of (2), above, was based on the binomial distribution calculated as $p(1-p)n$, where p = average species proportion for each unidentified species and n = number of unidentified birds. The variance of component (3), above, was calculated as the variance of a product of two independent variables, $U^2 \text{var}(S) + S^2 \text{var}(U) - \text{var}(U)\,\text{var}(S)$. The estimated total number of unobserved birds was $U = WR$, where W = total commercial catch of fish minus the observed weight of fish, R = ratio estimate of birds per fish-kg, and S = average proportion for species composition with $\text{var}(S) = p(1-p)/n$ where p = average species proportion composition for all birds and $n = U$ = estimated number of unobserved birds. The estimate of total commercial catch of fish had no estimate of variance therefore it only rescaled the variance among hauls without adding additional variation.

For observed but unidentified seabirds, the number of birds of each species or species group in each four-week period was estimated based on the three-period running average species composition of identified birds combining all five years of data. Misidentified bird species were assumed to be infrequent, at least for the species groups considered in this report. This partitioning was done with stratification by BSAI and GOA regions. Although the number of birds on unobserved hauls was estimated with region-year-period specific data, the species identity for unobserved birds was calculated for each region and period after combining all years of data. Unidentified albatrosses observed in each year, period, and region were assigned a species identity based on the combined average of species composition for three periods (previous period, same period, and following period) among the three identified albatross species. The same procedure was used to assign unidentified seabirds among the other four species groups. The data were again combined over years and using another three-period combined average, species composition was calculated for all species in each region and four week period (Fig. 2).

Results

Species Composition in the Observer Sample

The observed sample included 49 million fish, one million invertebrates, 16,768 birds, and 6 marine mammals. Pacific cod, the principal target of the BSAI longline fishery, accounted for 64% of the catch of all individual organisms and 67% of the total weight in the observer sample. From 1993 to 1997 in the Alaska longline groundfish fisheries, 6,042 of 51,643 observed hauls (11.7%) included one or more bird species, and 682 hauls
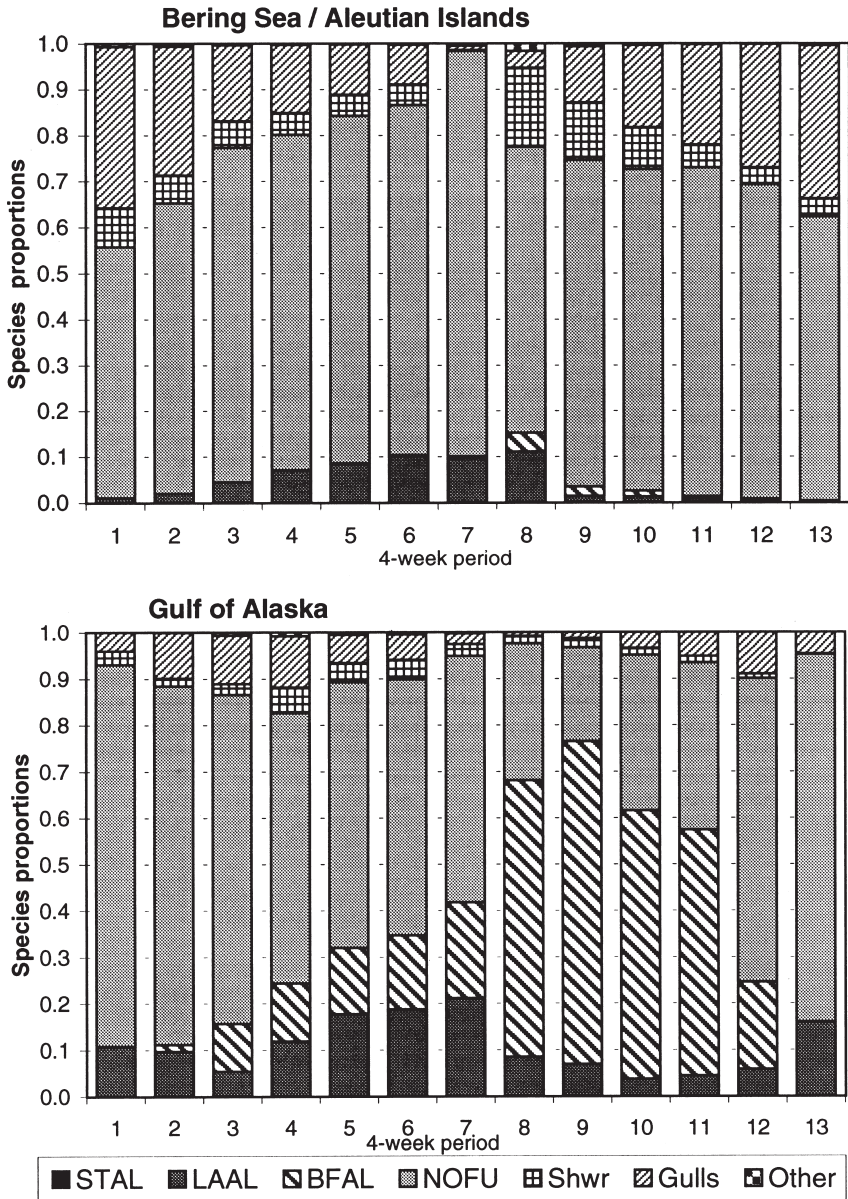
Figure 2. *Species composition of seabirds caught in longline hauls in the Bering Sea/Aleutian Islands and Gulf of Alaska. All observer data from 1993 to 1997 were combined.*

(1.3%) included an albatross species. Birds accounted for 0.0334% of the individual organisms caught. The most common bird species caught were the Northern Fulmar (58% of the birds caught), gull species (16%), and then all unidentified birds (15%) (Table 1). The three species of albatross (including unidentified albatross) totaled 6.4% of the individual birds in the sample, and only 1 of the 1,077 albatrosses taken was identified as the endangered Short-tailed Albatross (STAL).

The observer data on seabirds included 12 species, four species groups, and many birds not identified to species (Table 1). These were combined into seven groups for analysis. It was assumed that unidentified seabirds did not include any albatross species. The 226 unidentified albatrosses were split in proportion to the observed albatross species that totaled 1 STAL, 628 Laysan Albatross (LAAL), and 222 Black-footed Albatross (BFAL) (Table 1). Similarly the 2,538 unidentified seabirds were split in proportion to the identified catch of 9,726 Northern Fulmars (NOFU), 2,625 gulls, 752 shearwaters, and 50 birds of other species (Table 1). All years of data were combined assuming that any annual change in species composition was not as important as regional or seasonal patterns.

Estimated Catch of Seabirds

The total estimated average bycatch of seabirds was about 14,000 birds annually. For the BSAI region, total estimated bycatch was over 17,000 seabirds in 1995 and 1997 compared to 6,000 to 9,000 birds in the other years (Table 2). In the GOA, bycatch has declined over time and 1997 had a relatively low estimated bycatch of about 900 seabirds compared to over 2,000 in previous years. The estimated rate of bird bycatch per 1,000 hooks was not constant but instead it showed essentially the same pattern between years as the estimated total number of birds taken. For years 1993 through 1997, the bird bycatch rate (number of birds per 1,000 hooks) in the BSAI was 0.06, 0.08, 0.14, and 0.06, and in the GOA it was 0.05, 0.05, 0.07, 0.07, and 0.03. Both a greater number of hooks and a higher estimated catch rate contributed to the high estimated seabird bycatch in the BSAI region in 1997. A low number of hooks and a low estimated catch rate combined to cause the lowest annual bycatch in the GOA region in 1997. The estimated annual bycatch rate was 0.090 birds per 1,000 hooks in the BSAI and 0.057 birds per 1,000 hooks in the GOA regions between 1993 and 1997.

Seasonal patterns showed that April-May (four-week periods 3, 4, 5) and September-November periods (four-week periods 10, 11, 12) had higher estimated numbers of birds of some species taken and higher estimated catch rates of seabirds in the BSAI region (Fig. 3), while May-June and October (four-week periods 5, 6, 9, 10) were higher for the GOA region (Fig. 4). The number of seabirds taken and the rate of catch per hook followed roughly the same patterns; however, differences occurred among the various species. Approximately equal numbers of LAAL were taken in

Table 1. **Seabirds caught and reported by NMFS observers in the sampled portion of longline hauls in the Bering Sea/Aleutian Islands and Gulf of Alaska, 1993-1997.**

Species or group name	93	94	95	96	97	Total
Unidentified albatross	68	22	116	17	3	226
SHORT-TAILED ALBATROSS (STAL)	0	0	0	1	0	1
LAYSAN ALBATROSS (LAAL)	195	123	126	99	85	628
BLACK-FOOTED ALBATROSS (BFAL)	12	9	76	111	14	222
	275	154	318	228	102	1,077
NORTHERN FULMAR (NOFU)	1,254	1,323	2,569	1,387	3,193	9,726
GULLS (gulls)						
Unidentified gull	222	417	929	317	505	2,390
Glaucous-winged Gull	0	0	45	36	54	135
Glaucous Gull	0	0	17	16	48	81
Herring Gull	0	0	7	1	11	19
	222	417	998	370	618	2,625
SHEARWATERS (shwr)						
Unidentified shearwater	35	157	51	6	47	296
Dark shearwater species	0	0	18	114	22	154
Sooty Shearwater	0	0	18	13	0	31
Short-tailed Shearwater	0	10	4	4	2	20
Unidentified tubenose species	0	92	120	4	35	251
	35	259	211	141	106	752
OTHER SPECIES (other)						
Black-legged Kittiwake	2	1	12	10	2	27
Alcid species	0	0	0	7	0	7
Cormorant species	0	0	1	1	3	5
Waterfowl species	0	0	0	1	1	2
Guillemot species	2	0	0	0	0	2
Murre species	1	1	0	0	0	2
Common Murre	0	0	0	2	0	2
Thick-billed Murre	0	0	1	0	0	1
Loon species	0	0	0	0	1	1
Auklet/murrelet species	1	0	0	0	0	1
	6	2	14	21	7	50
Unidentified seabirds	110	485	686	58	97	1,436
Unidentified birds	358	187	426	54	77	1,102
	468	672	1,112	112	174	2,538
All species combined	2,260	2,827	5,222	2,259	4,200	16,768

Uppercase names and abbreviations indicate the seven species or species groups chosen to estimate species composition and provide estimates of seabird bycatch for the groundfish fishery.

Scientific names of above species (in order): *Phoebastria albatrus, P. immutabilis, P. nigripes, Fulmarus glacialis, Larus glaucescens, L. hyperboreus, L. argentatus, Puffinus griseus, P. tenuirostris, L. tridactyla, Uria aalge, U. lomvia.*

Table 2. **Estimated total number of seabirds caught by region and year based on the sum of birds observed and identified, birds observed but not identified, and unobserved birds apportioned to species for the Alaska longline fisheries in the Bering Sea/Aleutian Islands and Gulf of Alaska, 1993-1997.**

Year	STAL	LAAL	BFAL	NOFU	Shwr	Gulls	Others	Total
Estimated total birds:								
Bering Sea/Aleutian Islands								
93	0.1	475	11	4,367	292	1,110	24	6,279
94	1.1	350	40	6,606	808	2,078	35	9,917
95	1.1	550	52	11,911	990	3,872	56	17,433
96	1.7	237	23	5,278	496	1,568	43	7,646
97	1.0	439	27	12,156	736	3,601	42	17,002
Average	1.0	410	31	8,064	664	2,446	40	11,655
Gulf of Alaska								
93	0.0	459	647	1,684	117	157	11	3,076
94	0.0	414	803	1,451	96	141	8	2,912
95	0.0	266	984	1,279	86	163	9	2,787
96	0.0	277	496	1,208	62	111	6	2,159
97	0.0	110	123	604	30	71	4	943
Average	0.0	305	611	1,245	78	128	8	2,376
Standard error of estimated totals:								
Bering Sea/Aleutian Islands								
93	0.3	23.6	2.4	1,85.0	22.2	61.3	4.5	197.6
94	1.1	23.8	6.1	2,80.0	38.6	111.3	6.0	304.9
95	1.1	30.1	6.4	4,28.5	46.2	159.8	7.0	460.8
96	0.9	18.0	4.3	254.8	28.4	84.4	4.8	270.6
97	1.0	31.6	5.4	499.4	42.3	192.2	6.2	537.8
Average	0.9	25.9	5.1	349.5	36.7	131.0	5.8	376.0
Gulf of Alaska								
93	0.0	52.4	93.4	161.2	14.9	19.3	3.4	195.1
94	0.0	58.7	150.9	189.7	15.9	21.6	3.1	250.9
95	0.0	26.2	125.9	127.7	11.3	18.1	2.8	182.5
96	0.0	29.1	82.0	152.0	9.9	15.5	2.4	176.2
97	0.0	22.3	34.2	139.6	6.9	16.8	1.7	146.6
Average	0.0	40.6	105.1	155.5	12.2	18.4	2.7	193.3
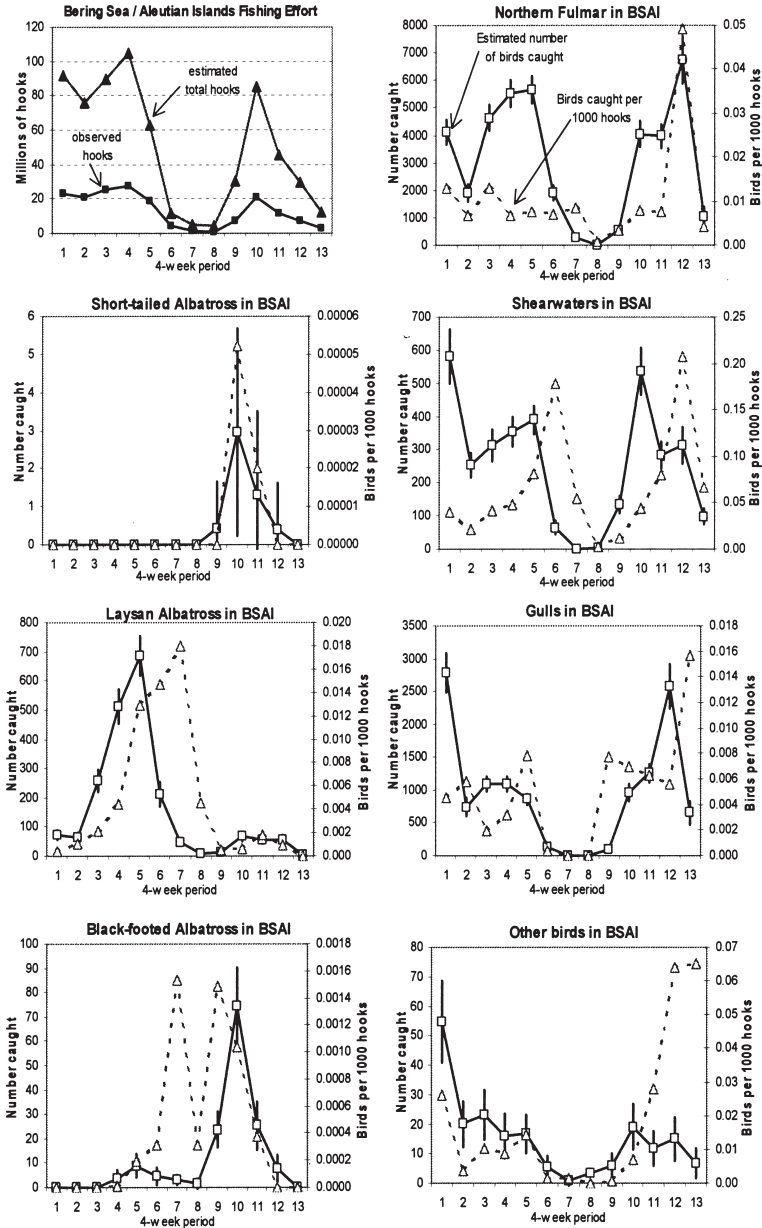
Figure 3. Observed and estimated total number of hooks in the Bering Sea/Aleutian Islands longline fishing effort as summarized by four-week periods. All observer data from 1993 to 1997 were combined. The seasonal pattern of the estimated number of birds caught by species or species group is indicated by solid lines with 95% confidence limits. The estimated seabird bycatch rate per 1,000 hooks is indicated by a broken line.
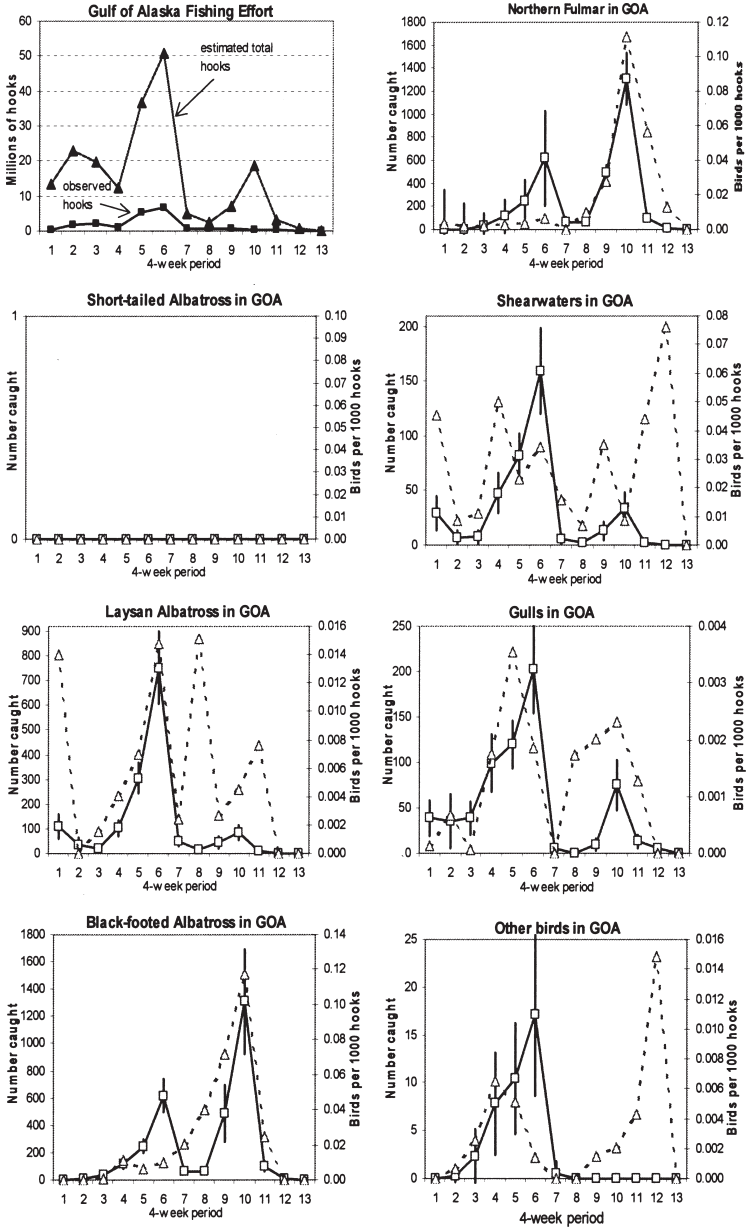
Figure 4. Observed and estimated total number of hooks in the Gulf of Alaska longline fishing effort as summarized by four-week periods. All observer data from 1993 to 1997 were combined. The seasonal pattern of the estimated number of birds caught by species or species group is indicated by solid lines with 95% confidence limits. The estimated seabird bycatch rate per 1,000 hooks is indicated by a broken line.

the BSAI and GOA regions with their catch peaking in April-June. BFAL were most frequently taken in September-October in the GOA.

Discussion

We used standard statistical procedures for estimating the mean from a sample, although the characteristics of the sampling design and the data available leave considerable space for interpretation and potential biases. The simple approach used reflects a first exploration of observer data on seabird bycatch in Alaska longline fisheries. Many other statistical approaches are possible, and if similar estimates are obtained, these will increase confidence in the estimate. Therefore, this analysis should be viewed as a starting point, not as documentation of a final answer. The probability of catching seabirds depends on many interrelated factors that may include type of vessel, fishing gear, length of time baits are near the surface, seabird feeding and foraging behavior, sea state and weather conditions, use of bird deterrent devices, and availability of other foods including bait and offal. Further analyses may indicate which variables are correlated with the seabird catch rate, thus allowing better stratification or regression approaches to obtain more rigorous estimates.

If the hauls sampled by NMFS-certified observers were not representative of all hauls in the longline fishery, substantial bias may exist in the ratio of birds per fish-kg and the estimate of total seabird bycatch may not be accurate. Both the mean catch rate of birds (number of birds per kg of fish, or birds per 1,000 hooks) and the catch rate of fish (weight of all fish species per hook) were assumed to be equal for observed and unobserved hauls. These assumptions may not be appropriate. Possibly the presence of an observer changed the fishing practices of the skipper or crew. More likely is that the mid-sized vessels (18.3 to 38.1 m) with 30% observer coverage, or the smaller vessels (<18.3 m) that do not have any NMFS-certified observers, may have different catch rates of fish or seabirds than the larger vessels. In some zones and time periods, observer sampling data from the larger vessels may not be representative of the total commercial catch of fish. The constant catch rates for birds and fish among vessel type and vessel size categories remain as untested and critical assumptions.

The assumption that annual changes in species composition were not as important as regional or temporal patterns has not yet been investigated. Any changes in fishing practices (gear, bait, setting speed, bird deterrent devices) could have species specific effects, thus using data from all years to assign unidentified birds to species may not be accurate. If there is a negative correlation in catch rate among any of the bird species, the assignment of unidentified or unobserved birds to species groups will be more variable than was estimated.

Seabirds hooked and drowned but scavenged or dislodged before coming onboard the vessel will cause the number of birds to be underesti-

mated. In the tuna pelagic longline fishery off Australia, unreported or dislodged birds may be as numerous as the reported birds (Gales et al. 1998). For longline fisheries in Alaska there were no data on unreported birds (scavenged or dropped off underwater), therefore we made no adjustment to the observed bird catch rates. Biases due to underwater loss, or non-reporting, were assumed to be zero. Given the location from where NMFS-certified observers of Alaska longline fisheries monitor the longline retrieval, drop-offs that occur between the water surface and being hauled on board are counted.

This paper focuses only on seabird mortality associated with the longline groundfish fishery. Work is under way to also describe seabird mortality related to other gear types, where very little seabird bycatch is reported. While there is also some concern regarding the Pacific halibut longline fishery, there has been no observer coverage in that fleet. Work is needed to examine similarities and differences between these longline fisheries to determine the applicability of extrapolating seabird mortality numbers or trends from the groundfish fleet to the Pacific halibut fleet.

Efforts to Reduce Seabird Bycatch in Alaska Longline Fisheries

Seabird avoidance measures were required in the groundfish longline fisheries of the BSAI and GOA in 1997 and in the Pacific halibut fishery off Alaska in 1998. The North Pacific Fisheries Management Council recommended revision of these regulations in 1999 (NMFS 2000). The University of Washington Sea Grant Program has undertaken a research study in 1999 and 2000 to evaluate the effectiveness of bird avoidance measures currently being used in the Alaska longline fisheries. Results from this effectiveness study will be used to further improve the methods available for longline vessels to reduce seabird bycatch. Analyses such as those reported here are imperative to effectively monitor the efficacy of bycatch reduction measures and to determine if such management regulations are effective.

Acknowledgments

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Deterring Albatrosses from Contacting Baits During Swordfish Longline Sets

Christofer H. Boggs
National Marine Fisheries Service
Honolulu, Hawaii

Abstract

The effectiveness of albatross deterrent techniques was examined during line setting operations in the Hawaii-based longline fishery for swordfish *(Xiphias gladius).* Methods tested were bird scaring streamer lines, weights added to baits, and camouflaging bait with food coloring. Observations were made on ca. 66 baited branch lines deployed on 96 occasions. Baits dyed blue and baits with added weight both reduced the number of contacts between baits and Black-footed *(Phoebastria nigripes)* and Laysan *(P. immutabilis)* Albatrosses by about 90%. Streamer lines reduced contacts between baits and albatrosses by about 70%.

Introduction

Longline-related mortality has been implicated as a major threat to albatross populations, and a worldwide effort is under way to mitigate this problem (Bergin 1997). Mortality caused by the Hawaii-based domestic longline fishery could impact North Pacific Black-footed *(Phoebastria nigripes)* and Laysan *(P. immutabilis)* Albatross populations nesting primarily in the Northwestern Hawaiian Islands (NWHI), although the relative importance of fishing mortality is difficult to determine (Gales 1997, Ludwig et al. 1997, Cousins and Cooper 2000). Of the two species the Black-footed Albatross is the most vulnerable because it has the smallest breeding population (ca. 120,000 birds) and is taken in larger numbers (1,600-2,000 birds annually) by the domestic fishery (Cousins and Cooper 2000). The foreign take of albatrosses is unknown. The domestic fishery largely overlaps the range of both species, fishing mostly from 15°-45°N and from 145°-180°W (He et al. 1997). Domestic effort reached about 15 million hooks in 1997,

and foreign longline fleets probably deployed about twice that much effort in the same general area (Cousins and Cooper 2000).

This study tested deterrents to albatross feeding on baited branch lines during longline setting. Studies on Southern Hemisphere pelagic longline fisheries indicate that southern species of albatrosses are mostly hooked during daylight setting, and are drowned as the line sinks, whereas those caught during line hauling are usually alive, sometimes uninjured, and may be released (Brothers 1994, Brothers et al. 1999). In the region around the NWHI only 5-40% of domestic longline sets are made in daylight (He et al. 1997) and sets are most often made in the afternoon or evening using light sticks attached to the branch lines to increase the nighttime catch rate of swordfish (Bigelow et al. 1999). Commercial vessel encounters with albatrosses may be somewhat reduced by setting at night and because commercial longlining is prohibited within 50 nautical miles of the NWHI (Boggs and Ito 1993). To increase the rate of bird encounters over that of commercial vessels for this study the National Marine Fisheries Service (NMFS) used a research vessel to conduct tests in daylight sets near the NWHI breeding colonies while albatrosses were foraging locally to feed small chicks (Anderson and Fernandez 1998, as cited by Cousins and Cooper 2000). To prevent albatross mortality, hooks were replaced with net pins to hold the bait.

The purpose of the study was to test seabird deterrent methods in the central North Pacific fishing grounds prior to enacting new bird deterrent regulations for the domestic fishery. The methods tested were: (1) a bird scaring streamer line, (2) addition of weight to the bait, and (3) dyeing the bait blue with food coloring. A streamer line (Brothers 1991, 1994) trails over the area in which the bait sinks as the vessel moves ahead, scaring birds away, and interrupting their flight paths to the bait. Adding weight (Brothers et al. 1995) causes bait to sink quickly below the limited plunging depth of albatrosses. And blue food coloring may make bait blend into the water, or make it appear deeper.

Methods

Longline Gear

Tests were conducted February 7-28, 1999, aboard the R.V. *Townsend Cromwell* near and between Laysan Island and French Frigate Shoals, mimicking swordfish longline techniques in which the main line is set much closer to the surface than tuna longline (Boggs and Ito 1993, He et al. 1997, Bigelow et al. 1999). A 4 mm monofilament main line was set tight at 7 knots (vessel speed = line setting speed) with branch lines attached at 16 second intervals (57.6 m apart). A float and float line were attached after every four branch lines (230 m between float lines). Branch lines were 14.6 m of 2.1 mm monofilament with 60 g swivel weights located 3.7 m above the bait. Float lines were 9 m of 6.25 mm polypropylene rope.

Squid *(Illex* sp.) weighing about 200 g each was used as bait and pinned to the end of each branch line using 8.25 cm nickel plated brass net pins weighing 13 g, about the same weight as typical straight shank #8/0 Mustad hooks. The pins resembled safety pins, having no exposed point. Bait thawing varied as in the commercial fishery, and was recorded, but was not a controlled variable. Typically, partially thawed bait (ice crystals present, but not rigid) was used in the morning and fully thawed bait (limp) was used in the afternoon. Bait was often reused to save money and because freezer space for bait was limited.

Experimental Design

A set about 16 km long with about 270 branch lines was made each morning and again each afternoon. Sections of these sets were observed, averaging 18 minutes duration (3.8 km in main line length), with an average of 66 attached branch lines. Each observed set section provided a record of contact rates between birds and baits for each species of albatross. Timed sections were intended to be of equal length, in order to utilize a prepackaged quantity of bait. However, accidental overruns and shortages of baits per case caused variation in the length and number of branch lines in each section. Bird contacts with bait were expressed as rates per 100 branch lines to adjust for variation in the number of branch lines observed per record.

Timed set sections were observed for each of four treatments (control, streamer line, dyed bait, and weighted bait). Four set sections were observed each morning and four each afternoon. It was assumed that bird behavior might be affected by setting operations commencing with a control treatment because the absence of a deterrent might encourage continued attempts to take bait during subsequent treatments. And it was assumed that behavior might differ between morning and afternoon. So, either the first or the last of each four morning and afternoon set sections was a control section, with the remaining three set sections used for replicate observations of a deterrent treatment. Order was classified as (1) control first in the morning, (2) control last in the morning, (3) control first in the afternoon, and (4) control last in the afternoon. Each order was applied an equal number of times to each deterrent treatment in a random sequence and the effects of treatments and order were evaluated with two-way analysis of variance (ANOVA, Sokal and Rohlf 1981).

The observation of one control treatment for every three deterrent treatments resulted in an equal number of records per treatment. Except for observing three replicates in a row of one deterrent treatment, and choosing the last few deterrent treatments to complete a balanced design, the deterrent treatments were applied at random. More complete randomization would have necessitated changing between deterrents several times each morning and afternoon. Changes in bird abundance, observers, and environmental conditions (e.g., visibility) between set sections qualified

each section as a separate observation. No pairwise comparison of control versus deterrent treatments was planned a priori. It was not anticipated which, if any, of the deterrents would be successful. Pairwise comparisons were made a posteriori using Fisher's least-significant-difference (LSD) test (Kendall and Stuart 1968).

Five experienced marine biologists and one NMFS longline fishery observer were trained by a U.S. Fish and Wildlife Service expert to identify local pelagic seabirds to genera and all North Pacific albatrosses to species. During each observed set section two of these observers called out bird contacts with bait, by species, while a recorder tallied the data. One observer scanned the entire area in which contacts occurred, extending 150 m behind the stern and 15 m to either side of the main line, and reported contacts between birds and baited branch lines. A second observer used binoculars to zoom in on suspected contact events to confirm reports of the first observer and to observe whether other birds contacted the same bait.

A contact was defined as an albatross grasping a bait in its beak while the bait was attached to a branch line. Contacts by birds contending for a bait already held by one bird were not counted unless it could be determined that the bait was taken away by another bird. A crowd of birds usually formed around the first bird contacting a bait, making it hard to determine if a bait was taken except when the successful contender was a different species than the first bird. Undoubtedly some contacts escaped observation. Difficulties and inaccuracies in the observations applied equally to all treatments.

At the end of each set section (every ca. 18 minutes) the observers and recorder were replaced by alternates to increase attentiveness. The resting observers estimated the number of birds of each species (or genera for species besides albatrosses) in the area extending 300 m behind and to either side of the stern at the start and end of each set section. The start and end estimates were averaged to provide an abundance estimate on each taxa for each observed section. The effects of treatments and order on bird abundance data were also analyzed using two way ANOVA.

Deterrent Techniques

The streamer line materials and construction followed the design described by Brothers (1994) except for some modifications similar to those suggested by Kalish and Tong (1993). The 150 m streamer line comprised a 10 m attachment section made of 6 mm yellow twisted polypropylene, a 40 m aerial streamer segment made of the same material with seven forked branch streamers, an 85 m × 3 mm red twisted nylon trailing segment with 8 small streamers on the first 40 m, and a 15 m × 12 mm yellow twisted polypropylene drogue segment. The streamer line was flown from a fiberglass pole mounted 4 m forward of the stern, extending 10 m above water and 2 m outboard. The streamer line was about 8 m high at the

stern, and the ends of the first forked streamer dangled just above water, 10 m behind the stern, about 5 m directly aft of the bait entry point. Changing between the streamer line and control treatments took about two minutes, during which main line setting continued but no baited branch lines were attached and observation was halted.

This streamer line differed from Brothers (1994) design by (1) replacement of the 30 mm barrel swivel end weight with a drogue segment, (2) the use of thicker line (6.25 mm as opposed to 3 mm) for the large streamer segment, (3) the use of different forked branch streamers, and (4) the addition of small streamers on the trailing segment. The drogue substituted for the heavy end swivel to add drag and keep the streamer line taut, but it was thought to be less likely to tangle with the longline. In case of such tangling the thicker forward segment was intended to defer breakage to the thinner and more easily replaced trailing segment.

Forked branch streamers were made from single (rather than double) 4 mm braided nylon cord with the upper half covered with 5 mm inside diameter clear plastic tubing crimped to the middle of the streamer along with a 40 g weight. The forked end of the branch streamer was made with three 1 m × 25 mm pieces of red, orange, and green plastic ribbon threaded through a swivel crimped to the end of the nylon cord such that the two ends of each ribbon dangled 0.5 m down from the swivel. This design (Kalish and Tong 1993) was substituted for that of Brothers (1994) to help prevent the branch streamers from wrapping around the streamer line in high winds.

The first branch streamer was attached 10 m from the stern, and the next six were attached at 5 m intervals behind the first. The length of nylon cord was adjusted so that the ends of the plastic ribbon occasionally touched the water. Brothers (1994) design calls for three branch streamers 7 m apart (or more as needed) to cover the length of the streamer line above the water. If the first of these three streamers was 10-20 m aft of the stern, this would suggest that the third streamer was only 24-34 m behind the stern. So in the present study the aerial portion of the streamer line extended at least as far back (>40 m) as in the nominal design recommended for the Southern Hemisphere tuna longline fishery (Brothers 1994). The aerial portion of the streamer line extended back about as far as birds made contacts with bait, except for cases where birds contacted baits already held by another bird. However, Kalish and Tong (1993) noted that the portion of the streamer line trailing in the water did little to prevent birds from taking baits that might still be near the surface that far back. And this study followed their recommendation in adding 8 short (0.15 m) streamers made by weaving yellow plastic strapping tape (bait carton straps) through the trailing segment at 5 m intervals.

Bait was dyed using a concentrate made from 0.45 kg of Virginia Dare FD&C Blue No. 1 powder dissolved in 7.2 L of water. Three 50 kg batches of partially thawed bait were soaked for 15-20 minutes each in 1.0 L of the

concentrated dye added to 18 L of water. Soaking in dye had the advantage of thoroughly thawing the bait. However, dyed bait was not always more thawed than other bait because dyed bait was often re-frozen and later used partially thawed.

All branch lines were weighted as in the commercial fishery. For weighted bait treatments, an additional 60 g swivel weight was pinned on along with the bait. The fishing equivalent would be a weighted hook or a weight within a few centimeters of the hook.

Results

Observations

Although many kinds of shearwaters, boobies, petrels, terns, and frigate birds were seen in the area, only Black-footed and Laysan Albatrosses ever made contact with the bait. No other species of albatross was seen in over 100 hours of observation. No injuries or mortalities were observed. Retrieval of branch lines with missing net pins was rare, indicating that few could have come off as birds interacted with the bait.

A total of 96 set sections from 24 sets were successfully completed, providing 24 observations of each treatment for each of the two albatross species (Table 1). There were six observations per species in each treatment-order combination. The number of contacts observed per set section ranged from zero in some set sections with deterrents to 43 Black-footed and 48 Laysan Albatross contacts in control set sections. The number of birds observed ranged from 5 to 125 for Black-footed Albatross and from 2 to 325 for Laysan Albatross (Table 1). Abundance was lowest in the dyed bait treatments (mean = 37.8 and 42.9, n = 24) and highest in the weighted bait treatments (mean = 61.0 and 68.7, n = 24) but there was no significant treatment effect on abundance (two-way ANOVA, F = 1.2 and 2.0, P = 0.1 and 0.3, d.f. = 3, for Black-footed and Laysan Albatrosses, respectively). Abundance was lowest when deterrent treatments preceded the control treatment in the morning (order 2 mean = 31.6 and 34.5, n = 24) and the effect of order was significant (two-way ANOVA, F = 4.0 and 4.3, P = 0.01 and 0.007, d.f. = 3, for Black-footed and Laysan Albatrosses, respectively). The presentation of deterrent treatments first in the morning seems to have discouraged birds from aggregating around the vessel until the first control treatment was conducted. After that, bird abundance was often high during deterrent treatments.

Contact Rates

Contact rates per 100 branch lines (Table 1) were highest for the control treatment and lowest during the dyed bait treatment (Fig. 1). Contact rates were significantly affected by the treatments (two-way ANOVA, F > 34, P < 0.0005, d.f. = 3) for both albatrosses, and by order (F = 7.1, P < 0.0005, d.f. = 3) and by the interaction between treatment and order (F = 3.1,

$P = 0.003$, d.f. = 3) for Black-footed Albatross. The significance of the order and interaction effects could lead one to question the treatment effect. Significant variation in the abundance of albatrosses by order probably contributed to the apparent effect of order on contact rates, suggesting that the results should be standardized for bird abundance. Furthermore, linear regressions of contact rates (per 100 branch lines) for the combined deterrent treatments on bird abundance indicated significant proportional effects of abundance on contact rates ($R^2 = 14.5\%$ and 10.4%, intercept = 0, slope = 0.087 and 0.060 contacts per bird per 100 branch lines, and 95% CI for slope = 0.022 and 0.018, $P < 0.0005$, $n = 72$, for Black-footed and Laysan Albatrosses, respectively). Therefore the contact data were re-analyzed as contact rates per bird per 100 branch lines for both species (Table 2).

Contact rates per bird (Fig. 2) were again highest for the control treatment (0.83 contacts per Black-footed Albatross per 100 branch lines, and 0.69 contacts per Laysan Albatross per 100 branch lines) and lowest during the dyed bait treatment (0.046 and 0.039 contacts per bird per 100 branch lines for Black-footed and Laysan Albatrosses, respectively). For both species the contact rate per bird was not significantly affected by order or by treatment-order interactions, but was significantly affected by the treatments (Table 2, two-way ANOVA, $F = 27.4$ and 36.9, $P < 0.0005$, d.f. = 3 for Black-footed and Laysan Albatrosses, respectively).

Pairwise comparisons conducted a posteriori using Fisher's LSD did not indicate that any of the deterrents was significantly better than any other ($P > 0.09$) although the dyed bait treatment came closest to being significantly better than the streamer line ($P = 0.094$ and 0.113 for Black-footed and Laysan Albatrosses, respectively). All of the deterrent treatments had significantly lower contact rates than the control treatment in a posteriori tests ($P < 0.0005$).

The effectiveness of the deterrents was calculated as the percent reduction in contact rates in comparison with control results (Fig. 3). In terms of the contact rate per 100 branch lines, the streamer line reduced contacts by 68% and 74%, dyed bait reduced contacts by 95% and 92%, and weighted bait reduced contacts by 91% and 92% for Black-footed and Laysan Albatrosses, respectively. Expressed as contact rate per bird per 100 branch lines, the effectiveness of the deterrents was slightly improved. The streamer line was 75% and 77% effective, the dye was 95% and 94% effective, and weights were 93% and 91% effective for Black-footed and Laysan Albatrosses, respectively.

Discussion

The Hawaii-based longline fishery includes a deep-set daytime tuna fishing component, a shallow-set nighttime swordfish fishing component, and components with mixed fishing strategies and mixed target species, including swordfish. The swordfish and mixed components are dominant

Table 1. Rates of albatross contacts with bait (per 100 hooks) in a two-way factorial experiment with four treatments and four orders.

Treatment	Order	Date (February)	Branch lines (no.)	Black-footed Albatross		Laysan Albatross	
				Abundance (no.)	Contacts (per 100 hooks)	Abundance (no.)	Contacts (per 100 hooks)
Control	1	11	71	23	16.9	39	28.2
	1	14	60	18	10.0	28	30.0
	1	16	64	41	28.1	43	34.4
	1	17	68	40	17.6	82	44.1
	1	18	67	82	13.4	162	53.7
	1	23	71	32	7.0	3	0.0
	2	8	71	75	26.8	57	35.2
	2	12	71	40	28.2	100	60.6
	2	13	71	32	46.5	32	8.5
	2	15	64	100	28.1	125	37.5
	2	20	67	40	44.8	7	9.0
	2	21	64	8	14.1	2	3.1
	3	8	75	100	44.0	75	28.0
	3	10	71	125	53.5	125	26.8
	3	11	75	26	12.0	46	64.0
	3	14	64	75	37.5	57	42.2
	3	15	64	50	32.8	50	59.4
	3	20	64	25	45.3	3	3.1
	4	7	64	40	32.8	40	26.6
	4	9	68	50	51.5	50	35.3
	4	13	45	57	64.4	32	15.6
	4	16	64	125	67.2	125	29.7
	4	17	64	125	48.4	75	46.9
	4	21	64	5	14.1	5	3.1
Streamer	1	16	64	100	7.8	75	6.3
	1	16	64	125	12.5	100	9.4
	1	16	64	125	10.9	125	21.9
	1	23	64	29	0.0	3	0.0
	1	23	64	17	0.0	2	0.0
	1	23	68	14	0.0	2	0.0
	2	15	68	16	0.0	23	7.4
	2	15	64	32	7.8	57	7.8
	2	15	64	57	7.8	100	3.1
	2	20	60	32	31.7	5	0.0
	2	20	68	32	10.3	7	1.5
	2	20	64	32	17.2	7	7.8
	3	11	68	40	11.8	75	16.2
	3	11	68	40	11.8	75	17.6
	3	11	67	32	11.9	75	23.9
	3	14	64	75	12.5	57	9.4
	3	14	64	75	10.9	57	7.8
	3	14	67	57	4.5	75	6.0
	4	9	68	21	5.9	21	1.5
	4	9	67	57	9.0	40	0.0
	4	9	71	40	7.0	40	2.8
	4	16	64	125	28.1	75	9.4
	4	16	64	125	14.1	100	15.6
	4	16	64	125	18.8	125	14.1

Table 1.   (Continued.)

Treatment	Order	Date (February)	Branch lines (no.)	Black-footed Albatross		Laysan Albatross	
				Abundance (no.)	Contacts (per 100 hooks)	Abundance (no.)	Contacts (per 100 hooks)
Dyed bait	1	14	68	25	0.0	40	0.0
	1	14	60	18	0.0	50	0.0
	1	14	67	18	1.5	40	0.0
	1	17	64	57	1.6	100	0.0
	1	17	64	100	0.0	100	0.0
	1	17	64	71	0.0	75	0.0
	2	12	67	14	1.5	21	3.0
	2	12	71	32	12.7	57	16.9
	2	12	71	40	9.9	75	26.8
	2	21	64	7	0.0	1	0.0
	2	21	64	8	0.0	2	0.0
	2	21	64	8	0.0	3	0.0
	3	8	71	82	0.0	57	0.0
	3	8	71	40	0.0	40	0.0
	3	8	53	32	0.0	40	0.0
	3	15	64	75	4.7	75	7.8
	3	15	64	75	6.3	75	1.6
	3	15	64	57	4.7	75	1.6
	4	13	71	57	0.0	40	0.0
	4	13	71	40	0.0	32	0.0
	4	13	68	40	0.0	25	0.0
	4	21	64	6	0.0	4	0.0
	4	21	64	7	0.0	6	0.0
	4	21	67	5	0.0	5	0.0
Weight	1	11	71	40	1.4	57	2.8
	1	11	71	40	1.4	40	0.0
	1	11	67	32	0.0	32	1.5
	1	18	64	125	1.6	325	7.8
	1	18	64	125	1.6	250	4.7
	1	18	64	125	4.7	200	7.8
	2	8	71	14	4.2	14	1.4
	2	8	75	32	1.3	25	0.0
	2	8	68	57	0.0	32	0.0
	2	13	71	12	0.0	16	0.0
	2	13	71	21	2.8	32	0.0
	2	13	71	25	2.8	32	1.4
	3	10	75	100	2.7	100	0.0
	3	10	71	100	5.6	100	4.2
	3	10	64	100	1.6	100	0.0
	3	20	64	25	3.1	3	0.0
	3	20	64	25	0.0	3	1.6
	3	20	64	21	0.0	3	0.0
	4	7	71	25	1.4	20	0.0
	4	7	71	36	0.0	36	0.0
	4	7	71	40	2.8	40	2.8
	4	17	64	102	10.9	46	4.7
	4	17	64	125	10.9	75	3.1
	4	17	64	125	12.5	75	15.6

Order: 1 = control first in the a.m., 2 = control last in the a.m., 3 = control first in the p.m., 4 = control last in the p.m.). Each observation (n = 96) is from a timed section (ca. 18 min, 3.8 km) of longline set for which the number of branch lines and number of birds present are shown.
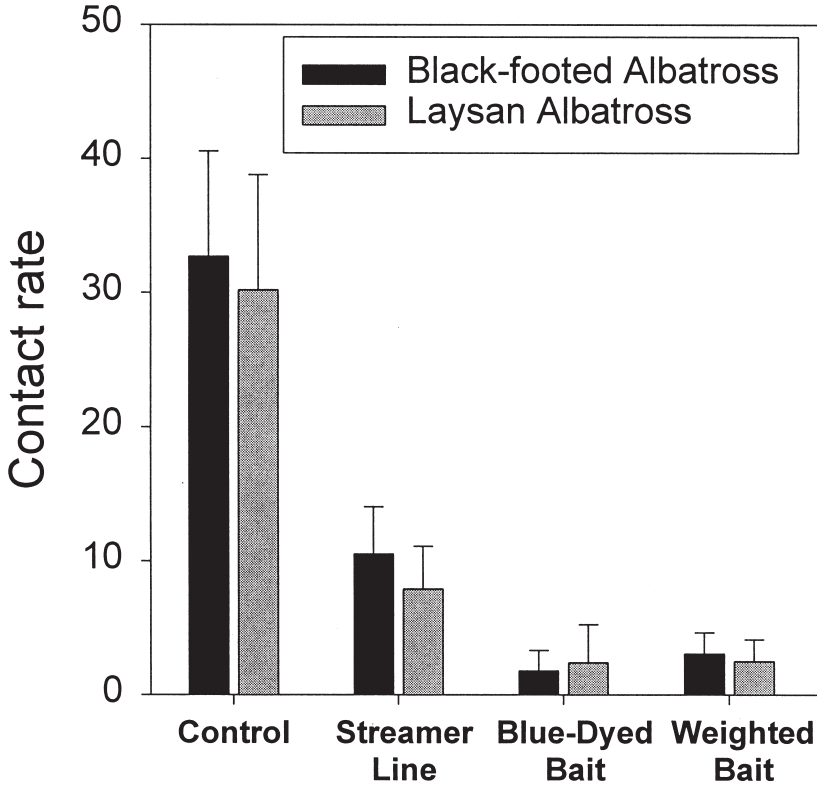
Figure 1. Mean contact rates (per 100 branch lines) between albatrosses and bait-
ed branch lines in observed sections of swordfish style longline sets sub-
jected to four treatments (no deterrent = control, streamer line to ward
off birds, bait dyed blue for camouflage, and bait weighted to sink fast-
er). Each bar shows a mean and 95% CI for 24 observed set sections for
each treatment and species of albatross. Sets were made in daylight near
the Northwestern Hawaiian Islands in February 1999. Contacts were
defined as birds grasping baits attached to branch lines.

Table 2. **Table of means and two-way analysis of variance (ANOVA) on the contact rate (per bird per 100 branch lines) for two species of albatross.**

		Treatment									
		Black-footed Albatross					Laysan Albatross				
Order		Control	Streamer	Dye	Weight	Total	Control	Streamer	Dye	Weight	Total
1	Average	0.47	0.044	0.018	0.022	0.14	0.58	0.059	0.000	0.030	0.17
	S.D.	0.24	0.049	0.033	0.016	0.22	0.37	0.072	0.000	0.019	0.30
2	Average	0.97	0.372	0.126	0.101	0.39	0.77	0.302	0.133	0.025	0.31
	S.D.	0.63	0.352	0.165	0.119	0.50	0.53	0.415	0.162	0.043	0.44
3	Average	0.73	0.227	0.038	0.038	0.26	0.86	0.193	0.024	0.111	0.30
	S.D.	0.56	0.113	0.042	0.049	0.39	0.49	0.084	0.041	0.252	0.43
4	Average	1.18	0.185	0.000	0.071	0.36	0.56	0.090	0.000	0.071	0.18
	S.D.	1.00	0.061	0.000	0.039	0.67	0.18	0.055	0.000	0.079	0.25
Total	Average	0.83	0.207	0.046	0.058		0.69	0.161	0.039	0.059	
	S.D.	0.67	0.213	0.095	0.070		0.41	0.224	0.096	0.130	

		Black-footed Albatross					Laysan Albatross				
ANOVA	Source	d.f.	MS	F	P-value	F crit	d.f.	MS	F	P-value	F crit
	Order	3	0.31	2.58	0.060	2.72	3	0.14	2.20	0.094	2.72
	Treatment	3	3.33	27.38	0.000	2.72	3	2.28	36.94	0.000	2.72
	Interaction	9	0.13	1.06	0.403	2.00	9	0.03	0.56	0.825	2.00
	Error	80	0.12				80	0.06			

The experimental design was composed of four treatments and four orders (1 = control first in the a.m., 2 = control last in the a.m., 3 = control first in the p.m., 4 = control last in the p.m.) with six observations in each cell. Each observation was from one timed section (ca. 18 min, 3.8 km) of longline set. S.D. = standard deviation, d.f. = degrees of freedom, MS = mean square, and *F* crit = the critical value of *F* at the 0.05 level.

in the northern fishing grounds (He et al. 1997), where most longline-related mortality takes place (Cousins and Cooper 2000). Although fishery opponents are highly critical of the current absence of seabird deterrent regulations, by setting primarily at night this fishery may already prevent 60% to 96% (Brothers et al. 1999) of potential longline mortality, and by using weighted branch lines this fishery may be preventing additional mortality (Brothers et al. 1998).

The time and location chosen for this study contributed greatly to its success. Strong season and area effects are typical of seabird fishery interactions (Brothers et al. 1999). The greatest localized foraging concentration of Black-footed Albatross occurs during the December-February incubation and hatching season near the largest colonies at Laysan Island and the Midway Islands, and the greatest incidence of seabird fishery interactions in the Hawaii fishery occurs just outside this area and northward (Cousins and Cooper 2000). Peak hatching occurs in early February, and for the first week to ten days after hatching the parent birds make relatively short foraging trips in contrast to the transoceanic foraging trips
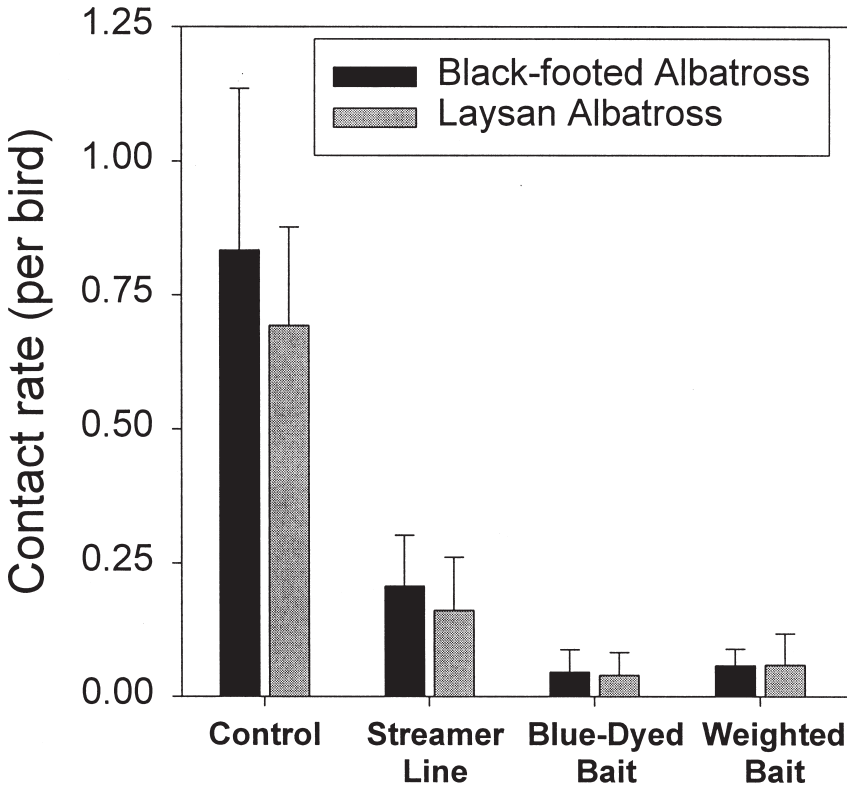
Figure 2. Mean contact rates per bird (per 100 branch lines) between albatrosses and baited branch lines in observed sections of swordfish style longline sets subjected to four treatments (control, streamer line, blue-dyed bait, and weighted bait). Each bar shows a mean and 95% CI for 24 observed set sections for each treatment and species of albatross.

that begin shortly afterward (Anderson and Fernandez 1998, as cited by Cousins and Cooper 2000).

Brothers (1991) stated that streamer lines were 69% effective in reducing bait stealing by Southern Hemisphere albatrosses in tuna longline fisheries. Other studies suggest albatross catch reductions of 31% to 71% using streamer lines in pelagic longline fisheries, but statistically significant results seem largely confined to studies of demersal longlines (Brothers et al. 1999). Weighted branch lines may reduce bird catches (Brothers et al. 1998) and experiments have demonstrated that adding weight does make even frozen bait sink faster (Brothers et al. 1995), but this study may be the first to demonstrate statistically significant results of this deterrent using pelagic longline fishing methods. Fishermen are at some risk of
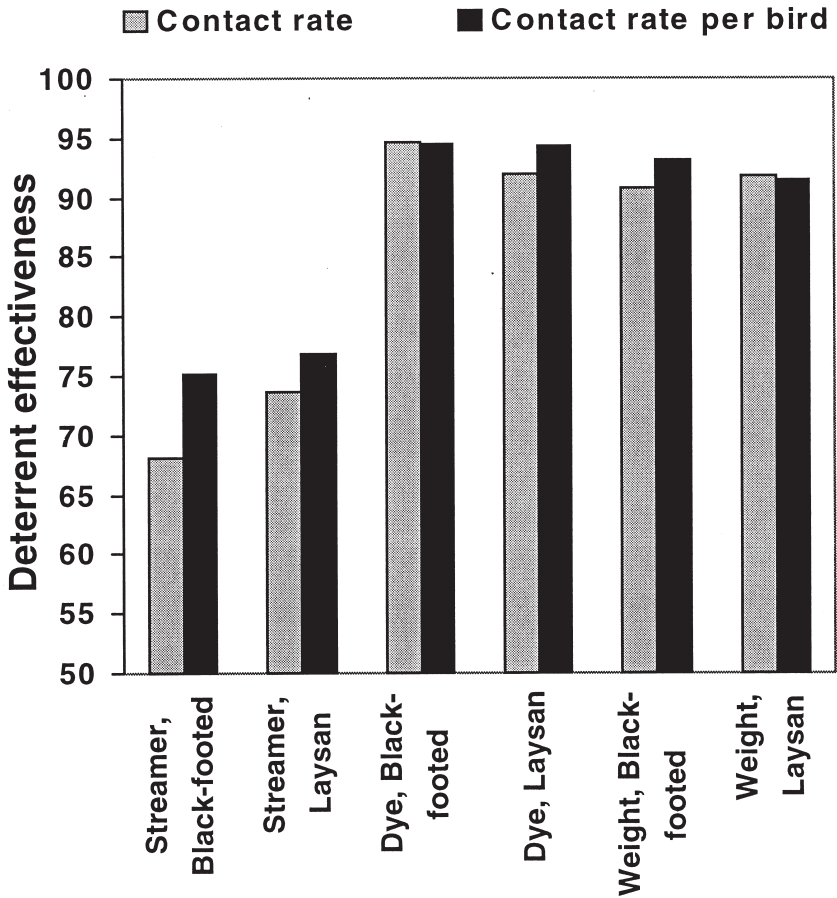
Figure 3. *Deterrent effectiveness calculated in comparison with the control treat-*
ment as the percent reduction in the contact rate (contacts per 100 branch
lines) or as the reduction in the contact rate per bird (contacts per bird
per 100 branch lines) for three deterrent treatments and two species of
albatrosses.

being hit by flying hooks that pop loose from fish as branch lines are hauled, and adding weight to the hooks might increase this danger.

The blue-dyed bait experimental results are original, although dyeing bait to increase the attractiveness to fish may have originated in the U.S. East Coast longline fishery for swordfish. The effectiveness of blue dye in reducing seabird scavenging of longline bait was first brought to the attention of the Western Pacific Regional Fishery Management Council (WPRFMC) by Hawaii fishermen. The cost of the food color used to dye the bait in this study was about $1.00 US per 100 squid.

Assuming that albatross mortality in real fishing operations is proportional to the number of times birds make contact with the bait, the deterrent effectiveness demonstrated by this study could be actualized as mortality reductions in the Hawaii-based swordfish fishery. However, implicit in this assumption is the idea that the behavior observed in this study is an accurate indicator of the risk of mortality. At the time this was written the WPRFMC was moving to include all three of the deterrent methods tested in the study in a list of alternative options to be required of Hawaii-based longline fishery participants. However, the efficacy of these measures will be hard to determine in the fishery because of the small sample sizes provided by very limited observer coverage (Cousins and Cooper 2000).

Actual hooking and mortality rates might be some unknown fractions of the contact rates measured in this study if there were a simple linear relationship between the bird behavior observed in the study (contacts) and hooking rates. The contact rate for Black-footed Albatross using the streamer deterrent, for the average number of birds in that treatment (59 birds) was 105 contacts per 1,000 branch lines. This was about 150 times higher than a seabird catch rate estimate of 0.71 birds per 1,000 hooks for the tuna longline fishery in Australia using streamer lines and monofilament longline gear (Brothers et al. 1999). The latter catch estimate was for a broad range of time and area, and the average number of birds present may have been much lower than in the present study.

Significant effects of the number of birds present on the number of bird mortalities on longline gear have not previously been documented, perhaps due to inaccurate or nonexistent bird counts (Brothers et al. 1999) or perhaps because rare events like hookings are not as simply related to bird density as are more common interactions like contact with baits. The number of albatross caught can also be affected by the number of birds of other species present. In the southern oceans many species besides albatrosses interact with the gear. Some seabirds are better divers than albatrosses and retrieve sinking bait that is subsequently taken away by albatrosses (Brothers 1991, Bergin 1997, Brothers et al. 1999). In the present study, behavioral observations demonstrated relationships between bird density and the number of bait contacts much more easily than a relationship between mortality and density could be demonstrated from analyses of fishery data. It could be inaccurate to project the effectiveness of the

deterrents in this study as a measure of effectiveness in deterring fishing mortality at much lower densities.

Brothers et al. (1999) noted the difficulty of demonstrating significant effects of seabird deterrents using data from observers and commercial fishing operations and recommended the experimental approach followed in this paper. The results reported here clearly establish the effectiveness of the streamer line, blue-dyed bait, and added weight in reducing contact rates between albatrosses and longline baits in the type of longline fishing operations primarily responsible for seabird mortality in the Hawaii-based swordfish longline fishery. The results also suggest that other deterrents might be as effective or more effective than the streamer line, and in particular, that blue-dyed bait could be a highly effective, safe, cheap and convenient method for reducing albatross feeding on longline baits.

Acknowledgments

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The Black-footed Albatross Population Biology Workshop: A Step to Understanding the Impacts of Longline Fishing on Seabird Populations

Katherine L. Cousins
National Marine Fisheries Service
Honolulu, Hawaii

Abstract

Experts in seabird ecology, fisheries management, and population modeling participated in a three-day workshop (October 8-10, 1998) at the Western Pacific Regional Fishery Management Council (WPRFMC) offices in Honolulu to investigate the population dynamics of the Black-footed Albatross *(Phoebastria nigripes).* The workshop's primary goal was to characterize the population biology of the Black-footed Albatross and evaluate its resilience to the effects of mortality due to longline fishery interactions. Worldwide there are 61,866 and 558,415 breeding pairs of Black-footed and Laysan *(P. immutabilis)* Albatrosses, respectively, and both species are caught in approximately equal numbers during longline fishing. This suggests that the Black-footed Albatross population may be more seriously affected. The Black-footed Albatross population suffers different combinations of both anthropogenic and natural mortalities, in common with many seabird populations. Thus, a series of simulations were conducted to investigate how population removals added onto baseline mortality would affect the sustainable population growth rates. Also, analyses generated from the bird-banding data sets found that juvenile Black-footed Albatrosses were caught on longline more frequently than adults. Simulated experiments also investigated how differences in juvenile and adult removals would affect the Black-footed Albatross population dynamics. The findings showed that over the long term, a chronic mortality such as longline fishing resulted in slow decline of species population size irrespective of uncertainties associated with the estimated parameters.

Workshop participants generated seven recommendations for consideration by the WPRFMC, including the improvement and standardization of data collection and the completion of analyses as studies progress.

Introduction

Hawaii-based longline vessels targeting broadbill swordfish *(Xiphias gladius)* and tuna *(Thunnus* spp.) inadvertently hook and kill both Black-footed Albatrosses and Laysan Albatrosses *(P. immutabilis)* that nest in the Northwestern Hawaiian Islands (NWHI). Records of fishing activity extend only from 1991, after logbook catch records were required of longline vessels under Amendment 2 to the Fishery Management Plan of the Pelagic Fisheries in the Western Pacific Region (FMP). In 1994, the National Marine Fisheries Service (NMFS) initiated an observer program to monitor the incidental catch of sea turtles in the Hawaii-based longline fleet. NMFS observers also reported the incidental catches of Black-footed and Laysan Albatrosses; however, the observer program was not initiated or designed to monitor seabird and fishery interactions. Consequently, methods to extrapolate seabird catch estimates from the logbook and observer data generated values with wide ranges of uncertainty. For instance, log transformed point estimates for Black-footed Albatross catch averaged about 1,704 per year with confidence intervals ranging between 616 and 3,329 (Table 1).

Few papers on the Black-footed Albatross are published, although a wealth of information exists in unpublished reports and raw data sets. In addition, thousands of albatrosses have been marked with bird-bands in the NWHI. Lack of understanding for NWHI Black-footed Albatross population dynamics and inconclusive albatross mortality figures for the Hawaii-based longline fishery prompted the Western Pacific Regional Fishery Management Council (WPRFMC) to convene a three-day workshop October 8-10, 1998 in Honolulu, Hawaii (Table 2).

The findings and recommendations from the workshop were timely because the WPRFMC was in the midst of developing a regulatory amendment for the Hawaii-based pelagic longline fishery mitigating impacts on seabirds. WPRFMC also hired a private contractor, Garcia and Associates, to conduct a seabird mortality mitigation study on board Hawaii-based longline vessels. In theory, if the effects of seabird mortality rates and population parameters could be measured and modeled, this could lead to better estimates of the effectiveness of proposed seabird bycatch mitigation methods for use on longline fishing vessels. This paper summarizes some of the findings from the Black-footed Albatross workshop and lists seven recommendations generated by the 21 workshop participants (Table 3).

Table 1. **Incidental catches of Laysan and Black-footed Albatrosses in the Hawaii-based longline fishery estimated by two methods (log transformed versus non-log transformed) from NMFS observer and logbook data, 1994 to 1997.**

Year	Method	Laysan Albatross catch			Black-footed Albatross catch		
		Lethal	Non-lethal	Total	Lethal	Non-lethal	Total
1991	Log	513	253	766	887	222	1,108
		(165, 853)	(81, 420)	(246, 1,273)	(488, 1,376)	(122, 345)	(610, 1,724)
	Non-log	554	273	828	4346	1,087	5,433
		(273, 1,032)	(134, 508)	(407, 1,540)	(1,019, 5,633)	(255, 1,408)	(1,273, 7,042)
1992	Log	554	273	826	1,270	318	1,588
		(290, 777)	(143, 383)	(433, 1,160)	(885, 1,646)	(221, 411)	(1,107, 2,056)
	Non-log	580	286	865	3,635	909	4,544
		(381, 902)	(188, 444)	(569, 1,346)	(1,834, 4,572)	(458, 1,143)	(2,292, 5,716)
1993	Log	1,175	579	1,754	1,981	495	2,477
		(567, 1,826)	(279, 900)	(846, 2,726)	(1151, 2,707)	(288, 677)	(1,439, 3,384)
	Non-log	1,159	571	1,729	5,762	1,441	7,203
		(706, 1962)	(348, 966)	(1,053, 2,928)	(1,757, 7,866)	(439, 1,967)	(2,196, 9,833)
1994	Log	666	328	994	1,685	421	2,106
		(412, 1,149)	(203, 566)	(615, 1,715)	(984, 2,008)	(246, 502)	(1,230, 2,511)
	Non-log	950	468	1,418	4,252	1,063	5,315
		(569, 1,322)	(280, 651)	(850, 1,972)	(1,273, 5,149)	(318, 1,287)	(1,592, 6,437)
1995	Log	536	264	800	1,287	322	1,609
		(305, 774)	(150, 381)	(456, 1,155)	(659, 1,602)	(165, 400)	(823, 2,002)
	Non-log	744	367	1,111	3,391	848	4,239
		(392, 977)	(193, 481)	(585, 1,458)	(777, 4,375)	(194, 1,094)	(972, 5,469)
1996	Log	397	196	592	1,069	267	1,336
		(281, 680)	(138, 335)	(419, 1,015)	(674, 1,272)	(168, 318)	(842, 1,590)
	Non-log	614	302	917	4,222	1,055	5,277
		(360, 848)	(177, 418)	(537,1,265)	(943, 5,088)	(236, 1,272)	(1,179, 6,360)
1997	Log	429	211	640	1,019	255	1,274
		(280, 625)	(138, 308)	(417, 934)	(666, 1,330)	(166, 332)	(832, 1,662)
	Non-log	597	294	891	5,263	1,316	6,579
		(336, 812)	(165, 400)	(501, 1,211)	(784, 6,140)	(196, 1,535)	(981, 7,674)

The 1991 to 1993 values are conditional on statistical models developed from 1994-1997 observer data. Values in parentheses are the confidence intervals. Estimates of non-lethal catches include albatrosses observed alive or injured. Lethal catch estimates include albatrosses that were known to be dead or their condition was listed as unknown. There were no sightings or incidental catches of Short-tailed Albatross reported in the fishery.

Source: P. Kleiber, NMFS, Southwest Fisheries Science Center, Honolulu Laboratory.

Table 2.   Agenda for the Black-footed Albatross Population Biology Workshop, held at the Western Pacific Regional Fishery Management Council, October 8-10, 1998.

Time	Day 1	Day 2	Day 3
0830	Plenary • Welcome from K. Simonds • Introductions and overview of agenda	Plenary • Summary of findings from working groups submitted	Data analysis and discussion within working groups
0900	Plenary • Presentations by:	Data analysis and discussion within working groups	
1100	K. Cousins H. Hasegawa S. Pooley P. Kleiber K. Rivera		• Summary of findings from working groups
1400	Plenary • Establishing working groups	Plenary • Review and discussion	
1500	Data analysis and discussion within working groups	Data analysis and discussion within working groups	
1600			Plenary • Review and discussion • Development of the workshop recommendations
1700	Plenary • Review and discussion		
1800 Evening	Data analysis and discussion within working groups		

Table 3. **List of participants, affiliations, and areas of specialty for the Black-footed Albatross Population Biology Workshop held in Honolulu, HI, October 8-10, 1998.**

Participant	Affiliation	Areas of Specialty
C. Boggs	NMFS, Hawaii, USA	Fish biology and ecology
J.F. Cochrane	University of Minnesota, USA	Population modeling
E. Cooch	Cornell University, USA	Wildlife ecology and population modeling
J. Cooper (Workshop Chair)	University of Cape Town, South Africa	Seabird ecology and conservation
K. Cousins (Workshop coordinator)	NMFS, Hawaii, USA	Marine biology and animal physiology
J.P. Croxall	British Antarctic Survey, UK	Seabird ecology
E. Flint	USFWS, Hawaii, USA	Seabird ecology
H. Hasegawa	Toho University, Japan	Seabird biology
D. Heinemann	CSIRO Division of Marine Research, Tasmania	Seabird ecology and modeling
P. Kleiber	NMFS, Hawaii, USA	Fisheries biology
J.D. Lebreton	C.N.R.S., C.E.F.E., France	Population ecology and modeling
J.P. Ludwig	The SERE Group, Ltd., Ontario, Canada	Population ecology and toxicology
M.A. Pascual	Centro Nacional Patagónia, Argentina	Population ecology and modeling
S. Pooley	NMFS, Hawaii, USA	Fishery management and performance investigation
R.L. Pyle	Bishop Museum, Hawaii, USA	Seabird ecology
K.S. Rivera	NMFS, Juneau, Alaska, USA	Fisheries management and protected resources
C. Robbins	Patuxent Wildlife Research Center, Maryland, USA	Seabird population ecology
M. Silva	University of Washington, USA	Population genetics
A. Starfield	University of Minnesota, USA	Population modeling
C. Swift	USFWS, Hawaii, USA	Seabird biology
J. Wetherall	NMFS, Hawaii, USA	Fisheries and population modeling

Data Sources

Sixty years of bird-banding data were obtained from the Bishop Museum, Honolulu; workshop participants J. Ludwig and C. Robbins, the National Bird-banding Laboratory, Maryland; and the Smithsonian Institution, Washington, D.C. The U.S. Fish and Wildlife Service (USFWS), Pacific Refuges Office, Honolulu, also provided bird-banding data, as well as census and reproductive success data. Seabird counts and sighting records were obtained from the Bishop Museum, Honolulu, and from private tour guides operating seabird cruises in Oregon (G. Gillson) and California (D. Shearwater). At-sea sightings and satellite tagging data sets were supplied by T. Wahl and D. Anderson (Anderson and Fernandez 1998), respectively. NMFS provided information regarding seabird mortality on Hawaii-based longline vessels and from annual pelagic fishery reports.

Notwithstanding problems of multiple banding and lost banding records presumed to be dead chicks, over a period of four months prior to the workshop, 116,752 Black-footed Albatross records were recovered (representing 100,862 individual birds). Band-numbers belonging to a single bird were manually linked together in a relational database.

Census and Reproductive Success Data

Prior to the 1960s, many of the historical counts of albatross breeding pairs in the NWHI appeared to be best guesses, especially those from the 1910s to the 1930s. None of these counts was supported by scientific surveys or represented a complete direct count (a direct count is a count of every bird on the island). In the 1960s, aerial photographs were used to count Black-footed Albatross colonies; however, these were later criticized for overestimating the population because Great Frigatebirds *(Fregata minor)* may have been mistaken for Black-footed Albatross (Amerson 1971). Since 1996, direct counts have been conducted for smaller colonies at Pearl and Hermes Reef and, since 1979, for Tern Island, French Frigate Shoals. In recent years direct counts of Black-footed Albatross breeding pairs were completed on the larger colonies at Midway Atoll and Laysan Island. The USFWS also extrapolated based on counts of all nests within randomly selected small plots or quadrats of large populations to estimate the number of breeding pairs on Laysan Island (Fig. 1). These counts were multiplied by the proportion of nesting area occupied by breeding birds. Direct counts of chicks corrected for an estimated loss of eggs and chicks were also used to estimate of the total number of breeding pairs.

Overall, in 1998 the USFWS reported approximately 59,622 Black-footed Albatross breeding pairs in 12 colonies in the NWHI, with about 74% of the population breeding on Midway Atoll and Laysan Island (E. Flint, unpubl. data). In addition to the colonies on NWHI, three colonies exist in the western Pacific near Japan. About 25 Black-footed Albatross breeding pairs were reported at Senkaku Island (Kita-Kojima), 1,000 breeding pairs at

Bonin Island (Chichijima), and 1,219 breeding pairs at Izu Island (Torishima) (H. Hasegawa, Toho University, Japan, unpubl. data).

Reproductive Success Data

Reproductive data, specifically the number of eggs, chicks and fledglings on Sand (Midway Atoll), Laysan, and Tern (French Frigate Shoals) islands, were supplied by the USFWS (Table 4). Sand and Laysan islands were plot estimates, whereas the numbers collected from Tern were direct counts.

Hawaii Longline Fishery Information and Data

The Hawaii longline fishery began as early as 1917, with immigrants from Japan (Boggs and Ito 1993). This fishery consisted of wooden sampans using poles and rope lines to target tuna within 2-20 nautical miles of the coast. The fishery peaked in the mid-1950s with landings exceeding 2,000 tons. With the establishment of the 200-nautical mile U.S. Exclusive Economic Zone (EEZ) in 1976, foreign fleets were removed, allowing further development of the domestic Hawaiian fisheries. The Hawaiian longline fishery grew from 37 vessels in 1987, to 80 in 1989, and then increased again to 144 vessels in 1991. The new entrants in the longline fishery were mostly steel-hulled vessels up to 33 meters in length. Their operators were former participants in the U.S. East Coast tuna and swordfish fisheries. Newer vessels used sophisticated electronic gear for navigation, marking deployed longline gear and finding fish. The revitalized fleet also adopted continuous nylon monofilament main lines with snap-on monofilament branch lines. Over the same period, the range of the longline fishery expanded, with some vessels fishing up to 1,000 nautical miles from Hawaii and over half of the longline sets made at distances greater than 50 nautical miles from the Main Hawaiian Islands (MHI).

Following the rapid expansion of the longline fishery between 1987 and 1991, entry to the fishery was halted through a moratorium on permit issuance in 1991, under Amendment 4 to the FMP. In early 1991, longline fishing was prohibited within 50 nautical miles of the NWHI to prevent interactions between the fishery and endangered populations of Hawaiian monk seals *(Monachus schauinslandi)*. A further longline exclusion zone of 50-75 nautical miles was established in mid-1991 around the Main Hawaiian Islands through further amendment of the FMP to address a gear conflict issue. In 1994, the FMP established a cap of 164 permits for the Hawaii longline fishery, and limited fishing capacity by restricting maximum vessel size to 101 feet. At present, vessels in the Hawaii-based longline fishery are categorized in three size classes: small (< 56 ft), medium (56-74 ft), and large (> 74 ft) vessels. The majority of vessels operating in the longline fishery are medium- and large-sized vessels.

The longline fleet comprises vessels with different gear configurations to target either swordfish or tuna. Some longline sets target both swordfish and bigeye tuna *(Thunnus obesus)* and are called "mixed" sets. These sets are typically made with a modified swordfish gear configuration and without the use of a hydraulic line-setting machine (line-shooter or line-setter). Both daytime and nighttime fishing are practiced and vessels set a single monofilament longline (i.e., mainline) up to 155.4 km (60 miles) in length. Generally, the mainline holds between 600 and 3,000 branch lines, each about 15-20 meters (49.2-65.6 feet) holding a single hook. The branch lines are usually weighted with 40-80 grams of lead, but the proximity of the weight to the hook varies by vessel and target species.

Hawaii-based longline vessels targeting tuna tend to operate in the relatively warm southern waters and set their lines relatively deep (15-180 m). To facilitate the deployment of tuna fishing gear, these vessels use a line-shooter and branch lines with 40-80 gram weights attached close (20-90 cm) to the hooks to increase the longline sink rate.

In contrast, for swordfish the longline is set at a shallow depth (5-60 m), and the line and baited hooks sink slowly. Swordfishing longline vessels operate in the colder and more northern waters between 25°N and 40°N latitude. Gear generally consists of fewer hooks between floats (3-5), branch line (gangion) weights attached farther from the hooks (4-5 m), and buoyant chemical light sticks attached about one meter from the hook. Consequently, albatrosses following a swordfishing vessel have a greater opportunity to dive on hooks and become caught. The vessels often set

Figure 1.   (Facing page.) *Number of Black-footed Albatross breeding pairs for three NWHI colonies and fishing effort for the Hawaii-based longline fishery (by millions of hooks) for the period between 1991 and 1998. Black dots (●) represent point estimates (with associated confidence intervals) of Black-footed Albatross breeding pairs extrapolated from quadrats on Laysan Island. Other symbols represent direct counts for Black-footed Albatross breeding pairs for Laysan Island (○), Midway Atoll (▽), and French Frigate Shoals (□). Linear regressions were performed on the number of breeding pairs for each colony. These analyses showed trends with the number of Black-footed Albatross breeding pairs declining by approximately 450 breeding pairs per year for Laysan Island ($r^2 = 0.06$), and increasing by about 165 and 24 breeding pairs for Midway Atoll ($r^2 = 0.20$) and French Frigate Shoals ($r^2 = 0.03$), respectively. Note that a direct count was not performed on Midway Atoll in 1993. Interestingly, all three colonies show a decline in the number of breeding pairs for 1994, although fishing effort had not changed appreciably. Also note that there are increases in the direct counts of breeding pairs for all three colonies in 1998 even though the fishing effort had increased by 5.6 million hooks. Sources: (USFWS Refuges, unpubl. data; Ito and Machado 1999).*
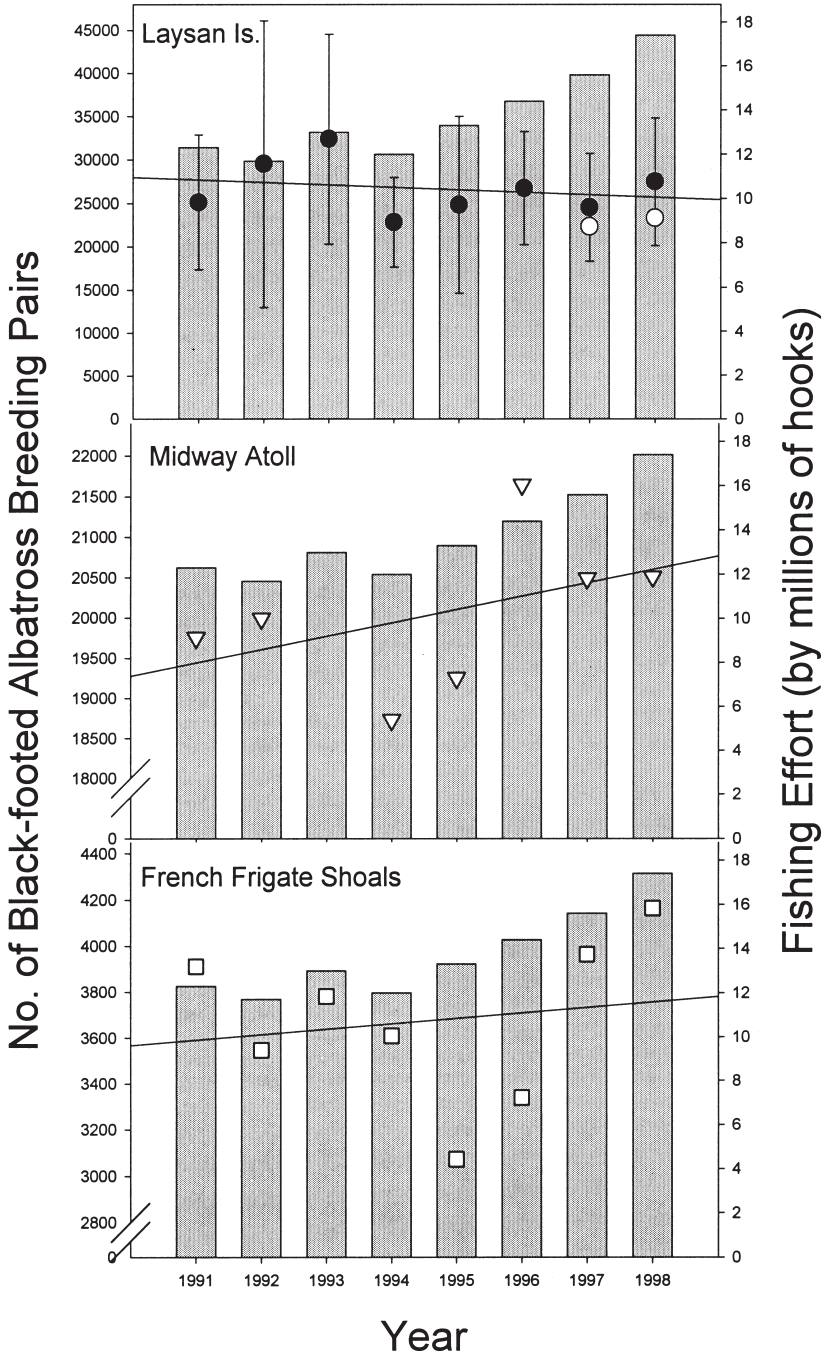
Table 4. Reproductive information for breeding Black-footed Albatrosses at three locations: Sand Island, Midway Atoll; Laysan Island; and Tern Island, French Frigate Shoals.

Location (area)	Year	Total no. of eggs	Total no. of chicks hatched	Total no. of chicks fledged	Mean hatching success (%)	Mean fledgling success (%)	Mean breeding success (%)
Sand Island,	1987	51	na	44	—	—	86.3
Midway Atoll	1992	98	74	63	75.6	85.0	64.4
	1993	100	84	79	84.0	94.2	79.0
Laysan Island	1992	201	95	81	47.5	77.4	40.0
	1993	205	163	78	79.9	48.9	37.7
	1994	220	166	93	75.5	55.8	42.3
	1995	212	148	83	70.2	55.9	39.4
Tern Island,	1981	96	—	56	—	—	58.3
French Frigate	1982	149	—	97	—	—	65.1
Shoals	1983	193	—	104	—	—	53.9
	1984	221	—	100	—	—	45.2
	1985	292	—	225	—	—	77.1
	1986	304	—	212	—	—	69.7
	1987	448	—	336	—	—	75.0
	1988	451	—	337	—	—	74.7
	1989	516	—	350	—	—	67.8
	1990	618	—	436	—	—	70.6
	1991	691	—	538	—	—	77.9
	1992	767	—	555	—	—	72.4
	1993	895	—	633	—	—	70.7
	1994	918	—	720	—	—	78.4
	1995	1,034	—	807	—	—	78.0
	1996	1,048	—	733	—	—	69.9
	1997	1,304	—	956	—	—	73.3
	1998	1,519	—	1,038	—	—	68.3

Reproductive data collected from Sand and Laysan islands were obtained from general plots and are presented as averages. Data collected from Tern Island were obtained by direct counts of all eggs and chicks fledged. Hatching success was calculated as the number of eggs hatched divided by the total number of eggs laid × 100. Fledging success was calculated as the total number of chicks fledged by the total number of eggs hatched × 100. Breeding success was calculated as the total number of chicks fledged divided by the total number of eggs laid × 100.

Source: USFWS Refuges, Honolulu, HI, unpubl. data.

their lines in the late afternoon or at dusk when the foraging activity of seabirds may be especially high.

The two major sources of information on albatross interactions with Hawaii-based longline vessels are the mandatory logbook and observer data collection programs administered by NMFS. Since 1991, the longline logbook program requires vessel operators to submit detailed catch and effort data on each set (50 CFR 660.14). Although extensive, the information was not as complete as data collected by NMFS observers. The NMFS Observer Program was implemented in February 1994 to collect data on protected species interactions, with marine turtles having the highest priority. Although data collection on protected species was the program's primary purpose, the observers also collected catch data on the fishery and in total recorded five different sets of data: (1) incidental sea turtle take events; (2) fishing effort; (3) interactions with other protected species; (4) fishes kept and discarded, by species; and (5) life history information, including biological specimens in some instances. The NMFS Observer Program achieved 3.5% to 5.5% coverage in the first four years. The selection of trips to observe was based on a sampling design by DiNardo (1993) to monitor sea turtle interactions.

The NMFS Southwest Fisheries Science Center, Honolulu Laboratory, used data from NMFS observer reports and the NMFS Western Pacific Daily Longline Fishing Log to estimate the annual incidental catch of seabirds in the Hawaii longline fishery between 1991 and 1997 (Table 1). Fleetwide incidental catch estimates were computed using a regression tree technique and bootstrap procedure (Skillman and Kleiber 1998). The regression tree technique was used on observer data sets (1994-1997), starting with an array of independent variables (e.g., month, latitude, longitude, target species, gear type, sea surface temperature, and distance to seabird nesting colonies). The model was "pruned" by cross validation, meaning that only the statistically significant predictors of seabird catches were kept in the analysis. Catches of Black-footed Albatrosses were significantly related only in proximity to nesting colonies and longitude, whereas catches of Laysan Albatrosses were significantly related only in proximity to nesting colonies and year. The model was then applied to daily logbook records (1991-1997) to generate estimates of fleetwide seabird bycatch estimates. Uncertainty, expressed as 95% confidence bounds, was assessed with a non-parametric bootstrap technique (Efron 1982, Efron and Tibshirani 1993).

Longline fishing effort was not uniform throughout the year, with a seasonal decline in the number of trips and hooks set in the third quarter (June, July, and August). Hooks set in this quarter represent 17.5% of the annual total number set, while the numbers set in the first, second, and fourth quarters are about equal at 27.5% (Ito and Machado 1999). The distribution of fishing effort was not homogenous. On average, 57% of longline fishing occurred within the U.S. Exclusive Economic Zone (EEZ) surrounding the Hawaiian Islands, with a further 40% on the high seas and

3% in the 200 nautical mile U.S. EEZs of islands such as Palmyra and Kingman Reef, Jarvis, Howland, and Baker (Ito and Machado 1999). The distribution of fishing effort in 1998 was notable for the high volume of fishing within the U.S. EEZs of these mainly uninhabited islands (11.4%), particularly around Palmyra and Kingman Reef. This was in response to the high abundance of bigeye tuna which occurs periodically in the lower latitudes to the south of Hawaii.

Records of fishing activity extend only from 1991, after logbook catch records were required under federal regulations. Although the number of vessels active in the fishery has decreased, the overall fishing effort in number of hooks deployed has risen from 12.3 million in 1991 to 17.4 million hooks in 1998 (Ito and Machado 1999; Fig. 1).

Workshop Highlights

The workshop opened with morning presentations followed by a plenary session and workshop participants dividing into smaller working groups. Participants engaged in detailed discussions about the data sets and the potential for modeling exercises. C. Robbins presented new information on a cohort of 1,000 Black-footed Albatross chicks that were banded by D. Rice in June 1957 on Eastern Island, Midway Atoll. Robbins reported that 313 of the 1,000 chick cohort were re-encountered and their bands read and then released alive (262 Eastern Island; 12 Sand Island, Midway Atoll; 11 Kure Atoll; one at Pearl and Hermes Reef) with only 273 surviving to breeding age. J. Ludwig reported that five birds from this cohort were seen in 1994; therefore, these birds were 37 years old when last seen. Robbins noted that 37 of the birds were taken at sea during the Pacific Ocean Biological Survey Program.

H. Hasegawa reported on the Black-footed Albatross colonies located on Torishima where a total of 914 Black-footed Albatross chicks were observed in two colonies on opposite slopes of this volcanic island. The colony on the volcano's rocky southeast slope had grown from six chicks in 1957 to 636 chicks in 1998. A second colony on the northwestern slopes was established in 1989, with the rearing of a single chick. This new colony produced 278 chicks in 1998. Hasegawa started the new colony by luring the birds to the site with decoy albatrosses.

M. Silva reported that findings from her genetic studies of Black-footed Albatross indicate the Japanese birds originated from NWHI populations. Japanese Black-footed Albatross tend to be smaller than the Hawaii Black-footed Albatross. It is unknown whether the Japanese population is growing or if the increases in breeding pairs reported by Hasegawa were solely due to immigration.

S. Pooley and P. Kleiber presented information on the Hawaii longline fishery. Prior to 1989, when vessels started to target swordfish, NMFS had little evidence that there were many interactions with seabirds. Pooley discussed the NMFS Observer and logbook data sets, and Kleiber described
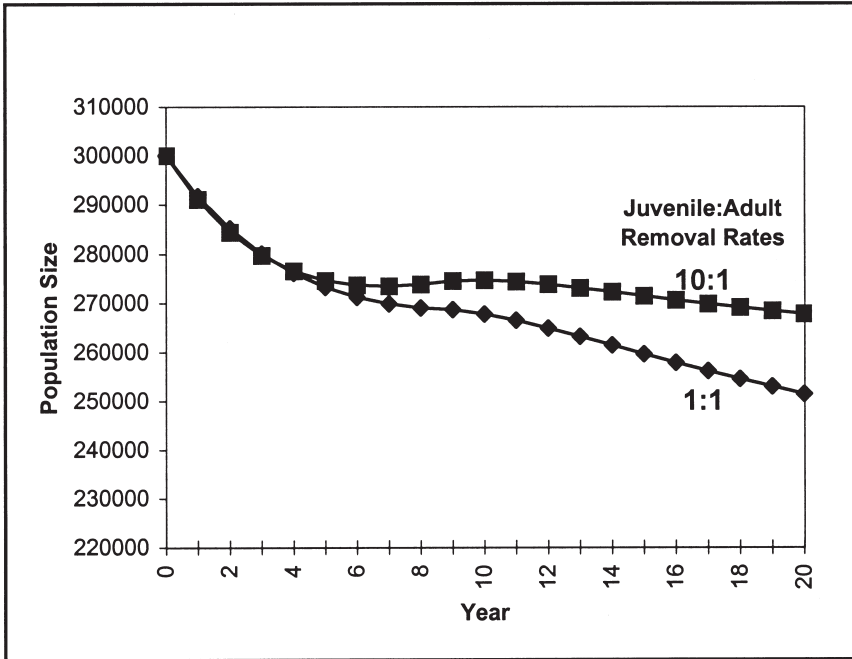
Figure 2. *A model showing the comparison of removals taken at an equal rate among adults and juveniles with removals at a rate 10 times higher for juveniles than for adults. The model was based on a population size of 300,000 birds, and each year 3,000 birds were removed from the population. If juvenile birds were removed at a greater rate than adult birds, then the population size decreased more slowly than if removal rates were equal. The difference was not apparent initially, but accumulated over time due to resulting changes in the population age structure. Also note that the population size declined more noticeably in the first five years of removals. After this initial period, further removals resulted in smaller changes in population size, such that the population would require at least a decade of monitoring to detect noticeable changes in the population size.*

the methods used to determine the seabird catch estimates (Table 1) and problems associated with them. Huge confidence levels were associated with the seabird catch estimates, and gross differences existed between the non-log and log transformed point estimates. Kleiber was unable to resolve the difficulties associated with the analyses in time for the workshop. However, the data supported his findings that (1) vessels targeting swordfish tended to incidentally catch more seabirds than vessels targeting tuna, and (2) the incidental catch of seabirds increased the closer a vessel fished to a seabird breeding colony.

K. Rivera reported on federal measures to reduce the incidental catch of seabirds employed in the demersal and hook-and-line fisheries in the Gulf of Alaska, the Bering Sea, and around the Aleutian Islands. Observer data were collected in the groundfish longline fisheries and any incidental take reported to the USFWS in Alaska, responsible for estimating takes in these fisheries. On average more Black-footed Albatross were caught in the Gulf of Alaska than in the Bering Sea. Rivera briefly discussed the March 1997 Food and Agriculture Organization of the United Nations Committee on Fisheries meeting in which the committee proposed a plan of action that would implement mitigation guidelines to reduce seabird takes. In Alaska, the primary concern was reducing the incidental takes of Short-tailed Albatross *(P. albatrus)* in longline fisheries and regulations were in place. NMFS observers on Alaska longline vessels started collecting information in April 1998 on measures being used and found that buoy bag, the bird-scaring line, and line weighting measures predominated. While Alaska had seabird bycatch regulations in place in the northern longline fisheries, these measures had not been tested on Alaska vessels. Rivera said agencies should consider the unique characteristics in their own fisheries before implementing measures, and this was the next step in Alaska.

Additional discussions varied from problems estimating population parameters and monitoring colonies to understanding the requirements and methods for population modeling exercises. E. Cooch said there were at least four fundamental parameter estimates critical to describing the basic dynamics of the albatross population: first year survival rate, adult survival rate, age of sexual maturity, and an estimate of fertility. J.D. Lebreton said maximum population growth was severely limited in albatross populations and rarely exceeded 3% (Lebreton 1981). He also provided an estimate for the total population based on the Leslie matrix model (Leslie 1945, 1948; Cull and Vogt 1973), indicating that the total population is five to six times the number of breeding pairs, or in the case of the Black-footed Albatross, about 300,000 birds. Lebreton proposed that workshop participants could estimate the four fundamental parameters while asking questions. For instance, were the estimates themselves influenced by longline fishing? Also, was longline fishing something that could be controlled (i.e., with regulation) and if so, could the pattern and extent of the fishing be measured?

C. Boggs said the pattern and extent of the Hawaii-based longline fishery was measurable, but this fishery only represented a fraction of the total longline effort in the North Pacific and comprised gear types different from foreign fisheries. D. Heinemann noted extra mortality factors that required consideration when comparing fishing and non-fishing mortality in a population, especially factors that had large impacts on the demographic behavior of the population, such as changes in overall productivity in the ocean. These factors needed to be built into a model and the model linked to a system that gathered information about the fishery and the mortality sources so that (1) changes in the fishery behavior or fishery regulations are measured, and (2) the length of monitoring intervals determined. A. Starfield explained that another approach to modeling exercises was to ask broad questions and not start with a preconceived four-parameter, end-parameter model. Starfield was interested in finding evidence for spikes of high recruitment, which could confound interpretation of the data.

J.P. Ludwig completed an analysis of the 255 known-age, at-sea Blackfooted Albatross bird-banding records, which spanned 1941 through 1998, and showed that 114 (44.7%) were young-of-the-year, 40 were two-year-olds (5.7%), 25 were three-year-olds (9.8%), and 52 (20.4%) were birds over five years. The data suggested that younger birds are more vulnerable to being caught by longline vessels. This finding was similar to reports from longline fisheries operating in the Southern Hemisphere, where about four times as many juveniles as adult albatrosses were taken (Brothers 1991).

The modeling exercises developed at the workshop were designed to generate robust conclusions; i.e., broad conclusions that are valid irrespective of the uncertainties associated with the parameters. For simplicity it was assumed that survival and fecundity rates remained constant with time. The model demonstrated that no matter what the exact values of the parameters were, a loss of about 1% of the adult population will reduce the growth rate of the population by an amount greater than 1%.

J.F. Cochrane developed an age-structured model and experimented with it on a spreadsheet while M.A. Pascual investigated changes in population growth rates during periods of large-scale impacts, such as ENSO (El Niño-Southern Oscillation) events. Lebreton and Cooch worked on a model that compared different rates of juvenile and adult removal from a baseline population. This model later graphically demonstrated that in a population of 300,000 birds, removal of 1% of the population (3,000 birds) each year resulted in rapid population decline in the first five to six years regardless of bird age (Fig. 2). Subsequent removals with more juveniles taken than adults resulted in the population size leveling and then slowly declining after a period of 10 years. This model demonstrated that noticeable changes in the population size could be difficult to detect in the short term. Not surprisingly, removal of more adults than juveniles resulted in a more dramatic decline in population size.

Heinemann said if an objective of the modeling exercises was to develop models into a management tool, three elements were missing: (1) the spatial context, especially with respect to the mortality rates due to fishing, such that proximity of the breeding colonies to the fishing front varies; (2) other forms of anthropogenic (human caused) mortality; and (3) stochastic variation in the system. Heinemann concluded that models could be used to test the potential efficiency of mitigation measures in a fishery.

Workshop Recommendations

On the final day of the workshop, the participants developed the following seven recommendations:

1. Complete, develop, and curate a relational database for banding records.

2. Encourage further analyses of the existing bird-banding data sets and conduct further modeling at a population dynamics modeling laboratory.

3. Design and implement a population-monitoring program at breeding sites at the NWHI and Torishima to address the effects of longlining mortality.

4. Obtain information and make best estimates of fishing effort and Black-footed Albatross mortality from the Pacific halibut and non-U.S. longline fisheries in the North Pacific Ocean.

5. Design, implement, and develop a longline fishery–monitoring scheme to test mitigation measures and to gather Black-footed Albatross mortality data.

6. Undertake comparative studies with Laysan Albatrosses and Hawaii versus Torishima Black-footed Albatrosses (i.e., to research possible competition for resources between species and to determine if there is genetic exchange between NWHI and Torishima Black-footed Albatrosses).

7. Convene a followup workshop in Honolulu, Hawaii, at the Second International Albatross Conference, May 8-12, 2000.

Discussion

Historical information on factors that affect bird populations, especially mortality figures and data on disturbances to the breeding colonies, is vital to population models. In addition, changes in the oceanic productivity, climate, and weather patterns can affect breeding albatross popula-

tions (Polovina et al. 1994). Fisheries that directly compete with the albatross for food resources, such as the mid-Pacific squid fisheries, could also possibly affect the population. However, all of these variables—including mortality of albatrosses caught incidentally by foreign fleets operating north of the NWHI—affect the Black-footed Albatross to a certain degree, complicating the assessment of a particular mortality on the population.

At the time of the workshop, the Black-footed Albatross mortality estimates for the Hawaii-based longline fishery had high levels of uncertainty, especially since NMFS had only four years of observed incidental catches of seabirds (1994 to 1997). Several workshop participants reviewed Kleiber's extrapolation methods and concluded that another year of observer data would most likely reduce the uncertainly in estimates. Indeed, a few months after the workshop, the 1998 observer data were added and resolved the problems associated with Kleiber's analyses (Table 5). At the workshop, however, all participants agreed that increasing the NMFS Observer Program coverage from 5% to at least 10% and restructuring the sampling strategy to include seabirds would be a critical first step.

Aside from the difficulties associated with estimating seabird takes, looking for impacts of the Hawaii-based longline fishery on the Black-footed Albatross breeding colonies was not without its own set of problems. For instance, at Midway Atoll there was an increase in reported Black-footed Albatross breeding pairs from 10,000 in 1988 (Tyler 1988) to 19,757 in 1991 (USFW unpubl. data). During this period the fishery was increasing, with 80 longline vessels fishing out of Hawaii in 1989, and 144 in 1991 (Ito and Machado 1999). During this same period the Hawaii-based longline vessels were fishing within 50 nautical miles of the NWHI breeding colonies, as this area was not closed to longline fishing until 1991. According to Kleiber, these longline vessels must have had high seabird catch rates because they were fishing close to breeding colonies where seabird densities are higher. If longline fishing had affected the breeding population on Midway Atoll, the impact was not reflected in the number of breeding pairs. According to the at-sea bird-banding data, more juvenile Black-footed Albatrosses are incidentally caught on longline gear than adult albatrosses. If so, then a decline in the recruitment rate would be expected approximately three to five years later. Indeed, the number of breeding pairs on Midway Atoll appeared to be lower in 1994 (Fig. 1), but without knowing the recruitment rate or the age structure and composition of the population it is difficult to know how the population was affected.

Noticeable changes in the number of breeding pairs occurred at French Frigate Shoals where the number of Black-footed Albatross breeding pairs declined from 5,067 in 1987, to 3,960 in 1991. The breeding colonies there differ greatly from the colonies at Midway Atoll in location and size. French Frigate Shoals represents approximately 7% of the total NWHI Black-footed Albatross population with 4,164 breeding pairs (USFWS, Honolulu,

Table 5.   Estimated annual total incidental catch of albatrosses in the Hawaii longline fishery based on catches recorded by NMFS observers on monitored fishing trips between 1994 and 1998.

Year	Black-footed Albatross		Laysan Albatross	
	Observed catch	Estimated total catch	Observed catch	Estimated total catch
1994	126	1,994 (1,508-2,578)	73	1,828 (933-2,984)
1995	105	1,979 (1,439-2,497)	107	1,457 (767-2,308)
1996	59	1,568 (1,158-1,976)	31	1,047 (569-1,610)
1997	107	1,653 (1,243-2,101)	66	1,150 (599-1,875)
1998	46	1,963 (1,479-2,470)	56	1,479 (822-2,336)

Values in parentheses are 95% confidence bounds.

Source: P. Kleiber, NMFS, Southwest Fisheries Science Center, Honolulu Laboratory.

HI, unpubl. data, 1998) and is the southernmost breeding colony for the species in the NWHI. Although other factors could have affected this population, it seems likely that longline fishing activities could have been responsible for the noted decline, especially since longline fishing was permitted within 50 nautical miles of the breeding colonies. Since 1991, the population size at French Frigate Shoals has not declined, although it is still below the 1987 count, suggesting that the management action restricting longline fishing near the breeding colonies may have provided some protection.

In addition, disruptions occurring at the breeding colony at the same time that the Hawaii pelagic longline fishery was in operation could obscure the effects of the Hawaii longline fishery on the population. For example, Midway Atoll became a National Wildlife Refuge in 1996, with closure of the U.S. Naval Station there. Massive restoration work was conducted on the atoll between 1994 and 1997. The U.S. Navy removed fuel storage tanks, abandoned buildings, rubble, and contaminants. During the cleanup of Sand Island, Midway Atoll, a Black-footed Albatross colony (approximately 590 nesting pairs) was displaced from the Fuel Farm area. Thus, the apparent increases and decreases in Black-footed Albatross breeding pairs cannot be attributed solely to changes in fishing effort and further analysis of the data must be completed before any conclusions can be made.

Certainly, this was where the findings generated from the population models at the workshop assisted the agencies. Population models can be developed to address broad or robust conclusions that are valid even if the parameters used to generate the models are full of uncertainties. Three conclusions were generated from the modeling exercises at the workshop: (1) in the absence of anthropogenic and catastrophic influences, the growth

rate of the Black-footed Albatross population ranges between zero and 4%; (2) if the total number of birds killed in the longline fishery each year is 1% of the total population, then the population growth rate will be reduced by more than 1%; and (3) a total population of 300,000 birds can withstand, maximally, a loss of 10,000 birds per year to all mortality sources including natural and anthropogenic sources. Without a doubt, all of the modeling exercises indicated that a loss of, for example, 1% of the Black-footed Albatross population had a fairly dramatic long-term effect on the population growth rate.

Workshops such as the Black-footed Albatross Population Biology Workshop bring experts together in a common forum to exchange information, identify problems, and offer recommendations to resource management agencies. The predominant need identified at this workshop was for both the USFWS and NMFS to standardize and complete their data sets for Black-footed Albatross population parameters and at-sea fishery interactions. Gaps in the data sets and problems with seabird catch and population estimates complicate the population dynamic analyses. Because disturbances at the breeding colonies have occurred at the same time mortalities have been reported in the Hawaii-based longline fishery, it is difficult to separate the effects of the different sources of mortality.

Acknowledgments

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Molecular Genetic Markers in the Analysis of Seabird Bycatch Populations

Scott V. Edwards and Mónica C. Silva
Department of Zoology and Burke Museum, University of Washington
Seattle, Washington

Theresa Burg
Department of Zoology, University of Cambridge
Cambridge, U.K.

Vicki Friesen
Department of Biology, Queen's University
Kingston, Ontario, Canada

Kenneth I. Warheit
Department of Fish and Wildlife
Olympia, Washington

Abstract

In the past 10 years a variety of molecular markers, each with particular strengths and weaknesses for population analysis, have been adopted by population geneticists and wildlife managers. These markers are powerful tools for supplementing management and conservation strategies for seabirds commonly entangled or hooked during fishing operations (bycatch seabirds). We review the biology of several types of markers, including mitochondrial DNA, nuclear introns, and microsatellites, and their utility in the context of seabird bycatch. These markers can serve a variety of important functions in understanding the origin of bycatch populations, the impact of bycatch on genetic variation within source populations, and the identification of bycatch specimens that are otherwise unidentifiable. We illustrate these concepts with case studies from four seabird species: Black-footed Albatrosses *(Phoebastria nigripes),* Wandering Albatrosses *(Diomedea exulans),* Common Murres *(Uria aalge),* and Marbled Murrelets *(Brachyrhamphus marmoratus).* However, the power of molecular markers

to help in the development of seabird management plans will depend on the size and geographic structure of the affected populations. If populations are large and well connected by high rates of gene flow, molecular markers may prove ineffective in identifying source populations of bycatch birds. Nonetheless, the ability to serve as individual-specific "color-bands" for birds and the emergence of rapid genotyping of individuals make molecular markers a crucial component of any large-scale conservation effort for bycatch seabirds. Both the storage of salvaged bycatch specimens in museum collections as vouchers and resources for genetic analysis, and further research on the geographic structure of colonial seabird species, will improve the ability of genetics to help solve bycatch problems.

Introduction

The use of molecular genetic markers has revolutionized population and evolutionary biology, and by extension conservation biology and wildlife management (Wilson et al. 1985; Barrowclough 1992; Avise 1994, 1996; Smith and Wayne 1996). The simple properties of Mendelian inheritance and genetic variation together conspire to make molecular markers effective and ubiquitous "color bands" for individuals in populations. Through the use of DNA fingerprinting techniques, population biologists can now realize in practice and apply the oft-touted phrase, "every individual is (genetically) unique." Increasingly sophisticated technologies allow biologists to glean highly informative genetic information from very small samples, such as individual feathers retrieved from degraded carcasses or decades-old museum specimens (Leeton et al. 1993), ancient ("millennia-old") specimens (Handt et al. 1994), hairs salvaged from nests (Morin et al. 1994), dung and feces (Wasser et al. 1997), and of course, minute amounts of blood or tissue. Elaborate field techniques for retrieving large numbers of such samples have been devised specifically to take advantage of the power of these new molecular approaches.

Seabird populations provide a challenge for managers because their geographic ranges can be quite large, they often breed on remote or inaccessible islands, or are generally unreachable on the open ocean. In recent years, satellite and radio telemetry have produced major advances in open ocean tracking of pelagic seabirds (e.g., Prince et al. 1998, Viswanathan et al. 1996), but even these technologies have not been applied on a scale that can provide robust descriptions of species movements to and from feeding grounds or breeding sites. By contrast, genetic markers are naturally harbored by every individual—the primary challenge lies in locating individuals directly, but through the use of sloughed off tissues or feathers individuals often can be sampled without direct encounter. As emphasized by Avise (1994), molecular markers provide remarkable tags that already mark each individual and are passed down to successive generations via inheritance. As such, they provide an important complement to

traditional methods of population monitoring that aim to assess the impact of bycatch on species' distributions and abundances.

The key contributions genetics can make to seabird bycatch include determining the origins and identity of bycatch birds and measuring parameters such as population growth rates, immigration, and emigration. Identifying the origin of individual birds killed in fishing nets requires a two-step process. First, baseline data for the known localities must be analyzed. Only if these localities have significantly different allele frequencies for any combination of loci can an unknown bird be identified to a locality based on its genotype. Second, bycatch specimens are analyzed using the same loci as the baseline data. Thus both basic data on geographic variation in seabirds as well as comparison with bycatch samples are critical to conservation.

The need for a geographic and genetic approach to problems of demographic modeling is exemplified by the recent workshop on population projections for Black-footed Albatross *(Phoebastria nigripes),* a species caught in large numbers (~7,300 birds per year; Cousins and Cooper 2000) in North Pacific longline fisheries nets. The demographic models used to estimate population viability of Black-footed Albatross incorporate a number of critical life history parameters, yet there is less emphasis on the possibility of metapopulation structure, i.e., a situation in which multiple colonies with separate demographies are connected by immigration and emigration (Hanski and Gilpin 1997). Some albatross colonies, by virtue of their demography or proximity to fishing areas, may produce bycatch birds out of proportion with their population size; management of such source colonies could prove more critical than others in mitigating bycatch effects. The assumption that migration between breeding colonies can be ignored because it is so rare is based on long-term banding records and estimates of band recapture rates on colonies different from natal colonies. However, several recent studies of seabird population genetics have suggested that rates of gene flow and effective migration between colonies are much higher than suggested by banding data, with its bias toward detecting individuals that do not leave the study colony or that move to another of a few monitored sites (Ovenden et al. 1991, Austin et al. 1994, Birt Friesen et al. 1992, da Silva and Granadeiro 1999). Would the results of models of the effects of bycatch on albatross populations be influenced by explicitly assuming a metapopulation structure? We do not yet know. But genetic data can surely help determine whether such populations conform to the definition of a metapopulation (as they likely do; Hanski 1997). Appropriately, the report on the Black-footed Albatross workshop included among its recommendations the collection of genetic resources (tissue, blood, feathers) from bycatch and breeding birds (Cousins and Cooper 2000). For example, the Burke Museum Genetic Resources Collection has been amassing tissues from seabird bycatch carcasses that will be invaluable for genetic analyses of carcass origins and bycatch management (Table 1).

Table 1.   Partial summary of specimens in the Burke Museum ornithology collection salvaged from fisheries driftnets in the North Pacific, generally between latitudes 39° and 45°N.

Number	Common name	Latin name
604	Sooty Shearwater	*Puffinus griseus*
211	Laysan Albatross	*Phoebastria immutabilis*
211	Short-tailed Shearwater	*Puffinus tenuirostris*
128	Buller's Shearwater	*Puffinus bulleri*
119	Black-footed Albatross	*Phoebastria nigripes*
87	Flesh-footed Shearwater	*Puffinus carneipes*
55	Northern Fulmar	*Fulmarus glacialis*
31	Horned Puffin	*Fratercula corniculata*
24	Common Murre	*Uria aalge*
23	Fork-tailed Storm Petrel	*Oceanodroma furcata*
15	Marbled Murrelet	*Brachyramphus marmoratus*
12	Rhinoceros Auklet	*Cerorhinca monocerata*
11	Black-legged Kittiwake	*Rissa tridactyla*
10	Tufted Puffin	*Fratercula cirrhata*
7	Mottled Petrel	*Pterodroma inexpectata*
6	Leach's Storm Petrel	*Oceanodroma leucorhoa*
6	Tristram's Storm Petrel	*Oceanodroma tristrami*
5	Streaked Shearwater	*Calonectris leucomelas*
5	Crested Murrelet	*Synthliboramphus wumizusume*
5	Parakeet Auklet	*Cyclorrhynchus psittacula*
4	Pink-footed Shearwater	*Puffinus creatopus*
4	Long-tailed Skua	*Stercorarius longicaudus*
4	Kittlitz's Murrelet	*Brachyramphus brevirostris*
3	Providence Petrel	*Pterodroma solandri*
3	Stejneger's Petrel	*Pterodroma longirostris*
3	South Polar Skua	*Catharacta maccormicki*
3	Brünnich's Guillemot	*Uria lomvia*
3	Short-tailed Albatross	*Phoebastria albatrus*
2	Hawaiian Petrel	*Pterodroma phaeopygia*
2	Pomarine Skua	*Stercorarius pomarinus*
2	Glaucous-winged Gull	*Larus glaucescens*
1	Bonin Petrel	*Pterodroma hypoleuca*
1	Red-tailed Tropicbird	*Phaethon rubricauda*
1	Herring Gull	*Larus argentatus*

Nomenclature according to Harrison (1983) and Robertson and Nunn (1998)

For carcasses that have been damaged beyond recognition during the fishing process, genetic techniques can easily be used to discern species and subspecies identities. Genetic methods can be used to identify seabirds found after they have been incapacitated by the fishing process or by other agents such as oil spills. Mitochondrial DNA is frequently used to verify the identification to species of a bird based on body parts, unidentifiable carcasses, and parts of extinct or endangered organisms. For example, Gary Nunn recently used a cytochrome *b* gene sequence to identify a Hawaiian Dark-rumped Petrel *(Pterodroma phaeopygia)* collected offshore of Washington state, USA (Gary Nunn, Applied Biosystems, Inc., Foster City, CA 94404, pers. comm.). Based on multiple gene sequences a large genetic difference was found between two traditional "subspecies" of the Dark-rumped Petrel, *sandwichensis* (Hawaiian Islands) and nominate *phaeopygia* (Galapagos Islands). By matching to these genes, the Washington state individual was determined to be phylogenetically close to gene sequences from Hawaiian *sandwichensis,* indicating the migratory origin. For many applications in bycatch, where a carcass is retrieved and expected to be one of a few commonly encountered species, mtDNA as well as other markers can provide a quick and powerful method of identification. Carcasses that have been submerged for days or even weeks in ocean waters are likely to retain enough DNA in their cells for characterization via PCR. PCR has also been used to identify and classify other problematic specimens, such as Cox's sandpiper (Christidis et al. 1996).

To date there is no published study using molecular markers to track the origin of bycatch birds and the impacts of bycatch on population viability. In this chapter we review the biology and application to seabirds of a set of molecular markers likely to be employed in bycatch studies, and outline several case studies of published work and work-in-progress that directly address problems of concern to seabird managers or illustrate the utility of a particular molecular or analytical approach to the analysis of seabird populations. Although the use of molecular markers in the analysis of bycatch seabird populations is in its infancy, there are some useful precedents from other endangered vertebrates for the type of studies that could be performed. For example, Bowen et al. (1995) used mitochondrial DNA and maximum likelihood analysis to suggest that 95% of the bycatch turtles caught in longline nets in the north Pacific originated from Japanese rookeries. Baker and Palumbi (1996) also used mitochondrial DNA to identify species, and in some cases geographic source, of samples of whale meat being sold in Japanese fish markets. Both these studies, and many others, used molecular markers in conjunction with modern statistical and phylogenetic analysis to trace the origin and identity of the individuals in question. Thus, they exemplify the type of analysis that managers of seabird species affected by bycatch can hope to accomplish in the coming years.
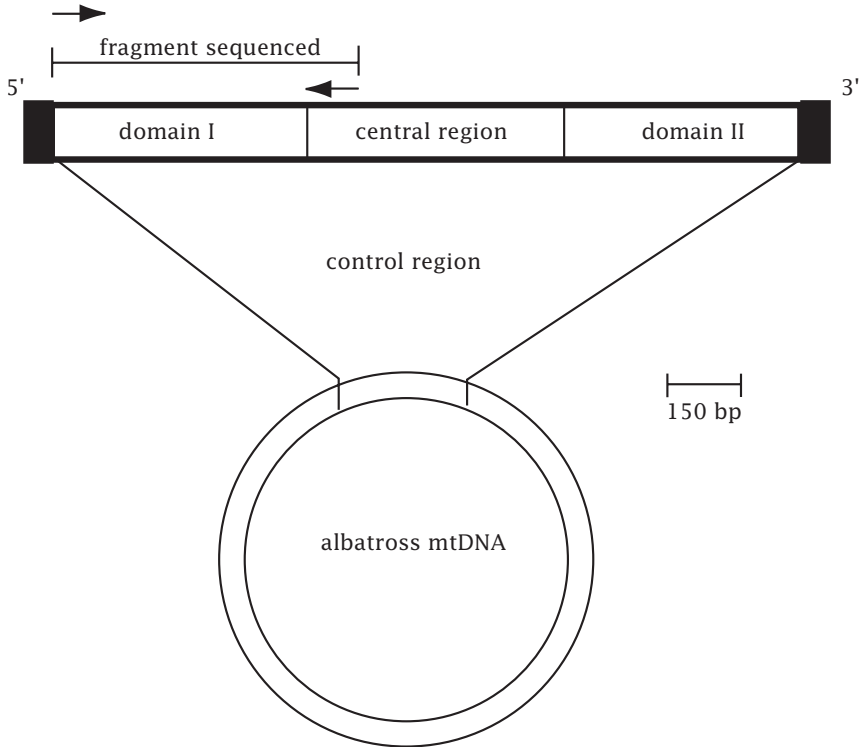
Figure 1.   Schematic diagram showing the control region of the mitochondrial DNA and location of the fragment sequenced (the nomenclature for control region domains differs slightly from that used by Baker and Marshall (1997). Position of the primers used are indicated by arrows. Shaded areas represent the flanking tRNA genes for proline and phenylalanine, respectively at the 5' and 3' ends.

Molecular markers

The Polymerase Chain Reaction

The polymerase chain reaction (PCR) is a molecular technique at the core of modern methods of molecular ecological analysis (Palumbi 1996). PCR was invented in the mid-1980s; technical advances in the late 1980s made PCR available to a wide range of biologists. The function of PCR is to produce many copies of a specific region of DNA, usually about 200-1000 base pairs long, specified by two short stretches of DNA ("oligonucleotides" or "primers") that are synthesized specifically to match two ends of a specific DNA sequence (Fig. 1). For most applications in molecular ecology, the knowledge of the focal species DNA sequence in that region of the genome is gleaned either by inference from closely related species or genera, as when amplifying mtDNA or nuclear introns, or by actively cloning

and characterizing the region from the focal species. The ability of the primers to target precisely a specific region of DNA, and of the PCR to amplify literally billions of copies from just a few starting copies, makes possible the PCR analysis of highly degraded specimens, including museum skins, single feathers, and bone.

Mitochondrial DNA

One of the most versatile molecules for analyzing the genetic structure of populations is the mitochondrial genome, a circular molecule in animals present in several copies per mitochondrion. In vertebrates, phylogenetically related mtDNA genotypes often constitute geographic assemblages separated by major genetic (and often geographic) breaks due to limited dispersal and high levels of philopatry in relatively discontinuous environments (Avise et al. 1987). More than a decade ago, Quinn and White (1987) proposed that if in birds, as in other vertebrates, one could detect assemblages of closely related mtDNA genotypes, then those assemblages could be genetically characterized and subsequently used to identify the geographic origin of any captured birds. Depending on which of the 37 mitochondrial genes is considered, DNA sequences of mitochondrial genome change approximately 5-10 times as fast as DNA sequences in the nuclear genome, making it very useful for comparing closely related individuals within populations. In addition, mitochondrial DNA (mtDNA) is inherited maternally in vertebrates (although some exceptions exist), and therefore its effective population size (N_e)—the parameter to be maximized in most conservation genetics and management applications—is only one-quarter that of a nuclear gene, when the sex ratio in the population is even. It takes a highly skewed sex ratio of about seven females for every male, to have the N_e of mtDNA match that of a nuclear gene (Birky et al. 1983). However, the small N_e of mtDNA means that it responds much more sensitively to population bottlenecks and other demographic events than a typical nuclear gene, making it of paramount importance when attempting to trace population histories and migration events. Moore (1995) has estimated that, under some simplifying assumptions and when populations are very closely related, 16 nuclear genes are required to resolve population histories and relationships with the same power of inference as the single mitochondrial genome. On the other hand, mtDNA can sometimes provide an idiosyncratic picture of population history in cases such as hybridization, making it necessary to complement its information with that of nuclear markers. Many oligonucleotide primers are available for amplification of several regions of avian mtDNA; some of the most popular include the cytochrome *b* gene, for its ease of PCR analysis due to the wealth of comparative sequence data, and the control region, because it is the only major non-coding region in the animal mitochondrial genome and hence changes very quickly.

Microsatellites

Microsatellites are short repeated stretches of DNA motifs—for example CACACACA [(CA)$_4$] or GGAATGGAATGGAAT (GGAAT)$_3$ (reviewed in McDonald and Potts 1997). They are of interest to seabird managers because they are highly polymorphic, with different alleles differing in the number of repeats. Surveys of microsatellites in birds, conducted primarily in terrestrial Passeriformes, typically reveal three to more than 20 alleles per locus and have estimated mutation rates of 10^{-3}-10^{-5} mutations per individual per generation, depending on the structure of the internal repeats, the species and the particular microsatellite locus. A battery of 6-10 microsatellites is frequently sufficient to obtain individual-specific genotypes for random birds. Microsatellites can sometimes mutate in such a way that alleles with similar lengths are unrelated—a type of convergence that can confound population genetic analysis. Nonetheless, they are of increasing importance in wildlife forensics and parentage studies, and thus are likely to be of use in the analysis of bycatch populations.

Introns

Nuclear introns also provide a potential source of markers for identifying the sources of birds caught as bycatch (Friesen 2000). Introns are non-coding segments of DNA that interrupt the coding sequences (exons) of nuclear genes of all eukaryotes (Alberts et al. 1994). Because introns are essentially neutral to selection, their substitution rate is greater than for other single-copy nuclear DNA (Li and Graur 1991). Introns occur in virtually all structural genes and are scattered throughout the genome, providing potentially thousands of independent markers (Lessa and Applebaum 1993). Recent studies indicate that introns provide useful markers for conservation and management in salmon *(Oncorhynchus* spp.; Moran et al. 1997) and humpback whales *(Megaptera novaengliae;* Palumbi and Baker 1994).

Case Studies of Black-footed Albatross in North Pacific Longline Fisheries

The Black-footed Albatross is a socially monogamous species and, as most Procellariiformes, exhibits extreme demographic characteristics: low reproductive rates coupled with high life expectancy (Warham 1990, Flint 1998). The adults (at least over 5 years old) breed on isolated oceanic islands, often in dense colonies (Whittow 1993) and the current population of breeding birds has been estimated to be approximately 60,000 pairs (Cousins and Cooper 2000). Current geographic distribution for the species comprises two main discrete populations: a western group, including colonies from the Izu, Bonin, and Senkaku islands (off the coast of Japan) and an eastern group, comprising the northwestern islands of Hawaii, which holds approximately 95% of the world's population.

Like all seabird species belonging to this group, Black-footed Albatross show high levels of nest fidelity, returning to the same colony (often where they were born) year after year to breed, frequently with the mate from previous seasons. There is geographic variation of some morphological traits, Japanese birds being smaller (Hiroshi Hasegawa, Toho University, Chiba, Japan, pers. comm.). Such life history characteristics suggest that this species may be genetically structured across its breeding range.

A few thousand Black-footed Albatrosses are caught every year in longline fisheries operating in the Gulf of Alaska, Bering Sea, and also in waters north of the Hawaiian archipelago. Although Laysan and Short-tailed Albatrosses are also caught by longliners, some evidence suggests that Black-footed Albatrosses may be being caught in disproportionately large numbers relative to their population size (Cousins and Cooper 2000). This potential threat to the viability of Black-footed Albatross populations motivated our genetic study, which had two goals: (1) to assess levels of DNA sequence divergence and thus genetic uniqueness of the two major groups of Black-footed Albatrosses; and (2) to determine the geographic origin of Black-footed Albatrosses caught in pelagic longliners operating in the North Pacific Ocean.

Thus far a total of 45 individuals have been screened for sequence variation in a short fragment, domain I of the mitochondrial control-region (ca. 350 bp; Fig. 1). Included in this sample were 16 individuals from Tern Island; 18 individuals from Torishima Island, Izu group; and 11 individuals salvaged from longlines in the North Pacific. Preliminary results indicate that Japanese individuals have very low levels of uncorrected average percent nucleotide difference: 0.58±0.28%. Hawaiian birds, on the other hand, show levels of percent nucleotide difference almost six times larger than the Japanese population (3.32±1.69%) and among the highest percent nucleotide differences reported for an avian population for this gene segment (Edwards 1993, Wenink et al. 1993, Baker and Marshall 1997).

We also constructed a phylogenetic tree of all the mitochondrial haplotypes identified among the 45 birds sampled (Fig. 2). In this tree, Japanese and Hawaiian birds cluster according to geographic origin, indicating population differentiation. The relationships of the bycatch birds suggest that birds being caught in longlines derive mainly from Hawaiian populations. Consistent with banding data, the tree suggests that two bycatch samples are probably of Japanese origin. According to our preliminary data, Black-footed Albatross cluster according to their geographical region and the two main breeding groups seem to have been at least historically isolated. Such lack of gene flow, in part probably due to the high levels of colony fidelity (Warham 1990), permits the development of population-specific genetic markers, which allows the assignment of captured birds to specific geographic regions.

The Hawaiian Islands hold about 20 times more breeding birds than the Japanese islands (Cousins and Cooper 2000), which is a likely
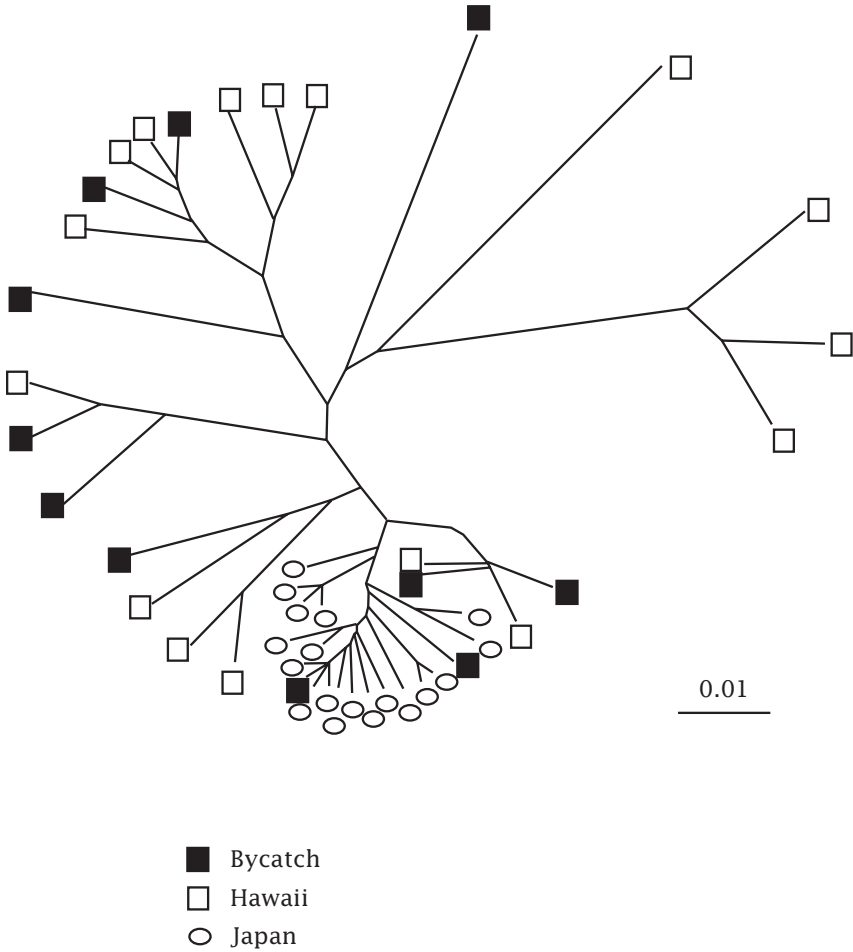
Figure 2.   *Unrooted phylogenetic tree built by calculating genetic distances between all pairs of sequences by the method of Kimura (1980) and then constructing a neighbor joining tree (Saitou and Nei 1987) using the PHYLIP program (Felsenstein 1995). Symbols refer to the geographic origin of the samples used in the study. Scale units are in number of substitutions per site.*

explanation for the difference in genetic diversity within each group. Also, population bottlenecks can result in a decrease of genetic variability and population heterozygosity (Menotti-Raymond and O'Brien 1993). Black-footed Albatross populations from both geographic groups have suffered periodic events of human exploitation (for feathers, oil, and meat) as well as threats to viability from environmental contamination. Japanese albatross populations (especially in Torishima) declined and remained in extremely low numbers until the end of the 1950s (Hasegawa, unpubl. in Cousins and Cooper 2000). It is therefore not surprising that Torishima birds display lower levels of genetic diversity.

Common Murres (Uria aalge) Caught in Washington State Gillnets

Common Murre is the seabird species most affected by coastal gillnet bycatch in the northeast Pacific (DeGange et al. 1993). Between 1983 and 1986, 50-97% of all seabirds killed in gillnets in the Gulf of Farallones and Bodega Bay, California, were Common Murres. Their estimated mortality in central California from 1979 to 1987 was 70,000-75,000 birds (Takekawa et al. 1990). In central and northern Puget Sound, Hood Canal, and in the waters around the San Juan Islands, Washington, Common Murre entanglement ranged between 39% and 95% of the total observed seabird entanglement for 1993 and 1994 (Erstad et al. 1994, 1996; Pierce et al. 1994), mirroring the California study.

Pierce (Washington Department of Fish and Wildlife, unpubl.) estimated that a total of 2,713 (420-5,005) Common Murres were entangled in the non-treaty sockeye fishery in the waters around and north of the San Juan Islands in 1994. If these entangled birds were part of the Washington breeding population, then over 25% of that population (roughly 11,000 birds; Parrish 1998 and U. Wilson, U.S. Fish and Wildlife Service, unpubl. data) would have been affected. However, not all birds killed in Puget Sound gillnets are Washington breeders (Thompson et al. 1998). Washington's outer coast waters and Puget Sound are wintering areas for Common Murres from at least Oregon and British Columbia, and perhaps California and Alaska. Therefore, during the late summer and fall, birds from each of these localities are vulnerable to being caught in Washington gillnets. The objective of this analysis was to test if the existing baseline data of microsatellite allele frequencies from a series of localities could provide reliable estimates of the geographical origin of Common Murres caught in Puget Sound nets.

Baseline genetic data were obtained from Common Murres from four breeding localities: British Columbia (Winter Harbour; 24 samples), Washington (Cape Flattery; 101 samples), Oregon (Newport; 34 samples), and California (Gulf of Farallones; 27 samples) (Warheit and Friesen, unpubl.). DNA was extracted from these samples using standard protocols and analyzing four microsatellite loci using an ABI 377 semi-automated sequencer.

Table 2.   **Test for allelic differentiation among localities of Common Murres using the 90% and 95% confidence intervals from 1,000 bootstrap runs.**

Comparison	uapi-23[a]	12a12[a]	12a22[a]	14b29[a]	All loci combined
WA × BC	*			*	**
WA × OR	*			*	*
WA × CA	**	**	**	*	**
BC × OR		**		**	**
BC × CA	*	**			**
OR × CA	*			**	**

* = $P < 0.10$; ** = $P < 0.05$

[a] Ibarguchi et al. 2000

A pairwise comparison of allele frequencies is considered significantly different if 90% or 95% confidence intervals do not overlap (Warheit and Friesen, unpubl. data).

We used a bootstrap procedure (see Weir 1996) to analyze baseline data on geographic differences among the four localities (Table 2).

To compare the baseline data to simulated "bycatch" populations and to assess our power to identify source populations of bycatch birds, we designed or simulated four mixtures by randomly selecting, with replacement, from the baseline data (see Table 3). Mixture 1 was composed entirely of individuals from Washington. Mixture 2 was composed entirely of individuals from Oregon. Mixture 3 was 50% each from Washington and Oregon. Mixture 4 was randomly selected from the entire data set. We compared these simulated mixtures to the baseline using SPAM (Alaska Department of Fish and Game 1999), a maximum likelihood program designed to analyze mixed-stock fisheries using genetic stock identification techniques.

Although there is significant differentiation in allele frequencies among the four localities (Table 2), maximum likelihood analyses indicated incomplete separation of individuals in our simulated mixings (Table 3). Overall the baseline data performed fairly well in correctly identifying the relative proportions of localities for two of the four simulated mixtures. In Mixture 2 there was an 11% error rate in identifying Oregon birds, distributed equally between Washington and California. There was a similar error in Mixture 3. The other two simulated mixtures did not perform as well as Mixture 2 and 3 (Table 3). Errors in Mixture 4 ranged from 25% for the Oregon birds up to 128% for the California birds, and in Mixture 1 the number of Washington birds was underestimated by nearly 40%.

These results indicate that a locality-specific signal for the allele frequencies in the baseline data exists, but that signal is weak. If more loci are added to the baseline data, the ability to differentiate populations and

Table 3. **The relative contribution of each locality to four simulated mixtures and the SPAM estimation of these contributions.**

Simulated mixture	1	2	3	4
BC	0.00	0.00	0.00	0.18
WA	1.00	0.00	0.50	0.58
OR	0.00	1.00	0.50	0.16
CA	0.00	0.00	0.00	0.08
Sample size	25	25	50	50
Estimation				
BC	0.14 ± 0.13	0.00	0.02 ± 0.03	0.29 ± 0.12
WA	0.61 ± 0.20	0.07 ± 0.09	0.56 ± 0.14	0.35 ± 0.15
OR	0.11 ± 0.11	0.89 ± 0.13	0.38 ± 0.13	0.12 ± 0.08
CA	0.06 ± 0.09	0.05 ± 0.08	0.05 ± 0.07	0.19 ± 0.11
Unknown	0.08			

Each estimation represents the means and standard deviations from 500 bootstrap runs where in each run both the mixture and baseline data (see text) are randomly resampled with replacement.

hence specify the geographical origins of bycatch murres would increase. The utility of such methods depends on the baseline data and the extent of geographic differentiation observed at the genetic loci; we believe the baseline here will be sufficient to identify the area of origin of Common Murres killed in Washington fishing nets once a sufficient number of loci are included.

Geographic Variation and Bycatch of Wandering Albatrosses

Wandering Albatrosses breed on remote subantarctic islands where risk of direct human impact at their breeding sites is minimal. Adult breeding birds are exceptionally site-faithful (Weimerskirch and Jouventin 1987; Croxall et al. 1990, Croxall and Gales 1998). The total annual breeding population of all Wandering Albatross taxa combined is about 20,600 pairs (*D. exulans* 8,500, *D. antipodensis* 5,000, *D. gibsoni* 6,200) (Croxall and Gales 1998, Gales 1998). Trends in *D. antipodensis* and *D. gibsoni* populations are unknown; *D. exulans* has declined markedly (1-7% per annum depending on site and period) at most breeding locations over the last 25 years, chiefly due to increased adult mortality (Weimerskirch and Jouventin 1987, de la Mare and Kerry 1994, Weimerskirch et al. 1997).

In *D. exulans,* foraging range is much reduced during the breeding period (Prince et al. 1992, 1998; Weimerskirch et al. 1993). In the non-breeding season the birds migrate eastward to Australian waters and may circumnavigate the globe in high latitudes. Movements of *D. antipodensis* and *D. gibsoni* are poorly known but the former travels at least to South

America (Nicholls et al. 1996). Juveniles of *D. exulans* are known to disperse very widely; this is presumably true of all taxa in the group. Such movements could lower the extent of among-population genetic differentiation critical to analysis of bycatch birds. During incubation and main chick-rearing parts of the breeding season, *D. exulans* travel very widely up to 3,000 km away from their breeding site on journeys lasting up to 15 days covering more than 15,000 km—taking them well into subtropical waters. The movements of *D. antipodensis* and *D. gibsoni* are less known (Walker et al. 1995).

Wandering Albatrosses feed predominantly on squid, fish, and carrion (Cherel and Klages 1998) and are readily attracted to ships. This and their wide pelagic distribution make them a particularly high risk for death by drowning after being caught on hooks (baited with squid or fish) of longline fishing vessels. Wandering Albatrosses were killed in very substantial numbers by longline fishing for southern bluefin tuna from the mid-1980s onwards, particularly in the Southern Indian Ocean but also in the South Atlantic Ocean (Prince et al. 1992, 1998; Weimerskirch et al. 1997; Croxall and Gales 1998). Widespread mortality still occurs (e.g., 600 per year estimated killed in the Australian Fishing Zone; Gales et al. 1998) and many doubtless go unreported in similar fisheries elsewhere. Longline fisheries in the higher latitudes of the Southern Ocean (e.g., for Patagonian toothfish) kill relatively few Wandering Albatrosses (compared to the numbers of Black-browed Albatrosses and White-chinned Petrels taken) but total mortality from these sources may still be many tens to low hundreds of birds.

Assessment of the magnitude and significance of interactions between Wandering Albatross populations and longline fisheries have been hindered by:

1. Lack of data on status and trends of most Wandering Albatross populations (apart from those at Bird Island, South Georgia, Possession Island, Crozet Islands and Macquarie Island).

2. The paucity of accurate data on bycatch rates in longline fisheries, compounded by under-reporting and misidentification.

3. Lack of knowledge on the provenance of Wandering Albatrosses caught in these fisheries (e.g., Patagonian toothfish).

To shed light on the movements of albatrosses and genetic differentiation among colonies, samples have been obtained from three of the Wandering Albatross taxa on five of the larger breeding colonies: *D. gibsoni* from Adams Island; *D. antipodensis* from Antipodes Islands; and *D. exulans* from Bird, Crozet, and Marion islands (Fig. 3; Nunn et al. 1996, Robertson and Nunn 1998). Fifteen samples from each island were analyzed using microsatellite markers described in Burg (1999). Fourteen of the 23 markers tested were variable. Several loci have quite varied allele frequencies
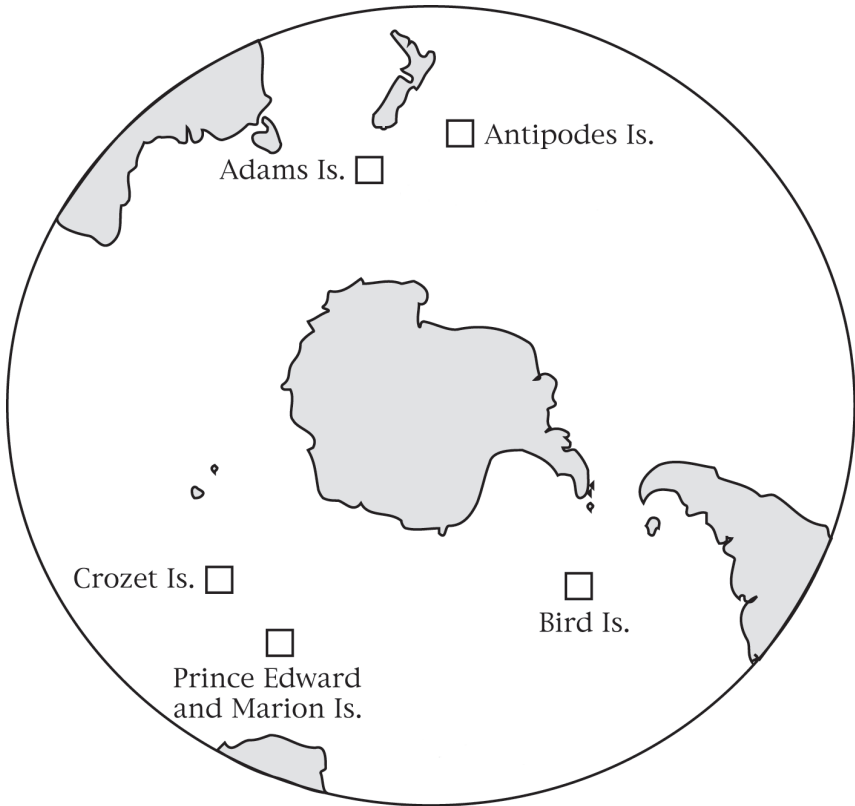
Figure 3. Distribution of Wandering Albatross sampling sites around Antarctica and the Southern Ocean.

between breeding sites (e.g., Marion and Crozet islands at locus De3) while other sites have unique alleles (e.g., Adams Island Dc16, allele 115; Table 4). Highly significant genetic differentiation ($P < 0.001$) was found between birds sampled across the five islands. The assignment test (see Paetkau et al. 1995 for description) correctly assigned between six and 15 of the albatrosses to their source populations using the expected genotype frequencies at four microsatellite loci. Samples from Adams (6 out of 15) and Antipodes (7 out of 15) islands proved the most difficult to assign to the correct source population. However, as the number of loci tested increases, the number of samples correctly assigned to the source populations should also increase.

Table 4.   Allele frequencies in Wandering Albatrosses at five breeding sites screened at four microsatellite loci.

		Allele frequencies at Wandering Albatross breeding sites				
Locus	Allele size	Crozet Islands	Marion Island	Adams Island	Antipodes Islands	Bird Island
De3	118				0.038	
	120		0.885	0.607	0.115	
	122	1.000	0.115	0.393	0.847	1.000
Dc5	163				0.067	0.024
	165			0.111		0.095
	167	0.900	1.000	0.722	0.700	0.881
	169	0.100		0.167	0.167	
	171				0.067	
Dc16	115			0.286		
	117	0.733	0.188		0.091	0.192
	119	0.267	0.813	0.714	0.909	0.808
Dc20	99		0.125	0.250	0.125	0.065
	109					0.043
	111	0.406				0.130
	113	0.594	0.875	0.750	0.875	0.761

Analysis of Alcid Populations Using Nuclear Introns

The Alcidae is a family of seabirds that forage by pursuit diving (Gaston and Jones 1998). Because of their method of foraging, alcids spend large amounts of time either on or in the ocean and therefore are highly vulnerable to entanglement in gillnets. Several species are subject to other forms of human disturbance, such as oil pollution and hunting (murres, *Uria* spp.), and logging (Marbled Murrelets, *Brachyramphus marmoratus*). As a consequence, several species of alcids are declining, and some are listed as Threatened or Vulnerable in all or part of their breeding range.

To aid the restoration of populations of common murres, pigeon guillemots *(Cepphus columba),* and marbled and Kittlitz's murrelets *(Brachyramphus brevirostris)* to the Gulf of Alaska following the *Exxon Valdez* oil spill, and to aid the management of the thick-billed murre hunt in arctic Canada, we have examined genetic differentiation among colonies using intron markers. Analysis of intron variation using single-strand conformation polymorphism (SSCP) analysis and direct sequencing of PCR products provides a highly efficient method of assaying population-level sequence variation (Friesen et al. 1997, Holder et al. 1999, Congdon et al.

2000). To gain insight into the utility of introns for discriminating the origin of birds caught as bycatch, preliminary analyses were run on intron variation in Marbled Murrelets (Congdon et al. 2000) using SPAM (Alaska Department of Fish and Game 1999) and Assign (M. Damus, Department of Biology, Queen's University, Kingston, Ontario, unpubl. program). Three sets of analyses were run with SPAM. In Simulation 1, a simulated bycatch was created from four localities chosen at random, each contributing 25% of individuals. In Simulation 2, 100% of bycatch individuals were from one population (the Shumigan Islands). In Simulation 3, each locality contributed equally to the bycatch. For each simulation, three data sets were tested: Set #1 used the absolute allele frequencies from the raw data; set #2 used relative allele frequencies with sample sizes set at 10 for each locality (the median sample size); and set #3 used relative allele frequencies with sample sizes set at 18. (Note that this analysis may not be appropriate to a sample of Marbled Murrelets from throughout the North Pacific, since murrelets probably do not migrate to a common wintering area. Nonetheless, results of the present analysis illustrate the potential power of introns in identification of bycatch seabird origins.) Mean estimates of percentage representation of the populations in the simulated bycatch from 100 bootstrap replications differed from the expected values for only 9 of 99 results (Table 5). Ninety-five percent confidence intervals generally were within 25% and sometimes approached 0%, although confidence intervals when all bycatch birds came from a single source population were as high as 71%. Estimates tended to be more accurate when bycatch birds were from a variety of sources, and when numbers of samples used to characterize source populations were larger and more similar. Results based on absolute allele frequencies were the poorest and were biased toward localities with larger samples. In a preliminary study of population differentiation among North American marbled murrelets, Friesen et al. (1996) could not detect any population differentiation in cytochrome *b* sequences and found only weak population differentiation in allozymes and microsatellites, but later found that murrelets from the Aleutian Islands are significantly different from those on mainland North America at nine introns. These results suggest that introns will be useful for the analysis of seabird and bycatch populations.

Preliminary analyses of intron variation in murrelets (Congdon et al. 2000) also was performed using Assign (M. Damus, unpubl. program), which predicts the origin of individuals from allele frequencies. Genotypes of three bycatch individuals (one with the most common genotype at each locus, one with a random genotype at each locus, and one with the least probable genotype at each locus) were simulated based on allele frequencies of murrelets sampled from Attu. The genotype of an individual chosen at random from the real data set also was tested. For all individuals except the simulated bird with least probable genotype, the most probable source population was determined to be Attu, and this population was significantly more probable as the source than was any

Table 5. Results of tests of the utility of introns for identifying the origins of murrelets.

Population		Simulation 1			Simulation 2			Simulation 3		
		mean	S.D.	exp.	mean	S.D.	exp.	mean.	S.D.	exp.
Set 1	Attu	0.001	0.004	0.00	0.003	0.005	0.00	0.070	0.032	0.091
	Adak	0.000	0.002	0.00	0.001	0.003	0.00	0.045	0.026	0.091
	Belk.	0.004	0.007	0.00	0.002	0.005	0.00	**0.028**	0.021	0.091
	Shum.	**0.064**	0.044	0.25	0.299	0.166	1.00	**0.027**	0.022	0.091
	Mitr.	**0.116**	0.055	0.25	0.080	0.073	0.00	0.060	0.038	0.091
	Shuy.	0.030	0.025	0.00	0.001	0.005	0.00	0.066	0.039	0.091
	Kach.	0.131	0.057	0.25	0.024	0.030	0.00	0.069	0.041	0.091
	Unal.	0.156	0.066	0.25	0.020	0.036	0.00	0.064	0.038	0.091
	Leme.	0.052	0.035	0.00	0.029	0.034	0.00	0.116	0.046	0.091
	B.C.	**0.175**	0.063	0.00	0.247	0.130	0.00	**0.247**	0.067	0.091
	Oreg.	0.002	0.004	0.00	0.002	0.005	0.00	**0.015**	0.018	0.091
Set 2	Attu	0.002	0.004	0.00	0.000	0.014	0.00	0.059	0.029	0.091
	Adak	0.000	0.002	0.00	0.000	0.000	0.00	0.072	0.030	0.091
	Belk.	0.013	0.015	0.00	0.004	0.008	0.00	0.076	0.033	0.091
	Shum.	0.173	0.063	0.25	0.716	0.183	1.00	0.074	0.033	0.091
	Mitr.	0.129	0.061	0.25	0.042	0.048	0.00	0.055	0.030	0.091
	Shuy.	0.001	0.003	0.00	0.000	0.000	0.00	0.062	0.026	0.091
	Kach.	**0.130**	0.048	0.25	0.001	0.003	0.00	0.061	0.033	0.091
	Unal.	0.160	0.062	0.25	0.014	0.022	0.00	0.075	0.037	0.091
	Leme.	0.015	0.015	0.00	0.008	0.015	0.00	0.055	0.032	0.091
	B.C.	0.028	0.028	0.00	0.033	0.045	0.00	0.051	0.030	0.091
	Oreg.	0.000	0.000	0.00	0.000	0.000	0.00	**0.068**	0.029	0.091
Set 3	Attu	0.001	0.003	0.00	0.000	0.001	0.00	0.073	0.030	0.091
	Adak	0.001	0.002	0.00	0.000	0.001	0.00	0.089	0.030	0.091
	Belk.	0.003	0.007	0.00	0.000	0.003	0.00	0.080	0.030	0.091
	Shum.	0.241	0.045	0.25	0.962	0.093	1.00	0.084	0.027	0.091
	Mitr.	0.191	0.055	0.25	0.013	0.037	0.00	0.081	0.034	0.091
	Shuy.	0.001	0.002	0.00	0.000	0.000	0.00	0.071	0.028	0.091
	Kach.	0.187	0.048	0.25	0.000	0.002	0.00	0.075	0.031	0.091
	Unal.	0.227	0.057	0.25	0.001	0.005	0.00	0.089	0.040	0.091
	Leme.	0.013	0.017	0.00	0.003	0.012	0.00	0.080	0.035	0.091
	B.C.	0.022	0.022	0.00	0.006	0.021	0.00	0.088	0.043	0.091
	Oreg.	0.000	0.000	0.00	0.000	0.000	0.00	0.085	0.029	0.091

Belk. = Belkofski Bay, Shum. = Shumigan Is., Mitr. = Mitrofania Bay, Shuy. = Shuyak I., Kach. = Kachemak Bay, Unal. = Unalaska I., Leme. = Lemesurier I., Oreg. = Oregon.

Frequencies in bold are significantly different from the expected frequency at $P = 0.05$.

other. Although both these analyses are preliminary, they suggest that introns provide potentially powerful markers for identifying the sources of bycatch seabirds.

Conclusions

The above case studies provide an overview of the diversity of questions relevant to seabird bycatch that can be answered using molecular markers, as well as the strengths and weaknesses of different molecular approaches to such problems. The determination of the geographic origin of bycatch birds, as illustrated in the Common Murre and Marbled Murrelet studies, is likely to be of paramount interest in efforts to determine the effects of bycatch on source colonies. As evident in these studies, this problem will likely require multiple polymorphic loci to achieve a high level of resolution. The problem is made more challenging by the apparent fluidity of seabird populations: most genetic analyses of geographic variation in seabirds have shown that seabird colonies harbor a surprisingly large amount of genetic variation and that there are few fixed allele frequency differences between colonies. These patterns, found in a wide diversity of seabirds (Birt Friesen et al. 1992, Austin et al. 1994, da Silva and Granadeiro 1999), suggest a history of gene flow among colonies, despite the prevailing assumption that natal philopatry as judged by banding programs would result in the accumulation of genetic differences between colonies. To find such large differences between any avian populations that are not cryptic species would indeed be surprising, and with sufficient effort a number of allele frequency shifts will likely be found that will be useful for bycatch analysis.

Genetic similarities among colonies of seabirds also could be due to recency of separation or founding of these colonies. If such colonies were founded less than on average 4N generations ago, where N is the effective population size, it is likely that some residual genetic similarities will remain among colonies even in the complete absence of gene flow. Since many seabird colonies are suspected to be quite large (several hundred thousand to millions of individuals) the time scale over which such residual shared polymorphisms could persist is correspondingly long, making it less likely that at the time of sampling genetic variants that distinguish a given colony will have risen to high frequencies. Baseline data on the population structure of pelagic seabirds, such as described in the Wandering Albatross case study, will be crucial to informed interpretation of genetic patterns observed in bycatch birds. The rate per year at which seabird genes mutate—an important population genetic variable that could decrease with increasing body size and generation time (Nunn and Stanley 1998)—could also influence levels of variability and the ease of identifying provenance markers within seabird populations.

The critical role of genetics in the design and implementation of demographic models is evident in the Black-footed Albatross study. With

sufficient data, it will be possible to provide detailed information on the extent of gene flow among potential source colonies as well as those colonies and bycatch populations. Such parameters can be critical components of demographic projections and population viability analyses of endangered species. Whether a particular colony is a source or a sink can have substantial consequences for its long-term fate and probability of extinction. Simply describing the metapopulation structure of pelagic species is important to understanding the demographic effects of bycatch. Sophisticated methods for testing hypotheses of population growth and decline are now available, although most such methods apply to single isolated populations and will probably address time scales somewhat longer than are the concern of seabird managers.

The information content from genetic data will be maximized when multiple different loci, both mitochondrial and nuclear, are employed to trace the sources of bycatch birds. As illustrated in the Marbled Murrelet case study, different types of loci provide variable levels of resolution, and the background knowledge about modes of change of such loci can be used judiciously to choose the appropriate tool for the particular level of comparison. Mitochondrial DNA will likely continue to play a primary role in species identification and the establishment of phylogenetically based taxonomies basic to conservation schemes. Molecular markers combined with rigorous statistical methods should provide managers with a powerful set of tools with which to determine the sources and identities of seabird bycatch populations as well as the viabilities of the colonies from which they originate.

Acknowledgments

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Central California Gillnet Effort and Bycatch of Sensitive Species, 1990-1998

Karin A. Forney
NMFS Southwest Fisheries Science Center
Santa Cruz, California

Scott R. Benson
Moss Landing Marine Laboratories and
Monterey Bay National Marine Sanctuary
Moss Landing, California

Grant A. Cameron
NMFS Southwest Fisheries Science Center
La Jolla, California

Abstract

During the 1980s, extensive bycatch of seabirds and marine mammals in central California's set gillnet fisheries prompted a series of area and depth closures, which ultimately appeared successful at reducing mortality of the species of primary concern, Common Murre *(Uria aalge)*, sea otter *(Enhydra lutris),* and harbor porpoise *(Phocoena phocoena)*. The effects of the restrictions, however, were confounded with changes in the distribution and intensity of fishing effort during the early 1990s. This study documents 1990-1998 patterns of fishing effort in the central California halibut *(Paralichthys californicus)* gillnet fishery and presents information on bycatch of the above three species. A National Marine Fisheries Service observer program obtained bycatch data from 1990 to 1994, but was discontinued after 1994. Since then, gillnet effort has increased and shifted into the southern areas of Monterey Bay, where bycatch was high during the 1980s. The recent increase in gillnet effort coincides with higher beach deposition rates for all three species. In this study, historical entanglement rate data are combined with estimates of fishing effort for 1995-1998 to produce several sets of mortality estimates based on a variety of assump-

tions. Without further data, it is not possible to validate most of the assumptions. The range of total mortality estimates for the 4-year period 1995-1998 is 5,918-13,060 Common Murres (S.E. 477-1,252), 144-662 harbor porpoises (S.E. 18-53), and 17-125 sea otters (S.E. 4-25), raising concern for all three species. The recent changes in fishing effort and distribution underscore the importance of monitoring variability in both fishing practices and the distribution of vulnerable species when evaluating long-term fishery impacts.

Introduction

Central California was an important area for the California halibut *(Paralichthys californicus)* set gillnet fishery during the 1980s. Several species of seabirds and marine mammals were susceptible to entanglement in these nearshore gillnets (Wild 1990), and there was particular concern over populations of Common Murre *(Uria aalge),* southern sea otter *(Enhydra lutris),* and harbor porpoise *(Phocoena phocoena).* At least 70,000 Common Murres died in set gillnets in the 1980s (Takekawa et al. 1990), along with hundreds of sea otters (Wendell et al. 1986), and about 2,000 harbor porpoises (Barlow and Hanan 1995). Concern about bycatch of these species resulted in a series of restrictions on fishing in shallow waters (Wild 1990). In the San Francisco area north of Pigeon Point (Fig. 1), a 73 m (40 fm) depth closure effectively shut down the fishery in early 1987. In the Monterey Bay and Morro Bay areas, a series of depth restrictions was implemented between 1987 and 1990 (Wild 1990), and since 1991 set gillnets in this region have been restricted to waters deeper than 55 m (30 fm).

A National Marine Fisheries Service (NMFS) observer program generated bycatch data for the California halibut set gillnet fishery during 1990-1994, and mortality estimates for this period were published for marine mammals, seabirds, and sea turtles (Julian and Beeson 1998). The observer program was discontinued at the end of 1994, mainly because harbor porpoise mortality was low and coastwide set gillnet fishing effort had declined. Since 1994, this fishery has undergone changes in effort and distribution that potentially affect the three species of concern, Common Murre, sea otter, and harbor porpoise. Because of these changes, previous methods of estimating mortality for central California may no longer be adequate. In this study, we summarize published mortality information for 1990-1994, present detailed information on the 1990-1998 distribution and magnitude of set gillnet fishing effort in central California with emphasis on the Monterey Bay region, and provide a range of mortality estimates for the above three species in the years since 1994. We further evaluate biases in the bycatch estimates, relate levels of mortality to these species' population status, and make recommendations for future monitoring.
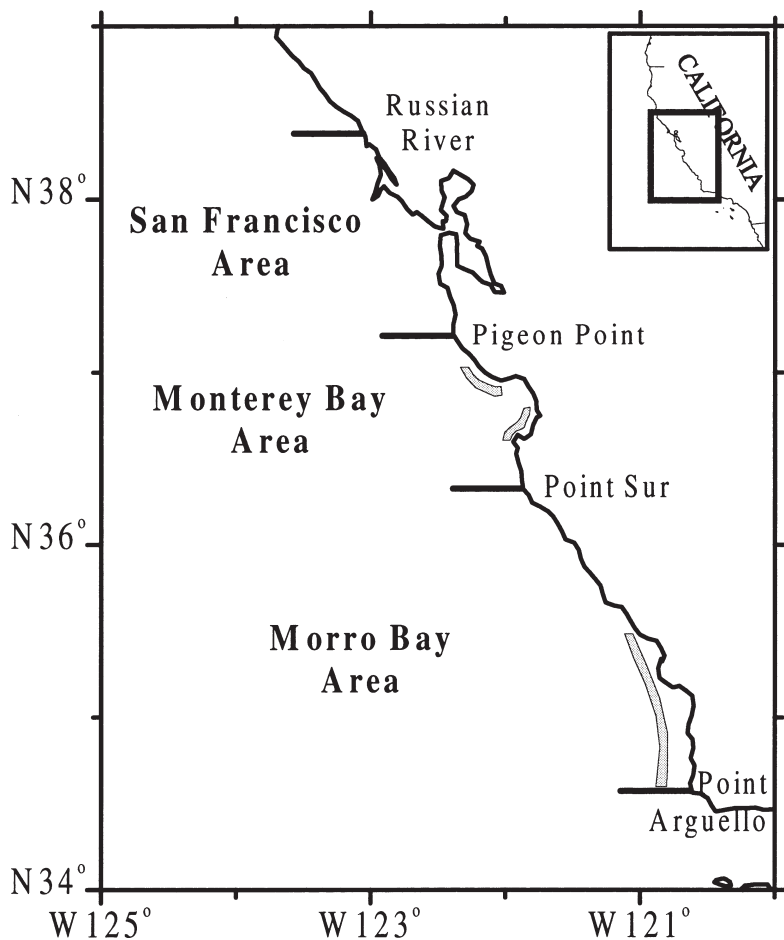
Figure 1. *Central California study area and major areas of gillnet fishing activity during the 1980s and 1990s. Shaded areas along sections of the coast correspond to approximate present fishing areas for the strata north Monterey Bay, south Monterey Bay, and Morro Bay.*

Methods
Fishery Description

The analyses presented below include data only for the central California halibut set gillnet fishery, which uses gillnets with a mesh size of >21.6 cm. This fishery currently operates year-round between Point Arguello and Pigeon Point (Fig. 1), commonly with a peak in effort between July and October. Typically, each vessel deploys one or more bottom-set gillnets of

Table 1. **Data summary for 1987-1990 California Department of Fish and Game (CDFG) and 1990-1994 National Marine Fisheries Service (NMFS) observer programs, restricted to >37 m water depth (as used in analyses E-F).**

Data Source		Morro Bay		South Monterey Bay		North Monterey Bay	
CDFG (1987-1990)	Observed sets	0		81		31	
	Entanglements	No.	No./set	No.	No./set	No.	No./set
	Common Murre	–	–	166	2.049	322	10.387
	Harbor porpoise	–	–	15	0.185	11	0.355
	Sea otter	–	–	5	0.062	0	0.000
NMFS (1990-1994)	Observed sets	53		14		242	
	Entanglements	No.	No./set	No.	No./set	No.	No./set
	Common Murre	50	0.943	25	1.786	776	3.207
	Harbor porpoise	0	0.000	3	0.214	14	0.058
	Sea otter	0	0.000	0	0.000	0	0.000

about 914 m length (not to exceed a combined net length of 2,745 m; California Fish and Game Code 8625) for a period of 24-48 hours (see Julian and Beeson 1998 for additional gear details). The number of sets per vessel-day has varied regionally between the Morro Bay area (3.1 sets per day, standard deviation S.D. = 1.1, based on n = 43 observed days during 1990-1994) and the Monterey Bay area (1.5 sets per day, S.D. = 0.7, n = 167). The overall coastwide average is 3.1 (S.D. = 1.3, n = 2,587; Julian and Beeson 1998). At times, vessels set additional nets with smaller mesh sizes targeting fish other than halibut, but these sets are not included in this study.

Effort and Mortality Estimation

The California Department of Fish and Game (CDFG) estimates annual fishing effort, measured as the number of vessel-days fished, by geographic region using vessel logbooks and landing receipts (Diamond and Vojkovich 1990, Julian and Beeson 1998). Effort is assigned to 10×10 minute geographic CDFG blocks whenever possible; unassigned effort is prorated among blocks within the fishing range of the port of landing. Entanglement rates in this study were estimated using data from two observer programs conducted in 1987-1990 and 1990-1994 (Table 1). The primary data source was a 1990-1994 NMFS observer program, which observed about 10% of central California fishing effort. However, very little fishing effort in 1990-1994 took place in the southern portions of Monterey Bay,

Table 2. **Summary of mortality estimation analyses. Method A corresponds to Julian and Beeson (1998).**

Analysis	Central CA strata	Depth restrictions	Effort unit	Sets/day (Mor, Mry)	NMFS data?	CDFG data?	Observed effort included		
							Mor	S.Mry	N.Mry
A	None	None	Day	1.8, 1.8	Yes	No	44 days	8 days	163 days
B	Mor, Mry	None	Day	3.1, 1.5	Yes	No	44 days	8 days	163 days
C	Mor, Mry	None	Day	3.1, 1.5	Yes	Yes	44 days	77 days	194 days
D	Mor, S.Mry, N.Mry	None	Day	3.1, 1.5	Yes	Yes	44 days	77 days	194 days
E	Mor, S.Mry, N.Mry	Only >37m	Set	3.1, 1.5	Yes	Yes	53 sets	95 sets	273 sets
F	Mor, S.Mry, N.Mry	Only >37m	Set	3.0, 3.0	Yes	Yes	53 sets	95 sets	273 sets

Key to strata: Mor = Morro Bay, Mry = Monterey Bay

where most effort has taken place since 1995, and therefore these data may not be representative of recent fishing activity. For this reason, the NMFS data were supplemented with data obtained by CDFG in 1987-1990, when about 5% of fishing activity within the Monterey Bay region was monitored.

The basic approach to mortality estimation follows that described by Julian and Beeson (1998) and involves a simple mean-per-unit estimator according to the following equations:

$$\hat{m} = D\hat{r} \qquad (1), \qquad \text{and} \qquad \hat{\sigma}_m^2 = D^2\,\hat{\sigma}_r^2 \qquad (2),$$

where $\hat{m}$ = total estimated mortality, $\hat{r}$ = estimated number of entanglements per unit effort, D = total fishing effort, $\hat{\sigma}_m^2$ = variance of $\hat{m}$, and $\hat{\sigma}_r^2$ = variance of $\hat{r}$, estimated from the individual effort days as in Julian and Beeson (1998) or from the individual sets using bootstrap sampling methods, depending on the analysis approach used (see below). Previously published mortality estimates for 1990-1994 (Julian and Beeson 1998) did not stratify geographically within central California. In this study, regional differences in entanglement rates were evaluated using an analysis of variance (ANOVA) model of the form $\log(n+1) = \mu + \beta_i x_i + \varepsilon$, where n is the number of observed entanglements, μ is the model mean, β_i is the coefficient for geographic stratum x_i, and ε is a random error term. Based on the ANOVA results for harbor porpoise and Common Murre (too few sea otter entanglements were observed for a meaningful test), we included geographic strata in the analyses below. Mortality for 1995-1998 was estimated using entanglement rate data from previous years, because no observer program data are available after 1994. This is only valid if prior-year data are representative of entanglement rates in the unobserved years and if certain assumptions are met. In this study, six mortality estimation

analyses (A-F, Table 2) were performed to bracket the range of potential mortality, given different assumptions relating to the following issues: (1) geographic stratification within central California, (2) choice of prior-year entanglement rate data, (3) depth effects on entanglement rates, and (4) number of sets per day.

Depth Distribution Data

During the 1987-1990 CDFG monitoring program, several depth restrictions were implemented to protect diving seabirds and sea otters, which are more abundant in shallower waters. To reduce potential bias caused by inclusion of CDFG data for shallow depths which may have higher bycatch rates than the current 55 m minimum, we evaluated survey data for Common Murres, sea otters, and harbor porpoises to determine a depth range within which relative abundances are similar and entanglement rates are expected to be comparable. The surveys were conducted in the Monterey Bay region, where the majority of bycatch for these three species has occurred. Common Murre distribution was investigated based on systematic shipboard strip transect surveys conducted monthly in Monterey Bay from May to November 1997-1998 (see Harvey and Benson 1997 for methodology details). The surveys consisted of seven inshore-offshore transects spaced 5.6 km apart and extending from 50 m depth in the southern bay and 30 m depth in the northern bay offshore to 122° 5′ W (Fig. 2). The distributions of harbor porpoises and sea otters were evaluated based on sighting and effort data from summer/fall aerial surveys conducted annually in 1988-1991 and biennially from 1993 to 1997 (Forney 1999a). Surveys were flown at 198 to 213 m altitude, zigzagging between the coast and the 92 m isobath (Fig. 3), and all sightings of cetaceans and sea otters were recorded. Only sightings and effort for Beaufort Sea states 0-2 and <25% cloud cover were included in the depth analyses. Transects were divided into 10 m depth intervals (Forney 1988), which were later combined to increase sample sizes. Standardized encounter rates were calculated as the number of animals seen per 100 km surveyed in each depth interval.

Stranding Data

Stranding rates of dead seabirds and marine mammals have been correlated with previous mortality events in central California (Wild 1990) and are provided below for reference. Detailed stranding information was available for the Monterey Bay area from the Monterey Bay National Marine Sanctuary's Beach COMBERS (Coastal Ocean Mammal/Bird Education and Research Surveys) project (Benson et al. 1999). Monthly surveys of the sandy beaches in Monterey Bay (totaling 47.4 km) have been conducted since May 1997 by trained volunteers. All beachcast birds and mammals are recorded, providing a comprehensive record of monthly deposition. For bird specimens, a toe is clipped each month, allowing determination
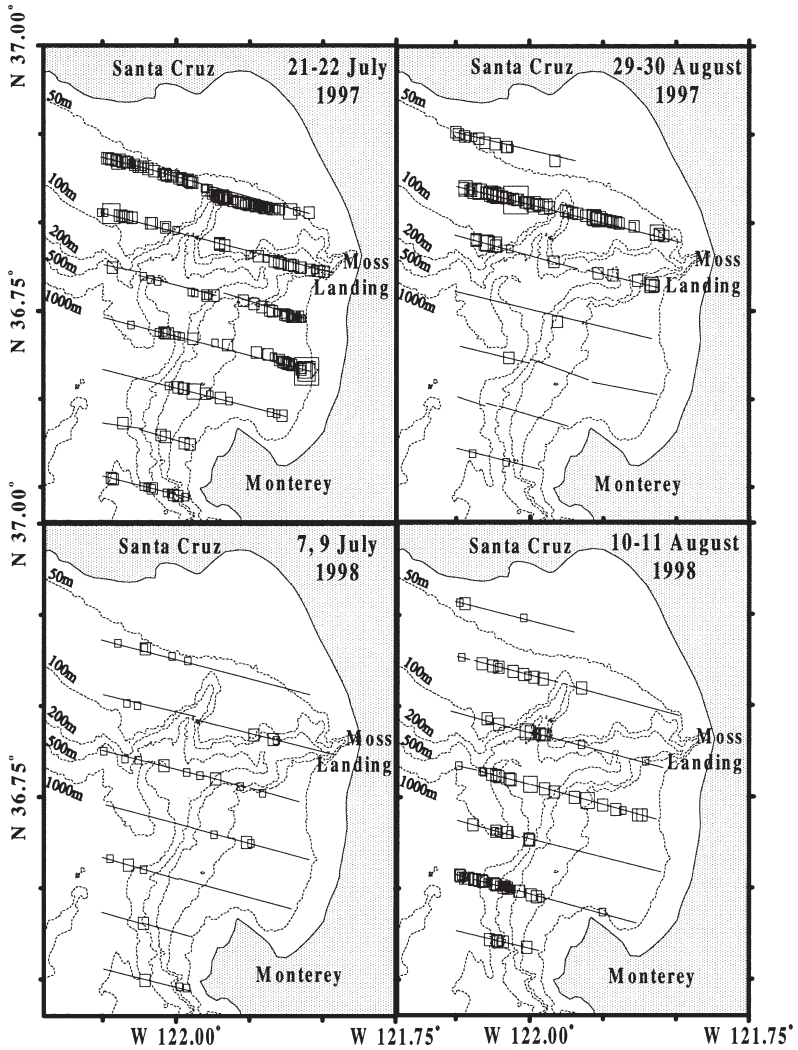
Figure 2.   Transect lines surveyed and sighting locations (squares) for Common Murres in July and August 1997-1998. Larger symbols indicate a greater number of individuals per sighting.
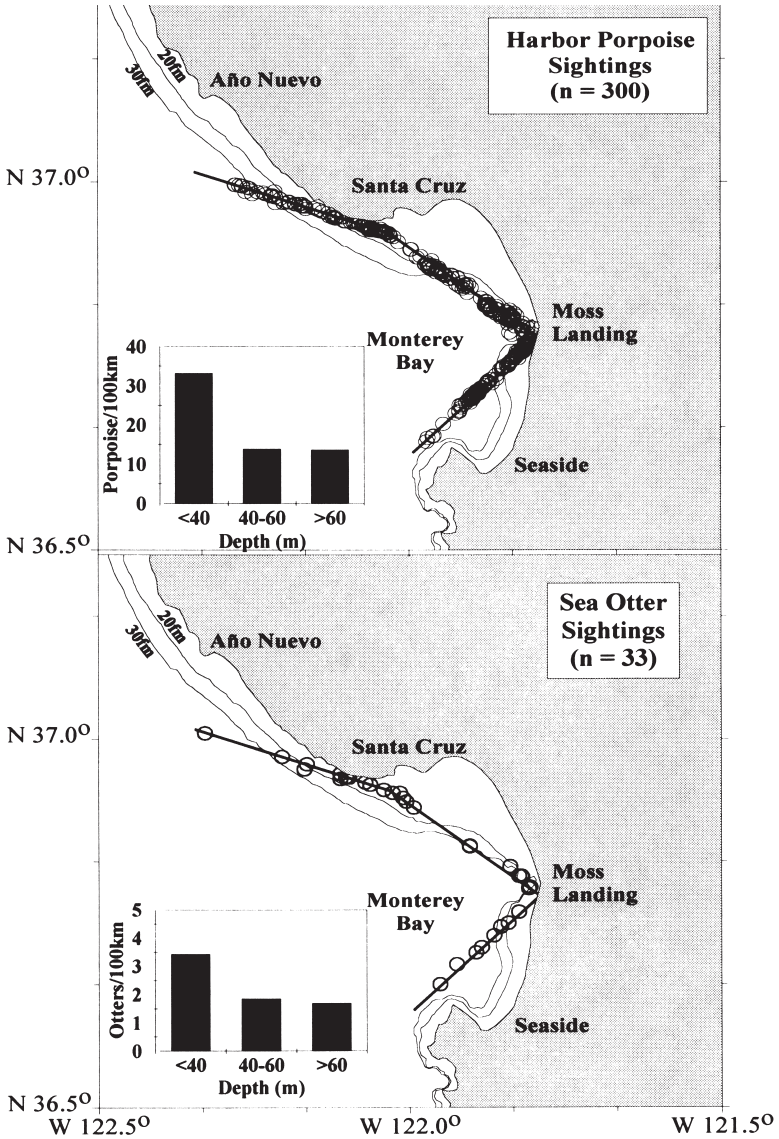
Figure 3.   1986-1997 aerial survey transects (lines) and sighting locations for sea otters and harbor porpoises (for all survey conditions). Bar charts summarize encounter rates (individuals per km) by depth, using only survey effort conducted in good conditions (see text).

of residence time and the number of newly deposited birds. A similar beach survey was conducted from April 1992 to April 1993 to investigate seabird deposition rates (Mason 1997), and these data are also summarized. Additional coastwide stranding information for marine mammals is compiled by NMFS (for pinnipeds and cetaceans) and by CDFG (for sea otters), based on reports from a network of participating institutions throughout California.

Results

Fishing Effort

From 1990 to 1994, effort in the Monterey Bay area was concentrated in the northern portions of the bay, ranging from 144 to 266 fishing days (Fig. 4). After 1994, gillnet effort in the Monterey Bay area increased to a high of 504 days in 1997, and since 1996 the majority of nets have been set in the southern parts of the bay. In the Morro Bay area, effort dropped from 687 fishing days in 1990 to 179 days after the 55 m depth closure was implemented in 1991 (Fig. 4) and has remained lower in this area through 1998 (range 34-179 days).

Depth Distribution

Visual inspection of Common Murre distribution data from the surveys in Monterey Bay indicates a temporally variable distribution covering both shallow and deep waters (see examples in Fig. 2), with highest densities in the northern bay. Temporal variations in the distribution of Common Murres include changes in depth ranges but are driven primarily by changes in prey availability (Croll 1989, Ainley et al. 1996). Because these patterns appear to be complex and inconsistent between years, we have assumed for analyses A-D that no systematic depth-related differences in entanglement rates are present within the range of observed fishing depths (77% of observed sets occurred at >37 m depth, 22% at 27-36 m depth, and 1% at 18-26 m depth). The 1988-1997 harbor porpoise aerial surveys covered a total of 1,915 km on three Monterey Bay area transects (Fig. 3), yielding 24 sightings of 47 sea otters and 192 sightings of 420 harbor porpoises during good weather. Encounter rates were highest in the <40 m depth category for both harbor porpoises and sea otters (Fig. 3). In waters deeper than 40 m, encounter rates for both species appeared to be relatively constant out to the maximum survey depth of about 92 m.

Mortality Estimates

Because the ANOVA indicated significant differences ($\alpha < 0.05$) in entanglement rates within central California (Table 3), the present study included geographic strata for all analyses except analysis A (which represents previously published estimates that used a single central California stratum).

Table 3.   Analysis of variance tests for differences in entanglement rates between potential geographic strata.

Model	Effect	Sum of squares	d.f.	F-ratio	Probability
Common Murre					
North vs. south Monterey Bay area	Stratum	4.77	1	4.99	$P = 0.026$
	Error	349.49	366		
Morro Bay area vs. Monterey Bay area	Stratum	29.20	1	37.47	$P \ll 0.001$
	Error	390.51	501		
Harbor Porpoise					
North vs. south Monterey Bay area	Stratum	0.17	1	2.93	$P = 0.088$
	Error	21.56	366		
Morro Bay area vs. Monterey Bay area	Stratum	0.43	1	9.66	$P = 0.002$
	Error	22.21	501		
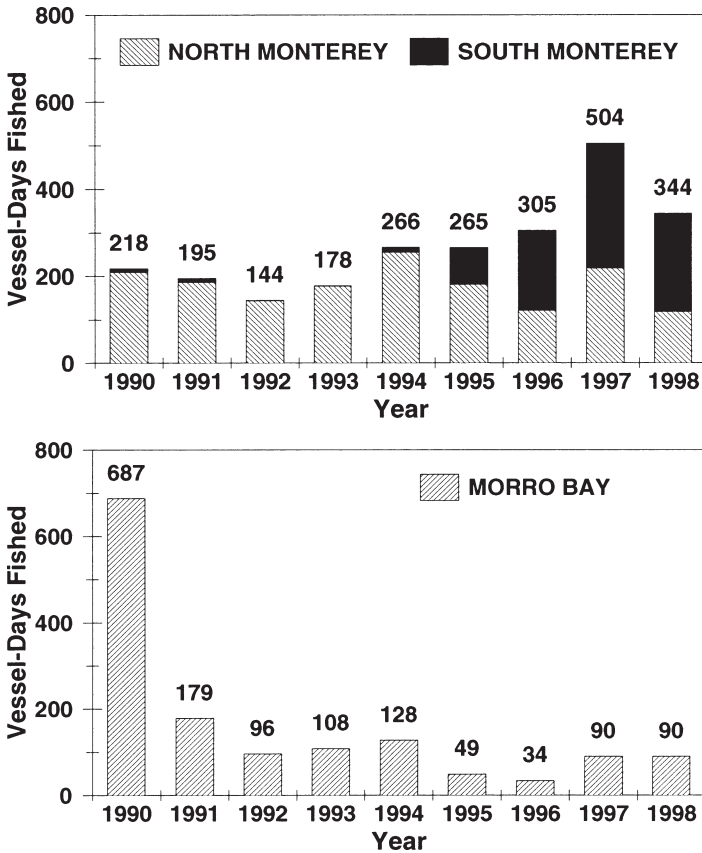
Figure 4.   *Fishing effort by region for the 1990-1998 central California halibut set gillnet fishery.*

Only analysis methods A and B were performed for 1990-1994, because year-specific entanglement rates were available for those years. For the unobserved years (1995-1998), methods C-F included different combinations of prior-year entanglement rate data and geographic strata. Analyses A-D included all observed fishing depths, as in Julian and Beeson (1998). Analyses E-F included only entanglement rate data for >37 m, to minimize potential depth-related bias while maintaining the largest possible sample size. The six analysis options yield a range of mortality estimates (Table 4); in all cases, estimates are highest in 1997 because of the increase in total effort in the Monterey Bay area. Without additional data to evaluate the assumptions of these six analyses, no single estimate can be considered the most accurate; however, the stratified analyses are expected to be more accurate than the unstratified analysis (A).

Other seabird and marine mammal species observed entangled during the 215 days (391 sets) of fishing effort monitored in central California during 1990-1994 (Julian and Beeson 1998) include two Double-crested Cormorants *(Phalacrocorax auritus),* one Pacific Loon *(Gavia pacifica),* six unidentified alcids, three unidentified cormorants, 101 California sea lions *(Zalophus californianus),* 44 harbor seals *(Phoca vitulina),* and 18 northern elephant seals *(Mirounga angustirostris).* Because these levels of mortality are low in relation to the estimated population sizes (Barlow et al. 1997, McChesney et al. 1998), they are not presently a management concern and therefore no mortality analyses were performed for these species.

Beach Deposition and At-sea Sighting Distributions

Beach deposition of Common Murres peaked during the summer months of both 1997 and 1998, with a sharp, short-lived peak in August-September 1997 and a broader peak in May-August 1998 (Fig. 5). In 1997, Common Murres dominated the deposition, whereas in 1998 a wide variety of other species was found (Benson et al. 1999). In both summers, deposition was distinctly higher than during the same period in 1992-1993 (Mason 1997), when no gillnet fishing took place in the inner areas of Monterey Bay (Fig. 4). Although there is no direct evidence linking the increased deposition to gillnet fisheries, there is reason to suspect that gillnets were at least in part responsible for the observed mortality, particularly in 1997. At-sea survey data in the Monterey Bay region indicate that Common Murres were abundant in the southern bay fishing areas (Fig. 2) during the time of peak fishery landings in July-August and just prior to the August-September peak in deposition (Fig. 5). Although Common Murres were also abundant in the northern parts of the bay, 82% (541/656) of the beachcast specimens were deposited on a 14 km section of beach facing the southern areas of gillnet fishing activity. Furthermore, deposited Common Murres were not young-of-the-year and showed no obvious signs of emaciation. In 1998, Common Murres were much less abundant in the areas of gillnet

Table 4.   Estimates of mortality for Common Murre, sea otter, and harbor porpoise in the 1990-1998 central California halibut set gillnet fishery, based on six analysis approaches (A-F, see Table 2).

Analysis	Estimated Mortality (standard error in parentheses)								
	1990	1991	1992	1993	1994	1995	1996	1997	1998
Common Murre									
A	1,300	2,201	2,333	879	284	1,319	1,424	2,500	1,830
	(273)[a]	(594)	(653)	(281)	(82)	(210)	(226)	(398)	(291)
B	2,104	1,148	1,388	560	218	1,366	1,531	2,597	1,824
	(658)	(326)	(423)	(196)	(64)	(219)	(249)	(416)	(288)
C						1,355	1,519	2,576	1,810
						(256)	(293)	(488)	(336)
D						1,326	1,178	2,064	1,350
						(246)	(205)	(353)	(229)
E			Not applicable			1,415	1,332	2,263	1,527
						(297)	(280)	(475)	(321)
F						2,824	2,663	4,525	3,048
						(593)	(559)	(950)	(640)
Harbor porpoise									
A	37 (21)[a]	38 (18)	48 (22)	13 (8)	14 (13)	27 (7)	29 (8)	51 (14)	37 (10)
B	42 (26)	20 (10)	29 (14)	8 (6)	11 (10)	28 (8)	32 (9)	54 (15)	37 (10)
C						42 (8)	48 (9)	80 (15)	56 (11)
D			Not applicable			43 (8)	56 (14)	92 (21)	66 (17)
E						49 (9)	69 (13)	113 (21)	80 (15)
F						97 (18)	137 (26)	227 (43)	161 (31)
Sea otter									
A	27 (14)[a]	0 (-)	0 (-)	0 (-)	0 (-)	5 (3)	5 (3)	9 (5)	6 (4)
B	64 (36)	0 (-)	0 (-)	0 (-)	0 (-)	3 (2)	2 (1)	6 (3)	6 (3)
C						7 (3)	7 (3)	14 (5)	11 (4)
D			Not applicable			8 (3)	12 (5)	21 (8)	18 (7)
E						7 (3)	14 (6)	24 (11)	18 (8)
F						13 (6)	29 (13)	47 (21)	36 (16)

[a] Julian and Beeson (1998) estimated 1990 mortality only for July-December.

Analysis A includes 1990-1994 mortality estimates from Julian and Beeson (1998) and follows their methodology (using 1990-1994 entanglement rates) for 1995-1998.
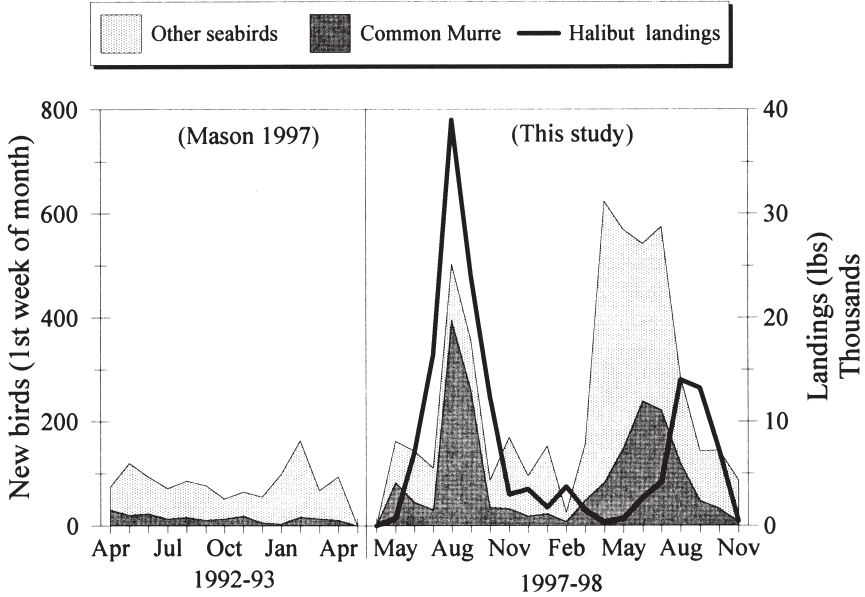
Figure 5. *Monthly beach deposition of seabirds in Monterey Bay, May 1997-November 1998. Halibut landings in the Monterey Bay area for the same period and similar beach deposition data for 1992-1993 are also shown for comparison.*

fishing during the summer halibut landing peak (Figs. 2 and 5), suggesting that fewer birds were susceptible to entanglement in that year.

Harbor porpoise stranding rates are available only for the entire California coast, but the majority of stranded individuals were found in the Monterey Bay area (NMFS, unpublished data). Sea otter stranding data have been summarized coastwide and separately for the Monterey Bay area (north of Pt. Sur). Strandings for both species have increased in recent years (Table 5). Harbor porpoises are known to be common in Monterey Bay in the areas where gillnet fishing has increased (Forney 1999a). The 1988-1997 aerial survey data (Fig. 3) also indicate that sea otters occur in waters deeper than 55 m, particularly in southern Monterey Bay. Although sea otter sighting efficiency is reduced at the altitudes flown during these porpoise surveys, the recorded sightings represent a minimum number present and should not exhibit any distributional bias within open waters. A recent low-altitude sea otter survey extending out to 92 m depth also recorded about 10% (9/93) of the sightings in Monterey Bay in water depths >55 m (J. Ames, CDFG, Santa Cruz, unpubl. data).

Table 5.   California strandings of dead harbor porpoises and sea otters in 1990-1998.

Species	Number of stranded individuals reported								
	1990	1991	1992	1993	1994	1995	1996	1997	1998
Harbor porpoise	17	11	8	4	8	16	18	26	37
Sea otter									
Total	–	78	110	126	128	160	179	152	213
Monterey Bay area	–	45	53	77	64	99	84	75	136

Discussion

In this paper, we have attempted to evaluate the effects of several assumptions on mortality estimates. Combined, the estimates in Table 4 provide a range of likely mortality during the period 1995-1998. Within each estimation method, however, uncertainty is probably underestimated, because total annual fishing effort has been assumed to be known without error, as in Julian and Beeson (1998). While this is clearly not the case, no data are available to quantify this likely source of error as part of the variance estimate.

The use of a single central California stratum by Julian and Beeson (1998) required one of two assumptions to be true: (1) entanglement rates are the same in all areas of central California, or (2) the proportion of observed effort is the same as the proportion of total effort in each area. Neither of these assumptions appears to be valid. Entanglement rates for 1990-1994 did differ between the Morro Bay and Monterey Bay areas (Table 3), and no fishing trips could be observed in the Morro Bay area during 1992-1993, while 42% of the effort occurred there in those years. Thus Julian and Beeson (1998; Analysis A this study) probably overestimated 1990-1994 mortality for harbor porpoises and Common Murres, because both were more frequently observed entangled in the Monterey Bay area. Our stratified analysis B should provide more accurate estimates of 1990-1994 mortality for these species. Analyses C-F also include geographic strata for central California (Table 2), which should make the mortality estimates more accurate, but less precise, because sample sizes within each stratum are smaller.

Assumptions for 1995-1998 Mortality Estimates

A number of additional assumptions and caveats are relevant to the interpretation of the 1995-1998 analysis results. First, present fishing restrictions require gillnets targeting halibut to be set in at least 55 m of water, but both the NMFS and CDFG observer program data included some effort in shallower waters. Previous mortality estimates (Julian and Beeson 1998)

included all observed depths, and the same approach was used in our analyses A-D. However, if densities of Common Murres, sea otters, or harbor porpoises are higher in shallower waters and entanglement rates are proportional to density, this could result in an overestimation of mortality. The observed depth distribution during aerial and shipboard surveys (Figs. 2 and 3) indicated that relative abundances of sea otters and harbor porpoises were similar in 40-60 m and >60 m depth, but higher in waters shallower than 40 m. Therefore, analyses A-D might be expected to have an upwards bias, and analyses E-F would be more accurate. However, mortality estimates for analyses A-D are in fact lower than those for analyses E-F, suggesting that depth-related bias in entanglement rates is absent or trivial.

A second assumption relates to the absolute abundance of Common Murres, harbor porpoises, and sea otters in the areas of gillnet fishing activity. If entanglement rates are related to abundance, then prior-year data will only be representative of present entanglement rates if abundance has not changed substantially. Harbor porpoise abundance estimates have been variable, but no trends are apparent (Forney 1999a,b). Sea otters increased from about 1,500 animals in the late 1980s to nearly 2,400 animals in 1995 before declining again to about 2,100 otters in 1998 (U.S. Fish and Wildlife Service 1997, unpubl. data). Sea otter entanglement rates therefore may have increased. Similarly, central California Common Murre abundance has slowly increased between 1987 and 1997 (McChesney et al. 1998) as the population recovered from a decline in the 1980s. The potential effects of these population increases on entanglement rates are difficult to assess because they also depend on the distribution of the animals with respect to the fishery, which is not known. Therefore, our analysis does not include a correction factor for increases in population size, and mortality for Common Murres and sea otters may be underestimated.

A final assumption is related to the measure of effort and the number of nets set per fishing day. The use of a fishing day as the unit of effort in analyses A-D requires the assumption that daily entanglement rates are constant, without explicit assumptions about the number of sets per day. In analyses E-F, individual nets set in <37 m water depth were excluded, requiring the unit of effort to be changed from fishing days to sets and the number of sets per day to be estimated. In analysis E, we used the mean values observed during 1990-1994 (1.5 and 3.1 sets per day, respectively, for Monterey Bay and Morro Bay). In analysis F, a value of 3.0 sets per day was assumed based on anecdotal information that fishermen tend to set three nets of 914 m length each to achieve the maximum daily net length allowed by law, 2,745 m (California Fish and Game Code 8625). Insufficient information is available regarding the details of the fishery in 1995-1998 to evaluate fishing practices and the true number of sets per day during these years, but analyses E and F encompass a likely range of values.

Species Implications

During the 1990s, gillnet mortality of Common Murres averaged in the low thousands of birds per year. This is lower than levels observed in the 1980s (averaging about 10,000 per year; Takekawa et al. 1990), but still may be affecting this species' recovery. Between 1980-1982 and 1986, the central California breeding population declined from about 229,080 to 108,530 individuals as a result of gillnet mortality, El Niño effects, and oil spills (Takekawa et al. 1990), then remained stable until the early 1990s (Ainley et al. 1994) when it began to show signs of recovery (McChesney et al. 1998). The effect of continued gillnet mortality on central California Common Murres therefore may not be a population-level concern. However, the Devil's Slide and Castle/Hurricane Complex breeding colonies, which disappeared and severely declined, respectively, in the 1980s (Takekawa et al. 1990), have not recovered despite considerable restoration efforts (McChesney et al. 1998, 1999). These two southern colonies are closest to Monterey Bay, and gillnet mortality may play a role in the lack of recovery at these sites.

The range of mortality estimates for harbor porpoise in the 1995-1998 central California halibut gillnet fishery (144 to 622 animals during the 4-year period) represents 2.5%-10.9% of the current population estimate of 5,732 (CV=0.39; Forney 1999b), or an average of 0.6%-2.7% per year. Average estimated mortality in 1995-1998 is higher than during the early 1990s, but lower than estimates for the 1980s (Barlow and Hanan 1995). Most mortality estimates for 1995-1998 exceed the potential biological removal (PBR) of 42 animals per year allowed under the Marine Mammal Protection Act (Forney et al. 1999), in some cases by a factor of two to four. These levels of mortality may not be sustainable for the central California harbor porpoise population. Stranding rates of dead harbor porpoises also doubled in California between 1990-1994 and 1995-1998 (Table 5), coincident with the expansion of the set gillnet fishery in the Monterey Bay region.

Estimated total mortality for sea otters in 1995-1998 (17-125 animals during the 4-year period) ranges from 0.7%-5.3% of the 1995 peak population count of 2,377 individuals (U.S. Fish and Wildlife Service 1997), or an average of 0.3%-1.3% per year. Clearly, the recent changes in the distribution of set gillnet fishing effort are of concern for this population, which is federally listed as threatened under the Endangered Species Act. Sea otter population counts declined from 2,377 to 2,114 animals between 1995 and 1998, and average stranding rates of dead sea otters increased by about 50% between 1990-1994 and 1995-1998 (Table 5). It is likely that gillnet mortality is at least in part responsible for the documented population decline, particularly since sea otters are found beyond 55 m depth in areas of gillnet fishing (Figs. 1, 3). Monitoring of gillnets set in the Monterey Bay region is imperative for an accurate assessment of sea otter mortality in this fishery. More detailed surveys of the distribution of sea otters in

the depth ranges and areas of gillnet fishing will also help shed light on the number of otters susceptible to entanglement.

Conclusions

There are many uncertainties in the mortality estimates presented in this study, but the high levels of estimated mortality raise concern. The results underscore the difficulties of managing vulnerable species when potential mortality sources such as gillnets are not monitored. Both fishing practices and the distribution of potentially entangled species can change dramatically between years, and it is therefore not valid to assume that patterns for any given year will be duplicated in future years. In the case of the central California halibut gillnet fishery, harbor porpoise mortality was low and sea otter mortality was thought to be zero in 1994, when the NMFS observer program was discontinued. However, the fishery subsequently underwent changes in distribution and effort, and these changes were not detected until 1997, when a large increase in Common Murre deposition on southern Monterey beaches was documented. Furthermore, the 55 m depth closure implemented in 1991 to protect the southern sea otter was assumed to be effective, but was never actually put to the test in southern Monterey Bay because fishing virtually ceased in that area after the closure (Fig. 3). Given that sea otters are present in these areas, it is likely that they were susceptible to gillnet mortality during 1995-1998.

A sound approach to monitoring species that are vulnerable to human-caused mortality requires some level of continued monitoring of potential mortality sources, such as gillnet fisheries. The halibut gillnet fishery is only one of the gillnet fisheries that operate in this area; other, smaller-mesh gillnet fisheries may also entangle seabirds and, to a lesser extent, marine mammals. In general, observer programs provide the most reliable data, but they are costly to implement. Because of concern over bycatch of harbor porpoise, the NMFS Southwest Region initiated a Monterey Bay area observer program in April 1999 to evaluate the effects of present fishing patterns. Preliminary data indicate that all three species of concern have been observed entangled and bycatch rates are within the range of those estimated in this study. This observer program will provide important new information for understanding bycatch patterns and determining ways to reduce bycatch in the future. Systematic monitoring of beachcast marine birds and mammals has also been demonstrated to provide valuable information during gillnet-related mortality events (Salzman 1989), particularly when combined with shipboard or aerial surveys that shed light on the distribution of animals at sea. Information on temporal and geographic patterns of fishing effort should also be documented on an ongoing basis whenever possible. Only with such comprehensive information will the agencies concerned with the management of sensitive species be able to evaluate the effects of changing fishing practices and quickly address problem situations.

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Novel Tools to Reduce Seabird Bycatch in Coastal Gillnet Fisheries

Edward F. Melvin
Washington Sea Grant Program, University of Washington
Seattle, Washington

Julia K. Parrish
Zoology Department, University of Washington
Seattle, Washington

Loveday L. Conquest
University of Washington
Seattle, Washington

Abstract

We examined several strategies to reduce seabird bycatch, primarily of Common Murres *(Uria aalge)* and Rhinoceros Auklets *(Cerorhinca monocerata),* in a coastal salmon drift gillnet fishery in Puget Sound, Washington (USA). Our goal was a significant reduction in seabird bycatch without a concomitant reduction in target catch or an increase in the bycatch of any other species. We compared fish catch and seabird bycatch in nets modified to include visual alerts (highly visible netting in the upper net) or acoustic alerts (pingers) to traditional monofilament nets set throughout the normal fishing hours over a five-week fishing season. Catch and bycatch varied significantly as a function of gear. With monofilament controls, murres responded to both visual and acoustic alerts; auklets and sockeye salmon responded to deeper visual alerts only. Seabird abundance varied across multiple temporal scales: interannually, within fishing season, and within day. At the interannual level, seabird entanglement was linked to regional abundance on the fishing grounds, a pattern which broke down at the local level. Within season, sockeye and murre abundance were negatively correlated, suggesting that if fishery openings were scheduled

on peak abundance of the target species, seabird bycatch would be significantly reduced as a function of increased target fishing efficiency. Finally, both sockeye catch and auklet entanglement were highest at dawn, whereas murre entanglement was high at both dawn and dusk. Our results identify three complementary tools to reduce seabird bycatch in the Puget Sound drift gillnet fishery—gear modifications, abundance-based fishery openings, and time of day restrictions—for a possible reduction in seabird bycatch of up to 70-75% without a significant reduction in target fishing efficiency. Although these tools are based on local conditions and will thus vary among years and locations, all might be exportable to other coastal gillnet fisheries worldwide.

Introduction

Mortality of nontarget organisms, or bycatch, has become an important conservation issue in the management of world fisheries (Alverson and Hughes 1996, Hall 1996). Long regarded as the price of fishing, the inadvertent capture of nontarget organisms is now seen as unethical (Murawski 1996), biologically and economically wasteful (Alverson and Hughes 1996), and potentially destructive at the population and ecosystem levels (Alverson and Hughes 1996, Hall 1996). Hall (1996) classifies bycatch by level and type of impact, including unknown, biologically insignificant, sustainable, unsustainable, critical/endangered, and charismatic. Although finfish and invertebrate bycatches may be addressed in the first five categories, the inadvertent capture of marine mammals, sea turtles, and seabirds are almost exclusively categorized as negative because of their status as charismatic fauna. In addition, some to all species within these taxonomic groups may suffer depressed populations (e.g., all seven species of sea turtles are critical/endangered) due to the cumulative effects of human pressures, including bycatch. Many of these taxa are subsequently protected by law (e.g., Endangered Species Act, Convention on International Trade in Endangered Species).

Because of their charismatic and legal status, attention has been focused on seabird bycatch in high-seas drift gillnet fisheries (Northridge 1991), and more recently, in longline fisheries (Brothers 1991). The estimated mortality of a half-million seabirds per year in high-seas drift gillnet fisheries in both the North Atlantic (Tull et al. 1972) and the North Pacific (Ogi et al. 1993, DeGange et al. 1993) was one factor contributing to a 1990 UN resolution outlawing drift-gillnets in international waters of the world oceans (Alverson et al. 1994). Persistent declines of several South Pacific albatross populations have been linked to extensive incidental mortality in longline fisheries operating in southern oceans (Croxall and Prince 1990, Vaske 1991, Cherel et al. 1996). The chronic mortality of albatrosses and other seabirds are a concern in Northern Pacific longline fisheries (USFWS 1998). Attention to seabird bycatch in coastal fisheries

has been inconsistent despite the fact that breeding colonies worldwide occur in coastal waters.

Seabird bycatch in coastal gillnet fisheries has been documented (Evans and Nettleship 1985). Most seabirds caught in these fisheries are diving seabirds, family Alcidae, and the species most affected worldwide is the Common Murre *(Uria aalge)*. Seabirds, like cetaceans and sea turtles, are long-lived, low fecundity animals with delayed maturity (Tuck 1960). These life history characteristics make alcid population growth rates highly sensitive to small changes in adult mortality (Ford et al. 1982, Hudson 1985). Because alcids are sensitive to climate change events (Hodder and Graybill 1985, Wilson 1991) and some species (e.g., murres) are highly vulnerable to oil spills (Piatt et al. 1990), additional anthropogenic sources of mortality, such as fishery bycatch, raise legitimate conservation concerns for these species.

Attempts to reduce seabird bycatch in coastal gillnet fisheries have been minimal. Most reductions have been inadvertent, resulting from either reductions in fishing effort (Evans and Waterston 1977, Piatt and Reddin 1984, Strann et al. 1991, Falk and Durinck 1991, Taylor 1992) or declines in forage fish abundance in the fishing area (Piatt and Reddin 1984, Piatt et al. 1984, Piatt and Nettleship 1987). Only in California, where murre populations in individual colonies declined by 47-100%, were fisheries managed to reduce seabird bycatch through progressively more restrictive depth and area closures (Takekawa et al. 1990, Wild 1990).

Technological solutions exploiting some aspect of differential behavior between target and nontarget species have been developed and applied to reduce nonfish bycatch in several fisheries (sea turtles in shrimp fisheries [Renaud et al. 1997], cetaceans in tuna purse seines [Francis et al. 1992], coastal gillnets [Kraus et al. 1997], fish traps [Lien et al. 1992], and longlines [Cherel et al. 1996, Løkkeborg 1998]) (Table 1); in gillnet fisheries gear modifications have been lacking. We found only one case where gillnet design was altered in an effort to reduce seabird bycatch. In the Japanese high-seas drift gillnet fishery for flying squid *(Ommastrephes bartrami)* Hayase and Yatsu (1993) found that seabird entanglements were significantly reduced in nets submerged 2 m below the surface compared to surface nets. Fishing efficiency of subsurface nets, however, was reduced by up to 95%, making fishing operations economically nonviable. Loss in fishing efficiency limits the economic viability of a gear because fishers catch fewer target individuals and may fail to compete with other fishing gears aimed at the same resource over limited time. The threat or reality of lowered target efficiency often leads to limited acceptance or noncompliance by individual fishers.

We examined several strategies to reduce seabird bycatch, primarily of Common Murres and Rhinoceros Auklets *(Cerorhinca monocerata),* in a salmon gillnet fishery in Puget Sound, Washington. We compared rates of seabird bycatch in nets modified in collaboration with the fishing industry

Table 1.   **Percent reduction in catch of target species and bycatch species as a function of alteration of the gear or fishing method (technology) for the specific purpose of bycatch reduction.**

Fishing gear	Technology	Target spp.	Percent change[b,c]	Bycatch	Percent change[c]	Reference
Trawl	TEDs[a]	Shrimp spp.	1-14	Sea turtles	16-100	Renaud et al. 1993, 1977
Trawl	FEDs[a] Nordmore grate	Shrimp spp.	5	Finfishes	95	Shick and Brown 1996
	Fish eye	Shrimp spp.	0-7	Finfishes	0-79	Watson 1996
Trawl	Separator panels	Cod	6	Finfishes	3-75	Stone and Bublitz 1996
Trawl	Square mesh codend	Large pollock	3-35*	Small pollock	30-64	Bublitz 1996
Trawl	Black tunnel w/ square mesh window	Large haddock/ whiting	ND	Small haddock/ whiting	35-59	Glass and Wardle 1995
Sink gillnet	Pingers	Cod/pollock	ND	Harbor porpoise	92	Kraus et al. 1997
Longline	Tori lines Setting funnel Offal discharge	Torsk/ling Torsk/ling Patagonian toothfish	7-69* 6-15* ND	Fulmars Fulmars Petrels	98 72 98	Løkkeborg 1998 Løkkeborg 1998 Cherel et al. 1996
Purse seine	Backdown/ medina panel/rescue	Yellowfin tuna	NR	Dolphin spp.	97	Lennert and Hall 1996 in Hall 1996
Traps	Escape rings	Legal red king crab	5	Sublegal king crab	73	Marshall and Mundy 1995 in Stevens 1996

[a] ` TED = turtle excluder device; FED = fish excluder device.
[b] An asterisk (*) indicates increases in target species catch; all other change is negative.
[c] A range of values indicates several studies were performed.
ND = no data and NR = not reported.

to include visual or acoustic alerts to traditional nets set throughout the normal fishing hours. Our results are presented in the context of natural sources of variation in both seabird and target fish abundance. Our work expands on initial success in pilot programs conducted during 1994 (Melvin 1995) and 1995 (Melvin and Conquest 1996). Our goal was to reduce seabird bycatch with two essential caveats: (1) no significant reduction in the fishing efficiency and (2) no increase in the bycatch of other species. Based on results of these comparisons and our earlier work, we propose seabird bycatch reduction strategies for coastal gillnet fisheries.
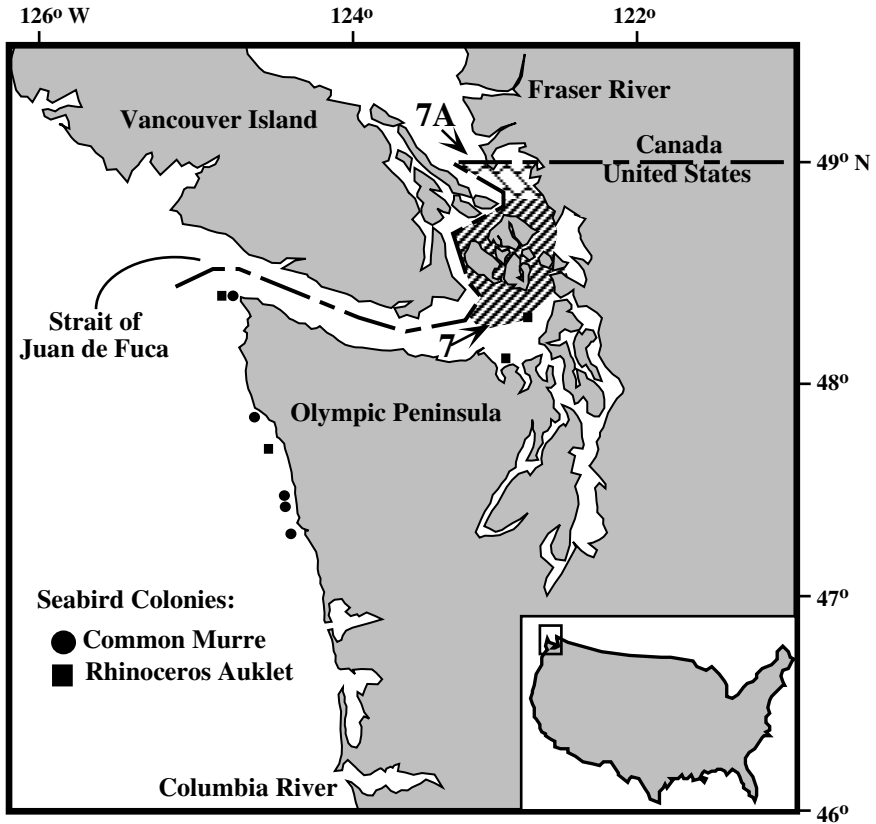
Figure 1. *Map of the Puget Sound, Washington sockeye study area including management areas 7 (dark hatch) and 7A (light hatch). Inset shows portion of the United States where study took place.*

Methods

Fishery and Fishing Protocol

The North Puget Sound sockeye fishery targets sockeye salmon *(Oncorhynchus nerka)* bound for the Fraser River between mid- to late July to early September (Fig. 1). Exact timing varies annually depending on the strength of more than 20 individual runs of sockeye salmon. Puget Sound commercial salmon resources are allocated among treaty tribes and non-treaty sectors by gear type (purse seine, gillnet, and reef net). The sockeye fishery is focused in areas 7 and 7A of North Puget Sound (Fig. 1). It is the most important commercial drift gillnet fishery in Washington ($5.1 million annual average from 1990 to 1996, Washington Department of Fish and Wildlife [WDFW]) with approximately 1,000 vessels participating.

The 1996 test fishing data of the Pacific Salmon Commission (PSC) (area 20 gillnet with 90 mesh deep gillnets) were used as an independent assessment of the number of sockeye entering the Puget Sound–San Juan Islands fishery (J. Woody, PSC, pers. comm). These data are reported as sockeye catch per unit effort (CPUE) by day and are used to set catch allowances in the U.S. and Canadian fisheries. Because area 20 runs along the northwestern section of the Strait of Juan de Fuca, data were lagged or offset three days to account for sockeye transit from area 20 to area 7/7A.

Fishing vessels were contracted by WDFW through the Puget Sound Gillnetters Association to fish experimental nets in the test fishery under our protocol. The test fishery arrangement provided two elements that greatly facilitated this study. Fishers were compensated for their fishing time with revenue derived from the sale of their fish, and the test fishery was given the flexibility to fish outside unpredictable commercial fishery openings. The experimental fishery ran from 28 July to 29 August 1996 in area 7, where high concentrations of seabirds and sockeye overlap. Eight fishing vessels were contracted and assigned to one of two teams of four. One fisher in each team was designated team leader and coordinated the fishing activities of his team. Each fisher fished all gear in weekly rotation. To minimize location effects, team members fished within sight of each other. Fishers were asked to fish aggressively near birds. They were asked not to harass birds away from the net or to chase fish into the net (run the net). Approximately five sets equaled one trip, which included one dawn (3-hour period centered on sunrise), one dusk (3-hour period centered on sunset), and three daytime sets (all daylight hours between dawn and dusk). Each team completed 17 trips for a total of 642 sets during the course of the experiment.

Experimental Gear

Drift gillnets used in Washington commercial salmon fisheries are made from single or multistrand monofilament nylon (approximately 0.5 mm in diameter), which is virtually invisible under water. The net is woven into a diamond pattern, where each diamond is referred to as a mesh. Mesh size, measured on the stretched diagonal, is regulated by state law and varies with target species: sockeye drift nets use 127-152 mm mesh. Most sockeye nets are 200 meshes, or 18.3 m, and a maximum of 549 m long. When deployed or set, the net remains attached to the vessel while both drift for about two hours. Traditionally, fishery openings were scheduled from dusk to dawn.

We compared traditional monofilament nets to three net treatments: traditional nets modified with visual alerts at one of two depths and nets modified with acoustic alerts. Each experimental gillnet was made of 127 mm mesh netting, 200 meshes in depth and 549 m long. All monofilament netting was high strength number 8, triple knot, shade green (M4
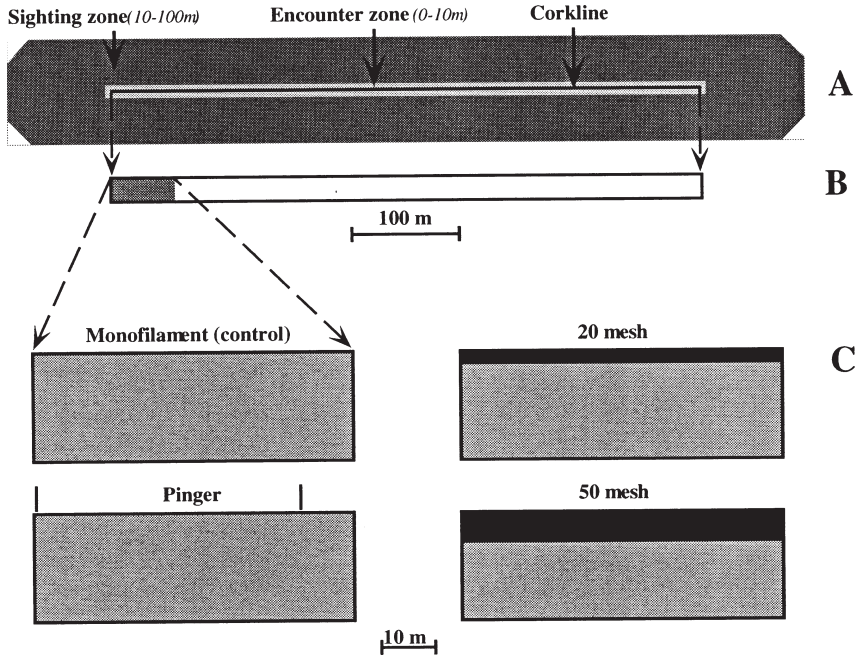
Figure 2.   *Scale illustration of the drift gillnets used in this study. (A) To scale over-*
          view (i.e., surface of the water) of the net (corkline) and surrounding
          seabird observation zones (encounter and sighting). See text for complete
          descriptions. (B) To scale elevation (i.e., under water at 90º) view of the
          net. (C) Expanded elevation view of the experiment setups: monofilament
          control, visual alerts (20 and 50 mesh), and acoustic alerts (pingers).
          Each net was a single treatment.

Momoi brand or matched equivalent). Two each of the following four ex-
perimental gillnets were built (Fig. 2):

1.   Monofilament (control), as described above.

2.   Visual alerts, 20 mesh: a monofilament net with the upper 20 meshes
     replaced with 20 meshes of 127 mm white number 18 multifilament,
     nylon seine twine. This configuration made the upper 1.8 m of the net
     highly visible.

3.   Visual alerts, 50 mesh: a monofilament net with the upper 50 meshes
     replaced with 50 meshes of 127 mm white number 18 multifilament
     nylon seine twine. This configuration makes the upper 4.6 m of the
     net highly visible.

4. Acoustic alerts (pingers): a monofilament net with acoustic pingers clipped to the corkline every 50 m, including each end of the net (total 13 pingers per net). Pingers emitted a 1.5 kHz (±1 kHz) frequency signal with a pulse width of 300 ms (±10%) every 4 seconds (±10%) at 120 dB re 1 µPa or 35-40 dB above background noise levels. Field measurements confirmed that pingers produced a 2.2 kHz signal at 37 dB re 1 µPa at the source and 9 dB re 1 µPa at 23 m (K. Neltnor, Dukane Corporation, St. Charles, IL, pers. comm.).

Seabird Observations

Experienced observers (National Marine Fisheries Service fishery observers with five or more years prior experience) aboard all vessels recorded seabird and marine mammal abundance and entanglement per set as well as a range of physical variables, including time, tide, visibility (as mediated by fog), cloud cover, precipitation, sea state, current speed, and location. Abundance data were defined based on distance from the corkline: encounters were defined as the total number of times any seabird came within 10 m of the corkline by species; sightings were defined as the maximum number by species between 10 and 100 m from the corkline. We assumed sightings were a measure of relative local abundance, whereas encounters were a measure of gear contact or awareness. All entangled specimens were labeled with a unique number and information on date, time, vessel, gear, location, and species and stored for later necropsy. Marine mammals were transferred to National Marine Mammal Laboratory. After each trip, observers were debriefed and their data sheets were reviewed by project coordinators.

We used the Puget Sound Ambient Monitoring Program (PSAMP) July aerial surveys for seabirds and waterfowl as an independent, pre–fishing season assessment of annual Common Murre abundance within the Puget Sound area (Nysewander and Evenson 1996). Rather than a specific population estimate, these data provide a rough, relative index of annual trends, because the birds counted include both resident breeders and transients moving through the system.

Statistical Analysis

To elucidate the relationships between fish and bird abundance and catch/entanglement, we held gear treatment constant by restricting the analyses to daytime sets of monofilament nets only (168 sets). To correct for rarity, data were collapsed across teams and sets into a single per set average within day. In addition, we only used data from days with multiple sets (e.g., from a sample size of 168 sets to 22 days). Finally, we combined Common Murre and Rhinoceros Auklet data into a single variable, total alcids.

Linear regressions on square root transformed data were used to explore the extent to which catch and entanglement could be explained by measures of abundance. The PSC area 20 sockeye CPUE were regressed against 1996 log-transformed sockeye catch data from our study collapsed across day. The PSAMP bird abundance data were regressed against annual measures of murre entanglement, where entanglement data were derived from 1993-1994 data from WDFW observer programs within the Puget Sound non-treaty sockeye fishery (Erstad et al. 1994, Pierce et al. 1994) and 1995-1996 data were derived from bird entanglement rates in monofilament nets within this gear study.

The number of sets required to compare seabird entanglements and fish catch among gear treatments was determined based on our 1995 work (Melvin and Conquest 1996), power analyses, and financial and logistical constraints. We estimated that a minimum of 150 sets would be required per gear treatment (600 sets total) to detect significant differences in rates of seabird entanglement among the four factors (i.e., 20 mesh, 50 mesh, pingers, and a monofilament control). Sets that did not conform to study protocols (nets not fully deployed, sets less than one hour in duration, or sets not made within time of day categories; 44 in total) were eliminated prior to statistical analyses. A total of 642 sets were used for the gear treatment analyses. All data are presented as rates of capture (sockeye) or entanglement (seabirds) per set, where sets were standardized to two hours.

The distributions of seabird entanglement rates per set (over 98% zeros) and sockeye salmon catch rates per set (over 37% zeros) were not normally distributed, even after transformation. Therefore, analyses were conducted using GLIM software for general linear models (Crawley 1993) because this class of techniques allows the user to run standard analysis of variance (ANOVA) and regression analyses using both normal and non-normal errors. Initially, all physical variables were used in the analysis with a cutoff for inclusion in the model set at $P \leq 0.05$. This reduced the number of variables to gear, time of day, time of season, location, and sea state. Although location was included in the model, it was not treated as a predictor in this analysis. The Poisson error term and loglinear model we used allowed for the large number of zeros characteristic of this data set. The actual fitted values of the dependent variable (sockeye catch or seabird entanglement) were obtained by exponentiating back from the loglinear predicted value. The estimated variance term was obtained in a similar way using the delta-method (Seber 1982). Comparisons of sockeye catch and seabird entanglement per set were made among gear treatments, time of day, and sea state using a multiple comparison technique similar to ANOVA with covariates, but with a Bonferroni correction (Miller 1966). Bonferroni-corrected post hoc contrasts were used to determine statistical differences within factors (e.g., time-of-day or gear type). For ease of presentation, only significant and definitive contrasts are presented. The

major null hypotheses tested in these comparisons were catch rates of sockeye salmon and entanglement rates of Common Murres and Rhinoceros Auklets per set were equal in all gear types across all times of day.

Results

Natural Sources of Catch and Bycatch Variation

The number of seabirds using Puget Sound fluctuated widely among years. In 1996, Common Murres were the most abundant bird in the study area, accounting for 83% of the alcids sighted at an average of 31 sightings per set, a rate 59 times greater than what we observed in the 1995 sockeye test fishery (0.5 sightings per set). Rhinoceros Auklets made up almost all other alcid sightings and were almost three times more abundant in 1996 (4.5 sightings per set) than in 1995 (1.6 sightings per set; Melvin and Conquest 1996).

Aerial surveys indicated that Puget Sound murre abundance indices ranged from a low of 5,274 (±4,036, 95% confidence) in 1995 to a high of 30,660 in 1996 (±10,356, 95% confidence; Nysewander and Evenson 1996; Fig. 3), mirroring murre entanglement ($R^2 = 0.594$, $n = 4$). Entanglement rates from our 1995 and 1996 gear studies might be inflated relative to observer program data because fishers were directed to fish aggressively on birds to ensure that gear were adequately tested. Nevertheless, a higher number of birds in the system increased entanglement.

Fish and bird abundance also varied greatly within year. Because sockeye move through the area in just a few weeks, availability, and thus catch, declined markedly through time (Fig. 4A). This pattern mirrors the regional-scale sockeye assessment of the Pacific Salmon Commission. Sockeye abundance as assessed by CPUE in the area 20 PSC test fishery was a highly significant predictor of subsequent catch in our experimental fishery (two-tailed t-test, log (experimental catch) = constant + area 20 CPUE; $t = 6.000$, $P < 0.0001$, $n = 22$, $R^2 = 0.636$). Patterns of intra-annual bird abundance were also pulsed. Murre numbers increased steadily throughout the 1996 season, reaching a maximum when fish were least abundant (Fig. 4B). Rhinoceros Auklets displayed almost the opposite pattern (Fig. 4C).

Within the local area, however, abundance-entanglement relationships broke down. Alcid sightings were a significant predictor of encounters (t-tests on 1996 data grouped by day; encounters = constant + sightings; $t = 3.426$, $n = 22$, $P = 0.003$, $R^2 = 0.338$). Neither sightings nor encounters were good predictors of entanglement (sightings: $t = -0.675$, $n = 22$, $P(2) = 0.507$, $R^2 = 0.000$; encounters: $t = 0.325$, $n = 22$, $P(2) = 0.749$, $R^2 = 0.000$). In other words, local abundance was not by itself a reliable measure of seabird bycatch, even though annual regional abundance was (i.e., Fig. 4). Entanglement was affected by sea state, a variable measuring wind strength and corresponding wave height. After correcting for the combined effects of date, location, depth, set duration, gear, and time of day, sea state was
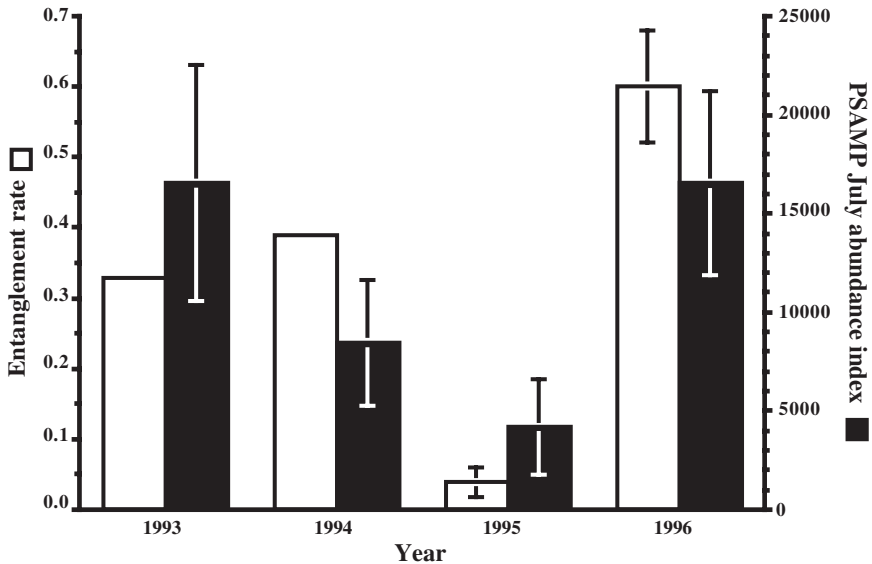
Figure 3. Interannual comparison of Common Murre abundance (PSAMP July aerial index ± SE) and mean murre entanglement rate from this study (± SE). In 1993-1994, entanglement rate was derived from a single set of measurements and no variance measure was calculated.

a significant linear predictor of entanglement ($\chi^2 = 5.71$, d.f. = 1; $0.025 < P < 0.01$), suggesting that other factors such as visibility or maneuverability may play a role in the probability birds will be entangled.

Finally, both catch and entanglement varied significantly as a function of time of day (χ^2 for loglinear model with Poisson error term on 1996 data by set; sockeye salmon $\chi^2 = 524$, d.f. = 2; $P < 0.001$; Common Murres: $\chi^2 = 24.1$, d.f. = 2, $P < 0.001$; Rhinoceros Auklets $\chi^2 = 21.8$, d.f. = 2, $P < 0.001$; Fig. 5). Both sockeye catch and auklet entanglement were highest during the morning change of light (Bonferroni-corrected a posteriori contrasts: sockeye, dawn vs. [day + dusk], $Z = 4.71$, $P < 0.0001$; auklets, dawn vs. [day + dusk], $Z = 4.63$, $P < 0.0001$). In contrast, murre entanglement was similarly high at both dawn and dusk (day vs. [dawn + dusk] $Z = 4.91$, $P < 0.0001$).

Variations in Catch and Bycatch as a Function of Gear

In 642 sets in the 1996 sockeye test fishery, 13,118 sockeye salmon, 258 Common Murres, and 85 Rhinoceros Auklets were caught. We caught a mix of other salmon species (216 fish) and 8,852 dogfish *(Squalus acanthias)*. Sockeye were caught in 71% of the sets; seabirds in 25%. All
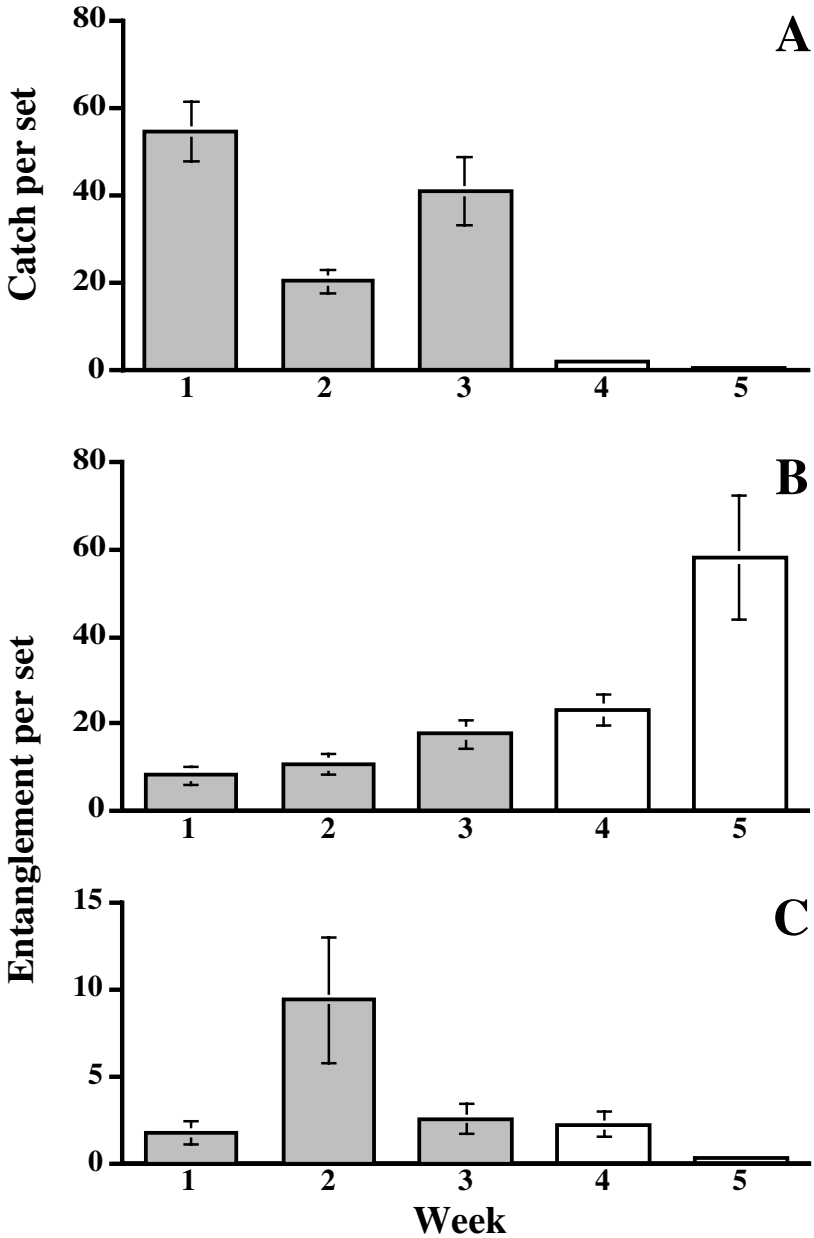
Figure 4.   *Intra-annual (weekly) variation of mean salmon catch and seabird en-tanglement per set: (A) sockeye salmon, (B) Common Murre, and (C) Rhi-noceros Auklet. Shaded bars indicate period of high sockeye abundance. Error bars are standard errors.*
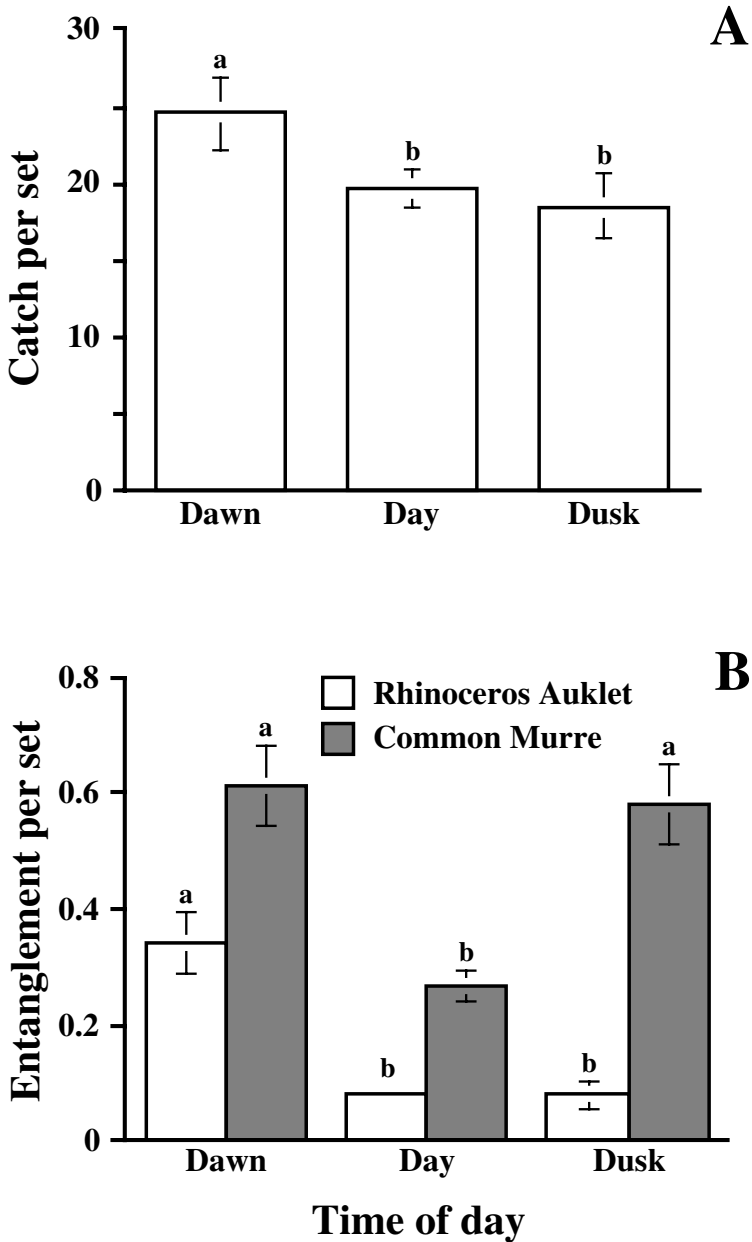
Figure 5.   Diel variation in mean salmon catch and seabird entanglement per set, as a function of time of day—dawn, day, and dusk: (A) sockeye salmon and (B) seabirds. Within species significant differences as calculated by post hoc contrasts (at least P < 0.05) indicated by lowercase letters. Error bars are standard errors.

other nonfish species were extremely rare (one Marbled Murrelet *(Brachyramphus marmoratum),* one Pigeon Guillemot *(Cepphus columba),* three harbor seals *(Phoca vitulina),* three Dall's porpoise *(Phocoenoides dalli),* and two harbor porpoise *(Phocoena phocoena).*

Capture (of sockeye) and entanglement (of the major seabird species) varied significantly as a function of gear and were greatest in monofilament nets (sockeye $\chi^2 = 725$, d.f. = 3; $P \ll 0.0001$; Common Murres: $\chi^2 = 21.5$, d.f. = 3; $P < 0.001$; Rhinoceros Auklets: $\chi^2 = 15.3$, d.f. = 3, $P < 0.002$; Fig. 6). In the 50 mesh nets, both sockeye capture and auklet entanglement were significantly lower than in all other net types (Bonferroni-corrected a posteriori contrasts; sockeye: 50 mesh vs. [mono, 20 mesh, + pinger] $Z = 20.39$, d.f. = 3, $P < 0.0001$; Rhinoceros Auklets: 50 mesh vs. [mono, 20 mesh, + pinger] $Z = 3.14$, $P < 0.002$). All net modifications, however, caught significantly fewer murres as compared to monofilament controls (mono vs. [20 mesh, 50 mesh + pinger] $Z = 4.34$, $P < 0.0002$).

Because the objective of the fishery is to maximize the catch of target species while minimizing interactions with all other species, we also examined our results in light of marine mammal, specifically harbor seal, interactions. Although harbor seals rarely become entangled (three were caught in our nets), they aggressively pilfer netted salmon, frequently removing fish from gillnets or leaving damaged (unsaleable) carcasses. After controlling for the effects of a range of variables (location, sea state, depth, duration, time of day, and time in season), gear was a statistically significant predictor of mean harbor seal encounter (χ^2 for loglinear Poisson model for 1996 data; $\chi^2 = 23.36$, d.f. = 3; $P < 0.001$). Specifically, pinger nets attracted significantly more seals compared to all other gear types (Bonferroni-corrected a posteriori contrasts; pinger vs. [mono, 20 mesh, + 50 mesh] $Z = 4.64$, $P < 0.0001$). Bycatch of all other species incidentally caught in the fishery (e.g., dogfish) was unaffected by the modified gear.

Discussion

Our work is the first to conclusively demonstrate a significant reduction in seabird bycatch in a coastal gillnet fishery through the application of two technological "fixes": visual alerts (visible mesh panels in the upper portion of the net) and acoustic alerts (pingers). Relative to monofilament controls, Common Murre bycatch was reduced by 40% and 45% in the 50 mesh and 20 mesh visual alert nets, respectively, whereas Rhinoceros Auklet bycatch was reduced only in nets with the deeper visual alerts (50 mesh: 42%). These trends mirror results from our preliminary work in the 1995 sockeye fishery (Melvin and Conquest 1996) and together provide solid evidence that nets modified with visual alerts can reduce seabird bycatch. Pingers reduced murre bycatch at rates similar to 20 mesh nets (50%), but had no significant effect on auklet bycatch. Prior work on coastal gillnet bycatch of seabirds has focused on demonstrating that bycatch occurs, rather than testing and implementing technical solutions
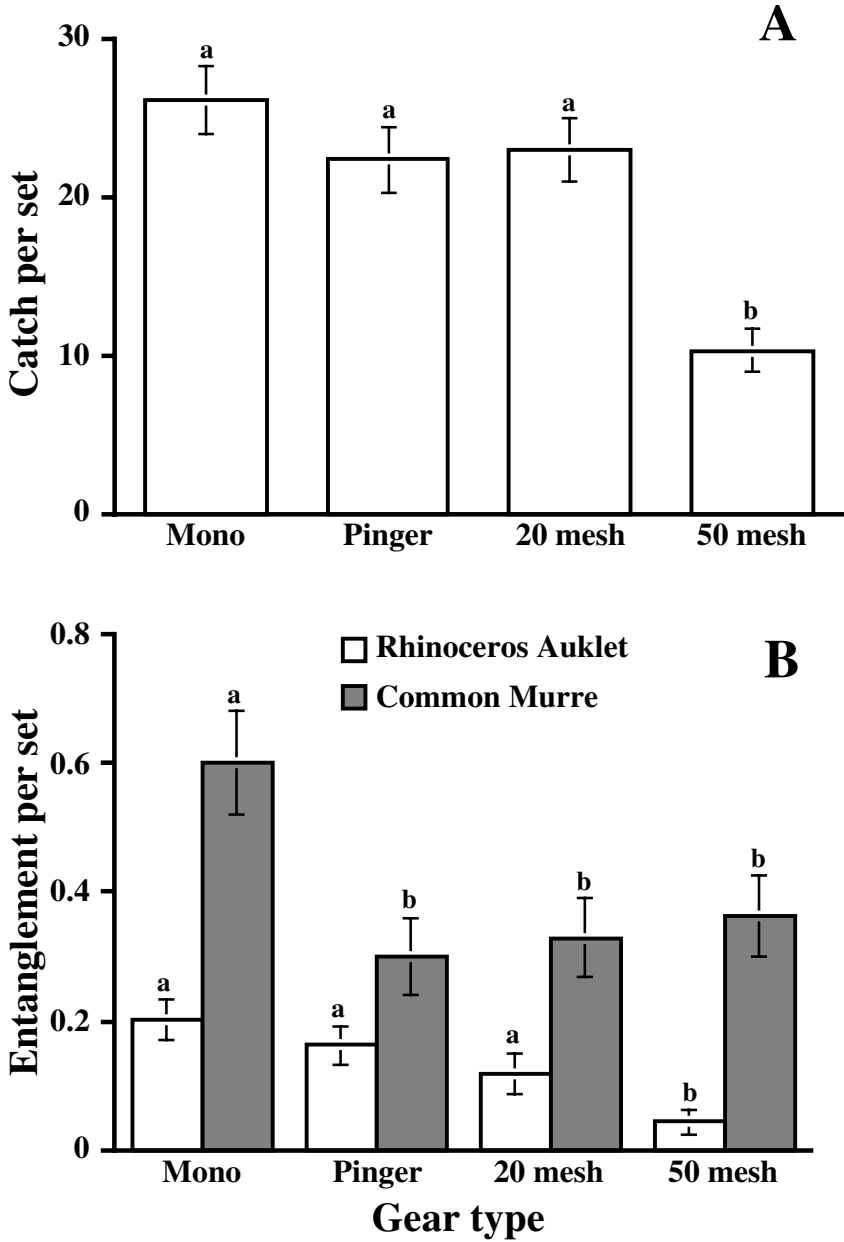
*Figure 6.   The effect of gear modification on mean salmon catch and seabird en-
tanglement per set: (A) sockeye salmon and (B) seabirds. Within species
significant differences as calculated by post hoc contrasts (at least P < 0.05)
indicated by lowercase letters. Error bars are standard errors.*

(Christensen and Lear 1977, Piatt and Nettleship 1987, Wild 1990). Only in California have resource managers attempted to reduce seabird bycatch, in that case by implementing time and area closures which effectively separated the fishers from the birds (Wild 1990).

On a broad scale, bycatch reduction via technological fixes is not new and has been well explored in a range of fisheries. For more than a century simple changes in mesh size and/or shape have been used to restrict the size and/or species of finfish captured (Alverson and Hughes 1996). More recent, and more complex, technological solutions include (1) devices that selectively deter nontarget species prior to gear encounter (e.g., pingers on nets, designed to deter marine mammals; tori or scaring lines on longline vessels, designed to deter seabirds); (2) additions to the gear that separate bycatch from target individuals prior to capture (e.g., separator panels in groundfish trawls; modifying trawl extensions with black tunnels and square mesh escape windows); (3) additions to the gear that allow nontarget organisms to escape once captured (e.g., trawls with excluder devices for turtles [TEDs] or finfishes [FEDs], traps with escape panels or grates); or (4) operational procedures to allow the escape of nontarget species after capture (e.g., backdown procedures of tuna purse seiners to allow escape of dolphin species; Table 1).

Although many technological solutions successfully reduce bycatch, the price is often a concomitant reduction of target fishing efficiency (Table 1). Ideally, a successful bycatch reduction device maximizes fish catch rate and the ratio of target to nontarget catch, rather than simply decreasing the latter. For instance in our study, 50 mesh, visible panels successfully reduced the bycatch of the major seabird species; however, this modification also reduced the rate of sockeye catch by more than half. Given the fact that fisheries are often quota rather than time-driven, less efficient gear will simply be fished additional hours until the target species quota has been reached. Extra fishing time effectively translates into additional bycatch, assuming no gear is completely successful at eliminating bycatch, only at reducing it. In comparison, our 20 mesh, visible panels were equally successful at bycatch reduction for at least the major seabird species—murres—while maintaining fishing efficiency for sockeye.

Clearly, 20 mesh panels are the superior choice if the objective is to sustain the fishery. Although we have recommended adoption of 20 mesh panels in the Puget Sound gillnet fishery (Melvin et al. 1997), we also encourage continuing efforts to develop and refine these prototypes both within and outside of this fishery. The depths and materials of the visual barriers tested here were chosen in cooperation with fishers and do not necessarily indicate the optimal depth, color, or configuration. Application of visual barrier concepts to other fisheries should take into account traditional fishing gear, practices, and conditions as well as local seabird and finfish species and should be tested locally to ensure their effectiveness.

Although we have demonstrated that nets with visual barriers can effectively reduce seabird bycatch, the mechanisms remain speculative.

Visual barriers were proposed by individual fishers based on their observations that most birds are entangled close to the surface. Despite the fact that Common Murres and Rhinoceros Auklets are capable of diving to 3-8 times the depth of our nets (Burger et al. 1993, Piatt and Nettleship 1985), most birds (70%) and few fish (21%) were caught in the upper quarter (50 meshes or 4.6 m) of traditional monofilament nets. Theoretically, visual barriers alert birds to the netting associated with the corkline, discouraging them from diving near or under the corkline. In contrast, any salmon near the surface would briefly follow the visual barrier laterally and dive into the relatively invisible monofilament netting below. Through our observations over several years, it appears also that gillnet corklines can be a barrier to alcids at the surface. Future work with modification to drift gillnets should include strategies to minimize this barrier effect.

Nets with pingers were also equally successful at reducing murre bycatch without compromising fishing efficiency. This is the first time pinger technology has been applied successfully to taxa other than marine mammals. The acoustic frequency range used in this study was patterned on the generic audiogram of birds (Dooling 1980) and the maximum hearing frequency of salmon (Hawkins and Johnstone 1978). It is likely that pinger effectiveness could be improved with more information on seabird hearing, background noise spectra, and possibly forage fish reactivity. Whether the sounds emitted by pingers elicit a direct behavioral response from birds, an indirect response by repelling prey, or some other means is unknown. The abundance of harbor seals was significantly greater near pinger nets suggesting a "dinner bell" effect. However, if the number of harbor seals following fishing vessels in a given area is constant in a fishery where all vessels use pingers, total harbor seal abundance and net depredation per vessel is likely to be unchanged and uniformly distributed among nets. The pinger results suggest that fishery managers must exercise caution when choosing bycatch solutions. Gear modifications designed too narrowly, that is with regard to a single or related set of species, may actually increase the rate of interaction and/or capture of others. The lack of pinger development notwithstanding, acoustic alerts offer broad promise for multispecies bycatch reduction in a range of conditions, including light levels at which visible panels would be compromised.

The temporal variation in seabird bycatch we documented provides both opportunity and challenge for seabird bycatch management. Murre abundance varied dramatically on the fishing grounds between years at levels approaching two orders of magnitude. These interannual changes are reflected by a 15-fold difference in entanglement. Rhinoceros Auklets, which breed during the fishing season within 2 to 14 nm of the fishing grounds (Wilson and Manuwal 1986; Fig. 1), vary little in abundance on the fishing grounds from year to year. Common Murres breed along the outer coast (over 150 km distant) but a significant post-season population

develops in Puget Sound (Manuwal et al. 1979), presumably to overwinter there. Inter- and intraannual variation in murre abundance on the fishing grounds is therefore related to factors affecting the timing and success of breeding on the colonies. This dramatic interannual variation illustrates how the importance of seabird bycatch management changes among years, and the folly of attempting to characterize seabird bycatch or definitively test bycatch solutions in a single year.

Within the brief five-week period of the 1996 test fishery, salmon and seabird abundance pulsed differently as each species migrated through the fishing grounds. Salmon and murres peaked in opposing patterns— early versus late—whereas Rhinoceros Auklets peaked early to mid-season. Scheduling fishery openings when salmon catch is known to be approaching zero and murre abundance is rapidly increasing, as happened in Puget Sound in 1996 (Melvin et al. 1997), illustrates the problem of not managing a fishery based on a multispecies approach. Fishery openings could be scheduled based on the relative abundance of both the target and bycatch species, or at a minimum, focused on peak abundance of the target species, minimizing the total time gear would be deployed.

In addition, attention to time of day effects could further alter sockeye catches and the target to nontarget capture ratio. In the Puget Sound gillnet fishery, 60% of Rhinoceros Auklet and 30% of Common Murre entanglements could be eliminated in years like 1996 by precluding sunrise fishing, with an overall loss in fishing efficiency of only 5%. Because our earlier work indicated that seabird entanglements at night were most rare (Melvin and Conquest 1996), we elected to not include night fishing in our comparisons, but rather to focus on times of day we knew to be important.

Our results identify three complementary tools to reduce seabird bycatch in the Puget Sound drift gillnet fishery: gear modifications, abundance-based fishery openings, and time of day restrictions. To illustrate how these might be used, we have calculated the percentage of seabirds that might be entangled in years like 1996 relative to a monofilament control. Scenarios include fishing the four gear types we tested, elimination of dawn and all crepuscular fishing versus fishing at all times of day, and fishing only during periods of high fish abundance versus for the entire period. If the assumption is made that loss in fishing efficiency is not offset with increased fishing time, then bycatch reduction estimates presented here would be increased, but at an economic loss. We estimated the number of sets required to catch a quota using the measured catch rate for each scenario and estimate the number of birds entangled for that scenario by multiplying the number of sets by the applicable seabird entanglement rate. Results are expressed as a percent reduction relative to the monofilament control fished at all times of day throughout the test fishery (Table 2). Results indicate that seabird bycatch can be reduced by 32-37% by fishing nets with pingers or 20 mesh panels, respectively, and that bycatch would actually increase 28% using 50 mesh nets. However, the greatest single reduction in seabird bycatch (43%) can be achieved by

Table 2. **Matrix of estimated seabird bycatch reduction (%) during the 1996 fishery by gear type and time-of-day relative to traditional monofilament nets fished dawn through dusk.**

Gear type [a]	Time of day		
	Dawn + day + dusk	Day + dusk	Day only
Monofilament	0	13	25
	43	50	57
50 mesh	+28[b]	40	41
	29	66	65
20 mesh	37	28	55
	66	70	75
Pinger	32	45	57
	64	70	77

[a] The second row within each gear type is the percent reduction if fishing occurred only during maximal sockeye abundance.

[b] Positive value indicates an increase in bycatch over traditional monofilament controls.

limiting fishery openings to periods of high salmon abundance simply because this approach reduces effort (i.e., total sets required to meet quota). Fishing 20 mesh nets at times of high fish abundance during openings that include either day plus dusk or day-only fishing have the potential to reduce seabird bycatch by up to 70-75%.

Although these percentages undoubtedly reflect the idiosyncrasies of 1996, they do provide at least three important lessons. First, target selectivity can be increased with technological solutions alone. Second, it may be possible to achieve substantial reductions in bycatch with season-specific restrictions on the timing, of both day and season, of the fishery. This would allow financially stressed fisheries the latitude to gradually implement more expensive gear modifications while still responding to the need to reduce bycatch. Third, a combination of bycatch reduction tools tailored to the fishery may be able to reduce bycatch dramatically. Ultimately, fishery managers will have to become ecosystem managers, whose tasks will include monitoring, manipulating, and allocating the interacting species within an ecoregion such as Puget Sound. Integrating technological solutions responsive to a group of species (whether target or not) with a broader understanding of the patterns and processes affecting organisms' residence in and movement through the system will be essential to successful sustainable use. Finally, successful bycatch reduction strategies can only be developed in close cooperation with commercial fishers. In our experience, their knowledge of fishing gear, practices, and culture were critical to identifying practical strategies, and their

involvement in the actual research led to establishing credibility of the study within the fleet, and later, acceptance of results.

Epilogue

In May of 1997 the Washington Fish and Wildlife Commission acted to reduce seabird bycatch in the Fraser River sockeye fishery in North Puget Sound based on the results presented here. With the support of the PSGA, WFWC adopted regulations for the non-treaty fleet that eliminated dawn fishing and required the use of nets modified with 20 mesh, visual alerts, but also provided the authority to manage the fishery based on the abundance of birds and fish. These regulations do not apply to the U.S. treaty-tribe gillnet fleet or the Canadian gillnet fleet, which together caught 99% of the Fraser River sockeye in the Puget Sound to Queen Charlotte Strait ecoregion in 1996. As a result of this inequity, non-treaty U.S. gillnet fishers sought and obtained a temporary injunction against the new regulations, which was later lifted on appeal by WDFW. However effective, it appears unlikely that regulations to reduce seabird bycatch will be ecoregion-wide any time soon.

Acknowledgments

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AFTERWORD
Epilogue Revisited: Constraints to Seabird Conservation in Northwest Salmon Drift Gillnet Fisheries

By Craig S. Harrison, Pacific Seabird Group, Washington, D.C.

Among the roadblocks to solving the seabird bycatch problem in the salmon driftnet fishery for Fraser River sockeye salmon in the shared waters of British Columbia and the state of Washington (Puget Sound, Strait of Georgia, Johnstone Strait, Vancouver Island coast, and Queen Charlotte Strait) are legal, socioeconomic, and political issues. Thus, the application of good science to find a reasonable and cost effective management solution is not necessarily sufficient to insure that such a solution is fully implemented by fishery managers. This is especially true where, as here, a variety of institutions have regulatory authority over the gillnet fleet.

On a global scale, the ecosystem in which Pacific Northwest salmon drift gillnetters fish seems modest in size. The complications arise from the involvement of two nations, each with a variety of its own internal jurisdictions, all of which must be involved in any comprehensive approach to fishery management.

Within Canada, the federal Department of Fisheries and Oceans and the federal Department of the Environment have management authority over seabird–marine fishery conflicts. Under Canadian law, the provincial British Columbia Ministry of Environment, Lands and Parks lacks jurisdiction to manage marine fisheries. Within the United States, primary fisheries management authority is shared among Washington Department of Fish and Wildlife and some 21 Native American tribes, depending on the provisions in each tribe's individual treaty with the United States in the nineteenth century. The Northwest Indian Fisheries Commission provides a data gathering and clearinghouse function for salmon fishery related information to most Washington Indian tribes. The federal U.S. Fish and Wildlife Service has indirect fisheries management authority by way of their responsibility to enforce statutes of the Migratory Bird Treaty Act and the Endangered Species Act. The National Marine Fisheries Service, also a U.S. federal agency, has indirect management authority for sockeye through their participation in the Pacific Salmon Treaty process and their primary responsibility for management of salmon other than sockeye through the Pacific Fisheries Management Council process. Finally, the Pacific Salmon Commission, an international administrative organ established to implement the Pacific Salmon Treaty between the United States and Canada, has some plausible authority pursuant to its implementation of a management plan for Fraser River sockeye salmon. However, the Pacific

Salmon Commission believes its mandate to be fish conservation only—not seabird conservation.

On May 30, 1997, the Washington Fish and Wildlife Commission adopted regulations to address the seabird bycatch problem in the non-tribal sockeye fishery using three management techniques: (1) eliminating sunrise fishing; (2) requiring fishermen to replace their nets with opaque netting in the upper 20 meshes; and (3) a modified form of abundance-based fishing (WAC 220-47-302). The rules largely implement the recommendations in the study by Melvin et al. (1999). The Washington Fish and Wildlife Commission provided a year between adopting its rules and their implementation to allow the affected fishing fleet sufficient time to modify its gear. Because of the Supreme Court decision in Washington v. Washington State Commercial Fishing Vessel Associations (443 U.S. 658 [1979]), as interpreted by Judge Boldt in United States v. Washington, 384 F Supp. 312, 342 (W.D. Wash. 1974), the State of Washington lacks authority to regulate salmon fishing by the treaty tribes. Thus, the state rules apply only to the non-treaty fishermen in the United States. Using landings data from 1994 to 1998 as a metric, the treaty tribes and the Canadian fishermen comprise about 30% and 60% of this salmon fishery, respectively. Thus, the Washington State regulations that were developed on a scientifically sound basis to minimize seabird bycatch applied in 1998 to only about 10% of the sockeye salmon gillnet fishery in the shared waters of British Columbia and Washington.

The non-treaty fishermen found this situation to be unfair. They filed suit to enjoin the implementation of the rules, asserting a claim that they violate the equal protection clause of the U.S. Constitution's Fifth Amendment. After initially winning a preliminary injunction to void the regulations, a state appeals court dissolved the injunction and reinstituted them on June 22, 1998 (Atwood v. Shanks, et al., 958 P.2d 332 [1998 Wash. App.]). Thus, just days before the fishing season began, the non-treaty fishermen learned that they must either implement the seabird bycatch rules or not fish.

The 1998 non-treaty sockeye fishery took place in northern Puget Sound during July and August. The five-inch opaque twine below the cork line on the gillnets presented a visual barrier to rhinoceros auklets, common murres, and other diving birds that fish the same waters as humans. When combined with a ban on fishing at dawn, anecdotal results from wide-scale deployment of this gear indicate that there were very few seabird deaths. Unfortunately, the Washington Department of Fish and Wildlife was unable to commit funds to scientifically assess the bycatch. By contrast, the non-treaty fleet killed about 3,500 birds in 1994. Year-to-year variations in fishing intensity and distribution of seabirds render any direct comparison between 1994 and 1998 fraught with analytical difficulties. A September editorial in *The Fisherman's News* entitled "Bird Panel a Real Success" stated the bird panels were "an unqualified success" and that gillnetters found that the panel has reduced the mortality of birds by

as much as 98%. It heralded this success story because fishermen were in danger of being banned from fishing if they could not reduce their bycatch of seabirds.

Despite the apparent success of this regulatory approach, both the State of Washington and the non-treaty fishermen remain frustrated with the situation. The State of Washington has no regulatory authority over the treaty tribes and cannot conduct its own foreign policy with Canada. For these reasons, the active participation of U.S. federal agencies is essential.

In an attempt to persuade all of the fishery managers to begin a dialogue on these issues, in April 1998 the Pacific Seabird Group (PSG, an international organization dedicated to the study and conservation of Pacific seabirds) wrote the agencies that manage this fishery in Canada and the United States, including the Northwest Indian Fisheries Commission. PSG recommended that minimizing seabird bycatch be made a priority in the shared waters of British Columbia and Washington. PSG suggested that monitoring programs are needed, that tools to minimize seabird bycatch should be employed, and that minimizing bycatch should be incorporated into fishery management plans. Finally, it noted that a goal of fishery and wildlife managers should be to keep common birds common so that officials can avoid the crisis management that is entailed when populations are listed under the Endangered Species Act.

The U.S. Fish and Wildlife Service (USFWS) is the key federal agency in managing seabird bycatch in this fishery because it implements the Migratory Bird Treaty Act. The act implements a 1916 treaty between the United States and Great Britain (on behalf of Canada), which makes the unintentional drowning of a single bird in a gillnet a potential criminal violation. USFWS has organized a series of meetings with the treaty tribes on this issue and has expressed optimism that they will recognize the need and value of implementing conservation measures in 1999. USFWS has apparently not used its enforcement authority under the Migratory Bird Treaty Act as a means of persuading the treaty tribes to agree to implement a regulatory regime to minimize seabird bycatch.

The treaty tribes have adopted the position that the tribes are not bound by the Migratory Bird Treaty Act, and therefore have no legal obligation to manage their fisheries to minimize seabird bycatch. Further, the tribes have indicated that they would consider taking action to reduce their bycatch if the USFWS can demonstrate that a conservation problem exists. This is, to put it mildly, a surprising view of application of a federal conservation statute to treaty tribes. The federal appellate court with jurisdiction over the State of Washington ruled long ago that the Eagle Protection Act modified treaty hunting rights and does prohibit treaty tribes from taking bald eagles without a permit (U.S. v. Fryberg, 622 F.2d 1010 [9th Cir. 1980]). The treaty tribes seem to acknowledge the authority of the federal government to enforce the Endangered Species Act where fishing may take Marbled Murrelets. Thus, a claim that treaty tribes are

not bound by the Migratory Bird Treaty Act seems frivolous. The Northwest Indian Fisheries Commission says that if USFWS develops a plan, they might abide by the plan's provisions if the non-treaty fishermen implement it first.

Within Canada, the Canadian Minister of the Environment expressed an interest in cooperating with U.S. agencies and has discussed this issue with the State of Washington. The minister indicated that fisheries observers aboard commercial vessels using experimental gillnets along the west coast of Vancouver Island have been trained in seabird identification.

The Canadian Minister of Fisheries and Oceans stated he has followed the bycatch work in Washington state closely and is interested in assessing the results from 1998 in a full fishery. The minister noted that gillnet salmon fisheries have been increasingly curtailed during recent years so that bycatch may be a diminishing problem in Canada because of an absence of fishing activity. In the Strait of Juan de Fuca, only four days of salmon gillnet fishing were allowed from 1996 to 1998 due to conservation concerns for Thompson River coho. Although there were reports of many Marbled Murrelets being killed in gillnet fisheries in Barkley Sound in 1984, the minister stated few seabirds were taken in Barkley Sound and Johnstone Strait in 1997. However, preliminary data from the Department of Fisheries and Oceans indicates that significant numbers of Marbled Murrelets, Common Murres, and Western Grebes were drowned in a 1998 test net fishery near Barkley Sound.

Canadian agencies and the U.S. Fish and Wildlife Service began a consultation on these issues in November 1998 under the auspices of the Migratory Bird Working Table which was formed under the North American Free Trade Agreement. They are focusing on seabird bycatch observer programs to standardize methods and data reporting. No doubt if these meetings continue the agencies will share other information.

Conclusion

Scientists and fishery managers in the state of Washington are to be congratulated for their successes in developing and instituting fishery techniques that minimize seabird bycatch in a cost-effective manner, but much work needs to be done. The treaty tribes must accept and implement a similar regime. The Washington Treaty Tribes no longer can claim that the non-treaty fishermen must implement avoidance techniques first—they have done so—and the U.S. Fish and Wildlife Service should consider enforcing the Migratory Bird Treaty Act against treaty tribe fishermen if this impasse continues much longer. Finally, the Canadian Wildlife Service should brief the Canadian Minister of Fisheries and Oceans concerning the bycatch problem in the Barkley Sound area in 1998. This should be sufficient motivation to institute a program to minimize bycatch in gillnet fisheries in British Columbia, at least along the west coast of Vancouver Island.

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Results of Seabird Avoidance Experiments and Observations of Bycatch Reported by Fishermen to IPHC Samplers in Alaskan and Canadian Ports in 1998

Robert J. Trumble and Tracee O. Geernaert
International Pacific Halibut Commission
Seattle, Washington

Regulations implemented in 1997 for groundfish and in 1998 for Pacific halibut to require seabird avoidance devices in Alaska longline fisheries also required monitoring of the effects of the regulations. The lack of observer coverage on halibut vessels precludes direct observations of seabird bycatch. At the request of the U.S. Fish and Wildlife Service (FWS) and the U.S. National Marine Fisheries Service, the staff of the International Pacific Halibut Commission (IPHC) interviewed Pacific halibut longline fishermen in Alaska (and British Columbia) to collect data concerning bycatch of seabirds and observations of Short-tailed Albatrosses. Tori lines and towed buoy bags were the most common avoidance devices, and had reported bird bycatch rates among the lowest of devices used. The reported seabird bycatch rates for the halibut fishery in 1998, after implementation of the avoidance regulations, were about 10-15% of the rates reported by FWS for the groundfish fisheries before the avoidance regulations. Either the avoidance regulations worked, the fishermen underreported seabird bycatch, a bird bycatch difference occurred between groundfish and halibut fisheries, or all three. Highest reported seabird bycatch in May and reported sightings of Short-tailed Albatrosses through the summer were consistent with previous reports. However, fishermen in some areas reported no seabird bycatch, a likely indicator of underreporting. The IPHC staff seeks comments on the suitability and desirability of collecting seabird bycatch data with interviews, as long as direct observations from observers are not available. During a longline survey in the Gulf of Alaska, IPHC staff alternated deployment of a bird bag with no bird bag as a pilot experiment to evaluate methods that might be employed in a larger comparison of effectiveness of bird avoidance devices. Thirteen sets, six with

bird bag deployment and seven without, caught no seabirds. Seabirds attacked longline gear about half as often when a seabird avoidance device was used compared to sets without a device. Longline sets made with the bird bag had proportionately more birds flying than sitting in the vicinity of the longline gear.

Industry Initiatives in Seabird Bycatch Avoidance

Thorn Smith
North Pacific Longline Association
Seattle, Washington

In 1995 freezer-longliners fishing off Alaska took two Short-tailed Albatrosses, and a third in 1996. The birds are highly endangered, and the news came as a great shock to the longline industry. The North Pacific Longline Association promptly developed seabird avoidance regulations through an industry notice-and-comment process and submitted them to the North Pacific Fishery Management Council (NPFMC) in the expectation that the regulations would be modified as more information on seabird bycatch becomes available. In December 1996 the NPFMC adopted the regulations, which became effective in May of 1997. Recently the freezer-longliner industry has recommended analysis of the use of streamer lines, lining tubes, and line setting devices to improve seabird avoidance. The National Marine Fisheries Service has recommended regulatory changes for the same purpose. Adoption of the regulatory amendments will be contingent in part on the results of research on the effectiveness of seabird avoidance techniques to be conducted by the University of Washington Sea Grant Program, with cooperation by the National Marine fisheries Service, the U.S. Fish and Wildlife Service, and the longline industry.

Mortality of Migratory Waterbirds in Mid-Atlantic Coastal Anchored Gillnets During March and April 1998

Douglas J. Forsell
U.S. Fish and Wildlife Service
Annapolis, Maryland

The U.S. Fish and Wildlife Service recently completed the first year of a study to assess bird mortality in anchored gillnets in the nearshore ocean of New Jersey, Delaware, Maryland, and Virginia. Twenty-five dead birds were observed being removed during 161 net retrievals. This equates to a minimum mortality of 0.16 birds per 300 foot net per set. Based on approximately 14,900 netsets, we estimate 2,387 diving birds were killed, mostly Red-throated and Common Loons. Beached bird surveys were conducted from 3 to 19 times at 20 locations along the 565 km shore. Two hundred and ten (210) dead diving birds were found on 1,732 km of surveyed beach or 0.12 birds per kilometer. Approximately ten times more dead birds per kilometer were found on beaches within 2 km of at least one gillnet than on beaches without nets. Two methods of estimating mortality based on the beached bird surveys estimated 1,265 and 3,390 diving birds killed per season. Live birds were counted to 400 m offshore on 590 km of shore with nets deployed within 1 km, and on 953 km of shore with no nets deployed within 1 km. For all diving birds, 10.3 birds per kilometer were counted in nearshore waters without nets and 4.6 birds per kilometer were counted in areas with nets. A vulnerability index was developed based on foraging behavior, distance from shore, and time in the study area during migration.

Problems with Pirates: Toothfish Longlining and Seabird Bycatch at the Subantarctic Prince Edward Islands

Peter G. Ryan
University of Cape Town
Rondebosch, South Africa

Martin Purves
Marine and Coastal Management
Roggebaai, South Africa

John Cooper
University of Cape Town
Rondebosch, South Africa

Longlining for Patagonian toothfish in the South African Exclusive Economic Zone around the subantarctic Prince Edward Islands commenced in 1996. Seabird bycatch data were obtained from observers aboard 21 sanctioned fishing trips (7.5 million hooks), during 1996-1998. 1,421 birds of ten species were reported killed. White-chinned Petrels *(Procellaria aequinoctialis)* predominated with large numbers of giant petrels *(Macronectes* spp.) and mollymawks *(Thalassarche* spp.). Most were male breeding adults. Average seabird bycatch rate in 1997-98 was 0.117 birds per 1,000 hooks, less than half that (0.289) reported in 1996-97. More than 1% of four local breeding populations were killed during the 1996-97 season. Low reproductive rates mean these levels of mortality are not sustainable, resulting in local population declines. The greatest improvement in bycatch relative to 1996-97 was among mollymawks, due to a decrease in daytime setting and increased use of streamer lines. Despite considerable improvements relative to the 1996-97 season, further efforts are needed to ensure that fishers adhere to permit conditions. The fishery should be closed during February to mid-March when White-chinned Petrels are caught in greatest numbers. Mortality from the unsanctioned (illegal and unregulated) fishery is the gravest concern, since it involves roughly ten times more effort than the sanctioned fishery and almost certainly has a greater bird bycatch rate.

How the F/V *Masonic* Reached Zero Seabird Bycatch in 1998 in Alaska

Mark S. Lundsten
Fishing Vessel Owners' Association
Seattle, Washington

In response to growing international pressure and threats to the Short-tailed Albatross *(Phoebastria albatrus),* seabird bycatch regulations were adopted that require fishers to deploy seabird deterrent devices in the Gulf of Alaska and the Bering Sea demersal longline fisheries in 1997. These regulations, which allow a range of alternative strategies, were proposed by industry and were patterned on those developed in the southern oceans and our own history of trying to keep seabirds away from our baited hooks. In order to find the best bycatch reduction strategy for my vessel, I compared several bird bycatch reduction devices and combinations of devices in the Gulf of Alaska during the 1997 and 1998 fisheries for Pacific halibut *(Hippoglossus stenolepis)* and sablefish *(Anoplopoma fimbria).* Devices included towing buoy bags, streamer lines, and boards, and increasing the weight of the fishing gear. As a result of my tests, I achieved zero take of seabirds on my vessel in 1998 by increasing the weight of the fishing gear in combination with deploying a streamer line with the fishing gear. Based on my results and that of fellow fishers, the industry is working with resource managers to develop new, more specific seabird bycatch regulations for the 1999 fishing season.

Recent Distributional Records of Short-tailed Albatross as a Tool for Longline Fisheries Management

Julie Michaelson and Scott Wilbor
University of Alaska Anchorage
Anchorage, Alaska

Jane Fadeley
U.S. Fish and Wildlife Service
Anchorage, Alaska

Judy Sherburne, Jerry Tande, and Frances R. Norman
University of Alaska Anchorage
Anchorage, Alaska

David Cameron Duffy
University of Hawaii Manoa
Honolulu, Hawaii

The Short-tailed Albatross *(Phoebastria albatrus)* is vulnerable to accidental catch in Alaska longline fisheries for species such as Pacific cod *(Gadus macrocephalus)* and sablefish *(Anoplopoma fimbria).* Using ArcInfo, we plotted the distribution of this species based on sight records and bycatch. Short-tails occur year-round in Alaskan waters but peak in summer. They are strongly associated with shelf-edges and seamounts in the Gulf of Alaska and along the Aleutian chain and with the edge of the deeper basin of the Bering Sea. Adult and immature distributions do not appear to differ. Short-tails occur in waters less than 50 m depth, but increase in frequency with depth, being most common at 150-200 m depths. This information may help fishermen avoid areas of high concentrations of albatross or take special precautions while setting their longlines in such areas. The distribution maps may be found on the Web at: http://www.uaa.alaska.edu/enri/aknhp_web/biodiversity/zoological/spp_of_concern/spp_status_reports/albatross/albatros.html.

Bird Interactions with Salmon Drift Gillnets in Prince William Sound, Alaska: 1990 and 1991

K.M. Wynne
University of Alaska Fairbanks
Kodiak, Alaska

Marine bird interactions with the Prince William Sound salmon drift gillnet fishery were documented by observers who monitored 9,041 net retrievals in 1990 and 1991. Of 2,291 birds observed approaching nets, 90 (3.9%) became entangled and died (in fewer than 1% of observed sets each year) and 13 were released alive. Marbled Murrelets and Common Murres were the most common birds taken, representing 47 and 22 of the 90 observed mortalities, respectively. Marbled Murrelet mortality was documented in both years, with extrapolated take estimates of 1,229 and 263 in 1990 and 1991, respectively. Common Murres accounted for 22 of 53 bird deaths observed in 1991 (total estimated take of 433); all were observed prior to 22 June. No murre mortality was observed in 1990, but observer effort was initiated on 10 June that year. Characteristics of the fishery, observer effort, and spatial and temporal (annual, seasonal, and diel) patterns of entanglement are discussed.

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