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Research paper

Fishery-specific solutions to seabird bycatch in the U.S. West Coast sablefish fishery

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ABSTRACT

Bird scaring lines (BSLs) protect longline fishing gear from seabird attacks, save bait, reduce incidental seabird mortality and are the most commonly prescribed seabird bycatch mitigation measure worldwide. We collaborated with fishermen to assess the efficacy of applying BSL regulations from the demersal longline sablefish fishery in Alaska to a similar fishery along the U.S West Coast. In contrast to Alaska, some U.S. West Coast vessels use floats along the line to keep hooks off the seafloor, where scavengers degrade the bait and the target catch. Our results confirmed that BSL regulations from Alaska were sufficient to protect baits from bird attacks on longlines without floats, but not baits on longlines with floats. Longlines with floats sank below the reach of albatrosses (2 m depth) at a distance astern (157.7 m ± 44.8 95% CI) that was 2.3 times farther than longlines without floats (68.8 m ± 37.8 95% CI). The floated longline distance was well beyond the protection afforded by BSLs, which is approximately 40 m of aerial extent. Black-footed albatross attacked floated longlines at rates ten times more (2.7 attacks/1000 hooks, 0.48–4.45 95%CI) than longlines without floats (0.20 attacks/1000 hooks, 0.01–0.36 95% CI). Retrospective analysis of NOAA Fisheries Groundfish Observer Program data suggested that seabird bycatch occurs in a few sablefish longline fishing sectors and a minority of vessels, but is not confined to larger vessels. Analysis also confirmed fishermen testimonials that night setting reduced albatross bycatch by an order of magnitude compared to daytime setting, without reducing target catch. Night setting could be an effective albatross bycatch prevention practice if applied to the U.S. West Coast sablefish longline fishery and provide a practical alternative for vessels that elect to use floated longlines. These results highlight the importance of understanding region-specific longline gear modifications to identify effective bycatch reduction tools and the value of working collaboratively with fishermen to craft solutions.

1. Introduction

1.1. Global seabird bycatch

Incidental mortality of seabirds in longline fisheries has been an international conservation concern for decades, with reported estimates of approximately 160,000 seabirds killed in longline fisheries annually (Anderson et al., 2011; Croxall et al., 2012; Lewison et al., 2004). Albatross populations are especially vulnerable to bycatch mortality because they exhibit delayed maturity and low fecundity. Commercial fisheries have been implicated in the decline of many albatross and petrel species (Lewison and Crowder, 2003; Weimerskirch et al., 1997). Fifteen of 22 albatross species (Family Diomedeidae) are threatened with extinction, one of the highest proportions among birds (Butchart et al., 2004; Croxall et al., 2012; IUCN, 2016; Phillips, 2013).

Most seabird mortality in demersal longline fisheries occurs as seabirds attempt to forage on baited hooks during longline deployment. Seabirds become hooked or tangled and subsequently drown (Brothers, 1991; Løkkeborg, 2011). Non-lethal interactions can also occasionally occur as fishermen retrieve their longlines and seabirds congregate to

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forage on discarded bait and offal. Seabird interactions with fishing gear have negative consequences for fishery participants because of the costs of bait lost to birds, and the cost of lost fishing opportunity if excessive seabird bycatch triggers a fishery closure. The development and implementation of best practice seabird bycatch mitigation technologies are critical to achieving global seabird conservation goals and sustainable ecosystem-based fisheries management (Brothers et al., 1999; Løkkeborg, 2011).

Global bycatch avoidance best practices for demersal longlines include deterring foraging seabirds with bird scaring lines (BSLs) and setting gear after dark (ACAP, 2016a; Melvin et al., 2004). The current international best practice guidelines, set out by the Agreement on the Conservation of Albatrosses and Petrels (ACAP), additionally rely on longline weighting to sink hooks rapidly and close to the stern of the vessel, thereby reducing the amount of time bait is vulnerable to birds and birds vulnerable to hooking. When efficient fishing requires longlines to be in contact with the seafloor, adding weight to the longline can be a practical method for reducing seabird bycatch because it reduces the time that baited hooks are at the surface.

Some demersal longline fishermen use floats placed at intervals along the groundline to suspend most hooks a few meters above the sea floor. Floats provide access to target species, while avoiding non-target benthic species or scavengers that degrade baits and target catch. However, floats also slow the sinking rate of longlines, thereby increasing both the time and the distance astern that baited hooks are available to birds at the surface of the water. The delayed sinking of floated longlines may keep baited hooks at the surface and increase bycatch risk for seabirds. The hooks on floated longlines may also snag the trailing ends of bird-scaring lines if the hooks remain near the surface beyond the aerial extent of BSLs. Developing effective seabird avoidance measures for floated demersal longlines has been identified as a priority for seabird conservation and has received increasing attention from the research community (ACAP, 2016c). Researchers have documented slower longline sink profiles and elevated levels of seabird bycatch in floated demersal longline fisheries off South America and New Zealand (Debski, 2016; Pierre et al., 2013; Seco Pon et al., 2007), which suggests there may be cause for concern in floated demersal fisheries off the U.S. West Coast. In artisanal demersal longline fisheries in the Mediterranean Sea, floated demersal longline configurations (Piedra-Bola zigzag and pyramid systems) were associated with seabird attacks on baited hooks further astern compared to non-floated longline configurations, but overall seabird bycatch rates were not elevated (Cortés et al., 2017). These contrasting findings highlight the need for a thorough understanding of the fishery, vessel specifications, longline configurations, and the attending seabird community to design fishery-specific seabird avoidance measures. Longline fishermen targeting sablefish off the U.S. West Coast use both floated and non-floated demersal longline gear, thus providing the opportunity to evaluate seabird interactions with both longline configurations within the same fleet.

1.2. Albatross conservation on the U.S. West Coast

Three albatross species (Laysan: *Phoebastria immutablis*, black-footed: *P. nigripes*, short-tailed: *P. albatrus*) range throughout the Northeast Pacific Ocean. The short-tailed albatross, listed as endangered under the U.S. Endangered Species Act (ESA), is the focus of an intensive multi-national recovery program as well as the driving force motivating seabird bycatch prevention requirements in Alaska and the U.S. West Coast (Washington, Oregon, California) longline fisheries. The population of the endangered short-tailed albatross (4700 in 2015, USFWS, 2014; Sievert and Hasegawa, unpublished data) is less than 1% of its historical abundance. However, it is growing at ≈8% per year and beginning to re-occupy its former range (USFWS, 2014; Sievert, and Hasegawa, unpublished data). In 2011, a longline vessel targeting sablefish (*Anaplopoma fimbria*) off central Oregon caught a short-tailed albatross (Good et al., 2015; Jannot et al., 2016; USFWS, 2012). This event confirmed the suspicion that short-tailed albatrosses are vulnerable to mortality in the U.S. West Coast groundfish fishery (Melvin et al., 2001; Suryan et al., 2007) and triggered an evaluation of bycatch prevention measures in this fishery. No albatross bycatch avoidance measures were required for U.S. West Coast groundfish fisheries at that time. There is also international conservation concern for black-footed albatross (IUCN Red Listed as vulnerable, IUCN, 2016). Chronic mortality of black-footed albatross occurs in U.S. West Coast groundfish fisheries, with estimated annual takes between 51 and 215 for the 2010–13 period (Jannot et al., 2016). Other species of conservation concern (Laysan albatross and Pink-footed shearwaters (*Puffinus creatopus*; USFWS, 2008)), and species protected under the Migratory Bird Treaty Act (50 CFR Part 10 and 21) are also potentially susceptible to interactions with U.S. West Coast longline fisheries. Thus, designing and promoting effective seabird bycatch mitigation for these fisheries has far-reaching conservation benefits for many seabirds in the Northeast Pacific Ocean.

We focused our research on developing best practices for the U.S. West Coast demersal longline fishery based on recent bycatch data and findings on seabird exposure to interactions in the U.S. West Coast groundfish fishery. Guy et al. (2013) found that the demersal longline fishery for sablefish presented the greatest threat to albatrosses off the U.S. West Coast, and demonstrated that black-footed and short-tailed albatross distributions and occurrence overlapped with the demersal sablefish longline fishery, particularly in shelf-slope habitats north of 36° N latitude. Good et al. (2015) and Jannot et al. (2011) showed that most of the observed bycatch of seabirds, and albatrosses in particular, also occurs in this fishery. Based on these findings, we staged our research in the fishery posing the greatest risk to seabirds – the sablefish fishery.

1.3. Objectives and hypotheses

Our research objectives were to characterize sink profiles and assess seabird behavioral responses to floated and non-floated longline configurations in the presence of bird-scaring lines in the U.S. West Coast demersal longline sablefish fishery. We hypothesized that floated demersal longlines would remain at the surface further astern than non-floated longlines and that seabirds would exploit this opportunity by attacking hooks on floated longlines at higher rates beyond the protection of bird scaring lines.

In response to fishermen testimonials during workshops held in ports throughout the region, we also explored alternative seabird bycatch tools for this fishery by examining the efficacy of night fishing as a tactic for avoiding seabird bycatch. We use 12 years of data from the NOAA Fisheries West Coast Groundfish Observer Program to compare seabird bycatch rates and fish landings in the fishery for sets made at night and during the day. Because albatrosses are primarily visual foragers and exhibit greater foraging activity during daylight (Fernández and Anderson, 2000), we anticipated that the bycatch of albatrosses and other seabirds would be lower on sets made at night. We also compared catch rates of target fish during day and nighttime sets, as profitability likely influences fishermen's receptivity to night fishing as a seabird bycatch avoidance measure. Many fishes exhibit diurnal behavioral patterns that can affect catchability (e.g., Hart et al., 2010). Sablefish, in particular, enter into contact with the seafloor at sunrise, and rise up into the water column at night (Doya et al., 2014). Therefore, we anticipated that the catch per unit effort of sablefish, the target species, might differ between nighttime and daytime fishing. It was also important to ensure that the catch of non-target species did not increase when setting at night. Further, we used observer program data to examine the relative albatross bycatch rates for large (≥16.8 m) vs. small (< 16.8 m) vessels and the variation in albatross bycatch among individual vessels in order to better understand seabird bycatch trends in this fishery.

2. Methods

2.1. U.S. West Coast sablefish longline fleet

We obtained data on vessels participating in the U.S. West Coast longline fisheries for sablefish to determine the number of vessels and range of vessel lengths comprising the longline fleet. The sablefish fishery includes vessels participating in the limited entry sablefish endorsed longline sector, with fixed allocations of fish over a season (NOAA Fisheries, 2015a; Stelle, 2013). Federal regulations permit approximately 80 vessels to fish in the limited-entry fishery during a seven-month period from April through October. These same vessels also make landings outside the limited entry season, under daily landing limits. Of these, 24 large vessels (> 55 ft. in overall length) control nearly half of the allowed catch annually, and therefore have a large impact on the fishery. NOAA Fisheries estimates that between 333 and 385 vessels annually participated in the open access fishery for sablefish from 2010 to 2015, wherein vessels without a limited entry permit land sablefish throughout the year under daily landing limits. Of the vessels participating in the open access sector, only 3.7% to 7.2% were large vessels. A small number of longline vessels (4–11) lease sablefish quota (catch shares) from trawl vessels. Based on landings information, we estimate that, depending on the year, between 475 and 675 longline vessels annually participated in these fisheries from 2010 to 2015.

2.2. Vessels and longline gear

Seven vessels from the limited entry sablefish endorsed longline sector joined our collaborative research program, in which we collected data during fishing operations out of ports in California, Oregon and Washington between 22 May 2010 and 6 October 2014 (Fig. 1, Table S1). Fishing vessels used for research ranged in size from 9.4 to 24.7 m, and included three large (≥16.8 m) and four small (< 16.8 m) vessels, and carried 2–5 crew members. Fishing took place on the continental slope at an average fishing depth of 486 m (min = 225 m; max = 954 m). The majority of vessels used hand-baited tub longlines, with the groundline coiled in tubs with baited hooks (squid or herring) that were deployed over the stern of the vessel (Fig. 2). Each tub contained a groundline segment (skate) with 160–200 hooks spaced 36–48 inches apart. A set consisted of 8–30 skates (mean = 2400 hooks, range = 1200–5200 hooks). Two vessels used auto-bait longlines, wherein a machine baits hooks with squid as they were deployed over the stern of the vessel during the set. The two vessels that deployed a longline configuration without floats ("non-floated") generally attached weights at skate junctions, and occasionally an additional weight in the middle of a skate (Fig. 3a). The five vessels that used a longline configuration with floats ("floated"), alternated weights and floats with approximately 20–25 hooks between the weight and float. A typical skate had three floats and four weights with additional floats attached at the skate junctions (Fig. 3b). Both longline configurations (floated and non-floated) were used on both types of vessels (large and small); however, any single vessel only used a single configuration. We requested that all vessels deploy two BSLs, one on either side of the sinking longlines, with an aerial extent of 40m, in order to match Alaska seabird bycatch avoidance requirements for vessel under 30.5 m (50 CFR part 679).

2.3. Seabird diversity

We described the seabird species diversity around vessels by counting all seabirds by species on the water and flying within a 100 m radius hemisphere centered at the midpoint of the stern (Dietrich et al., 2008; Melvin et al., 2001, 2011). We conducted counts during or within five minutes following gear deployment (mean gear deployment = 17.15 min) to ensure counts represented the assemblage of seabirds present during longline setting. Following the same methods, counts of seabirds attending the vessel were made midway through the several hour long process of longline retrieval.

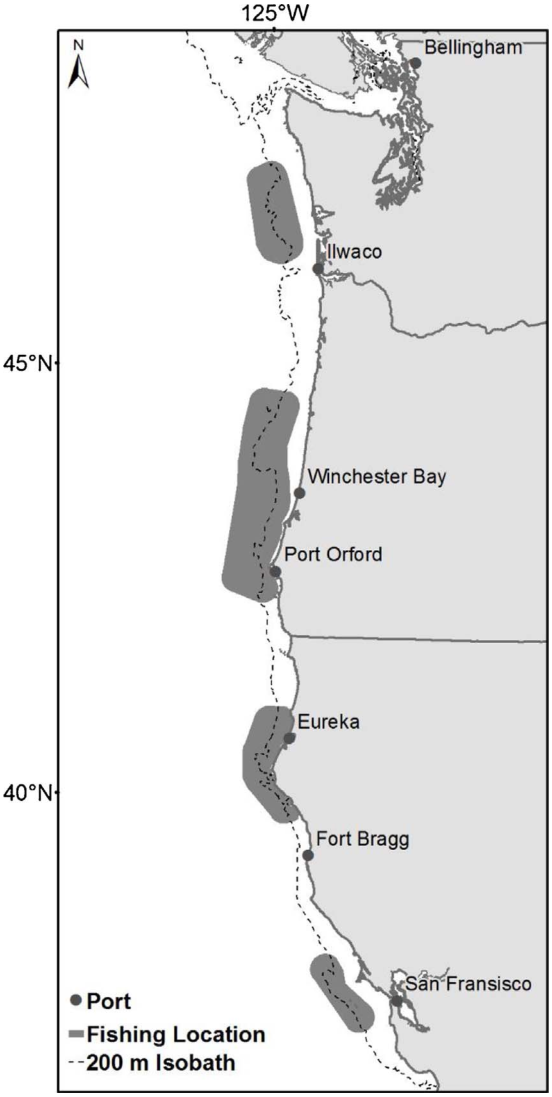

Fig. 1. Map of the study area, showing major ports, generalized fishing areas, and 200 m isobath.

2.4. Sink profiles

The sink profiles of floated and non-floated configurations were measured using Mk-9 time-depth recorders (TDRs, Wildlife Computers, U.S.A.), which record depth at 0.5 m increments every second. To minimize anomalous measurements, TDRs were acclimated to surface seawater temperatures for up to 30 min following protocols described by Robertson (2000). On floated longlines, we attached a TDR at the skate junction adjacent to a float, located at the midpoint between weights, and another TDR to the next adjacent weight. On non-floated longlines, we consulted with the crew to determine where they planned to add weights. If crew added weights only at skate junctions, we attached the TDRs at the skate junction and at the midpoint of the skate. If crew added an additional weight at the midpoint between skate junctions, we attached a TDR at the skate junction, and one quarter the length of the skate. TDRs attached at the midpoint of non-floated longline are representative of the sink profile of the majority of hooks (Robertson, 2000), while TDRs attached to the midpoint on floated longline represent the slowest sinking portion of the longline, likely one

Fig. 2. Floated demersal longline tub gear, staged on the stern of the vessel in preparation for setting. Inset photo shows two styles of floats (hard plastic and glass) with a typical 20 oz. (567 g) weight placed in between the floats. The floats and weights were coiled within the tubs when gear was prepared for setting.

third to half of hooks. In all cases, TDRs were attached to skates near the middle of the set, ≥1 km from anchors. Between one and 14 TDRs were deployed on each of 29 floated and 16 non-floated sets.

We estimated how far astern baited hooks sank below where birds can access them by multiplying the time required for gear to sink beyond the diving range of the birds by the vessel speed. We calculated the time in seconds from the time the TDR entered the water until the TDR sank to 2 m and 5 m depth. We recorded the time the TDR entered the water based to the nearest second. We multiplied the number of seconds required for the TDR to reach the benchmark depth by the vessel speed (m/s) to calculate the distance astern of the vessel (m) that the TDR reached the benchmark depth. We selected benchmark depths of 2 m and 5 m based on surface foraging and seabird dive depths (Melvin et al., 2014). Albatrosses, gulls and fulmars are considered surface foraging birds, and only have access to gear in the upper 2–3 m of the water column (Melvin et al., 2014) pink-footed and sooty shearwaters have deeper average dive depths, and can dive to a maximum of 36 m and 93 m respectively (Hodum and Shaffer, unpubl. data 2006; Mallory et al., 2012; Taylor, 2008).

To estimate the distance astern at which the average floated and non-floated longline sank beyond the diving range of seabirds, we modelled the relationship between longline configuration and distance astern at which the longline reached 2 m and 5 m depth. We used R (R Development Core Team, 2016 Version 3.3.2) statistical software and lme4 (Bates et al., 2015) to construct an initial linear mixed effects model using Gaussian distribution for the random effects. We included three categorical fixed effects in the model: 1) longline configuration (floated or non-floated), 2) TDR placement (weight or midpoint between weights), and 3) vessel size (large or small), and one interaction term of longline configuration*TDR placement. We included random intercepts for set and vessel in the model to account for multiple TDR measurements taken on the same set, and vessel-specific longline

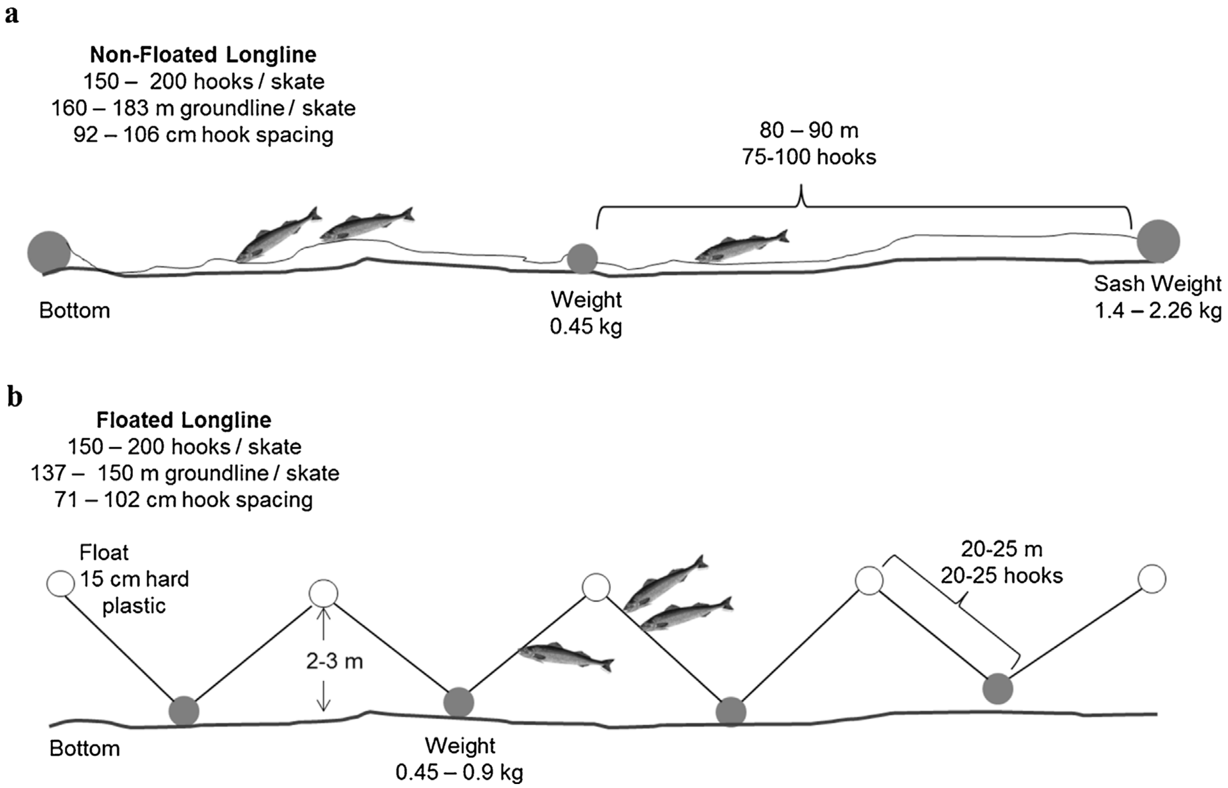

Fig. 3. (a) Conceptual illustration showing a single skate of non-floated demersal longline gear when deployed to the seafloor. (b) Conceptual illustration showing a single skate of floated demersal longline gear when deployed to the seafloor.

configuration, gear idiosyncrasies, and variability in setting practices. Visual inspection of residual plots did not reveal obvious deviations from homoscedasticity or normality, which supported the use of a Gaussian distribution without data transformations.

We used Akaike's Information Criterion, adjusted for small sample sizes (AICc) to select the two final models for estimating distance astern at which the longline sank to benchmark depths of 2 m and 5 m. We compared the full models that included all fixed and random effects to null models that excluded individual fixed effects and the interaction term. Models with the lowest AICc and ≥ 2 ΔAICc from competing models were retained. If the ΔAICc between competing models was < 2, then the model with the least number of variables was retained as the most parsimonious final model. We used the final models to calculate estimates for distances astern at which weights and midpoints between weights reached the 2 m and 5 m benchmark depths for both floated and non-floated longlines and the proportion of the remaining variance explained by the random effects. We estimated 95% confidence intervals of the fixed effects using Wald's method, which uses the estimated local curvature of the likelihood surface to determine appropriate confidence interval cut-offs.

2.5. *Attack rates*

Because seabird bycatch events are relatively rare, we used seabird attacks on baited hooks as a proxy of bycatch risk. Attacks were defined as an unambiguous attempt by an individual bird to take bait from a hook, typically a dive, or lunge directly over a sinking hook (see Melvin et al., 2001). Attacks were observed during daytime sets for periods ranging between 10 min and the entire setting period, up to 45 min (mean = 17.15 min, SD = 8.79 min, median = 17 min). We recorded attacks by species in 10 m bins from the point of longline deployment at the stern of the vessel out to 90 m astern of the vessel. Bird scaring lines were deployed primarily in pairs (29 paired vs. 4 single) with a mean aerial extent of 34 m. We used the 5 m spacing of individual streamers on streamer lines to estimate the attack location. We calculated attack rates (attacks/1000 hooks) by dividing the number of attacks by the number of hooks observed, to allow for comparisons across observations periods and gear deployments of different length. We used Welch's *t*-tests to compare mean black-footed albatross attack rates on floated and non-floated longline sets within the protection of BSLs (0–40 m astern) and outside the protection of BSLs (40–90 m astern). Because attack rate data were not normally distributed, we used the R package boot (Canty and Ripley, 2014; Davison and Hinkley, 1997) to perform bootstrapping to calculate 95% confidence intervals for the means using the percentile method and 1000 replicates.

2.6. *Observer program data*

We examined U.S. West Coast Groundfish Observer Program data to determine if albatross bycatch and target/non-target fish catch rates differed between daytime and nighttime sets. Data sources for this analysis included fishery observer data from 2002 to 2013 for several different fishery sectors that target sablefish using longline gear. In addition to the limited entry sablefish quota sector, from which we drew our collaborating vessels for at-sea research, we included data from limited entry daily landing limits, open access sablefish fisheries and quota leased from trawl vessels and fished using longline gear (catch shares) sectors of the fleet. The observer program monitors fishing sectors based on the observed landed catch as a percentage of the total landed catch. Observer coverage for limited entry sector sablefish averaged 23% (range: 7–38%) (Jannot et al., 2016; Somers et al., 2015). Only a small proportion of trips were monitored for vessels in the limited entry daily landing limits fishery (1–13% coverage) and the open access fishery (1–5% coverage, Somers et al., 2015). During 2010–2013, 100% of the trips fished by longline vessels using leased trawl quota (catch shares) were observed to allow for a full accounting of target catch and bycatch. The primary sample unit for fishery observers was the set and a minimum of 50% of each set was randomly sampled.

Fishery observers record a variety of fishery interactions with seabirds; the interactions range in severity from birds simply being sighted from the vessel to birds being killed by fishing gear. For species not listed as endangered or threatened under ESA, bycatch events are interactions documenting mortality or likely to have resulted in mortality. Birds that were bleeding, had broken bones, lost feathers, or that did not fly away or return to normal behavior within a few minutes of the interaction were counted as bycatch (Good et al., 2015). Consistent with Section 3 of the ESA, bycatch designations for endangered short-tailed albatross included a wider range of interactions (16 USC 1532). Four of the five events that involved short-tailed albatross were non-lethal interactions. We calculated the bycatch rate for all albatrosses for each set by dividing the number of observed albatross bycatch events by the number of hooks observed in that set, which we report as the number of albatrosses caught per 1000 hooks. For sets with missing observed hook data, we estimated the number of hooks using the mean from other observed sets within the same trip or from trips made on preceding or following days. We also calculated the bycatch rate (birds/1000 hooks) for gulls, shearwaters, and northern fulmars.

Sets were categorized as day or night based on when the first hook entered the water. We examined several different definitions of night, based on sunset and sunrise as well as three categories of twilight. Night sets were defined as those deployed a) after sunset or before sunrise (sun angle $> 0^\circ$ below horizon), b) after civil dusk or before civil dawn (sun angle $> 6^\circ$ below horizon), c) after nautical dusk or before nautical dawn (sun angle $> 12^\circ$ below horizon), and d) after astronomical dusk or before astronomical dawn (sun angle $> 18^\circ$ below horizon). Sets generally took < 45 min to deploy, so assignment to a twilight category was relatively straightforward. Sun position relative to the horizon at the time of set was determined by the combination of latitude and longitude, time (first hook in the water), and date using the R spatial packages 'maptools' and 'sp' (Bivand and Lewin-Koh, 2017; Bivand et al., 2013; Pebesma and Bivand, 2005). Because the seabird bycatch rate data were zero-inflated, we made comparisons between diurnal categories using a non-parametric rank Mann–Whitney *U* test in R statistical software (R Development Core Team, 2016 Version 3.3.2).

3. Results

3.1. *Seabird diversity*

On average, 41 seabirds attended the vessel during longline deployment (sets). Black-footed albatrosses were the most frequent (97% of sets) and the most abundant bird (mean = 17; Table 1). Western gulls were another important component, attending 82% of all sets and averaging just fewer than 11 birds. Sooty and pink-footed shearwaters attended about 50% of all sets. Northern fulmars were observed at just 24% of all sets, and eight other seabird species were observed rarely ($< 10\%$; Table 1). We observed two seabird mortalities: one sooty shearwater and one pink-footed shearwater. Both mortalities occurred on floated longlines, during longline deployment with paired BSLs deployed to the target 40 m aerial extent as requested.

Significantly more seabirds (mean = 121 birds) attended longline retrievals (hauls) than deployments (mean = 41 birds, Table 1, $p < 0.001$). This difference was due to the significantly higher mean abundance of black-footed albatross during longline retrievals (103 birds) versus deployments (20 birds; $p < 0.001$). The abundance of other seabirds (western gull, sooty shearwater, pink-footed shearwater, and northern fulmar) did not significantly differ ($p > 0.05$) between longline deployment and retrieval (Table 1). Two black-footed albatross were observed hooked in upper mandible during longline retrieval. Both were released at the hauling station, located at the side of the vessel, without apparent significant injury and were presumed to have survived.

Table 1

Proportion of sets each seabird species was present (set occurrence), mean seabird attendance and 95% confidence interval (95% CI) during the set and during gear retrieval (birds), attack rate (attacks per 1000 hooks) within 90 m of the stern of the vessel, total mortalities (birds). Attack rate and set data are from daylight observations of 33 research sets made from 7 fishing vessels from 25 May 2012 to 6 October 2014. Gear retrieval data are from a subset of 16 of the aforementioned research sets.

Species	Scientific name	Set Occurrence	Number of birds per gear deployment		Number of birds per gear retrieval		Attacks per 1000 hooks		Observed mortalities
			Mean	95% CI	Mean	95% CI	Mean	95% CI	n
Black-footed albatross	*Phoebastria nigripes*[a]	0.97	17.44	5.95	103.06	30.65	1.12	0.82	0
Western gull	*Larus occidentalis*[b]	0.82	10.85	3.70	10.81	6.86	0.26	0.22	0
Sooty shearwater	*Puffinus griseus*	0.55	4.31	1.47	1.19	0.78	0.01	0.01	1
Pink-footed shearwater	*Puffinus creatopus*	0.48	3.95	1.35	3.50	1.90	0.11	0.11	1
Northern fulmar	*Fulmaris glacialis*	0.24	0.85	0.29	1.06	0.95	0	0	0
Short-tailed albatross	*Phoebastria albatrus*	0.09	0.08	0.03	0	0	0	0	0
Sabin's gull	*Xema sabini*	0.06	0.36	0.12	0	0	0	0	0
Common murre	*Uria aalge*	0.06	0.10	0.03	0.94	1.59	0	0	0
Fork-tailed storm-petrel	*Oceanodroma furcata*	0.06	0.08	0.03	0	0	0	0	0
Black-legged kittiwake	*Rissa tridactyla*	0.06	0.05	0.02	0	0	0	0	0
Buller's shearwater	*Puffinus bulleri*	0.03	0.05	0.02	0	0	0	0	0
California gull	*Larus californicus*	0.03	0.51	0.17	0.5	0.44	0	0	0
Heermann's gull	*Larus heermanni*	0.03	0.03	0.01	0.13	0.17	0	0	0
Rhinoceros auklet	*Cerorhinca monocerata*	0	0	0	0.06	0.12	0	0	0
All Birds		1.00	41.18	14.05	121.25	25.34	1.98	1.12	2

[a] Includes one observation of a hybrid Black-footed/Laysan *Phoebastria immutablis/nigripes*.

[b] Western gulls often hybridize with Glaucous-winged gulls in this region. Also includes immature gulls, which were almost exclusively immature Western Gulls.

3.2. Longline sink profiles

Model results were similar for distance to the 2 m and 5 m benchmark depths. Vessel size (large vs. small) was the only variable not retained in the final full model, suggesting that it did not affect the distance astern at which the longline sank to benchmark depths (Table 2). There was, however, strong support for retaining the interaction of TDR placement and longline configuration. Therefore, we used separate models to assess the effect of TDR position and longline configuration on sink profile (Table 2). TDR position was an important determinant of sink profile; models containing TDR position had more support than models containing only random effects for both longline configurations (Table 2). When TDRs were placed at weights, longline configuration did not affect sink profile; the model with only random effects was < 2 ΔAIC from a model including random effects plus longline configuration (Table 2). However, when TDRs were placed at midpoints the model with the most support included longline configuration (Table 2).

Table 2

Results of model selection to determine the best model to estimate distance astern of the vessel that the longline gear sinks to 2 m and 5 m depth. We report on the degrees of freedom (df) in the model, the difference in the Akaike's Information Criterion value adjusted for small sample sizes (ΔAICc) for the model compared to the best model, and the residual deviance (Dev). Because the interaction between longline configuration and TDR position was retained in the best overall model, we used separate models to assess the effect of TDR position and longline configuration on longline sink rate. Best model highlighted in bold.

<table>
<tr><th>Distance astern to 2 m benchmark depth</th><th>df</th><th>ΔAICc</th><th>Dev</th></tr>
<tr><td>Full Dataset</td><td></td><td></td><td></td></tr>
<tr><td>Longline Configuration + TDR position + (Longline Configuration) * (TDR position) + (1|set) + (1|vessel)</td><td>7</td><td>0</td><td>1567.8</td></tr>
<tr><td>Longline Configuration + TDR position + Vessel Size + (Longline Configuration) * (TDR position) + (1|set) + (1|vessel)</td><td>8</td><td>2.8</td><td>1568.3</td></tr>
<tr><td>Longline Configuration + TDR position + Vessel Size + (1|set) + (1|vessel)</td><td>7</td><td>31.3</td><td>1599.1</td></tr>
<tr><td><i>1</i> + (1|set) + (1|vessel)</td><td>4</td><td>161.8</td><td>1736.0</td></tr>
<tr><td>TDR Position = Weights</td><td></td><td></td><td></td></tr>
<tr><td>1 + (1|set) + (1|vessel)</td><td>4</td><td>0</td><td>395.3</td></tr>
<tr><td>Longline Configuration + (1|set) + (1|vessel)</td><td>5</td><td>2.0</td><td>394.8</td></tr>
<tr><td><i>TDR Position = Midpoints between Weights</i></td><td></td><td></td><td></td></tr>
<tr><td>Longline Configuration + Vessel Size + (1|set) + (1|vessel)</td><td>5</td><td>0</td><td>1122.31</td></tr>
<tr><td>1 + (1|set) + (1|vessel)</td><td>4</td><td>3.1</td><td>1127.6</td></tr>
<tr><th>Distance astern to 5 m benchmark depth</th><th>df</th><th>ΔAICc</th><th>Dev</th></tr>
<tr><td>Full Dataset</td><td></td><td></td><td></td></tr>
<tr><td>Longline Configuration + TDR position + (Longline Configuration)*(TDR position) + (1|set) + (1|vessel)</td><td>7</td><td>0</td><td>1701.1</td></tr>
<tr><td>Longline Configuration + TDR position + Vessel Size + (Longline Configuration) * (TDR position) + (1|set) + (1|vessel)</td><td>8</td><td>2.0</td><td>1700.9</td></tr>
<tr><td>Longline Configuration + TDR position + Vessel Size + (1|set) + (1|vessel)</td><td>7</td><td>6.7</td><td>1707.8</td></tr>
<tr><td>(1|set) + (1|vessel)</td><td>4</td><td>99.2</td><td>1806.7</td></tr>
<tr><td>TDR Position = Weights</td><td></td><td></td><td></td></tr>
<tr><td>Longline Configuration + (1|set) + (1|vessel)</td><td>5</td><td>0</td><td>514.9</td></tr>
<tr><td>1 + (1|set) + (1|vessel)</td><td>4</td><td>0.4</td><td>517.8</td></tr>
<tr><td>TDR Position = Midpoints between Weights</td><td></td><td></td><td></td></tr>
<tr><td>Longline Configuration + (1|set) + (1|vessel)</td><td>5</td><td>0</td><td>1187.2</td></tr>
<tr><td>1 + (1|set) + (1|vessel)</td><td>4</td><td>2.4</td><td>1191.8</td></tr>
</table>

Table 3
Estimated distance astern of the vessel that baited hooks sank to benchmark depths on non-floated gear and floated gear using the final linear mixed model: Distance ~ (Longline Configuration) + (TDR position) + (Longline Configuration)*(TDR position) + (1|set) + (1|vessel). The 95% confidence intervals were calculated using Wald's method. The sample size reported is the number of TDR casts with number of sets in parentheses. We report the proportion of variance not explained by fixed effects in the model that was explained by the random effects of set and vessel, and residual variance.

	n	2 m		5 m	
	TDR casts (sets)	Estimate (m)	± 95% CI	Estimate (m)	± 95% CI
TDR at weight					
Non-floated	20 (4)	20.9	21.3	48.3	32.6
Floated	26 (17)	32.6	25.8	123.7	38.7
TDR at midpoint between weights					
Non-floated	56 (15)	68.8	37.8	120.8	85.4
Floated	57 (28)	157.7	44.8	250.0	100.3
Random Effects	Set	16.3%		30.3%	
	Vessel	34.4%		37.7%	
	Residual	49.3%		32.0%	

3.2.1. *Fastest sinking portion of the line*

The distances astern at which the weighted portion of the longline sank below 2 m depth were fairly similar between non-floated (20.9 ± 21.3 m) and floated (32.6 ± 25.8 m) longlines (Table 3), consistent with modelling results indicating no effect of longline configuration for the fasting sinking portion of the longline (Table 2). A similar comparison for the 5 m benchmark depth showed a considerably larger difference between non-floated (48.3 ± 32.6 m) and floated (123.7 ± 38.7 m) configurations. This finding was in contrast to modelling results which suggested that longline configurations did not affect sink profile at the 5 m distance astern benchmark.

3.2.2. *Slowest sinking portion of the longline*

When measured at the midpoint between weights, floated longlines sank out of the reach of albatrosses to the 2 m and 5 m benchmark depths more than twice as far astern of the vessel compared to non-floated longline (non-floated = 68.8 ± 37.8 m and 120 ± 85.4 m, respectively, floated = 157.7 ± 44.8 m and 250 ± 100 m; Table 3). These results are consistent with model results indicating that longline configuration most affected sink profile of the slowest sinking portion of the longline.

3.3. *Attack rates*

Black-footed albatrosses attacked baited hooks on floated longlines at significantly higher rates (mean = 2.7 attacks/1000 hooks, 1.05–4.95% CI) than non-floated longlines (mean = 0.20 attacks/1000 hooks, 0.05–0.40 95% CI, Welch's *t*-test, $p < 0.001$). The distribution of attacks as a function of distance astern differed between longline configurations (Fig. 4). Within the aerial extent of BSLs (< 40 m astern), black-footed albatross attacked floated longlines at higher rates (0.8 attacks/1000 hooks, 0.11–1.60 95% CI, Fig. 4) than non-floated longlines (0.08 attacks/1000 hooks, 0.00–0.22 95% CI, Fig. 4). but this difference was not significant (Welch's *t*-test, $p = 0.094$). However, beyond the aerial extent of BSLs, there were significantly more attacks (Welch's two sample *t*-test, $p = 0.036$) on floated longlines (4.67 attacks/1000 hooks, 1.48–8.90 bootstrapped 95% CI, Fig. 4) compared with non-floated longlines (0.32 attacks/1000 hooks, 0.00–0.72 bootstrapped 95% CI, Fig. 4).

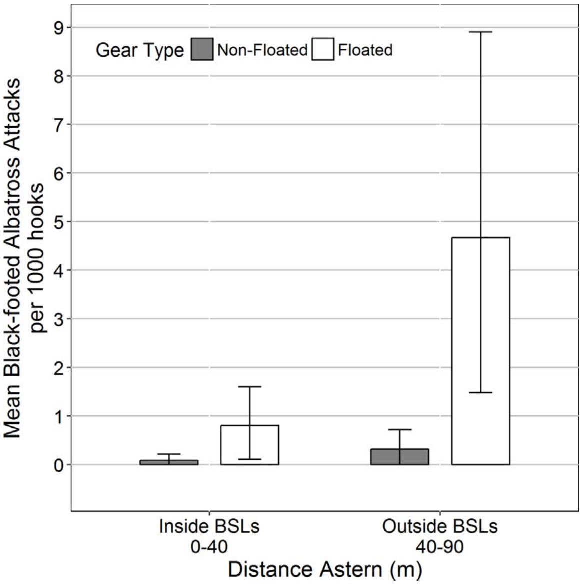

Fig. 4. Comparison of black-footed albatross attacks (mean attacks per 1000 hooks) on baited hooks inside and outside the aerial extent of BSLs, for non-floated and floated longline gear. Error bars show bootstrapped 95% confidence intervals.

3.4. *Bycatch rates in U.S. West Coast groundfish observer data*

NOAA Fisheries West Coast Groundfish Observer Program's data showed that incidental catch of albatross occurred across multiple hook-and-line sectors, but was concentrated in the limited entry sablefish longline fishery. Notably, of the 259 unique vessels observed in hook and line fisheries from 2002 to 2013, only 26 vessels had albatross bycatch. Of those, three vessels accounted for 62% of the 204 albatross takes in the observer sample. Across all sectors, albatross bycatch (the number of birds/haul) for larger vessels (≥6.8 m) was six to seven times greater than for smaller vessels (< 16.8 m). However, of the 20 vessels with the highest bycatch rates in the analysis, half of them were vessels under 55 feet long.

Retrospective analysis also showed the rate of albatross bycatch was significantly higher during daytime sets compared with night-time sets, but varied based on how night was defined (Table 4; Fig. 5). Our examination of twilight sets using sunrise/sunset, civil, nautical, and astronomical dawn and dusk revealed that albatross bycatch rates dropped dramatically after civil dusk (sun angle 6° below horizon, Fig. 5). Gulls also were taken as bycatch at a higher rate during day sets, however this difference was not significant ($p = 0.09$, Table 4). Bycatch of other seabirds did not exhibit clear diurnal patterns, with low rates of bycatch during both day and night sets (Table 4). Contrastingly, retained and discarded catch were significantly higher at night (Table 4). The average retained catch per set was more than 40% greater during night-time sets (0.61 mt) compared with day sets (0.43 mt), which has clear biological as well as statistical significance. Discarded catch was only slightly higher at night (0.27 mt) compared with day sets (0.23 mt), which was statistically significant but of questionable biological significance.

4. Discussion

4.1. *Seabird assemblage*

Black-footed albatross dominated the seabird assemblage during both gear deployment and gear retrieval, and attacked baited hooks more often than other seabird species in our study. Our observations were consistent with estimates indicating that black-footed albatross are the seabird species most commonly taken as bycatch in U.S. West

Table 4
Mean retained and discarded catch per set, and albatross bycatch rate for day sets and night sets. Daytime sets (n = 8639) were made after civil dawn and before civil dusk. Night sets (n = 1972) were made after civil dusk and before civil dawn. Significance was assessed using a non-parametric Mann–Whitney *U* test.

	Unit	Mean Day (± SE)	Mean Night (± SE)	Mann–Whitney U	P-value
Retained Catch	Metric tons	0.43 (0.006)	0.61 (0.011)	$4.96*10^6$	< 0.00001
Discarded Catch	Metric tons	0.23 (0.005)	0.27 (0.009)	$5.82*10^6$	< 0.00001
Albatross BPUE	Albatrosses per 1000 hooks	0.009 (0.001)	0.0003 (0.0002)	$7.45*10^6$	< 0.00001
Gull Bycatch BPUE	Gulls per 1000 hooks	0.002 (0.0008)	0.0002 (0.0002)	$7.36*10^6$	0.09
Fulmar BPUE	Fulmars per 1000 hooks	0.00034 (0.00025)	0.00025 (0.00025)	$7.34*10^6$	0.69
Shearwater BPUE	Shearwaters per 1000 hooks	0.0008 (0.0008)	0.00000 (0.0000)	$7.35*10^6$	0.22

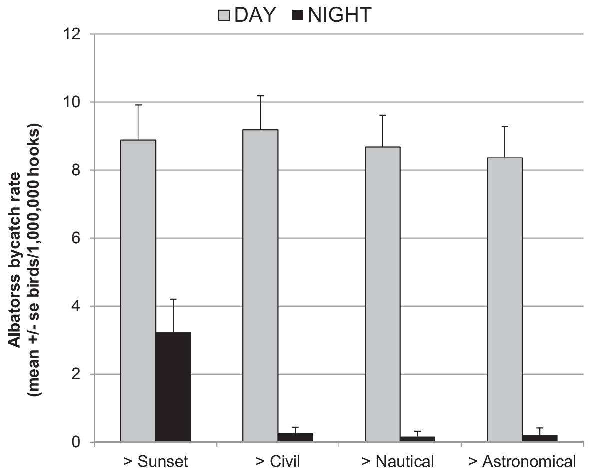

Fig. 5. Albatross bycatch rate (birds caught/1000 hooks) in sets (n = 9997) categorized as day or night where night sets were defined as those deployed after sunset or before sunrise (sun angle > 0° below horizon), after civil dusk or before civil dawn (sun angle > 6° below horizon), after nautical dusk or before nautical dawn (sun angle > 12° below horizon), and after astronomical dusk or before astronomical dawn (sun angle > 18° degrees below horizon).

Coast groundfish fishery and exhibit high spatiotemporal overlap with the sablefish fishery (Guy et al., 2013; Jannot et al., 2011, 2016). The dominance of black-footed albatrosses in the seabird assemblage during both longline setting and retrieval highlighted that, among seabirds species in our study region, black-footed albatross are at greatest risk of detrimental interaction with longline fishing gear in the sablefish fishery.

The higher seabird abundances we observed attending longline gear retrieval is consistent with other studies of demersal longline gear. Vessels move more slowly while retrieving longlines (~1 knot) compared with gear deployment speeds (~5–7 knots). Discarded bait and offal serves as an additional attractant to seabirds, which congregate around slowly moving vessels. Interactions in demersal longline fisheries are relatively uncommon during longline retrieval under normal circumstances, and generally non-lethal when they do occur. Hooks are less accessible to seabirds than during longline deployment because fishermen draw the longlines back to the vessel vertically off the bottom, therefore hooks are only briefly at the surface before they are brought onboard. Additionally, many are unavailable to seabirds because fish occupy many of the hooks. Our observations of two non-lethal interactions occurred on sets where the longline gear fouled during deployment. In these cases when hauling the fouled gear, fishermen were unable to retrieve the line vertically off the bottom, which instead trailed at the surface behind the vessel.

4.2. Sink profiles and seabird response to floated and non-floated demersal longlines

Consistent with previous studies in Alaska and elsewhere in the world, our results showed that bird-scaring lines prevent albatross attacks on non-floated demersal longlines (Dietrich et al., 2008; Gilman et al., 2005; Løkkeborg, 2011; Melvin et al., 2001). However, our findings provide evidence that BSLs alone may not adequately protect floated demersal longlines, across a range of vessel lengths. Portions of the floated demersal longlines remained near the surface well beyond the protective aerial extent of BSLs, and albatrosses responded with significantly higher attack rates. Both small and large vessels using floated demersal longlines incurred more black-footed albatross attacks than vessels using non-floated longlines. Floated longlines are at greater risk of fouling with BSLs since they remain near the surface, which can lead to damaged gear and lost fishing opportunity. While only a subset of hooks on floated longlines are available at the surface for this extended distance astern, the additional availability of baited hooks at the surface was sufficient to elicit a behavioral response from black-footed albatrosses and, presumably, other seabird species.

4.3. Reducing the risk to seabirds from non-floated demersal longlines: consider avoidance measures for small vessels

Our results suggest that vessels using non-floated demersal longlines should be able to minimize albatross bycatch by using paired BSLs, a bycatch avoidance measure recognized as "best practice" internationally in demersal longline fisheries (ACAP, 2016a). While not required at the initiation of our research, large vessels (≥55 ft) are now required to deploy paired streamer lines on the U.S. West Coast except under certain high wind conditions (NOAA Fisheries, 2015b). However, both large and small vessels take albatrosses, albeit at different rates. We requested that participating vessels in this study use two streamer lines (versus one). After consultation and training, large vessels successfully deployed BSLs during our study. However, it was more challenging to convince fishermen on small vessels to use paired BSLs because of concerns about gear fouling.

Small vessels had difficulty elevating BSLs to an adequate height and carried fewer crew members which made BSL deployment more challenging. Some vessels set at low speeds, which made optimal BSL aerial extent more difficult to achieve. While the majority of small vessels participating in our research overcame these challenges, one small vessel that set at very low speeds used a single BSL. Small vessels in Alaska face similar challenges and their efforts to develop seabird bycatch avoidance strategies provide an example of tailoring BSL specifications to smaller vessels (Melvin and Wainstein, 2006). However, further engagement with small vessels on the U.S. West Coast will ensure that BSL designs are adequately adapted to the unique fishing practices in this region.

4.4. Reducing the risk to seabirds from floated demersal longlines: longline modification and night fishing

In anticipation of the possibility that BSLs may not fully protect floated longlines, we considered longline modification and night setting as potential albatross bycatch avoidance strategies.

4.4.1. Longline modification

Longline gear modification, such as adding a dropper line between individual floats and the groundline on floated longlines, has been implemented elsewhere to overcome the delayed sink profile of floated longlines (Debski, 2016; Pierre and Goad, 2016; Pierre et al., 2013). In this gear modification, separating the float from the groundline by a few meters sinks hooks beyond the diving range of birds while the floats remain near the surface dramatically reducing seabird bycatch. However, in our experience, this gear modification might not be practical for the predominant fishing gear used in the U.S. West Coast sablefish fishery. Because the majority of vessels in this fleet prepare their gear for deployment by coiling the groundline within tubs, a dropper line would need to be coiled within the coiled groundline. Collaborating fishermen in this study were unwilling to use such an approach, citing practicality and safety concerns. It is likely that experimentation with modified longline configurations will only occur if other safe and effective mitigation measures are lacking.

4.4.2. Night fishing

Some fleet members reported that they consistently set longlines at night as part of their standard operations to avoid seabirds. This is consistent with policies for many demersal longline fisheries worldwide, for which night setting is an effective seabird deterrent strategy. Night setting gained prominence as an albatross bycatch avoidance strategy in Southern Ocean fisheries and ACAP later adopted night setting as a component of best practice seabird mitigation for both demersal and pelagic longline fisheries. However, this practice can result in unintended consequences, in some cases. For instance, night fishing is associated with increased bycatch of some sharks in pelagic longline fisheries (Bromhead et al., 2012; Petersen et al., 2009). Another concern is a decrease in fishing efficiency for target catch, which might result in a higher number of hooks deployed with a concomitant elevated risk of hooking albatrosses. In Alaskan demersal longline fisheries, significantly higher bycatch rates of seabirds at night (northern fulmars in particular, Melvin et al., 2001) as well as extremely limited hours of darkness in high latitude fisheries during boreal summer served to dissuade managers from requiring night setting as a seabird avoidance strategy. Night setting, therefore, cannot necessarily be considered best practice mitigation for all fisheries.

However, in the case of the U.S. West Coast sablefish fishery, night setting meets the criteria for a best practice seabird bycatch avoidance measure and is consistent with ecosystem-based fisheries management. Our results show that night setting reduced bycatch of albatrosses without increasing the bycatch of non-albatross seabirds, increased retained sablefish catch, and had little effect on the total amount of discarded catch. Although our evidence that night setting could be an alternative to using BSLs in this fishery, we urge wildlife and fisheries managers to continue to monitor and evaluate the relative efficacy of night setting and BSLs and to take an adaptive management approach based on the resulting information. We did not determine if the slight increase in fish bycatch consisted of constraining stocks or other species of concern and were unable to evaluate the effect of night vs. day setting for floated versus non-floated demersal longlines, as data on longline configuration were unavailable. Given that both floated and non-floated demersal longlines were present in the fishery in roughly equal proportions, we infer that night setting could be an effective mitigation strategy for both gear types, if applied to this fishery.

4.5. Data limitations

There are limitations to our inference from this research. First, the observation period of attack rates varied. For 11 sets, we observed for 10 min at the start of the set, while we observed for the full gear deployment period during the remaining 22 sets. Because the intensity of seabird foraging behavior during longline sets can be influenced by the success of other seabirds feeding on baits (Melvin et al., 2014), it is possible that the attack rates at the start of the set were less than attack rates near the end of the set. The shorter, 10 min observation periods occurred on vessels using both floated and non-floated longline gear, and therefore we think it is unlikely that this affected our overall results or interpretation. Second, it is important to recognize that we examined a surrogate measure (black-footed albatross attacks) of one aspect of bycatch risk (hooking during longline deployment). Other types of interactions, such as non-lethal hooking during longline retrieval and albatrosses feeding on discarded baits, catch and offal may also be important to albatross bycatch avoidance but were outside the scope of our research.

4.6. Collaborative problem solving and targeted outreach

Rushing to implement regulations is a recognized roadblock to developing seabird bycatch avoidance best practices (Melvin and Parrish, 2001) and our results highlight the potential pitfalls of transferring bycatch deterrence regulations from one regional fleet to another, even when fishing for the same species using similar vessels. We demonstrated that BSL performance standards adopted from Alaska sablefish demersal longline fisheries were not adequate for preventing seabird bycatch for a unique gear type used by some vessels along the U.S. West Coast. Others have experienced similar challenges in transferring seabird bycatch mitigation strategies across different fisheries or geographic areas. For instance, underwater setting devices showed early promise when tested in Hawaiian pelagic tuna fleets (Gilman et al., 2003), but were not successful at reducing bycatch in Australian pelagic longline fisheries because of differences in the seabird assemblage (Brothers et al., 2000) and have ultimately remained unproven and not recommended as best practice (ACAP, 2016c).

Fishermen have experience that can inform the development of successful bycatch avoidance approaches through collaborative research (Gilman et al., 2005). Additionally, researchers and managers can support successful implementation of bycatch avoidance strategies through early and continuous engagement with fleet members (Cox et al., 2007). We collaborated with fishermen to evaluate potential strategies that might reduce the risk that floated demersal longlines pose to seabirds, with the goal of recommending best practice mitigation (as defined by ACAP, 2016b; Melvin et al., 2014) for the U.S. West Coast demersal longline fleet. We worked to develop collaborations and knowledge exchange between fishermen, managers, and researchers through numerous one-on-one contacts and a total of 25 visits to 13 U.S. West Coast ports. Although time consuming, these outreach efforts were essential to gain insights on the feasibility of potential bycatch mitigation strategies, and resulted in adoption of bycatch avoidance strategies by the fleet prior to regulatory action. We found that the majority of the impact to albatrosses comes from a minority of vessels, and therefore future outreach and engagement targeted toward vessels with higher encounter rates has the potential to have an appreciable impact on the reduction of seabird bycatch in this fleet.

Vessel- and region-specific differences, as well as the evolution of gear modifications are important to identify and track in fisheries over time. Ongoing information collection on bycatch rates, the factors driving albatross bycatch, the evolution of longline configurations, and shifts in fishing practices will be required for adaptive management to reduce albatross bycatch to the lowest levels possible in this fishery. The West Coast Groundfish Observer Program has been collecting detailed data on longline vessel gear characteristics and configurations and seabird mitigation practices since 2015. These data will allow for evaluation of the effectiveness of our suggested mitigation strategies (BSLs and night setting) and ongoing, adaptive improvement of seabird avoidance measures to minimize the total estimates and rates of bycatch of rare, ESA-listed seabirds as well as seabird bycatch overall.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2017.08.015.

References

ACAP, 2016a. ACAP Summary advice for reducing impact of demersal longlines on seabirds. In: Reviewed at the Ninth Meeting of the Advisory Committee. La Serena, Chile 9–13 May 2016. . https://acap.aq/en/bycatch-mitigation/mitigation-advice/198-acap-review-of-mitigation-measures-and-summary-advice-for-reducing-the-impact-of-demersal-longlines-on-seabirds/file.

ACAP, 2016b. Best practice bycatch mitigation criteria and definition. In: Reviewed at the Ninth Meeting of the Advisory Committee. La Serena, Chile 9–13 May 2016. . https://acap.aq/en/bycatch-mitigation/mitigation-advice/2595-acap-best-practice-seabird-bycatch-mitigation-criteria-and-definition/file.

ACAP, 2016c. Report of seabird bycatch working group. In: Ninth Meeting of the Advisory Committee. La Serena, Chile 9–13 May 2016. . https://acap.aq/en/advisory-committee/ac9/ac9-meeting-documents/2836-ac9-doc-10-report-of-seabird-bycatch-working-group/file.

Anderson, O.R.J., Small, C.J., Croxall, J.P., Dunn, E.K., Sullivan, B.J., Yates, O., Black, A., 2011. Global seabird bycatch in longline fisheries. Endanger. Species Res. 14, 91–106. http://dx.doi.org/10.3354/esr00347.

Bates, D., Machler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Software 67, 1–48. http://dx.doi.org/10.18637/jss.v067.i01.

Bivand, R., Lewin-Koh, N., 2017. Maptools: Tools for Reading and Handling Spatial Objects. R Package Version 0. 9-2. https://CRAN.R-project.org/package = maptools.

Bivand, R.S., Pebesma, E.J., Gomez-Rubio, V., 2013. Applied Spatial Data Analysis with R, second edition. Springer, NY ISBN 978-1-4614-7618-4.

Bromhead, D., Clarke, S., Hoyle, S., Muller, B., Sharples, P., Harley, S., 2012. Identification of factors influencing shark catch and mortality in the Marshall Islands tuna longline fishery and management implications. J. Fish Biol. 80, 1870–1894. http://dx.doi.org/10.1111/j.1095-8649.2012.03238.x.

Brothers, N., Gales, R., Reid, T., 1999. The influence of environmental variables and mitigation measures on seabird catch rates in the Japanese tuna longline fishery within the Australian Fishing Zone, 1991–1995. Biol. Conserv. 88, 85–101. http://dx.doi.org/10.1016/S0006-3207(98)00085-8.

Brothers, N., Chaffey, D., Reid, T., 2000. Performance Assessment and Performance Improvement of Two Underwater Line Setting Devices for Avoidance of Seabird Interactions in Pelagic Longline Fisheries. Marine Conservation Unit, Resource Management and Conservation, Department of Primary Industry, Water and Environment, P.O. Box 44A, Hobart 7000, Tasmania, Australia. https://bmis.eightyoptions.com.au/system/files/zotero_attachments/library_1/FU33FWU6%20-%20Brothers%20et%20al%202000%20AFMA%20line%20setting.pdf.

Brothers, N., 1991. Albatross mortality and associated bait loss in the Japanese longline fishery in the Southern Ocean. Biol. Conserv. 55, 255–268.

Butchart, S.H.M., Stattersfield, A.J., Bennun, L.A., Shutes, S.M., Akçakaya, H.R., Baillie, J.E.M., Stuart, S.N., Hilton-Taylor, C., Mace, G.M., 2004. Measuring global trends in the status of biodiversity: red list indices for birds. PLoS Biol. 2, e383. http://dx.doi.org/10.1371/journal.pbio.0020383.

Canty, A., Ripley, B., 2014. Boot: Bootstrap R (S-Plus) Functions. R package, 1. 3–13 ed.

Cortés, V., Arcos, J.M., González-Solís, J., 2017. Seabirds and demersal longliners in the northwestern Mediterranean: factors driving their interactions and bycatch rates. Mar. Ecol. Prog. Ser. 565, 1–16. http://dx.doi.org/10.3354/meps12026.

Cox, T.A., Lewison, R.L., Žydelis, R., Crowder, L.B., Safina, C., Read, A.J., 2007. Comparing effectiveness of experimental and implemented bycatch reduction measures: the ideal and the real. Conserv. Biol. 21, 1155—1164. http://dx.doi.org/10.1111/j.1523-1739.2007.00772.x.

Croxall, J.P., Butchart, S.H.M., Lascelles, B., Stattersfield, A.J., Sullivan, B., Symes, A., Taylor, P., 2012. Seabird conservation status, threats and priority actions: a global assessment. Bird Conserv. Int. 22, 1—34. http://dx.doi.org/10.1017/S0959270912000020.

Davison, A.C., Hinkley, D.V., 1997. Bootstrap Methods and Their Applications. Cambridge University Press, Cambridge ISBN 0-521-57391-2.

Debski, I., 2016. Characterisation of subsurface float configurations used by New Zealand small vessel demersal longliners. In: Seventh Meeting of the Seabird Bycatch Working Group. La Serena, Chile 9–13 May 2016. . https://acap.aq/en/documents/working-groups/seabird-bycatch-working-group/seabird-bycatch-wg-meeting-7/sbwg7-information-papers/2710-sbwg7-inf-02-characterisation-of-subsurface-float-configurations-used-by-new-zealand-small-vessel-demersal-longliners/file.

Dietrich, K.S., Melvin, E.F., Conquest, L.L., 2008. Integrated weight longlines with paired streamer lines—best practice to prevent seabird bycatch in demersal longline fisheries. Biol. Conserv. 141, 1793–1805. http://dx.doi.org/10.1016/j.biocon.2008.04.023.

Doya, C., Aguzzi, J., Pardo, M., Matabos, M., Company, J.B., Costa, C., Mihaly, S., Canals, M., 2014. Diel behavioral rhythms in sablefish (Anoplopoma fimbria) and other benthic species, as recorded by the Deep-sea cabled observatories in Barkley canyon (NEPTUNE-Canada). J. Mar. Sys. 130, 69–78. http://dx.doi.org/10.1016/j.jmarsys.2013.04.00.

Fernández, P., Anderson, D.J., 2000. Nocturnal and diurnal foraging activity of Hawaiian albatrosses detected with a new immersion monitor. Condor 102, 577–584. http://dx.doi.org/10.1650/0010-5422(2000)102[0577:NADFAO]2.0.CO;2.

Gilman, E., Brothers, N., Kobayashi, D.R., Martin, S., Cook, J., Ray, J., Ching, G., Woods, B., 2003. Performance Assessment of Underwater Setting Chutes, Side Setting, and Blue-dyed Bait to Minimize Seabird Mortality in Hawaiian Longline Tuna and Swordfish Fisheries. National Audubon Society, Hawaiian Longline Association, U.S. National Marine Fisheries Service Pacific Islands Science Center, U.S. Western Pacific Regional Fishery Management Council, Honolulu, Hawaii p. vi + 42. http://citeseerx.ist.psu.edu/viewdoc/download?doi = 10.1.1.164.3396&rep = rep1&type = pdf.

Gilman, E., Brothers, N., Kobayashi, D.R., 2005. Principles and approaches to abate seabird bycatch in longline fisheries. Fish and Fish. 6, 35—49. http://dx.doi.org/10.1111/j.1467-2679.2005.00175.x.

Good, T.P., Tuttle, V., Jannot, J., Shama, R., Riley, N., McVeigh, J., 2015. Observed and Estimated Bycatch of Short-tailed Albatross in U.S. West Coast Groundfish Fisheries 2010–2013. Northwest Fisheries Science Center, Conservation Biology Division, 2725 Montlake Boulevard East, Seattle Washington 98112. http://www.pcouncil.org/wp-content/uploads/2015/06/D4_Sup_Att5_Bycatch_Rpt_short-tailed-albatross_E-ONLY_JUN2015BB.pdf.

Guy, T.J., Jennings, S.L., Suryan, R.M., Melvin, E.F., Bellman, M.A., Ballance, L.T., Blackie, B.A., Croll, D.A., Deguchi, T., Geernaert, T.O., Henry, R.W., Hester, M., Hyrenbach, K.D., Jahncke, J., Kappes, M.A., Ozaki, K., Roletto, J., Sato, F., Sydeman, W.J., Zamon, J.E., 2013. Overlap of North Pacific albatrosses with the U.S. west coast groundfish and shrimp fisheries. Fish. Res. 147, 222–234. http://dx.doi.org/10.1016/j.fishres.2013.06.009.

Hart, T.D., Clemons, J.E.R., Wakefield, W.W., Heppell, S.S., 2010. Day and night abundance, distribution, and activity patterns of demersal fishes on Heceta Bank, Oregon. Fish. Bull. 108, 466–477.

Hodum, P.J., Shaffer, S.A., 2006. Pink-footed Shearwater Movement and Dive Behavior. University of Puget Sound, Tacoma, WA and San Jose State University, San Jose, CA Unpublished raw data.

IUCN, 2016. The IUCN Red List of Threatened Species. Version 2016-3. http://www.iucnredlist.org/.

Jannot, J., Heery, E., Bellman, M.A., Majewski, J., 2011. Estimated bycatch of marine mammals, seabirds, and sea turtles in the US West Coast commercial groundfish fishery, 2002–2009, In: West Coast Groundfish Observer Program. National Marine Fisheries Service, N. (Ed.), 2725 Montlake Blvd E., Seattle, WA 98112. https://www.nwfsc.noaa.gov/research/divisions/fram/observation/pdf/mmsbt_report02-09.pdf.

Jannot, J.E., Tuttle, V., Somers, K.S., Lee, Y.-W., McVeigh, J., 2016. Marine Mammal, Seabird, and Sea Turtle Summary of Observed Interactions, 2002–2014. Fisheries Observation Science, Fishery Resource Analysis and Monitoring Division, Northwest Fisheries Science Center, NOAA, Seattle, WA. https://www.nwfsc.noaa.gov/research/divisions/fram/documents/MMSBT_AnnSum_Website.pdf.

Løkkeborg, S., 2011. Best practices to mitigate seabird bycatch in longline, trawl and gillnet fisheries-efficiency and practical applicability. Mar. Ecol. Prog. Ser. 435, 285–303. http://dx.doi.org/10.3354/meps09227.

Lewison, R.L., Crowder, L.B., 2003. Estimating fishery bycatch and effects on a vulnerable seabird population. Ecol. Appl. 13, 743–753. http://dx.doi.org/10.1890/1051-0761(2003)013[0743:EFBAEO]2.0.CO;2.

Lewison, R.L., Crowder, L.B., Read, A.J., Freeman, S.A., 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol. Evol. 19, 598–604. http://dx.doi.org/10.1016/j.tree.2004.09.004.

Mallory, M.L., Hatch, M.A., Nettleship, D.N., 2012. Northern fulmar (*Fulmaris glacialis*). In: Poole, A. (Ed.), The Birds of North America Online. Cornell Lab of Ornithology, Ithaca. https://birdsna.org/Species-Account/bna/species/norful.

Melvin, E.F., Parrish, J.K., 2001. Symposium Synthesis, Seabird Bycatch: Trends, Roadblocks, and Solutions. University of Alaska Sea Grant. AK-SG-01-01. http://bmis.wcpfc.int/docs/references/Lokkeborg_2001_Reducing_seabird_bycatch_PLL_by_bird-scaring_lines_underwater_setting.pdf.

Melvin, E.F., Wainstein, M.D., 2006. Seabird Avoidance Measures for Small Alaskan Longline Vessels. Washington Sea Grant Program. Project A/FP-7. https://wsg.washington.edu/wordpress/wp-content/uploads/publications/Seabird-Avoidance-

Small-Vessels.pdf.

Melvin, E.F., Parrish, J.K., Dietrich, K.S., Hamel, O.S., 2001. Solutions to Seabird Bycatch in Alaska's Demersal Longline Fisheries. Washington Sea Grant Program. Project A/FP-7. WSG-AS 01-01. https://wsg.washington.edu/wordpress/wp-content/uploads/publications/Solutions-to-seabird-bycatch-in-Alaska's-demersal-longline-fisheries.pdf.

Melvin, E.F., Sullivan, B., Robertson, G., Wienecke, B., 2004. A Review of the effectiveness of streamer lines as a seabird by-catch mitigation technique in longline fisheries and CCAMLR streamer line requirements. CCAMLR Sci. 11, 189—201.

Melvin, E.F., Dietrich, K.S., Fitzgerald, S.M., Cardoso, T., 2011. Reducing seabird strikes with trawl cables in the pollock catcher-processor fleet in the eastern Bering Sea. Polar Biol. 34, 215–226. http://dx.doi.org/10.1007/s00300-010-0873-1.

Melvin, E.F., Guy, T.J., Read, L.B., 2014. Best practice seabird bycatch mitigation for pelagic longline fisheries targeting tuna and related species. Fish. Res. 149, 5–18. http://dx.doi.org/10.1016/j.fishres.2013.07.012.

NOAA Fisheries, 2015a. Pacific Coast Fisheries Permit System. NOAA Fisheries, West Coast Regional Office. https://www.webapps.nwfsc.noaa.gov/apex/ifq/f?p=112:23.

NOAA Fisheries, 2015b. Public Notice: Pacific Coast Groundfish Fishery Implementation of Seabird Avoidance Program, NMFS-SEA-15-28, Seattle, Washington. http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/groundfish/public_notices/nmfs-sea-15-28.

Pebesma, E.J., Bivand, R.S., 2005. Classes and Methods for Spatial Data in R. R News 5. https://cran.r-project.org/doc/Rnews/Rnews_2005-2.pdf.

Petersen, S.L., Honig, M.B., Ryan, P.G., Underhill, L.G., Compagno, L.J., 2009. Pelagic shark bycatch in the tuna- and swordfish-directed longline fishery off southern Africa. Afr. J. Mar. Sci. 31, 215–225. http://dx.doi.org/10.2989/AJMS.2009.31.2.9.881.

Phillips, R.A., 2013. Requisite improvements to the estimation of seabird by-catch in pelagic longline fisheries. Anim. Conserv. 16, 157—158. http://dx.doi.org/10.1111/acv.12042.

Pierre, J.P., Goad, D.W., 2016. Conservation Services Programme Project MIT-02: Improving Tori Line Performance in Small-Vessel Longline Fisheries. Department of Conservation, Wellington, NZ, pp. 35. http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservation-services/reports/mit2014-02-toriline.pdf.

Pierre, J.P., Goad, D.W., Thompson, F.N., Abraham, E.R., 2013. Reducing seabird bycatch in bottom-longline fisheries. Final Research Report for Department of Conservation Projects MIT2011-03 and MIT2012-01. pp. 59. https://files.dragonfly.co.nz/publications/pdf/Pierretal_2013_reducing-seabird-bycatch.pdf.

R Development Core Team, 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria ISBN 3-900051-07-0. http://www.R-project.org/.

Robertson, G.G., 2000. Effect of line sink rate on albatross mortality in the Patagonian toothfish longline fishery. CCAMLR Sci. 7, 133—150.

Seco Pon, J.P., Gandini, P.A., Favero, M., 2007. Effect of longline configuration on seabird mortality in the Argentine semi-pelagic Kingclip Genypterus blacodes fishery. Fish. Res. 85, 101–105. http://dx.doi.org/10.1016/j.fishres.2007.01.002.

Sievert, P.R., Hasegawa, H., 2016. Deterministic Population Model for the Short-tailed Albatross (*Phoebastria albatrus*). USGS – Massachusetts Cooperative Fish and Wildlife Research Unit, Amherst, MA and Toho University, Chiba, Japan Unpublished raw data.

Somers, K.A., Jannot, J.E., Hastie, J., Lee, Y.W., McVeigh, J., Whitmire, C.E., 2015. Fishing Effort in the 2002–2013. U.S. Pacific Coast Groundfish Fisheries. West Coast Groundfish Observer Program. National Marine Fisheries Service, NWFSC, 2725 Montlake Blvd E., Seattle, WA 98112. http://www.pcouncil.org/wp-content/uploads/2015/06/D4_Sup_Att1_BO_FishingEffortRpt_E-ONLY_JUN2015BB.pdf.

Stelle, W.J., 2013. Measures to Minimize the Take of Short-Tailed Albatross in the Pacific Coast Groundfish Fisheries Including the Environmental Assessment (EA) and Initial Regulatory Flexibility Analysis (IRFA). NOAA Fisheries, Northwest Regional Office, Seattle, WA. http://www.pcouncil.org/wp-content/uploads/H1b_DraftEA_NOV2013BB.pdf.

Suryan, R.M., Dietrich, K.S., Melvin, E.F., Balogh, G.R., Sato, F., Ozaki, K., 2007. Migratory routes of short-tailed albatrosses: use of exclusive economic zones of North Pacific Rim countries and spatial overlap with commercial fisheries in Alaska. Biol. Conserv. 137, 450–460. http://dx.doi.org/10.1016/j.biocon.2007.03.015.

Taylor, G.A., 2008. Maximum dive depths of eight New Zealand Procellariiformes, including *Pterodroma* species. Pap. Proc. R. Soc. Tasmania 142, 89–97 ISSN 0080-4703.

USFWS, 2008. Birds of Conservation Concern 2008. Division of Migratory Bird Management, Arlington, VA, pp. 93. https://www.fws.gov/migratorybirds/pdf/management/BCC2008.pdf.

USFWS, 2012. Biological Opinion Regarding the Effects of the Continued Operation of the Pacific Coast Groundfish Fishery as Governed by the Pacific Coast Groundfish Fishery Management Plan and Implementing Regulations at 50 CFR Part 660 by the National Marine Fisheries Service on California Least Tern (*Sterna antillarum browni*), Southern Sea Otter (*Enhydra lutris nereis), Bull trout (Salvelinus confluentus*), Marbled Murrelet (*Brachyramphus marmoratus*), and Short-tailed Albatross (*Phoebastria albatrus*). U.S. Fish and Wildlife Ecological Services Office, Portland, Oregon. https://www.st.nmfs.noaa.gov/Assets/nationalseabirdprogram/pcgf_biop1112.pdf.

USFWS, 2014. Short-Tailed Albatross Endangered Species Recovery Plan: 5-Year Review. U.S. Fish and Wildlife Service, 4700 BLM Road, Anchorage, AK, pp. 43. https://ecos.fws.gov/docs/five_year_review/doc4445.pdf.

Weimerskirch, H., Brothers, N., Jouventin, P., 1997. Population dynamics of wandering albatross *Diomedea exulans* and Amsterdam albatross *D. amsterdamensis* in the Indian Ocean and their relationships with long-line fisheries: conservation implications. Biol. Conserv. 79, 257—270. http://dx.doi.org/10.1016/S0006-3207(96)00084-5.