Exempted and Research Deep-Set Fishing Trials for Swordfish, *Xiphias gladius,* in the Southern California Bight, 2017–21

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Introduction

This work reports on the second phase of gear development research and exempted fishing trials for swordfish, *Xiphias gladius*, using deep-set fishing techniques within the Southern California Bight (SCB). Following recommendation from the Pacific Fisheries Management Council (PFMC), NOAA's National Marine Fisheries Service (NMFS) issued an exempted fishing permit (EFP) to the Pfleger Institute of Environmental Research (PIER) in August 2015 to test the use of an artisanal gear type designed to selectively target swordfish below the thermocline during the day (Sepulveda et al., 2014).

The initial EFP application included up to five independent cooperative fishing vessels and allowed them to target swordfish using deep-set buoy gear (DSBG), a hook and line gear type that was developed by PIER for targeting swordfish in the SCB (Sepulveda et al., 2014; Sepulveda and Aalbers, 2018). Cooperative fishermen selected for the EFP trials were chosen based on past experience level, willingness to participate in the research trials, and availability during the California swordfish season (August–December). Average experience level of the selected EFP participants using either harpoon or driftnet gear types was >18 yr.

During 2015–16, the first phase of exempted trials yielded relatively high selectivity for swordfish (>80%) with marketable catch making up > 98% of total landings (Sepulveda and Aalbers, 2018). Catch rates during the initial study were shown to increase over the course of the EFP, with an overall average of 1.75 swordfish/std. 8-h day. Additionally, the early EFP efforts reported a higher price-point received for deep-set landed swordfish compared to other concurrent domestic and foreign sourced product (i.e., drift gillnet, longline; Sepulveda and Aalbers, 2018; PFMC, 2020). Findings from the first 2 yr of EFP fishing effort were reported to NOAA (PFMC[1]) and published in Sepulveda and Aalbers (2018).

In 2017, PIER submitted a subsequent EFP application to test the use of linked buoy gear (LBG), a modified configuration of DSBG that retains serviceability but also connects all buoys, weights, and baited gangions to a single mainline (Fig. 1a; Aalbers et al., 2021). Following approval of the LBG EFP in September 2018, three cooperative fishermen were permitted to use both DSBG and LBG interchangeably, given that both gear configurations: 1) showed similar catch composition during research trials, 2) targeted similar depths, 3) incorporated active tending and strike indication, and 4) allowed for a maximum of 30 baited hooks per set (Fig 1a). Because both DSBG and LBG were new gear types that cooperative fishermen had not used previously, an effort was made to offer the EFP team flexibility on the simultaneous use of DSBG and LBG, so long as no more than 10 pieces of either DSBG or LBG were de-

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doi: https://doi.org/10.7755/MFR.84.3-4.3

[1]National Oceanic and Atmospheric Administration. 2019. (Avail. at https://www.federalregister.gov/documents/2019/03/04/2019-03493/fisheries-off-west-coast-states-highly-migratory-fisheries-amendment-6-to-fishery-management-plan, and accessed 10 May 2022.

ABSTRACT—This work reports on exempted and research fishing trials using Deep-set Buoy Gear (DSBG) and Linked Buoy Gear (LBG), two commercial gear types designed to target swordfish, Xiphias gladius, *off the coast of southern California. This study covers the period from 2017 to 2021 and supplements previous published data on the development and initial exempted fishing permit (EFP) trials of deep-set techniques for swordfish within the Southern California Bight (SCB; 2015–16). In this work, five cooperative EFP participants deployed 12,015 pieces of DSBG on 1,225 sets during 299 individual trips (mean=4.1 d/trip). DSBG catch composition was found to be similar to previously published data obtained from the first 2 years of exempted effort, with swordfish comprising ~94% of the total catch from 2017 to 2021. DSBG non-marketable catch (bycatch) primarily consisted of blue sharks and made up ~1% of the DSBG catch. Collective DSBG catch rates ranged from 1.2 to 2.1 swordfish per standardized 8-h fishing day (mean =1.7 swordfish/std. 8-h day) over the course of this study. Commercial exempted testing of LBG resulted in similar swordfish catch composition (~92%) and average daily catch rates (1.5–1.7 swordfish/std. 8-h day), with fewer overall species caught. Research sets using LBG yielded similar catch composition to DSBG and included a wider range of species than the exempted trials. The findings from this work align with previous exempted and research efforts using both DSBG and LBG and continue to suggest high selectivity in the developing California deep-set fishery for swordfish.*

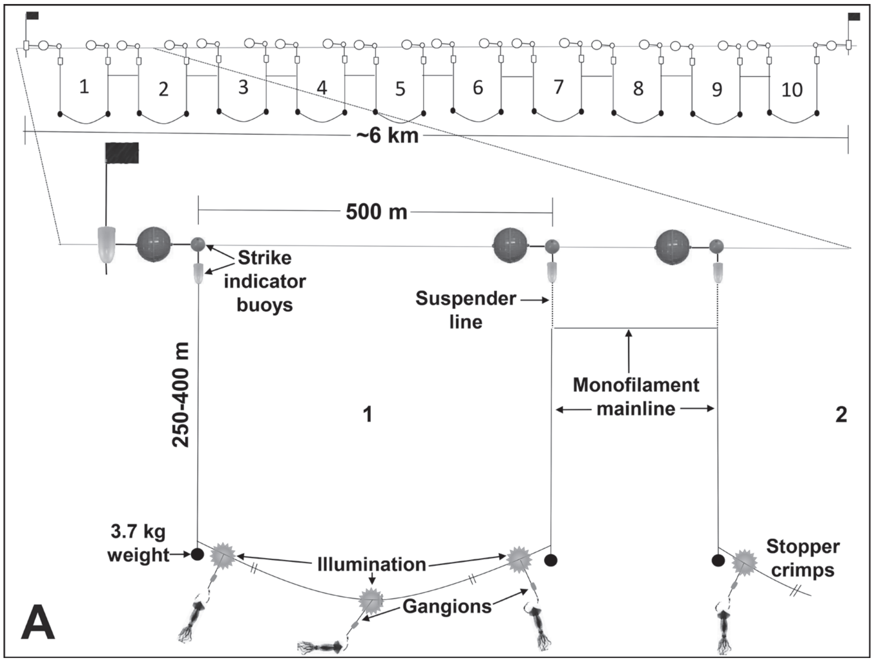

Figure 1a.—Diagram of the linked-buoy gear (LBG) configuration developed by PIER using up to 10 sections of monofilament mainline suspended from strike indicator buoys with heavy weights to descend baited hooks to depths exceeding 300 m.

ployed on a single day (i.e., 30-hook maximum).

During the DSBG and LBG exempted trials, concurrent research sets were performed from the PIER research vessel *Malolo* to further improve gear performance, train cooperative fishermen on its use, and conduct swordfish tagging and population dynamics research[2] (Sepulveda et al., 2019a; Griffiths et al., 2020). Collective catch and effort data from initial research and EFP trials were summarized to better inform NMFS and the PFMC prior to the preliminary authorization of DSBG and LBG in 2019 (Sepulveda and Aalbers, 2018).

This work reports on the results from exempted testing using both DSBG and LBG during the 2017–21 swordfish seasons as well as concurrent deep-set research trials performed from 2015 to 2022. The collective data sets are provided to further inform managers and stakeholders on catch rates, selectivity, and market trends for deep-set gear configurations targeting swordfish within the SCB.

Methods

Study Location and Permitting

Catch and effort statistics were summarized across five fishing seasons (2017–21) from up to six commercial vessels operating concurrently under a Highly Migratory Species (HMS) Exempted Fishing Permit (EFP) issued by NMFS. This work reports on two independent EFP's that were issued to PI Sepulveda and managed by PIER (PIER DSBG-EFP[3] and PIER LBG EFP[4]). The DSBG EFP included five vessels while the LBG EFP included four. Although the PIER DSBG-EFP was approved in 2015, this study reports on EFP activity since 2017, with findings from the initial two seasons of DSBG trials summarized by Sepulveda and Aalbers (2018).

All DSBG and LBG deployments, gear rigging, and set protocols followed the mandates outlined in the terms and conditions of the PIER DSBG and LBG EFP's and aligned with those described in Sepulveda and Aalbers (2018). EFP fishing was permitted to occur from the Oregon/Washington border (seaward off the coast at lat. 46.25°N) south to the Mexican border, excluding state waters off California (i.e., 3 nmi from the mainland and Channel Islands). All fishing occurred during daylight hours with gear haul-back initiated by sunset. Deep-set gear development and research trials were conducted under a NOAA Letter of Acknowledgment issued through the NMFS West Coast Regional Office (WCR) and a California Department of Fish and Wildlife (CDFW) Scientific Collection Permit (SCP-2471 and S-183330009-19106-001). PIER research trials were performed alongside cooperative fishermen operating under both DSBG and LBG EFP's, with catch being tagged and released (i.e., research catch was not sold and did not contribute to EFP landings).

Cooperative Fisherman Selection

Cooperative fishermen participating in the PIER EFP's were chosen based upon a selection rubric described in Sepulveda and Aalbers (2018). Briefly, parameters such as availability during the primary season (July–Dec.), previous swordfish experience, as well as willingness to cooperate and work as a unit were considered. Similarly, all cooperative fishermen needed to have valid permits, a violation-free history, and be willing to carry observers upon request. As described by Sepulveda and Aalbers (2018), the EFP manager (PI Sepulveda) was held equally liable and responsible for the actions of the EFP participants.

DSBG

The DSBG design and gear configuration used from 2017 to 2021 did not vary from that described during the first phase of the EFP trials (Sepulveda and

[2]National Oceanic and Atmospheric Administration (NOAA) Saltonstall-Kennedy Program (Grant # NA16NMF4270257; California Ocean Protection Council Grant # R/OPCSFAQ-07 issued through the Sea Grant College Program).

[3]Sepulveda, C. A. 2015. (Avail. at https://www.pcouncil.org/documents/2015/03/agenda-item-h-3-a-attachment-2.pdf/, and accessed 11 May 2022.

[4]Sepulveda, C. A. 2016. (Avail. at https://www.pcouncil.org/documents/2016/11/agenda-item-i-4-supplemental-attachment-1-pier-efp.pdf/, and accessed 11 Mar. 2022).

Aalbers, 2018). All EFP participants were provided identical gear sets that were designed and constructed by the EFP manager. Gear sets were measured to the nearest meter to ensure comparable rigging and performance. As described previously, all gear sets were designed to fish below the upper mixed layer with a set of crimps positioned at 90 m down the vertical mainline to demarcate the minimum hook depth.

Gear sets were designed to target depths between 250 and 350 m, with a maximum of 3 hooks per individual piece of gear and a maximum of 10 individual pieces deployed at one time (maximum of 30 hooks soaking simultaneously). Gangions were ~8 m long and constructed of 1.8–2.2 mm monofilament leader terminating with an 18/0 circle hook (Mustad model 39960DT)[5]. Battery-operated illumination (i.e., Power Light, SNL Corp., Fla.) was provided with fishermen given the choice of colors to be used (most deployments used either green or blue). Cooperative fishermen were also given the option to use either squid (*Illex* spp.) or finfish bait (i.e., chub mackerel, *Scomber japonicas;* saury or sanma*, Cololabis saira*). Although bait type was not logged for all EFP trips, *Illex* squid was predominantly used for bait on nearly all (>95%) DSBG sets.

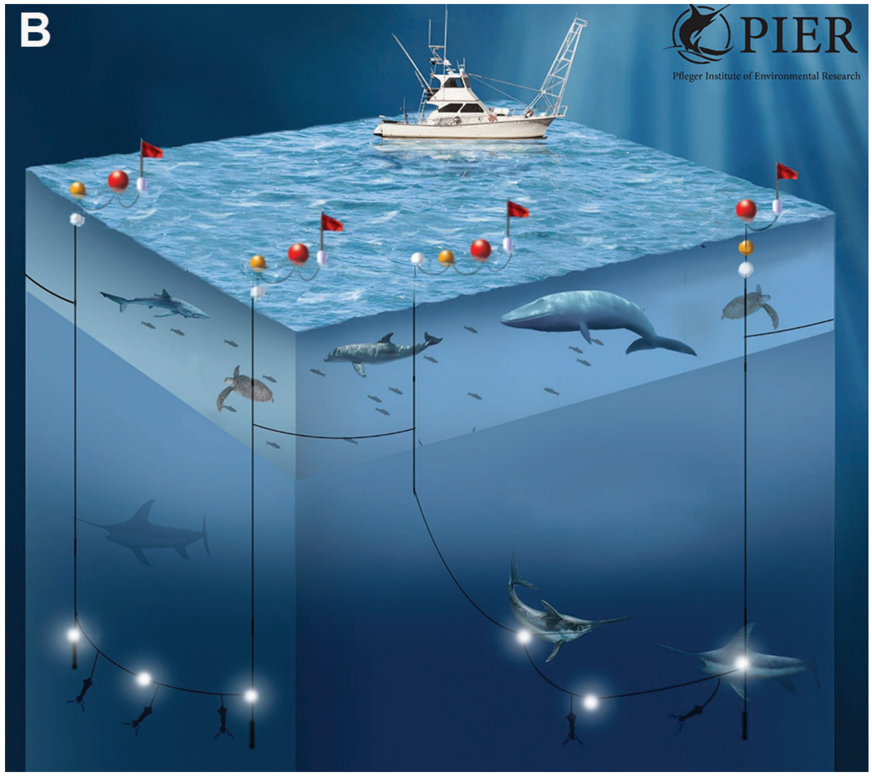

Figure 1b.—Graphic depicting LBG suspended within the water column as designed to selectively target swordfish at depth during the daytime based on swordfish tagging data along southern California.

LBG

LBG design and construction was consistent across research and cooperative vessels, with all sets measured and built by the research team. As described previously by Aalbers et al. (2021), LBG sets consisted of up to 10 serviceable sections with fishermen given the option on how many sections they deploy daily (Fig. 1b). Each section used two 3.6 kg descending weights to expedite the sink rate of the monofilament mainline (2.8–3.2 mm) to a target depth between 250 and 400 m. Monofilament mainline was deployed from a hydraulic powered longline spool (super mini spool-28; Lindgren-Pittman, Pompano, Fla.) and all EFP sets included the use of a hydraulic line setter to further increase gear sink rates (LS-5, Lindgren-Pittman, Pompano, Fla.).

For each section, the vertical legs were suspended by a set of strike indicator buoys that were used on each end to signal when something was on the line, tethered to a ~15 m (≥50-ft suspender) monofilament suspender line (Fig. 1b; Sepulveda et al., 2019a; Aalbers et al., 2021). Upon visual detection of a strike, specific sections could be individually serviced using a hydraulic line puller (Pelagic Performance, San Diego, Calif.), and the section could be subsequently re-deployed with a fresh bait and reconnected to the mainline. Similar to DSBG, a maximum of 30 hooks per set (18/0 Mustad 39960D circle hooks) were baited with either squid or mackerel, with up to three gangions per section of LBG. In line with the DSBG deployments, gangions were ~8 m and outfitted with an illumination source and a 45 g swivel positioned ~2 m from the hook to expedite sink rate and reduce tangling upon retrieval.

Observation and EFP Monitoring

From 2017 to 2021, field observation of EFP activity was conducted through the NMFS WCR assigned contractor, Frank Orth and Associates (FOA, Long Beach, Calif.). EFP observer placement was managed by the WCR and FOA observer coordinator. Because DSBG demonstrated minimal bycatch and protected-species interactions during initial research (Sepulveda et al., 2014) and EFP trials (Sepulveda and Aalbers, 2018), NMFS maintained a lower observer coverage mandate on DSBG trips than for LBG. LBG trips required higher observation rates due

[5]Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA

to the additional entanglement risk perceived by the NMFS Protected Resource Division (PRD). All EFP participants were required to notify PIER, NMFS, CDFW, and the FOA coordinator prior to each trip departure for determination of observer placement. Other considerations for carrying an observer included mandatory placement if drift gillnet gear was going to be fished on the same fishing trip.

In addition to physical monitors, vessels were also required to fill out logbook entries for every set made during the EFP and also comply with both a daily and trip level check-in and check-out procedure, as described by Sepulveda and Aalbers (2018). For all EFP activities, logbooks were collected monthly and analyzed by the PIER team independent of PFMC and WCR EFP assessments. All catch was collectively recorded using traditional CDFW landing receipts, logbook records, and daily fishing reports. Additionally, all swordfish landed by the PIER EFP group were tracked with traceability tags that were affixed near the collar of each fish. The traceability tags used a unique identification number, gear code, and vessel name that could be verified on the PIER website.

EFP Deployment Protocols

Cooperative fishermen were allowed the flexibility to deploy deep-set gear anywhere outside of California state waters (>3 nmi from the coastline or Channel Islands), as long as sets complied with the PIER-DSBG-EFP terms and conditions. Daily set location, duration, and amount of gear deployed was up to the discretion of the EFP participant, assuming that the combined total number of DSBG pieces and LBG sections did not exceed 10, and the total number of baited hooks did not exceed 30. In accordance with the EFP terms and conditions, DSBG and LBG sets had to be initiated after sunrise and gear haul-back procedures had to commence by sunset.

Catch and Bycatch Estimation

All catch was enumerated using logbook entries verified against CDFW landings receipts, daily check-in reports, and onboard observer records to ensure alignment of dates, catch statistics, and nontarget interaction rates. If discrepancies were identified, then individual fishermen were contacted directly to confirm and correct uncertainties. Swordfish size estimates, ex-vessel prices, and landing totals were derived from landing receipt and logbook records at the trip level. Mean market price and swordfish dressed weight values were calculated for each DSBG or LBG trip based on the ex-vessel revenues, total weight, and number of fish recorded on official landing receipts. Because the number of offloaded swordfish was not recorded on landing receipts prior to 2018, size and price estimates were only included if catch numbers at the trip level could be accurately validated from logbooks and daily check-in data. Mean ex-vessel values were weighted based on the percent volume of landed swordfish at each price point.

Specific size and price metrics from other marketable species, including bigeye thresher sharks, *Alopias superciliosus;* mako sharks, *Isurus oxyrinchus;* and escolar/oilfish, *Gempylidae*, were not estimated because of the low volume landed and inconsistent landing trends between species and vessels (some of which were retained for personal use).

Target and nontarget catch rates were standardized to 10 pieces of DSBG or 10 sections of LBG fished over an 8-h fishing day (std. 8-h day) to evaluate and compare catch and effort metrics with previous studies (Sepulveda et al, 2014; Sepulveda and Aalbers, 2018). Nontarget catch was further classified into either marketable or non-marketable species based on retention and if there was an existing market history for that species off the west coast.

Estimates for non-marketable catch, including marine mammals and species with extended federal or state protections, were calculated based on both actual and extrapolated values. Extrapolated catch estimates were performed for all non-marketable species based on the ratio of observer coverage to the total number of EFP set days. Because the only observed interaction with a northern elephant seal, *Mirounga angustristris,* resulted in a reported "live and alert" release, no further estimates of fishing mortality were performed.

Research Sets

DSBG and LBG research sets were performed aboard the PIER research vessel *Malolo* from 21 October 2015 through 06 January 2022. Because the primary objectives of the research trials were to further develop deep-set gear configurations and deploy electronic tags on live swordfish rather than maximize commercial harvest, research sets were analyzed and reported separately from EFP catch and effort data.

Considering that several deep-set gear configurations were tested over the course of research trials, only LBG sets that used the same configuration as EFP fishermen and targeted the same depths (250–400 m) were included in the analyses. As with previous experimental deployments, no catch was landed or retained for sale and all swordfish captured in good physical condition were outfitted with electronic tags for population dynamics and stock structure studies (Sepulveda et al., 2019a; Griffiths et al., 2020). Hook descent rates and fishing depths were determined from the archived records (30-s resolution; n=660) of depth and temperature sensitive data storage tags (DST's; Cefas Technology Ltd., Lowestoft, U.K.) affixed to gangion clips on each section of LBG sets deployed either with (n=17) or without (n=17) a line setter.

Data Analyses

Validated logbook records were categorized by vessel into a project database for subsequent analyses. Catch statistics were performed for all species that were retained for sale or intentionally released during gear trials and did not include species captured on other gear types (i.e., hook and line, harpoon). In line with previous analyses performed by Sepulveda

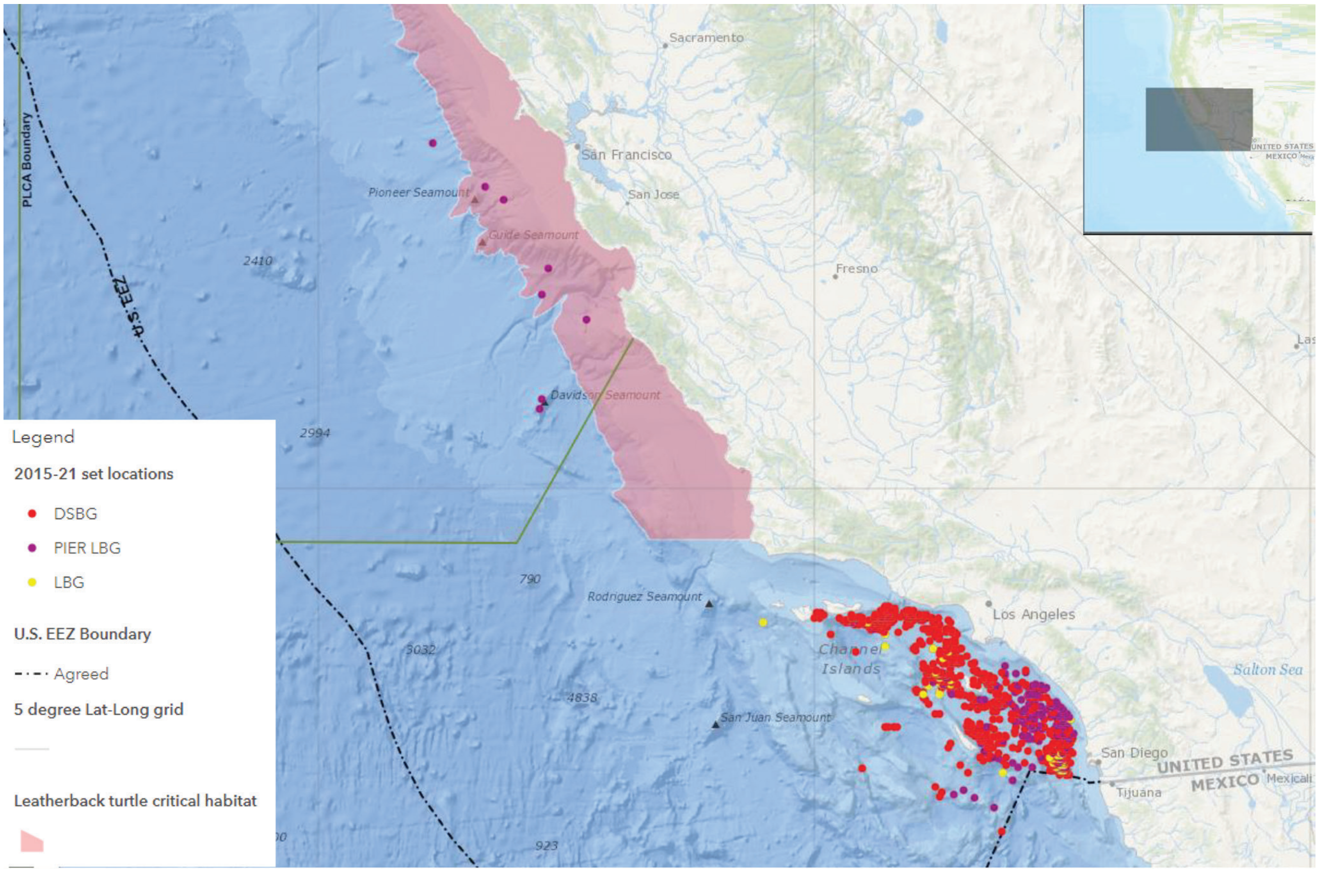

Figure 2.—Set locations of research and exempted fishing trials conducted off California from 2015–21 using both deep-set buoy gear and linked buoy gear.

and Aalbers (2018), data comparisons primarily focused on the number of set days, buoys/sections deployed, and soak duration.

Fishing effort was standardized to account for partial fishing days, that usually occurred on the first and last days of a trip because of travel or during periods of inclement weather. Effort standardization was based on typical EFP fishing conditions observed since 2015 and provided a consistent metric for comparison (Sepulveda and Aalbers, 2018). A standardized 8-h fishing day (std. 8-h day) was defined as ten pieces of buoy gear or ten sections of LBG soaked over an 8-h period.

Results

Location

All DSBG and LBG EFP sets occurred within the southern California Bight from Santa Cruz Island, Calif. (lat. 33.9°N, long. 119.8°W) to the Mexican border (lat. 32.6°N, long. 117.4°W; Fig. 2). Although set activity was permitted to occur within the entire 200 nmi exclusive economic zone (EEZ) off California, more than 90% of PIER EFP sets occurred from 3 to 30 nmi off the coast of southern California and around the Channel Islands. Research sets using DSBG and LBG were also primarily performed within the SCB; however, seasonal set activity extended up to the Farallon Islands off San Francisco, Calif.

DSBG Exempted Fishing Catch and Effort (2017–21)

Five EFP vessels deployed 12,015 pieces of DSBG on 1,225 sets during 299 individual trips (mean trip duration = 4.1 days) between 26 May 2017 and 03 December 2021. The total number of DSBG sets performed by the EFP group within a single season ranged from a high of 326 in 2017 to a low of 135 during 2021. Fishing effort fluctuated over the study period (Fig. 3a), with an overall average of 245 sets performed per season by the collective PIER EFP group. The maximum effort exhibited by any one vessel over the 5-yr study period was 396 DSBG sets performed.

Daily fishing times varied between vessels, with seasonal averages ranging from 6.8 to 7.4 h/set and a collective mean of 7.1 h/set. To allow for inter-annual comparisons between vessels, catch rates were normalized to an 8-h day, with a collective effort of 1,086 8-h day. Similarly, because nearly all sets consisted of 10 pieces of DSBG (mean = 9.9 pieces/set), fishing effort was standardized to a full 10 buoy compliment, which provid-

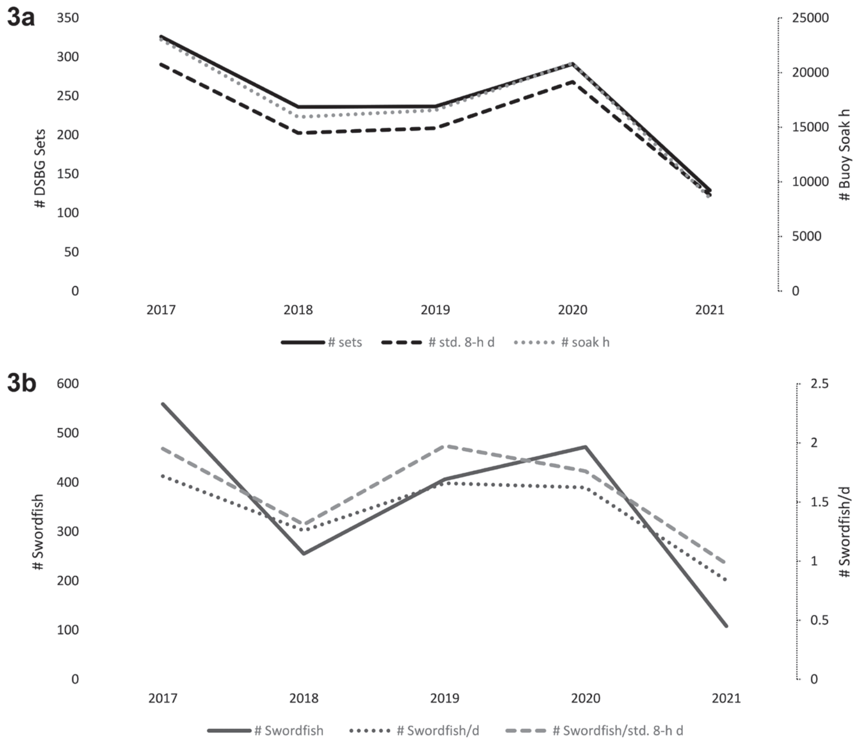

Figure 3.—Mean annual estimates of (a) fishing effort and (b) swordfish catch and CPUE during deep-set buoy gear exempted fishing trials conducted over five seasons (2017–21) off the coast of California.

ed a comprehensive effort estimate of 1,070 std. 8-h day over the EFP reporting period.

In total, 1,806 swordfish were caught on DSBG by five vessels from 2017 to 2021. Catch rates by vessel varied between seasons (Fig. 3b; Table 1), ranging from 1.1 to 1.7 swordfish per set (mean=1.4 swordfish/set), which equated to 1.2–2.1 swordfish per std. 8-h day (mean =1.7 swordfish/std. 8-h day). Annual catch rates, averaged across all EFP vessels, varied from a low of 0.8 swordfish per set in 2021 to a maximum of 1.7 swordfish per set in 2019 (mean=1.4 swordfish/set), with standardized annual catch rates ranging from 1.0 to 2.0 swordfish per std. 8-h day (mean=1.6 swordfish/std. 8-h day; Fig. 3b). The maximum seasonal catch rate observed for any EFP participant occurred during the 2019 season with 2.6 swordfish/set or 3.3 swordfish/std. 8-h day. The maximum daily catch rate observed in this study was 11 swordfish caught during a single set day using 10 pieces of DSBG.

Collectively, the mean catch rate was approximately 0.15 swordfish per individual piece of DSBG, or the equivalent of 1 swordfish for every ~6.7 DSBG pieces deployed. Although cooperative fishermen had the option to deploy up to three hooks per piece of DSBG, nearly all sets (<95%) consisted of a single 8 m gangion positioned at the terminal end of each vertical mainline rigged with a 18/0 circle hook baited with *Illex* squid.

Swordfish comprised 93.9% of the collective DSBG catch among EFP vessels, with bigeye thresher sharks (*n*=89) making up an additional 4.6% (Fig. 4, Table 2). Other marketable species, including escolar (*n*=7) and mako shark (*n*=3), comprised an additional 0.5% of the total catch. Species that were not retained for sale (i.e., non-marketable/bycatch) were typically released alive upon haul back and constituted the remaining 1.0% of DSBG catch, which included blue shark, *Prionace glauca* (*n*=16); salmon shark, *Lamna ditropis* (*n*=1); ocean sunfish, *Mola mola* (*n*=1); and a northern elephant seal, *Mirounga angustirostris* (*n*=1). The single protected species interaction was detected by the tending vessel with the strike indication system. The onboard observer reported that the male northern elephant seal was released in good physical condition within 20 min of the strike. Upon retrieval of the mainline, the release was accomplished by severing the monofilament leader < 3 m from the hook.

Collectively, 349 set days were monitored by NMFS-certified observers (29%), with coverage rates consistently maintained above 20% for all DSBG sets. Onboard observer records were consistently in agreement with logbooks (Table 3). An extrapolated interaction rate of 3.5 northern elephant seals was calculated based on the 29% observation coverage to align with Endangered Species Act (ESA) consultation process. Similar extrapolation estimates for all other non-marketable species interactions remained below 3% of the collective catch.

LBG Exempted Fishing Trials

Following issuance of the LBG EFP in September 2018, 475 LBG sections consisting of 1,425 hooks were deployed over the course of 52 sets by four EFP vessels during a 3-yr period. Daily fishing time averaged 7.3 h/set across vessels and seasons with a maximum daily soak duration of 10.8 h/set in 2020. A total of 380 fishing hours were accumulated across LBG EFP efforts. Similar to DSBG sets, LBG effort was normalized to an 8-h day (*n*=47.5 8-h day) and standardized to a full deployment of 10 full LBG sections (*n*=44.5 std. 8-h day).

A total of 69 swordfish made up 92.0% of the LBG catch, with marketable catch also including escolar (*n*=3), two bigeye thresher sharks, and a single mako shark. Across vessels, mean annual LBG catch rates ranged from a high of 2.1 swordfish per set in 2020 to a low of 0.9 swordfish per

Table 1.—Catch statistics among five commercial vessels during exempted fishing permit (EFP) trials using deep-set buoy gear to target swordfish (SF) off southern California from 2017–21, with some values standardized to an 8-h fishing day using 10 sets of gear (std. 8-h day).

EFP Vessel	# trips	# sets	Mean # day/trip	# buoys	# soak h	# 8-h day	# std 8-h day	# soak h/day	# SF/set	# SF/std 8-h day	# SF caught
FV *Gold Coast*	81	396	4.9	3,923	2,870	359	355.3	7.3	1.7	1.9	669
FV *Leah Gail*	85	342	4.0	3,380	2,336	292	288.6	6.8	1.7	2.1	596
FV *Three Boys*	55	167	3.0	1,598	1,314	164	157.0	7.9	1.2	1.2	193
FV *Aurelia*	60	228	3.8	2,280	1,522	190	190.2	6.7	1.1	1.3	251
FV *Spirit*	18	92	5.1	894	646	81	78.5	7.0	1.1	1.2	97
Total	299	1,225	4.1	12,075	8,688	1,086	1,069.6	7.1	1.5	1.7	1,806
Mean	59.8	245	4.2	2,415	1,737	217	214	7.1	1.4	1.6	361

set in 2018, which was equivalent to an average annual catch rate of 1.5–1.7 swordfish per std. 8-h day. Similar to DSBG, swordfish catch rates varied between vessels (Table 1), ranging from 0.6 to 1.6 swordfish per set, or 1.1–2.1 swordfish per std. 8-h day, with an overall mean catch rate of 1.5 swordfish per std. 8-h day. Collective catch rate averaged approximately 0.15 swordfish per section of LBG, with no observed non-marketable catch.

Due to mandates outlined in the EFP terms and conditions, observer coverage rates were maintained at 100% in 2018, but dropped to zero coverage during the 2020 fishing season due to staffing issues related to the Covid-19 pandemic. The overall observer coverage rate for the LBG EFP was 69%. Because all LBG catch was marketable and no protected species interactions were reported during the EFP trials, data extrapolations based on observer coverage were not calculated for LBG sets.

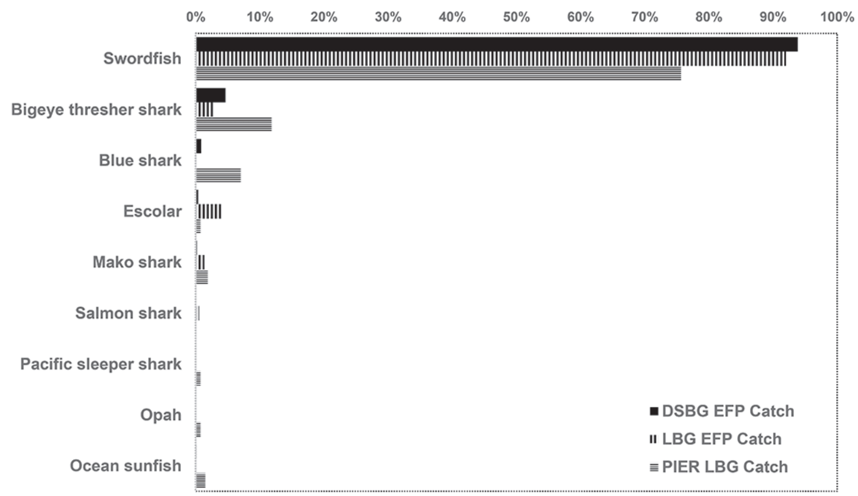

Figure 4.—Catch composition data from five cooperative fishing vessels collected from the deployment of 12,015 pieces of deep-set buoy gear (DSBG) on 1,225 sets during the PIER DSBG EFP trials between 26 May 2017 and 3 December 2021.

PIER LBG Research Sets

A total of 144 LBG research sets were performed aboard the PIER research vessel between San Francisco, Calif. (lat. 37.7°N, long. 123.0°W) and the Mexican border. The majority of PIER research sets (*n*=136) occurred within the SCB between October 2015 and January 2022, with eight LBG sets conducted above Point Conception, Calif. Experimental LBG sets were deployed either as a full complement of 10 sections (*n*=79) or in combination with DSBG (*n*=65; mean=6.2 sections/set), with an overall mean of 8.3 LBG sections per set. The initial 30 LBG sets performed in 2015 and early 2016 were deployed directly from the mainline spool, without the use of a hydraulic line setter. All sets performed after 12 October 2016 were performed using a hydraulic line setter to expedite gear deployment and hook sink rates. The line setter enabled two crew members to deploy LBG at a faster rate, with a full complement of 10 LBG sections set in approximately 60 ± 3.3 min, or ~6 min per LBG section.

A comparison of sink rates between LBG sets with and without a line setter showed that baited hooks remained in the upper mixed layer (<50 m) for a reduced amount of time (~3 min) when a setter was incorporated into the deployment. Sink rates increased from 10.0 m/min (without a setter) to 17.1 m/min when a setter was used. Additionally, without a line setter, the descent rate slowed considerably as depth increased, with baited hooks reaching target fishing depths (>250 m) more than three times faster when a line setter was used (median descent time=19.9 min) than during sets made directly from the spool (median descent time = 66.5 min). The mean settled fishing depth of hooks 1 and 3 of each section was approximately 295 m, while the middle hooks fished at an average maximum depth of ~370 m (Fig. 5).

Over the course of the research trials, average daily fishing time was approximately 7.4 h/set, which resulted in 1,058 fishing hours performed during the reporting period. For consistency and comparison with EFP efforts, research sets were normalized to a collective effort of 132 8-h day and a standardized deployment of 10 LBG sections (*n*=112 std. 8-h day).

Table 2.—Catch composition from exempted fishing permit (EFP; 2017–21) and PIER research (2015–21) trials using both deep-set buoy gear (DSBG) and linked-buoy gear (LBG) configurations.

Catch	Species	DSBG EFP catch (2017–21)	DSBG EFP catch (%)	LBG EFP catch (2018–21)	LBG EFP catch (%)	PIER LBG catch (2015–22)	PIER LBG catch (%)
Swordfish	*Xiphius gladius*	1806	93.9%	69	92.0%	225	76.3%
Opah	*Lampris guttatus*	0	0%	0	0.0%	2	0.7%
Bigeye thresher	*Alopias superciliosus*	89	4.6%	2	2.7%	31	10.5%
Pacific sleeper	*Somniosus pacificus*	0	0%	0	0.0%	2	0.7%
Mako shark	*Isurus oxyrinchus*	3	0.2%	1	1.3%	3	1.0%
Escolar/oilfish	*Gempylidae* spp.	7	0.4%	3	4.0%	2	0.7%
Salmon shark	*Lamna ditropis*	1	0.1%	0	0.0%	0	0.0%
Blue shark	*Prionace glauca*	16	0.8%	0	0.0%	26	8.8%
Common mola	*Mola mola*	0	0.0%	0	0.0%	4	1.4%
Pacific hake	*Merluccius productus*	0	0.0%	0	0.0%	2	0.7%
Protected species							
Elephant seal[1]	*Mirounga angustirostris*	1	0.1%	0	0.0%	0	0.0%

[1]Released Alive and Alert

A total of 225 swordfish were caught during LBG research trials, which comprised 76.3% of the collective catch. Other species captured on LBG included bigeye thresher sharks (*n*=31), blue sharks (*n*=26), ocean sunfish (*n*=4), mako sharks (*n*=3), escolar (*n*=2), opah, *Lampris incognitus* (*n*=2); Pacific sleeper sharks, *Somniosus pacificus* (*n*=2); and Pacific hake, *Merluccius productus* (*n*=2). Marketable species comprised approximately 90% of the total catch. Annual swordfish catch rates ranged from 1.1 swordfish per set in 2020 to 2.0 swordfish per set in 2017, or the equivalent of 1.3 to 2.7 swordfish per std. 8-h day. For all LBG research sets combined, the mean swordfish catch rate was approximately 1.5 swordfish per set or 2.0 swordfish per std. 8-h day. Catch rate across all research sets averaged approximately 0.19 swordfish per section of LBG.

EFP Effort and Landings

Based on a review of landing receipts and associated logbook records from all EFP vessels, swordfish caught on deep-set gear configurations ranged in size from 11 to 230 kg dressed with peduncle weight (DPW; Uchiyama et al., 1999), with an overall mean DPW of approximately 64.1 kg. Mean swordfish size based on landing receipt records increased slightly during each year of the study period from approximately 58 kg DPW in 2017 to approximately 71 kg DPW in 2021 (Table 4).

Table 3.—Catch statistics recorded during exempted fishing permit (EFP) trials of deep-set buoy gear (DSBG) off southern California documenting agreement between most cooperative-fishermen logbook entries and NMFS-certified observer records.

Catch	Species	Recorded in logbook	Recorded by observer
Swordfish	*Xiphius gladius*	493	494
Bigeye thresher shark	*Alopias superciliosus*	42	42
Escolar/oilfish	*Gempylidae* spp.	2	4
Blue shark	*Prionace glauca*	5	5
Mako shark	*Isurus oxyrinchus*	2	2
Salmon shark	*Lamna ditropis*	1	1
Common thresher shark	*Alopias vulpinus*	0	1
Jumbo squid	Unidentified	1	1
Market squid	*Doryteuthis opalescens*	0	1
Pacific hake	*Merluccius productus*	0	2
Elephant seal	*Mirounga angustirostris*	1	1

Based on the mean calculated swordfish size, collective EFP landings in California were estimated at 127 t from 2017 to 2021. Based on landing receipts verified against EFP logbook records, ex-vessel prices ranged from a low of $7.70/kg ($3.50/lb) during the winter of 2020 to a high of $25.30/kg ($11.50/lb) in the summer of 2021. The overall mean ex-vessel price received over the 5-yr study period was $13.90/kg ($6.30/lb), with a mode of $13.20/kg ($6.00/lb). However, the mean ex-vessel value increased nearly 25% in 2021 to approximately $18.25/kg ($8.30/lb), with a mode of $17.60/kg ($8.00/lb).

Monthly ex-vessel price across the study period went from a high of $18.00/kg ($8.20/lb) at the beginning of the season in July to a low mean price of $12.30/kg ($5.60/lb) in November. The seasonality of swordfish landings showed that catch occurred from June through January, with a peak number of swordfish landed during the month of October (Fig. 6). The majority of EFP fishing effort occurred from August through November and peaked in September, whereas research sets occurred across all months of the season (July–January).

Discussion

This study presents findings from the second phase of research and exempted testing of deep-set techniques targeting swordfish off southern California. The findings directly support previous exempted and research trials of DSBG and also provide comparable catch composition and gear trial data for LBG (Sepulveda et al., 2014; Sepulveda and Aalbers, 2018). This work also provides consistent inter-seasonal gear performance metrics (i.e., catch rates, composition, and selectivity) which continue to suggest that daytime deep setting can be used to target swordfish and simultaneously avoid unmarketable bycatch off southern California (Sepulveda et al., 2014; Sepulveda and Aalbers, 2018).

Given the small regional footprint of the deep-set operations performed to date, the future growth and success of the fishery moving forward will depend on several factors including local swordfish availability, market dynamics, and resource competition between recreational and commercial fishing efforts. To promote growth and increase fishery resilience to changing ocean conditions as well as fluctuations in regional abundance, future deep-set fishery development efforts should focus on expanding to: 1) areas outside of the Southern California Bight, 2) seasons and configurations that result in the harvest of other valuable HMS, and 3) the development of markets to further reward fishermen for sustainably caught local seafood.

Given the continued decline of domestic swordfish operations off California and Hawaii (Urbisci et al., 2016; Helvey et al., 2017), competition with foreign-sourced product will continue to be the largest hurdle to face the future growth of any domestic west coast swordfish fishery. This problem further validates the need to expand deep-set gear catch portfolios and markets which may increase resilience in the developing domestic swordfish fleet.

Study Area

Throughout this study as well as in previous exempted trials, deep-set fishing has been largely confined to the SCB (Sepulveda and Aalbers, 2018), with most of the deployments performed off the southern California coastline and Channel Islands (Fig. 2). Limited spatial effort and the lack of expansion to other areas is likely due to several factors including the small size of most vessels participating in the EFP, the milder weather conditions within the Bight, and the increased costs associated with exploratory fishing.

Although several EFP fishermen expressed interest in targeting swordfish outside of the SCB, deep-set fishing largely occurred within day-trip

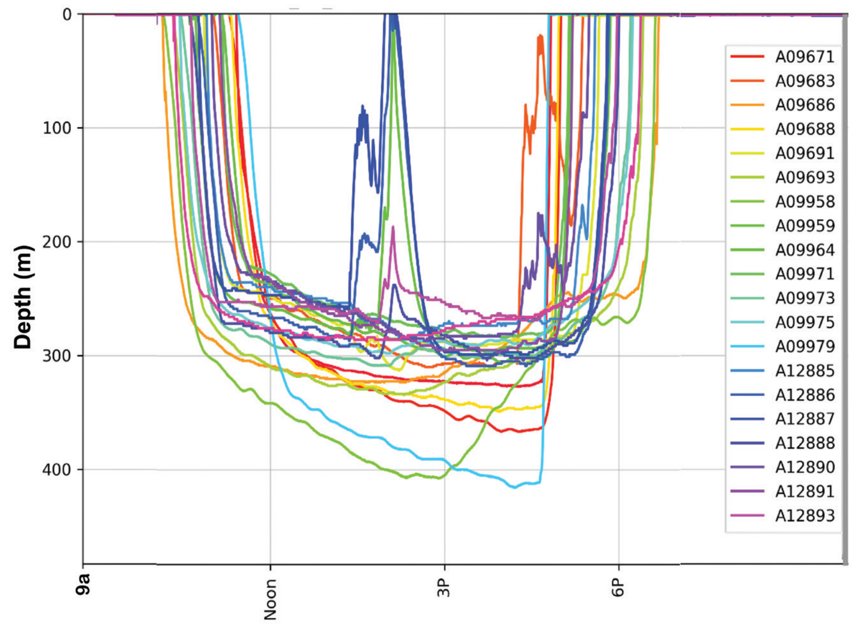

Figure 5.—Vertical profile of hook depths and descent rates from a linked-buoy gear (LBG) set on 26 January 2016 aboard the PIER research vessel, based on depth data obtained from 20 electronic tags affixed to baited gangions clipped along the horizontal mainline. Vertical spikes represent swordfish moving towards the surface following capture at depth and associated haulback events.

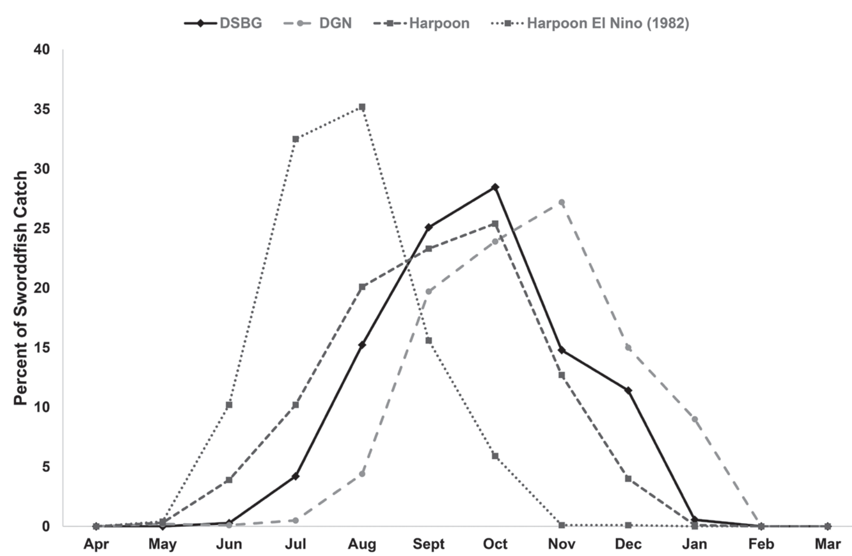

Figure 6.—Seasonal distribution of swordfish catch during exempted fishing trials using deep-set buoy gear (DSBG) from 2017–21 coupled with seasonal catch statistics for swordfish landed off California using both harpoon and drift-gillnet gear (1980–96), based on data from Coan et al. (1998) and Hanan et al. (1993).

range of secure and protected anchorages (i.e., harbor, island, or coastal embayment). The only sets made outside of the SCB were those performed by the research team during efforts to deploy electronic tags on swordfish within the Pacific Leatherback Conservation Area (PLCA) (Sepulveda et al., 2019a). The Sepulveda et al. (2019a) work provides insight into the use of deep-set gear off central and northern California and suggests that the techniques may prove to be productive outside of the SCB.

Due to the foul weather conditions commonly present above Point Conception and the higher variability in depth distribution of swordfish off Central California compared to the SCB, the research team consistently relied upon LBG over DSBG for the more northern deployments. This was mainly due the relative ease of monitoring LBG under all weather conditions as well as the expanded range of fishing depths covered by the gear (Sepulveda et al., 2019a). Given the added expenses associated with supporting longer duration trips and offshore fishing, it is likely that larger-vessel owners will feel the need to further expand current deep-set techniques (i.e., LBG) to ensure economic viability.

Although the EFP terms and conditions allowed participants flexibility on where to set, the observed temporal and spatial distribution of successful catches was similar between years, suggesting heightened resource availability within specific areas. Localized swordfish concentrations have been supported by Hanan et al. (1993) as well as recent tagging studies, which reported that swordfish tagged off California often return seasonally to specific locations year after year (Sepulveda et al., 2010; Sepulveda et al., 2019a; Griffiths et al., 2020; Sepulveda and Aalbers, 2022).

Similar site fidelity trends have been reported for swordfish around seamounts off Australia and in the Atlantic Ocean and have also been proposed in recent stable isotope analyses (Nielsen et al., 2009; Acosta-Pachón et al., 2020; Logan et al., 2021; Campbell and Hobday[6]; Wilcox[7]). Historic catch data off California as well as interviews with seasoned fishermen with over 40 years of experience also support the patchy distribution of swordfish off California and their seasonal occurrence within small pockets of regional productivity from year to year (Hanan et al., 1993; Sepulveda et al., 2010; Mintz[8]).

In this study, above average swordfish catch rates were typically aggregated in small areas of concentrated effort. For example, nearly 25% (*n*=125) of the swordfish landed on DSBG during the 2017 fishing season were caught by three of the participating EFP vessels fishing within a single 10 x10 nmi; CDFW statistical block in August–September 2017. Daily catch rates exceeded two swordfish per day during this period for the three vessels that fished within the aggregation area.

In contrast, the single vessel that avoided the crowded area and set in adjacent waters had a CPUE that was four times lower than the other vessels during the same period. The patchy distribution of the SCB swordfish resource will likely lead to future challenges between stakeholders, particularly as the deep-set commercial and recreational fisheries grow over time (Aalbers et al., 2022).

Swordfish Availability and Exempted Fishing Effort

Although swordfish availability off California is seasonal and dependent upon regional oceanic conditions (i.e., SST, productivity, currents), historic landings in the harpoon and drift gillnet (DGN) fisheries typically peak at different times, suggesting differences in seasonal gear vulnerability (Hanan et al., 1993; Coan et al., 1998; Sepulveda et al., 2010). The harpoon fishery typically starts in May, with a peak in July–August under El-Niño conditions or during October in other years and can extend through December (Coan et al., 1998; Fig. 6).

In contrast, the majority of swordfish landings from the California DGN fishery typically occur from August through January, with a peak in November (Fig. 6; Hanan et al., 1993). Although harpoon-caught swordfish were not included in this study, EFP fishermen recorded logbook entries for opportunistically harpooned swordfish from late May through December. Both DSBG and LBG catch and effort remained low through July and increased considerably in August, as reports of basking swordfish diminished (Krebs[9]). Over the course of the study, relatively consistent seasonal trends were observed between years, with the number of swordfish caught on DSBG peaking in October and slowly tapering off following the onset of driftnet fishing in November (Sepulveda and Aalbers., 2018; PFMC, 2020). In most years, DSBG catches remained high through December with effort diminishing into January as driftnet landings continued through the end of the month, a time when DGN activity typically shifted further offshore with the onset of winter conditions.

Although preliminary, initial findings suggest that deep-setting can complement the harpoon and driftgillnet fisheries, as each of the three gear types have different peaks in performance that occur during different months of the year (Fig. 6). The variability in gear success is likely due to changes in seasonal movement patterns and depth distribution, which can influence gear effectiveness and swordfish catchability. For instance, surface basking behavior is often more prevalent in the early months (May–

[6]Campbell, R. A., and A. J. Hobday. 2003. Swordfish -seamount -environment -fishery interactions off eastern Australia. Working Paper presented to the 16th meeting of the Standing Committee on Tunas and Billfish, July 9–17, 2003 Mooloolaba, Australia. Hobart, Tasmania: CSIRO, Div. Mar. Res.

[7]Wilcox, C. 2014. Defining regional connections in southwestern Pacific broadbill swordfish. Fish. Res. Develop. Corp. Proj. 2007-036, Deakin, Victoria, Austr. (avail. at https://publications.csiro.au/rpr/download?pid=csiro:EP159228&dsid=DS2, accessed 11 June 2022).

[8]Mintz, S. Captain. Personal commun. F/V D.J., San Diego, Calif.

[9]Krebs, D., Captain. Personal commun. F/V Goldcoast, San Diego, Calif.

July) and sometimes completely absent in the winter (Sepulveda et al., 2010). Additionally, recent depth distribution data obtained from California swordfish suggests that the range of daytime depths broadens in the fall and early winter. The expanded daytime depth distribution in the later months (December–January) may support the use of gear types that cover a greater portion of the water column, like LBG, rather than more depth-specific gear types like DSBG (Sepulveda et al., 2019a). However, the exempted efforts performed during this study did not adequately test LBG during the late fall and early winter months.

During the exempted trials, deep-set fishing effort fluctuated from a high of 326 days fished in 2017 to a low of 135 days in 2021. The two primary factors that seemed to influence fishing effort the most were market price and catch rate. From 2018 through 2020, effort in the late fall (November–December) decreased substantially when market price fell below $5.00/lb for dressed swordfish. For this 3-yr period, the market price dipped below the $5/lb threshold when the volume of swordfish landed by the California driftnet fishery began to increase or when foreign import volume (i.e., Mexico, Ecuador) began to rise during the late fall and winter months (Heflin[10]).

Throughout the EFP period, it was apparent from deep-set research trials that swordfish remained locally available and accessible on deep-set gear well after EFP fishing effort ceased. When EFP fishermen were asked why they stopped fishing, all respondents noted that the price was too low to offset trip costs and that market variability became too high to support continued effort.

Throughout 2021, market price remained well above the $5.00/lb threshold, with an average price of approximately $8.00/lb across the entire season; however, fish availability and catch rates were lower than previous years. In 2021, the average catch rate of the EFP vessels dropped below one swordfish per day for the first time since the EFP started (Sepulveda and Aalbers, 2018). However, because both the price and the average swordfish size were both higher than any other year, deep-set fishing effort continued (although limited) through the end of the year for several of the EFP vessels. Limitations on fresh-seafood imports due to shipping and supply-chain constraints likely helped reduce import volume and supported higher swordfish prices throughout the 2021 season. Similarly reduced landings were also reported in 2021 from both the CA DGN and neighboring Mexican longline fishery, suggesting reduced local volume/availability (Sosa-Nishizaki[11]). The lack of DGN and Mexican landings also likely contributed to the stability of the deep-set swordfish market in 2021.

One factor that also influenced the productivity and landings generated from the PIER EFP's was the amount of effort individual fishermen dedicated toward targeting swordfish. Although this work only incorporated full-time fishermen in the EFP selection process, all of the vessel operators are portfolio fishermen who also engage in other fisheries and or work. Throughout the EFP period, there were several instances in which fishermen used deep-set gear for only brief periods of a season, with some sitting out an entire season.

As the fishery moves towards authorization, this type of intermittent and sporadic effort will likely be common, as portfolio fishermen who participate in seasonal fisheries often weigh their options on where to focus their effort on a daily basis. Increased effort and success was observed by those cooperative EFP participants that maintained communication with each other, a strategy that have enabled the group to better track small pockets of productivity and increase CPUE.

Catch Composition

The catch composition reported in this study as well as that documented previously showed that there were relatively few species caught and that swordfish and bigeye thresher sharks (BETS) consistently made up the bulk of the catch (Fig. 4). Over the course of the entire EFP (2015–21), the team observed an increase in gear selectivity for swordfish that ranged from 64% in 2015 (Sepulveda and Aalbers, 2018) to 97% of the catch in 2021 (this study). Increased gear selectivity may be attributed to experience in avoiding areas of high BETS abundance, as BETS are often caught in association with specific bathymetric features, such as submarine canyons and seamounts (Aalbers et al., 2021). Although BETS are marketable, most fishermen in the PIER-EFP preferred to release this species due to their resiliency (i.e., being alive at haul back) and low-market value.

To better inform fishermen and management on post-release disposition, BETS caught during both research and EFP efforts were tagged to document survival rates following release on both DSBG (Sepulveda et al., 2019b) and LBG (Aalbers et al., 2021). Bigeye thresher sharks captured on both DSBG and LBG exhibited relatively high post-release survival rates (~93%), which further encouraged fishermen to release BETS in the latter years of the EFP.

Other marketable catch, like opah, were also more prevalent during the initial 2 years of EFP trials (2015–16) (Sepulveda and Aalbers, 2018), which may be partially attributed to changes in fisherman behavior. In the early years of the EFP, fishermen often used up to three vertically-spaced hooks on each piece of DSBG, while nearly all sets after 2016 consisted of just one terminal hook at the bottom of the gear. The transition to using a single baited hook occurred due to frequent tangles on upper gangions and the low financial return from the additional bait investment. Removing the upper hooks from DSBG sets

[10]Heflin, J. Chula Seafoods, San Diego, Calif. Personal commun.

[11]Sosa-Nishizaki, O. CICESE Professor, Ensenada Mex., Personal commun.

may have resulted in fewer mid-water or thermocline-associated species (i.e., opah, mako sharks, common thresher sharks, *Alopias vulpinus*), as reported by Sepulveda et al. (2018).

Non-marketable catch (bycatch) primarily consisted of blue sharks, a common species that is largely discarded in most domestic HMS fisheries in the North Pacific (Hanan et al. 1993; Campana et al., 2009). Although post-release disposition for blue sharks caught on deep-set gear has not yet been studied, it does not appear that projected catches from a larger fleet would be a major conservation concern based on the low blue shark catch rates observed in deep-set EFP efforts to date[12] (Sepulveda et al., 2018).

For example, the total number of blue sharks caught in both previously reported EFP efforts (*n*=8; Sepulveda and Aalbers, 2018) and in this study (*n*=23) collectively represent less than the average number caught in one single shallow-set longline deployment in the North Pacific (Moyes et al., 2006; Campana et al., 2009). However, because most of the blue shark catches observed during research trials occurred during sets made outside the SCB or later in the season (November–February), it may be that future efforts from an expanded California fleet would result in slightly higher blue shark catches compared to findings presented here.

Observation and Catch Reporting

Considering that this EFP incorporated several additional accountability measures (i.e., physical observers, daily check-ins, electronic monitoring), it was not surprising that self-reported logbooks showed high agreement with NMFS-trained observer data records (Table 3). Given that logbooks did not vary significantly from physical observer records and because of the very low numbers of non-retained catch, catch estimates were not extrapolated for all incidental catch. To account for any under-reporting of the most prevalent bycatch species observed in this study, an extrapolation of the blue shark catch (*n*=23) would still only amount to 81 individuals caught and released by all fishermen over the entire study period.

Deep-set Configurations

Although DSBG and LBG vary in configuration and deployment methods, similar bycatch mitigation features were incorporated into both deep-set gear designs (Aalbers et al., 2021). Both DSBG and LBG were designed to descend rapidly through the upper-mixed layer to similar target depths and each possess strike detection capacity which allows for rapid processing of catch (Fig. 1). The primary advantages of LBG are that all baited hooks can be deployed at target swordfish depths along the deep horizontal sections of mainline (depths of 250–400 m) and that the interconnected configuration of the gear can make it easier to monitor and keep track of compared to individual pieces of DSBG.

In contrast, DSBG has the advantage of being more precise and maneuverable, and it is easier to deploy and retrieve. Additionally, DSBG is very simple, requires fewer crew, and has a set-up cost that is roughly half that of LBG. The deployment and haul back of LBG is more technical and time consuming and requires the use of additional equipment (i.e., hydraulic line setter, longline spool). Several fishermen expressed concern over the need to have either competent or additional crew for the deployment of LBG, while less-experienced crew members were capable of DSBG deployments (Krebs[9]).

Although PIER has seamlessly deployed LBG research sets since 2015 and worked directly with cooperative fishermen on LBG set-up, training, and setting, the EFP team continued to rely more heavily on DSBG. In addition to the technical challenges associated with LBG deployments, several factors may have further contributed to reduced LBG effort.

One major difference between the DSBG and LBG EFP's was that the terms and conditions of the EFP mandated 100% observer coverage for LBG, compared to a 20%–30% observation mandate for DSBG. The 100% observer coverage rate reduced LBG effort as fishermen could not deploy LBG unless a NMFS-certified observer was assigned to the vessel prior to departure, which was often weighed by fishermen, particularly during periods when COVID-19 exposure was a concern (2020–21).

Additionally, the increased complexity of LBG deployment and haulback procedures required more-experienced crew members, which were often difficult to acquire, especially in the latter years of the EFP when unemployment rates were at near record lows[13]. The increased costs associated with the deployment of LBG also likely influenced the collective number of sets performed, as fishermen ideally needed one extra crew member and also had to purchase additional baits for each LBG set (30 vs. 10). It was also the case that LBG sets were reduced among fishermen that predominantly fished close to the coastline or around offshore banks and pinnacles because LBG hangs across a greater depth range and is less maneuverable than DSBG.

Concern was also expressed over setting LBG close to other DSBG fishermen, so EFP fishermen were more inclined to use DSBG if there were other vessels present. Because DSBG consists of a single mainline suspended vertically from a series of surface floats, DSBG is more versatile than LBG and can be deployed in almost any situation regardless of bathymetric features (>300 m) or proximity to other sets of gear. It is likely that future trends in gear use will continue to favor DSBG configurations within the SCB, while LBG will be more commonly used by larger vessels fishing in offshore waters.

[12]U.S. Dep. Commer. NOAA. 2021 (avail. at https://media.fisheries.noaa.gov/2021-08/Draft-EIS_Authorization-DeepSetBuoyGear.pdf), and accessed 11 May 2022.

[13]U.S. Dep. Labor. 2022. Bureau of Labor Statistics, Regional and state unemployment-2021 annual averages. Avail. at https://www.bls.gov/news.release/pdf/srgune.pdf, and accessed 4 June 2022.

LBG EFP Catch

LBG yielded similar catch composition as DSBG over the course of the study, with swordfish making up > 92% of the total catch across both EFP's (Sepulveda and Aalbers, 2018). Although several EFP vessels have demonstrated success using LBG, the slightly higher LBG swordfish catch rates were apparently not sufficient to warrant the additional logistical and financial burden associated with LBG deployments. Thus, direct comparison of catch rates between DSBG and LBG are premature and may be misleading given the differences in sample sizes and because sets were conducted on different spatial or temporal scales. The limited number of LBG deployments by any single EFP vessel and the lack of full-season comparisons between fishermen also prevented valid assessments between the two gear types.

Subtle differences in the catch rates of target and nontarget species using DSBG and LBG were likely related to the timing and location of sets. For example, the blue shark catch was shown to be higher during both the DSBG EFP and the PIER LBG research trials when compared to the LBG EFP trials. This is most likely due to the seasonality of sets, as the research sets during the same period revealed similar catch composition. Further, nearly all LBG EFP sets occurred during the months of July through October, whereas the majority of the blue shark catch occurred later in the swordfish season (November–January) when blue shark abundance increased off southern California (Hanan et al., 1993; Sepulveda and Aalbers, 2018; Godínez-Padilla et al., 2022).

PIER LBG Research Trials

Throughout the EFP period, LBG research sets were conducted by PIER to further develop and increase gear performance and simultaneously perform tagging studies to address questions related to swordfish habitat utilization and stock structure. In contrast to the EFP trials, which focused exclusively on maximizing target catch, the research team took measures to optimize tagging success and post-release survival, usually at the expense of maximized production. Additionally, in some instances, directed sets were made to target species other than swordfish, such as directed sets for BETS to assess post release survival (Aalbers et al., 2021).

Because measures such as reducing the amount of gear set on a given day and setting to target species other than swordfish were sometimes employed, LBG research sets do not provide an accurate assessment of true catch potential. For instance, on 8 December 2018, the team tagged 8 swordfish on 5 sections of LBG and refrained from setting additional gear to avoid having too many fish on the line at the same time. The research vessel then returned to port, rather than making additional sets in the area to capitalize on the swordfish aggregation. Similarly, the slightly higher BETS catch rate observed during the research sets is likely an artifact of set location and intentional targeting for tagging purposes (i.e., setting in locations that previously resulted in BETS catch).

Additionally, to assess seasonal trends in catch and gear performance, research sets were conducted across the entire study period and throughout the entire swordfish season (July–January). This resulted in much shorter trips than the commercial vessels participating in the PIER EFP's and spread effort out more evenly across the season. Although data from research sets may underestimate the true catch potential of LBG, a comparison of catch rates from EFP and research trials showed that they were similar, and in several years the research catch rates were higher than those of the EFP participants. Additionally, the research sets were also used as a training platform to demonstrate LBG deployment and haul-back procedures and provide cooperative fishermen training on the use of LBG.

Collectively, LBG research catch consisted predominantly of swordfish (76.3%), bigeye thresher sharks (10.5%), and blue sharks (8.8%), and catch composition included a wider variety of species than LBG EFP sets. Small numbers of other marketable species (i.e., opah, mako sharks, escolar, Pacific hake) contributed to an additional 2.4% of the catch and nonmarketable species (i.e., ocean sunfish, Pacific sleeper sharks) comprised another 2.0% of the catch.

Differences in catch composition and rate between research and EFP vessels were likely due to set location, time of year, and subtle gear changes that occurred over the course of developing LBG. For instance, many of the blue sharks caught during the LBG research sets occurred either late in the fishing season (November–February), outside of the SCB fishing grounds in areas that were not fished by EFP vessels, or prior to the use of a hydraulic line setter (a tool that expedited hook sink rates, incorporated in October 2016). Hydraulic line setters strip mainline from the primary spool at an adjustable rate to increase the amount of slack in the line as it enters the water, which allows the gear to sink at a faster rate.

Line setters have been shown to reduce interaction rates with nontarget, surface-oriented species in tuna fisheries while simultaneously increasing target catch on deep-set longlines (Beverly and Robinson, 2004; Beverly et al.[14]). In this study, we observed much faster hook-decent rates when using a line setter, with baited hooks remaining within the upper-mixed layer for less than ~3 min. Because most bycatch interactions occur above the thermocline (reviewed by Swimmer et al., 2020), higher sink rates likely contribute to the selectivity observed in this study.

Despite conducting LBG research sets across multiple areas over a 7-yr period, no interactions with threatened or protected species listed under ESA or the Marine Mammal Protection Act were recorded, suggesting that fu-

[14]Beverly, S., L. Chapman, and W. Sokimi. 2003. Horizontal longline fishing methods and techniques: a manual for fishermen. Secretariat Pac. Community, New Caledonia, 130 p.

ture fishery interaction rates with sensitive species have the potential to remain low. Additionally, LBG research sets conducted within portions of the PLCA off central California were successful in catching swordfish while avoiding protected species, despite numerous observations of marine mammals (i.e., sperm whales, *Physeter microcephalus*; fin whales, *Balaenoptera physalus*; elephant seals, and orcas, *Orcinus orca*) around gear sets (Sepulveda et al., 2019a). Although additional research and EFP sets within the PLCA are necessary to better assess LBG performance (i.e., maintaining catch while avoiding protected species), initial trials have suggested that deep-set techniques may provide a way for fishermen to sustainably capitalize on the swordfish resource that seasonally resides within the productive waters off northern California and Oregon.

EFP Revenues

Previous work by Sepulveda and Aalbers (2018) performed a cursory analysis of revenues and related expenses associated with swordfish catches. In this study, revenues from concurrent fishing activities outside of deep-setting (i.e., harpooning or hook-and-line fishing) were relatively minimal for both EFP's. However, fishermen often reported the use of harpoon methods for swordfish as well as trolling for other HMS (i.e., Pacific bluefin tuna, *Thunnus thynnus*) during a set. Additionally, deep-set fishermen reported harpooning swordfish that were lost during DSBG retrieval, as fatigued swordfish often surfaced after struggling on the line (Krebs[9]).

Revenues from other marketable species caught on either DSBG or LBG were also minimal, particularly after fishermen transitioned towards using a single baited hook early in the trials. Because most EFP fishermen primarily targeted swordfish by location, time of year, and hook depth, incidental catch rates were low, especially in the latter portion of the EFP when fishermen used past experience to guide set locations. As the deep-set fishery grows or during periods of reduced swordfish availability, future efforts will likely expand to include fishing at different times of the year and varying target depths, which will likely lead to additional revenues from other marketable catch species (e.g., opah, tuna).

Next Steps

In September 2019, the combination of gear performance and catch data from both PIER research and EFP activities was used to inform and advance the gear authorization of DSBG and LBG by the PFMC[15] under the Fishery Management Plan for U.S. West Coast Fisheries for Highly Migratory Species (HMS FMP). This work has also helped promote the use of low-impact fishing techniques and has strengthened local fishing opportunities for swordfish off southern California.

Although this work has made a step towards increasing sustainable domestic fishing opportunities, as of this publication most of the California swordfish grounds still remain unfished. The massive PLCA encompasses a productive region that once supported considerable fishing effort and swordfish harvest from the California DGN fishery (Hanan et al., 1993). The swordfish resource along central and northern California has been proposed to be part of the western and central North Pacific swordfish stock, a stock that is currently considered to be healthy (WCPFC, 2018; IATTC, 2021; Brodziak and Ishimura[16]). To grow the deep-set fishery and also help develop our domestic fleet, there is a need to expand efforts beyond the areas currently fished and also broaden the current catch portfolio to include other valuable HMS that can be sustainably harvested within California waters.

[15]PFMC. Deep-set Buoy Gear Authorization Final Action (avail. at https://www.pcouncil.org/documents/2019/09/agenda-item-i-4-situation-summary.pdf/, and accessed 23 June 2022).

[16]Brodziak, J., and G. Ishimura. 2010. Stock assessment of North Pacific swordfish (Xiphias gladius) in 2009. NMFS Pac. Isl. Fish. Sci. Cent., Admin. Rep. H-10-01, 37 p. (avail. at https://repository.library.noaa.gov/view/noaa/3749, and accessed 11 Jan. 2023).

Acknowledgments

This material is based upon project support from several independent sources including the NOAA Saltonstall-Kennedy Grant Program (SK Award # NA17NMF4270216, # FNA16NMF4270257) and the Bycatch Reduction and Engineering Program (BREP Award #s NA18NMF4720288, FNA15NMF42720380). Support was also provided by the California Ocean Protection Council (Award #C0303000, project #R/OPCSFAQ-07) issued through the Sea Grant College Program. Additional funding and support was provided by The Nature Conservancy (TNC), PEW Charitable Trust, the George T. Pfleger Foundation, the Offield Family Foundation, Santa Monica Seafood and the Fishwise Program, and the William H. and Mattie Wattis Harris Foundation. Special thanks are offered to our fellow fishermen: Donald Krebs, Anthony Makul, Lance Rinehart, Bill Sutton, Johnny Foster, Kelly Fukushima, Tim Athens, Andrew White, and Jim Heflin. We would also like to thank fellow colleagues for their efforts and support, including Oscar Sosa-Nishizaki, Chris Fanning, Christina Fahy, Ralph Pace, Thomas "Cowboy" Fullam, and Jennifer Thirkell. We would also like to acknowledge the support and hard work from state and federal management partners at the California Department of Fish and Wildlife, National Marine Fisheries Service, Pacific Fisheries Management Council, as well as the PFMC HMS Management Team and Advisory Subpanel.

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