Development and Trial of Deep-set Buoy Gear for Swordfish, *Xiphias gladius*, in the Southern California Bight

C. A. SEPULVEDA, C. HEBERER, and S. A. AALBERS

Introduction

Several management concerns have been raised over swordfish, *Xiphias gladius*, fisheries and their interactions with nontarget species (Carretta et al., 2003; Gilman et al., 2006). Within the U.S. west coast Exclusive Economic Zone (EEZ), swordfish are landed domestically by the California Drift Gillnet (DGN) fishery and, to a lesser extent by a small southern California-based harpoon fleet (Bedford and Hagerman, 1983). The remaining domestic demand for swordfish is met annually by imports from the Hawaii shallow-set longline fishery and from foreign longline fleets (Bartram and Kaneko, 2004; PFMC, 2011).

Off California, DGN interactions with nontarget species of concern (e.g., marine mammals, Physeteridae, and sea turtles, Dermochelyidae) have spurred numerous restrictions that have directly affected local fishermen through time and area closures (including the ~200,000 nmi^2 Pacific Leatherback Closure Area (PLCA)) and mandated gear and operational modifications (Hanan et al., 1993; Carretta et al., 2003; PFMC, 2011; Benson et al.[1]).

Despite recent information that suggests a healthy and underexploited population of north Pacific swordfish (Brodziak and Ishimura[2]), a consistent decline in DGN participation and ex-vessel revenues has ensued over the past 30 years. In 2012, DGN operations reached historic lows in both landings and participation, with fleet operations restricted to the Southern California Bight (SCB), a relatively small portion of the former fishery range (PFMC, 2013). These declines have resulted in adverse economic impacts on ports and associated businesses located adjacent to the PLCA (e.g., Morro Bay and Monterey) and have consolidated effort to a small geographic region that has been shown to historically fluctuate in swordfish landings (Bedford and Hagerman, 1983).

Commensurate with the decline of DGN operations off California, traditional harpoon fisheries have also dwindled, with effort and landings also reaching their lowest points in over three decades (PFMC, 2013). This decline has occurred despite the open-access nature of the harpoon fishery and the local market void produced by the reduction of DGN operations.

Several factors account for the decline in the harpoon industry, including the rise in operational costs (i.e., fuel prices), inconsistent catch rates, and the lack of new entrants into the fishery. Because harpoon operations require relatively calm conditions, this fishery has historically been limited to the waters of the SCB with landings

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ABSTRACT—Fishery interactions with nontarget species (including U.S. federally protected sea turtles and marine mammals) have severely impacted U.S. west coast swordfish, Xiphias gladius, *fisheries and have hindered the development of alternative domestic operations. This study used swordfish depth distribution data to aid in the design of deep-set fishing gear to target swordfish in the Southern California Bight (SCB). To minimize nontarget interactions, the deep-set gear was designed to fish at depths between 270 and 320 m during daylight hours. The deep-set buoy gear (DSBG) configuration consisted of a vertical mainline (2.2 mm monofilament) affixed with a 4 kg weight and two 8 m gangions (1.8 mm monofilament), each rigged with an 18/0 circle hook and baited with mackerel,* Scomber *spp., or squid,* Illex *spp., or* Dosidicus gigas.

Surface floatation included a 36 cm diameter (21 kg) longline float and two smaller (3 kg) strike indicator floats. Experimental fishing trials were conducted using ten individual pieces of DSBG deployed simultaneously. Soak duration was maintained at 4 h/set and the gear was hauled immediately upon detection of a strike. Gear trials were conducted within the SCB from August to January of the 2011 and 2012 swordfish seasons from both research and cooperative fishing vessels. From 54 sets (4,320 hook-hours), 14 swordfish were captured without any interactions with bycatch/nontarget species of concern (i.e., sea turtles and marine mammals). Additional species captured during the trials included: bigeye thresher sharks, Alopias superciliosus *(7); opah,* Lampris guttatus *(2); blue sharks,* Prionace glauca *(2); and common thresher shark,* Alopias vulpinus *(1). These data suggest that deep-set fishing operations can selectively target swordfish during the day within the SCB and provide a basis for further testing using commercial applications.*

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[1] Benson, S., H. Dewar, P. Dutton, C. Fahy, C. Heberer, D. Squires, and S. Stohs. 2009. Swordfish and leatherback use of temperate habitat (SLUTH): Workshop Report. *In* H. Dewar (Editor), U.S. Dep. Commer., NOAA, SWFSC Admin. Rep. LJ-09-06, La Jolla, Calif.

[2] Brodziak, J., and G. Ishimura. 2010. Stock assessment of North Pacific swordfish (*Xiphias gladius*) in 2009. U.S. Dep. Commer., NOAA, NMFS, Pacific Islands Fish. Sci. Cent., Admin. Rep. H-10-01, 37 p.

Table 1.—Information from 5 swordfish tagged using PSAT's.

Swordfish tag #	Location lat./long.	Displacement (km)	Est. mass (kg)	Days at liberty	Avg. day depth (m)	Avg. day depth below the thermocline (m)	Thermocline depth (m)	Avg. night depth (m)	Basking events
2	33° 17.08 117° 47.53	21	110	5	196	291	59	8	7
1	33° 06.23 117° 26.55	41	90	5	209	268	68	12	3
7	33° 06.97 117° 58.09	1	70	1	177	209	66	n/a	1
6	32° 52.32 117° 19.33	27	110	2	152	237	70	66	0
4	33° 17.09 117° 47.52	22	130	4	226	275	73	6	4

largely dependent on environmental conditions (Bedford and Hagerman, 1983).

The development and use of alternative swordfish gears within the west coast EEZ is complicated by several factors including the presence of a juvenile shark rookery (Hanan et al., 1993), spatial overlap with several species of concern (i.e., sea turtles and marine mammals; Carretta et al., 2003), and California's long-standing prohibition of pelagic longline gear within the EEZ (Obrien and Sunada, 1994; PFMC, 2012). Collectively these obstacles have prevented the development of alternative gear types more commonly used in global fisheries for swordfish (e.g., pelagic longline) and have resulted in the under-utilization of the west coast swordfish resource (Brodziak and Ishimura[2]). The reduction in domestic landings have also increased the reliance upon foreign swordfish imports to accommodate domestic demand (Rausser et al., 2009).

Given the continued decline of swordfish fisheries within California waters, recent work has highlighted the use of depth distribution and vertical niche partitioning of target and nontarget species for fishery development (Sepulveda et al., 2010; Benson et al.[1]). Despite spatial overlap with numerous species, recent swordfish tagging data suggest that daytime depth segregation within the SCB provides an opportunity to target swordfish selectively while simultaneously avoiding nontarget species of concern (Sepulveda et al., 2010; Dewar et al., 2011). Using depth to selectively target a specific catch has been examined in several commercial fisheries around the globe (Suzuki et al., 1977; Beverly and Robinson, 2004; Shiode et al., 2005; Beverly et al., 2009), but has only recently been considered to be an option for the U.S. west coast swordfish fishery.

Given the extreme diurnal segregation exhibited by swordfish when compared to most species of the SCB (including sea turtles (Eckert, 1999; Polovina et al., 2003; Polovina et al., 2004)), this study 1) designed a deep-set daytime gear configuration (deep-set buoy gear (DSBG)), and 2) tested the hypothesis that DSBG can effectively target swordfish while simultaneously avoiding nontarget species of concern.

Materials and Methods

Prior to the initiation of any experimental trials, an Environmental Assessment was performed by NOAA's NMFS Southwest Regional Office (SWRO). All experiments were conducted under California Department of Fish and Wildlife Scientific Collection Permits (SPC-2471, 5463) and in accordance with a NOAA Letter of Acknowledgement. Gear development and experimental deployments were performed from June 2010 through November 2012 in the SCB. Experimental trials and gear deployments were performed from the Pfleger Institute of Environmental Research vessel *Malolo* (14 m power vessel equipped with a swordfish harpoon plank) and the federally permitted commercial fishing vessel *Gold Coast* (13 m DGN/harpoon vessel).

PSAT Tagging

To design DSBG, validate target-species (swordfish) depth and concurrently tailor gangion depth, Wildlife Computers (Redmond, Wash.[3]) Mk 10 pop-up satellite archival tags (PSAT's) were deployed on five swordfish caught using both harpoon and DSBG techniques (Table 1). Tagging efforts were performed prior to and during the DSBG trials aboard the R/V *Malolo* using protocols outlined in Sepulveda et al. (2010).

Briefly, swordfish were spotted at the surface using stabilized binoculars, and the PSAT was inserted into the dorsal musculature from an extended bow pulpit using a modified harpoon and tag applicator. Similarly, swordfish captured during the DSBG trias were leadered and brought alongside of the vessel and a tag was inserted proximal to the base of the dorsal fin. Tag deployment duration ranged from 1 to 5 days, and all tags were recovered using a radio signal direction finder (Sepulveda et al., 2010). Data were downloaded at sea and DSBG configuration was adjusted accordingly.

Depth data were assessed for average daytime depth as well as the average depth below the thermocline in accordance with previous studies (Sepulveda et al., 2010). Thermocline depth was verified by visual inspection

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

of the depth and temperature plots for each fish. Cumulative depth plots of the joint distribution of depth and time over a 24 h period were constructed using MatLab (R12). Basking events were defined as daytime depth records in which tagged swordfish were within 3 m of the surface, and successive events were defined as periods in which the swordfish traversed the thermocline and subsequently returned to the surface (<3 m).

Experimental Gear Design

The DSBG design used in this study was derived from existing commercial gear configurations used in the federally authorized Florida shallow-set buoy gear fishery (NMFS, 2010) as well as South Pacific vertical longline fisheries (Preston et al., 1998). Additional information from consultations with active California DGN participants as well as depth distribution statistics for swordfish and other species that coinhabit the SCB (previous studies and concurrent short-term PSAT deployments) were also used to tailor DSBG configuration (Holts and Bedford, 1990; Sepulveda et al., 2004; Sepulveda et al., 2010; Cartamil et al., 2010; Dewar et al., 2011).

The DSBG configuration consisted of a three-float system which included two strike-indicator floats (3.2 kg) and one 36 cm diameter (21 kg), noncompressible longline float. For most deployments, the configuration also included a hi-flyer locator flag, radar reflector (Mobri Marine, Den.) and strobe (OPI, Strobe-CH-201) to prevent gear loss (Fig. 1). Collectively, each piece of DSBG included from 270 to 320 m of 2.2 mm monofilament mainline rigged with two monofilament ganions and drop sinker. Drop sinker mass was chosen based on initial trial sets with sinkers ranging from 2 to 6 kg in mass (see Results).

Two monofilament gangions branched from the mainline, one at the base and the other approximately 30 m above (Fig. 1). Gangions were 8 m in length and constructed of 1.8 mm monofilament leader containing a crimped 18/0 circle hook (Mustad model 39960D) baited with either squid, *Illex* spp. or *Dosidicus gigas*, or mackerel, *Scomber* spp. Battery-operated illumination (Power Light, SNL Corp., Fla.[3]) was used at the juncture of the mainline and gangion, with alternating green and blue colors similar to protocols used in the Florida shallow-set buoy fishery (Burlew[4]). One full set of DSBG was defined as 10 individual pieces of gear deployed simultaneously (20 hooks/set).

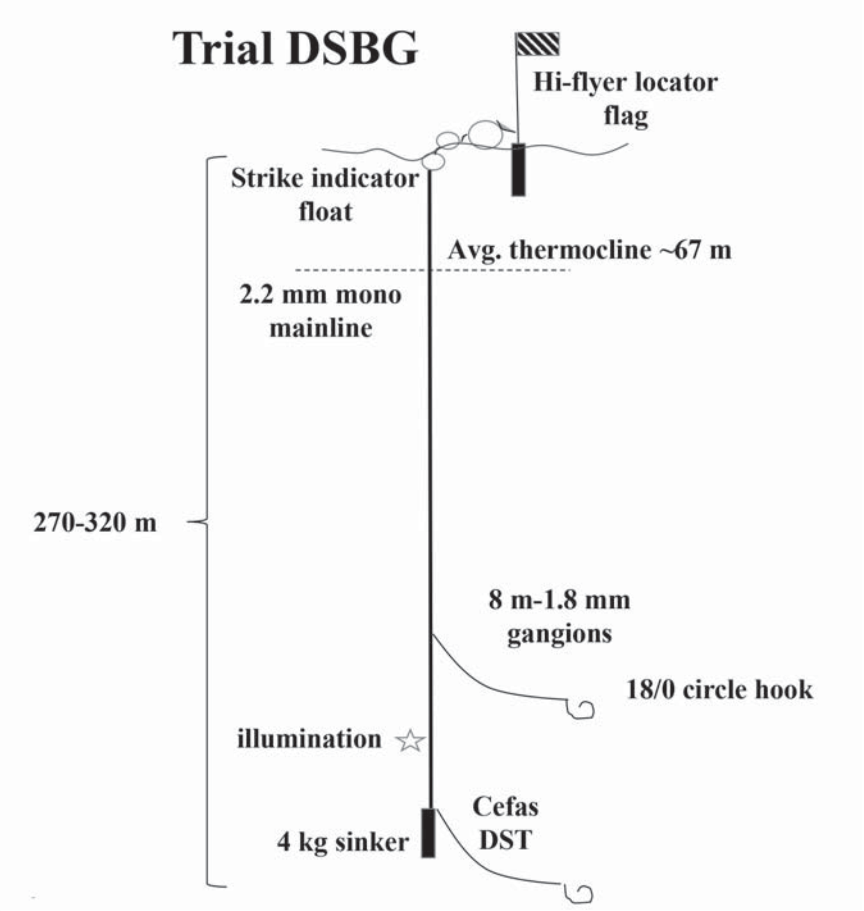

Figure 1.—Diagram of the DSBG configuration used in this study. Average thermocline obtained from PSAT tagged swordfish indicated by dashed line. Gear details are further described in the Experimental Gear Design section.

Gear Deployment Protocol

DSBG was deployed along a 3 km path at a consistent heading to ensure that the gear was visible by the fishing vessel at all times. Initial test sets were deployed with data storage tags (Cefas, Suffolk, U.K.) affixed to the gangion swivels to ensure that the gear did not drift into the upper water column or descend at a rate that would facilitate nontarget interaction (Fig. 2). Set locations were based on concurrent harpoon and DGN operations as well as satellite imagery (i.e., sea surface temperature (SST) charts and chlorophyll concentration images) and locations in which basking swordfish were observed.

Once deployed, DSBG was continually monitored using stabilized binoculars (Fujinon S-1640, 16X). Set duration was defined as a 4-h soak period in which all 10 pieces of DSBG were deployed simultaneously. The

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[4] Burlew, C., Deerfield Beach, Fla. Personal commun., May, 2011.

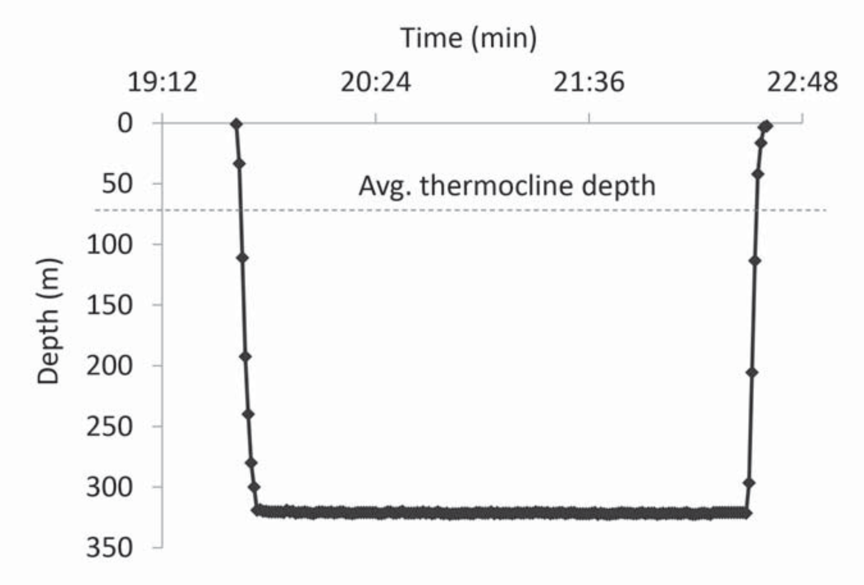

Figure 2.—Plot of the test deployments using 4 kg of lead. Plot illustrates gear sink rates that are sufficient to position hooks below the average thermocline depth in <1 min. Once at the target depth, the gear is maintained at a relatively constant position throughout the deployment period.

gear was pulled immediately upon detection of a strike, which was identified through the misalignment of the gear (due to the captured species' swimming effort) or by the floatation of the strike indicator float. Once hauled, the piece of gear was rebaited and subsequently deployed for the remainder of the set period. DSBG was hauled using either an electric or hydraulic Custom Sea Gear reel (Blue Ocean Tackle, San Diego, Calif.).

Detailed records collected for each trial included capture locations, disposition of catch, bait type, gear configuration, set duration, depth fished, and environmental conditions (i.e., current direction, SST, water color, dissolved oxygen concentration). Catch condition was assessed upon capture using metrics previously defined by Obrien and Sunada (1994).

"Good" was used to represent individuals that were hooked in the mouth, had no obvious signs of trauma, and were vigorous upon release; "Poor" was used to characterize individuals hooked in the gut or esophagus, lethargic, and showing obvious signs of stress; and "Moribund" was used for fish that were severely lethargic or dead. Successful captures were defined as any instance in which the 8 m gangion was in hand and the fish could be visually identified by the crew.

Results

Initial experiments were performed in July 2011 to identify appropriate drop-sinker mass and to develop the deployment protocol that resulted in the least tangling of the gear. A 4 kg drop sinker was determined to be adequate for sinking the gear below the thermocline within 1 min and maintaining the hooks at a constant depth throughout the deployment period (Fig. 2).

Experimental Deployments

Experimental gear trials were conducted within the SCB from August to January 2011 and August through October of the 2012 swordfish seasons. Collectively, this study deployed 54 sets of DSBG resulting in 4,320 hook-hours in the SCB (Fig. 3). Thirty nine of the sets were performed aboard the R/V *Malolo* and 15 aboard the F/V *Gold Coast*. The total drift distance of each 4 h set ranged from 0.4 to 6.1

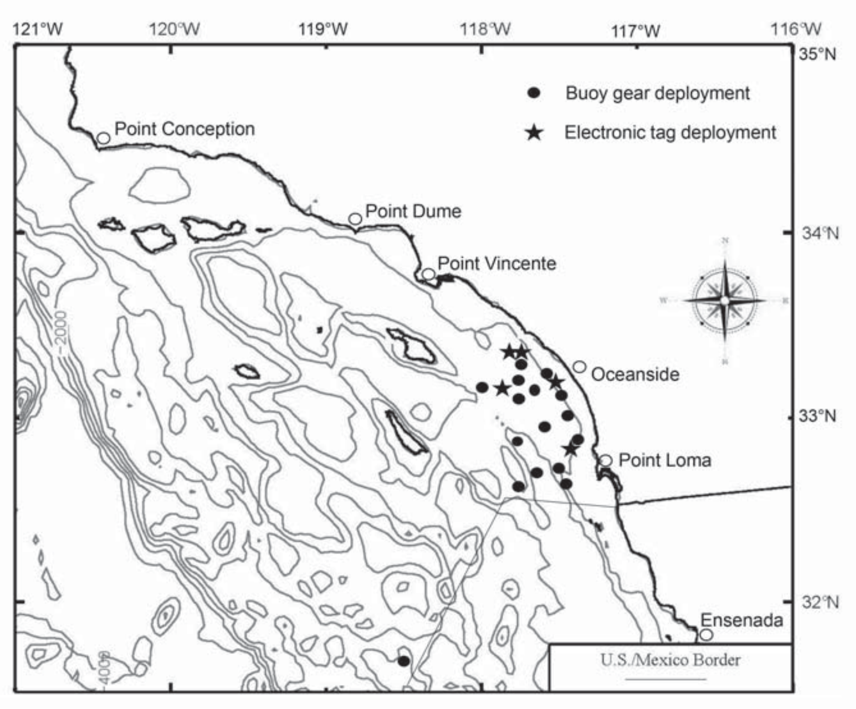

Figure 3.—Study area showing the DSBG deployments (circle) and location of the swordfish tagged in this study (star).

km and averaged 2.13 ± 1.2 km. Sea surface temperature ranged from 15.8° to 23.9°C and averaged 21.3° ± 1.8°C. Average set duration was maintained at 4 h and ranged from 3.5 to 5 h.

Catch Details

A total of fourteen swordfish were captured without any interactions with nontarget species of concern (i.e., sea turtles and marine mammals). Swordfish mass (estimated using Uchiyama et al., 1999) ranged from 90 to 195 kg round weight (RW) with an average length of 200 ± 20 cm lower jaw fork length (LJFL). Average swordfish capture depth was 299 ± 8 m. Of the 14 swordfish captured, 10 individuals were caught using green lights and four with blue (Table 2).

Additional species captured during the deep-set trials were bigeye thresher sharks, *Alopias superciliosus* (7); opah, *Lampris guttatus* (2); blue sharks, *Prionace glauca* (2); and common thresher shark, *Alopias vulpinus* (1) (Table 2, Fig. 4).

Table 2.—Catch information for experimental DSBG trials in the Southern California Bight.

Species	Vessel	Capture depth (m)	~Size (FL)	Light color	Bait type	Hook location	Catch condition
Swordfish	R/V *Malolo*	300	191	Green	Squid	Lower	Good
Swordfish	R/V *Malolo*	300	165	Green	Squid	Upper	Good
Swordfish	R/V *Malolo*	300	191	Blue	Mackerel	Lower	Good
Swordfish	R/V *Malolo*	329	201	Blue	Mackerel	Lower	Good
Swordfish	R/V *Malolo*	295	211	Blue	Mackerel	Lower	Good
Swordfish	R/V *Malolo*	300	188	Green	Mackerel	Lower	Good
Swordfish	R/V *Malolo*	300	~191	Green	Squid	Lower	Good
Swordfish	R/V *Malolo*	278	231	Green	Squid	Upper	Good
Swordfish	R/V *Malolo*	300	224	Green	Mackerel	Lower	Good
Swordfish	R/V *Malolo*	295	239	Green	Squid	Lower	Good
Swordfish	R/V *Malolo*	290	198	Green	Mackerel	Lower	Good
Swordfish	F/V *Gold Coast*	300	191	Blue	Squid	Lower	Good
Swordfish	F/V *Gold Coast*	300	191	Green	Squid	Lower	Good
Swordfish	F/V *Gold Coast*	300	~191	Green	Squid	Lower	Good
Opah	R/V *Malolo*	200	109	Blue	Squid	Lower	Good
Opah	R/V *Malolo*	200	112	Green	Mackerel	Upper	Good
Blue shark	R/V *Malolo*	250	117	Green	Mackerel	NA	Poor
Blue shark	R/V *Malolo*	270	117	Green	Mackerel	NA	Poor
Common thresher	R/V *Malolo*	200	170	NA	Mackerel	Upper	Moribund
BET[1]	R/V *Malolo*	305	198	Green	Mackerel	Lower	Good
BET	R/V *Malolo*	315	~216	Green	Squid	Lower	Good
BET	R/V *Malolo*	320	163	Green	Mackerel	Lower	Good
BET	R/V *Malolo*	270	173	Disco	Mackerel	Lower	Good
BET	R/V *Malolo*	290	152	Green	Squid	Lower	Good
BET	F/V *Gold Coast*	300	~191	Green	Mackerel	Lower	Good
BET	F/V *Gold Coast*	300	~178	Green	Squid	Lower	Good

[1] BET=Bigeye thresher

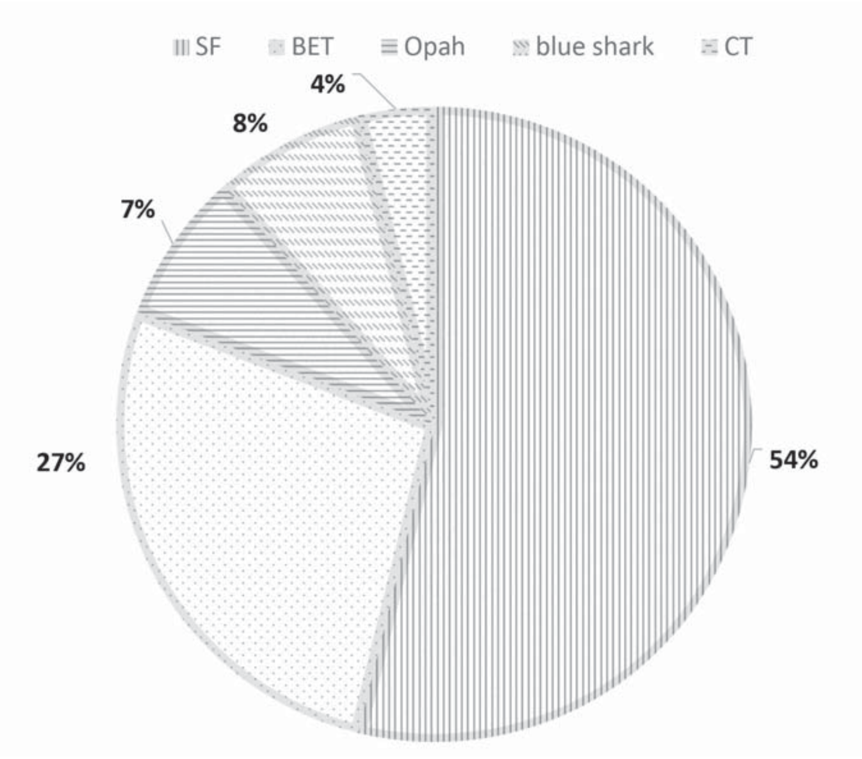

Figure 4.—Catch associated with 54 4-h sets of DSBG; SF=swordfish, BET=bigeye thresher shark, and CT=common thresher shark.

Tagging Data

Five swordfish were opportunistically tagged within the study area during the DSBG deployments (Fig. 3, 5; Table 1). The average daytime depth for all swordfish tagged in this study was 192 ± 25 m while the average night depth was 23 ± 28 m. The average depth while below the thermocline (excluding periods of ascent, descent, and basking activity) was 256 ± 32 m.

For all five swordfish, average thermocline depth was 67± 5 m (Table 1). Basking events were observed in four of the five tracked individuals and collectively accounted for 9 (± 8%) of the daily daytime records. Total horizontal displacement ranged from 1 to 41 km, with the greatest net movement being from swordfish # 05A0197 which moved on average 8.2 km/day over the 5-day deployment period (Table 1).

Discussion

This study coupled vertical distribution data from target and nontarget species with conventional fishery methods to develop and trial an alter-

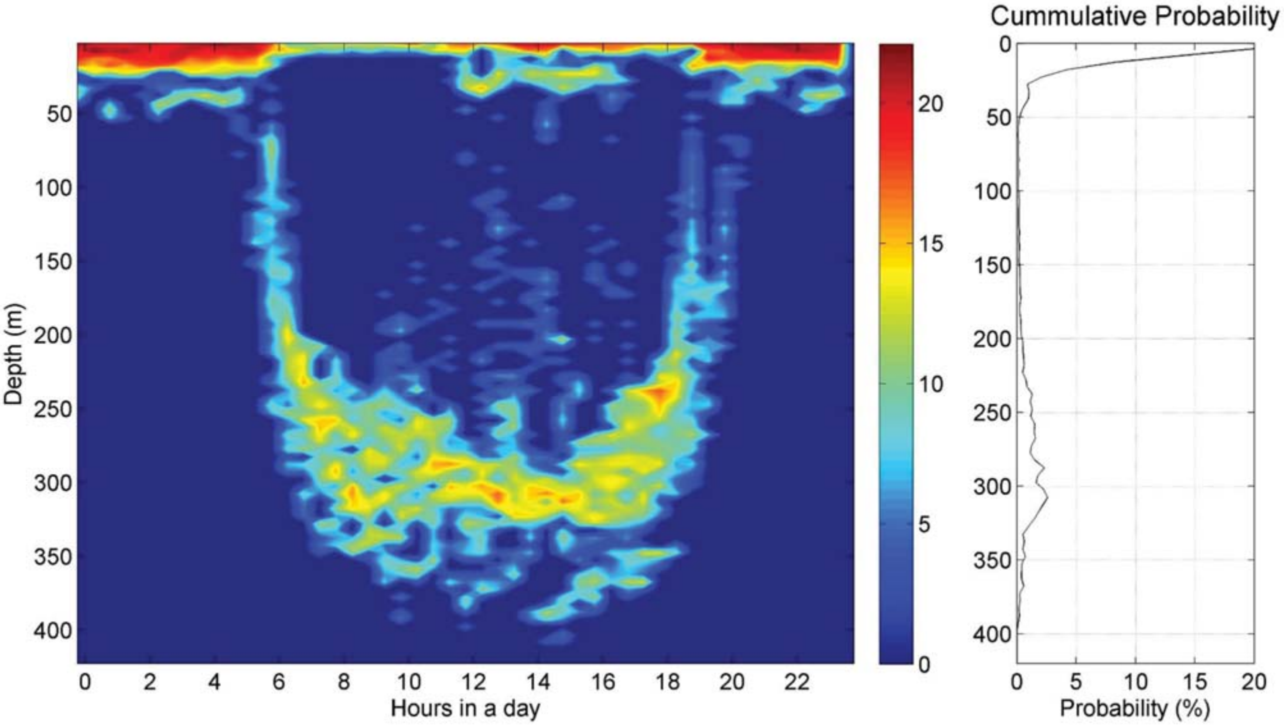

Figure 5.—Depth distribution plotted over a 24 h period and associated probability plot for 5 swordfish tagged with short-term PSAT's. Data were plotted on a log 10 scale.

native fishing gear that targets swordfish below the thermocline during the day. Findings suggest that DSBG can be used to selectively target swordfish off southern California and may provide an additional harvest method for local fishermen.

Targeting swordfish at depth also reduces the potential for interaction with species of special concern (i.e., sea turtles, marine mammals) and thus may be suitable for areas in which fleet operations are currently limited. Further, the development of selective fishing methods may lead to increased domestic opportunities for both fishermen and consumers and warrants future investigation off the U.S. west coast.

Previous Deep-set Experiments

Using hook depth as a tool to selectively target pelagic species has been used extensively in commercial fisheries for decades, with most of the effort focused on bigeye tuna, *Thunnus obesus*, and albacore, *Thunnus alalunga*, (Suzuki et al., 1977; Sakagawa et al., 1987). Although different deep-set configurations exist, hook depths are typically maintained between 50 and 300 m, which overlap with the depth distribution of targeted tuna species (Suzuki et al., 1977; Sakagawa et al., 1987; Holland et al., 1990; Schaefer and Fuller, 2002). In addition to the increased targeting of tunas, deep-set operations also have the added benefits of reduced interactions with nontarget and incidental species as well as surface oriented fisheries that may operate within the same region (Nakano et al., 1997; Polovina et al., 2003; Beverly and Robinson, 2004; Beverly et al., 2009). One drawback to deep-set operations is that they often catch fewer valuable incidental species and also incur additional cost, with more time required to set and retrieve the gear compared to surface operations (Beverly and Robinson, 2004).

Deep-set operations for swordfish are much less common, as night-based surface deployments are particularly effective for this species (Ueyanagi, 1974; Bigelow et al., 2006). Exceptions to this include deep-set operations off the coast of Australia which have successfully increased catch per unit of effort for swordfish when compared to other species (Beverly and Robinson, 2004). Also, Onada et al. (2006) have reported on a traditional deep-set vertical longline fishery that targets swordfish during the day off the coast of Japan.

The vertical longline fishery is similar in many ways to the DSBG trialed in this study; however, the vertical gear also uses surface-oriented hooks for targeting bigeye tuna and other valuable target species (Onada et al., 2006). Similarly, there are small-scale deep-set operations in use off the coast of Florida and within the Gulf of Mexico as well as in the Mediterranean Sea.

Deep-set longline trials for swordfish have also been performed off Hawaii with limited success (Boggs,

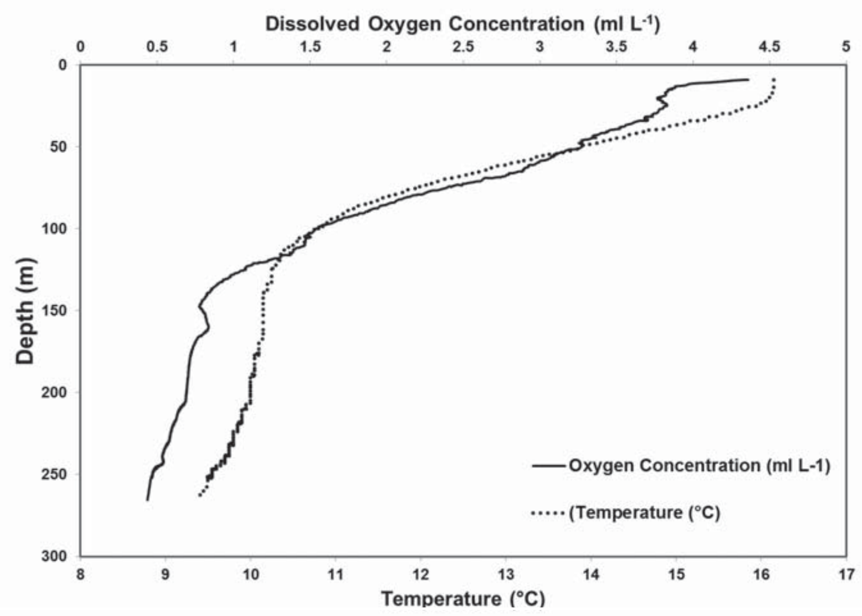

Figure 6.—Depth vs. water temperature (°C) and dissolved oxygen concentration (ml/L) collected during deep-set buoy gear trials off the coast of southern California.

2004; Gilman et al., 2007). The low success was likely influenced by the depth distribution of swordfish in this region (500–800 m; Dewar et al., 2011), which is much greater than that described for the eastern North Pacific (250–400 m; Sepulveda et al., 2010; Dewar et al., 2011).

Unlike the waters off Hawaii and the central North Pacific, the coastal waters off California exhibit a relatively shallow thermocline (67 m in this study (22–33 m; Palacios et al., 2004)) and an oxygen minimum zone (OMZ) that ranges from 250 to 500 m (Bograd et al., 2008; Fig. 6). The shallow OMZ has been hypothesized to compress the vertical habitat available for pelagic species, which concentrates pelagic resources within depths that are more accessible to modern day fisheries (Prince and Goodyear, 2006).

Catch Rates

Swordfish comprised 54% of the catch during the 2 yr project. This contrasts with previous shallow-set longline experiments that had over 90% shark catch (i.e., mako shark, *Isurus oxyrinchus*, and blue shark, *Prionace glauca*) from the same study area and during a similar time of year (Obrien and Sunada, 1994). Because the goal of this study was to design DSBG and assess the feasibility of deep-set techniques in the SCB, standard comparisons of catch per unit effort (CPUE) with other gears are not appropriate. Regardless, initial catch rates were positive, considering the poor swordfish landings observed in both the California DGN and harpoon fisheries during the duration of this study (PFMC, 2013).

In 2012, the harpoon fishery had a total catch of about 5 t from a fleet of about 25 permitted vessels (Pacific Coast Fisheries Information Network, PacFIN data query, 5/2013[5]). Further, in 2012 there were more individual swordfish captured using DSBG than landed by any one harpoon vessel.[5] Similarly, the California DGN fleet had low catches in 2012, with about 75 t landed for 15 active vessels.[5] The majority of the DGN harvest in 2012 came from outside of the area in which these experimental trials were conducted (northern portions of the SCB).[5]

The ratio of target to nontarget catch during experimental trials suggests DSBG to be relatively selective for swordfish with overall low nontarget catch rates (Fig. 4). Bigeye thresher sharks made up the bulk of the nontarget catch (Fig. 4). The bigeye thresher shark is a relatively common nontarget species of the California DGN fishery that is not typically retained for sale given their low market value when compared to swordfish and other species captured in the fishery (Hanan et al., 1993; PFMC, 2006).

Nonetheless, the bigeye thresher shark is occasionally retained and processed by local fresh markets in the United States and Mexico (Hanan et al., 1993). Because bigeye threshers are common inhabitants of the SCB that share similar diel distributions with swordfish (Nakano et al., 2003; Weng and Block, 2004), interactions with deep-set operations are likely unavoidable without additional information on their specific movements within the SCB.

Additional nontarget species captured in the trials were opah (2), blue shark (2), and common thresher shark (1), which collectively accounted for less than 20% of the total DSBG catch. All of the nontarget species encountered in this study are common in the California DGN fishery, with opah and common thresher sharks providing valuable revenue as secondary and tertiary targets of the fishery (Hanan et al., 1993).

Among the total catch, the common thresher shark was the only mortality observed during the DSBG trials. This is likely because the common thresher shark was landed by the caudal fin, a capture method that has been shown to result in increased mortality in this species (Heberer et al., 2011). The ability to detect strikes and the rapid processing of hooked fish, likely led to the overall good condition of the captured fish in this study (Table 2). The ability to release fish in good condition may provide an additional opportunity for fishermen to reduce gear impacts on nontarget species.

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[5] PacFIN data query accessed on 5/2013 (http://pacfin.psmfc.org/pacfin_pub/data.php).

Movements

The depth records from the five swordfish tagged in this study were similar to those presented in previous swordfish movement studies for this region (Sepulveda et al., 2010; Dewar et al., 2011). For all individuals, the predominant depth distribution consisted of a diurnal pattern in which the swordfish remained largely below the thermocline during the day and within the upper mixed layer at night (Fig. 5). This distribution has been suggested to be in response to the diurnal movements of prey species that make up the deep scattering layer (DSL) (Carey and Robison, 1981; Carey, 1990; Takahashi et al., 2003; Sepulveda et al., 2010).

Daytime basking events occurred in all tag records and collectively accounted for less than 10% of the daytime depth distribution. This finding was similar to that of previous studies by Sepulveda et al. (2010) and provides insight into the difficulty associated with augmenting domestic landings with harpoon-based operations alone. We acknowledge, however, that in certain areas and time periods, basking behavior may be more prevalent than that observed in this study. This is evident in historical harpoon fishery records off California which show some years to be exceptionally productive for harpoon fishermen (Bedford and Hagerman, 1983). The presence of periodic basking activity supports hypotheses on behavioral thermoregulation (Takahashi et al., 2003, Sepulveda et al., 2010), and remains an important factor in understanding fishery dynamics and the limitations of harpoon operations.

Applicability and Limitations

Given that DGN operations are particularly effective in targeting swordfish off California with a relatively small net length (<1,000 fm or 1 nmi: Hanan et al., 1993), it may be that the coastal aggregation of the swordfish resource in the eastern North Pacific provides suitable conditions for buoy-based fisheries to operate. Despite positive results from the initial trials performed in this study, DSBG operations are artisanal in nature and present several limitations when compared to higher capture-volume gears such as DGN and pelagic longline.

Among the limitations are the low number of hooks deployed at a single time and the need for continued monitoring of the gear. These traits reduce the ability of the gear to operate on a larger scale, and therefore concentrate fishing effort within a relatively small (3–4 km) target area. Nonetheless, the shallow-set buoy fishery in operation off the Florida coast has provided on average 75 t/year from a small fleet of about 40–50 vessels (NMFS, 2012). The Florida fishery consists predominantly of small vessels (<15 m) with day-trip operations within the coastal waters <50 nmi (NMFS, 2010). The Florida buoy-gear caught product is typically received at higher prices than longline caught swordfish and fulfills a market niche that is similar to that of the west coast harpoon fleet.

In this study, harpoon tagging of swordfish was performed throughout the DSBG deployments, and in many cases provided the criteria for which the set location was determined. The daytime deployment regime and relatively small operation area of DSBG are compatible with modern west coast harpoon operations. Given the valuable market niche that has been developed by the California harpoon fishery, perhaps DSBG can be used to complement and augment California harpoon operations which are severely degraded compared to previous years. Further, given that DGN operations are conducted at night, it may be that DSBG can also be used to augment current DGN operations.

Management Implications

The current decline in California swordfish landings does not align with projected population abundance estimates for the North Pacific swordfish stock (Hinton and Maunder, 2012; Brodziak and Ishimura[2]). Reductions in domestic swordfish landings are more likely a byproduct of increasing regulations geared toward the conservation of protected resources in California waters as well as increasing operational costs for traditional west coast fisheries.

Because domestic swordfish production is unable to meet U.S. consumer demand, the majority of U.S. seafood is imported from foreign nations which often lack comparable management, compliance, and enforcement measures (Rausser et al., 2009). This study provides the initial steps towards identifying new domestic swordfish fishery options for the U.S. west coast while minimizing interactions with species of concern. Similar experiments that expand the gear trials are necessary for better understanding catch rates, potential for bycatch interaction and feasibility of commercial application off the U.S. west coast.

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