Characterization of a developing recreational deep-drop fishery for swordfish off southern California

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FULL RESEARCH ARTICLE

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Abstract

California recreational anglers have recently started using specific deep-drop tackle to target swordfish (*Xiphius gladius*) below the thermocline during the daytime. Increased rod-and-reel fishing effort stems from promising experimental fishing trials of a recently approved commercial gear type off California (deep-set buoy gear), along with the widespread growth of deep-drop recreational fisheries for swordfish around the world. The rapid development and vast growth potential in this emerging recreational fishery, has outpaced the implementation of sampling programs to accurately quantify swordfish catch, effort, and economic output. We characterized recent sportfishing practices for swordfish and reviewed available California recreational fishery data sources. Findings suggest a sharp increase in estimated catch relative to previous decades and a major shift in the techniques used by local fishers to target swordfish beginning in September 2019. Recent increases in recreational swordfish catches aligned directly with heightened tackle sales for gear specific to deep-drop practices. Given the increased deep-set effort for swordfish within the region and the limited coverage of existing private-vessel catch documentation, additional monitoring efforts are needed to better gauge the potential social, economic, and ecological impacts of this emerging recreational fishery.

Key words: highly migratory species, hook-and-line angling, southern California sportfishing, swordfish catch estimates, *Xiphius gladius*

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Introduction

Swordfish (*Xiphius gladius*) are a cosmopolitan species that support extensive commercial fisheries across the globe (Ward et al. 2000). Although primarily harvested by commercial operations, swordfish are also a highly-valued big-game species prized by international anglers because of their potential size, outstanding endurance, and renowned meat quality (Bedford and Hagerman 1983; Ward et al. 2000). Recreational fisheries targeting swordfish have expanded across many parts of their range, largely within discrete locations where swordfish aggregate seasonally to forage or possibly spawn (Lerner 2009; Fenton et al. 2012). Productive U.S. commercial and recreational swordfish operations have historically been based out of South Florida and along the Gulf Coast (Davis et al. 2017; Kerstetter et al. 2017; Lerner et al. 2017). Since the 1980s, directed recreational fisheries have expanded significantly between South Florida and the Texas Gulf Coast, where a growing fleet of recreational and charter vessels now generate millions of dollars in revenues and support the largest group of swordfish anglers in the world (Ditton and Stoll 2000, Kerstetter et al. 2017; Lerner et al. 2017). The revenues generated from expanding recreational fisheries throughout the southeast region of the United States, as well as the development of deep-set buoy gear (DSBG) along the west coast (Sepulveda et al. 2014), have acted as both a model and catalyst for the recent growth of a directed recreational fishery for swordfish off Southern California.

In 2019, state and federal fisheries managers (National Marine Fishery Service [NMFS] and the Pacific Fisheries Management Council [PFMC]) voted to expand the types of legal commercial swordfish gear to include DSBG, a hook and line technique that targets swordfish below the thermocline during the day (Sepulveda et al. 2014; Sepulveda and Aalbers 2018). Initial success from the developing DSBG fishery generated considerable interest among the recreational community with information disseminated through published literature, PFMC publications, and online platforms [1]. Data collected during DSBG exempted fishery trials have been used to improve the efficacy of directed efforts to target swordfish at depth on rod and reel [2].

The developing commercial DSBG and deep-drop recreational fisheries off southern California have incorporated regional movement patterns to selectively catch swordfish during the daytime (Sepulveda et al. 2010; Sepulveda and Aalbers 2018). Like commercial operations, recreational fisheries have adapted over time to target swordfish at specific depths based on their distinct diel dive patterns (Carey

and Robison 1981; Lerner 2009; Davis et al. 2017). Swordfish are unique in their capacity to occupy extreme depths throughout the daylight hours where they primarily forage well below the thermocline (300–600m), in contrast to a shallow nighttime distribution within the waters of the upper mixed layer (Carey and Robison 1981; Sepulveda et al. 2010; Dewar et al. 2011).

South Florida anglers traditionally targeted swordfish at night by drifting shallow baited lines within the waters of the upper mixed layer (Romanov et al. 2013; Kerstetter et al 2017; Davis et al. 2017). However, following the development of deep-drop techniques off the coast of Venezuela in the 1990s and subsequent achievements by innovative fishers off Islamorada during the early 2000s, South Florida anglers began successfully catching swordfish at depth during the day (Davis et al. 2017; Tracey and Pepperell 2018). By 2010, the practice of daytime deep-dropping became widespread and gradually transitioned into the most common recreational method used to target swordfish across South Florida and along the Gulf Coast (Davis et al. 2017). Although recreational daytime fisheries for swordfish have since expanded to areas off New Zealand, southeast Australia, Tasmania and Chile (Holdsworth and Saul 2017; Tracey and Pepperell 2018), the practice of deep-dropping for swordfish remains relatively novel and continues to increase in popularity.

While California sportfishers have harvested swordfish since the early 1900s (Bedford and Hagerman 1983), the southern California recreational fishery has been relatively limited in terms of participation and swordfish catch compared to the more established operations in the southeastern U.S. (Kerstetter et al. 2017). Historically, southern California big-game fishers were often unsuccessful upon opportunistically presenting baits to swordfish found basking at the surface during the daytime (Bedford and Hagerman 1983). However, sportfishers were also allowed to harvest basking swordfish with a harpoon until 1971, when the California Fish and Game Commission began requiring a commercial license for this activity. Swordfish landings are occasionally made by California-based commercial passenger fishing vessels (CPFV), although the vast majority of southern California recreational fleet that target swordfish and other pelagic species is comprised of privately-owned vessels berthed in marina slips (private-access fleet). In the past, California catches of swordfish on rod and reel were considered negligible (Bedford and Hagerman 1983; PFMC 2021); however, a sudden renewed interest for swordfish deep-dropping has spurred new tackle sales and been the focus of recent fishing seminars [3] and tournaments [4].

Off California, the novelty and rapid development of the deep-drop fishery for swordfish has outpaced the implementation of sampling programs to accurately monitor swordfish catch and effort [5], especially among the private access fleet that is largely inaccessible to conventional fishery-dependent data collection programs. Monitoring changes in fishery dynamics and the characterization of new fishing methods remains critical for documenting harvest levels, as well as assessing environmental impacts and the economic benefits associated with the activity (Lerner et al. 2017). Given the recent increase in swordfish catch and directed participation, the objectives of this work were to characterize current deep-drop fishing practices, document the dynamics of this emerging recreational fishery, and highlight data gaps that may allow for better quantification of the economic and ecological impacts of the developing recreational fishery off California.

Methods

Fishery and Gear Characterization

Multiple sources of information were assembled through stakeholder interviews, reviews of scientific manuscripts and popular literature, as well as through angling club and state catch records. Standard recreational gear configurations and common practices for both surface-based and deep-drop methods were assessed through consultation with key recreational representatives, regional fishing seminars, popular literature, and online forums. Additionally, scientific literature and catch data from both regional fishing clubs and the California Department of Fish and Wildlife (CDFW) were reviewed to gather specific information on historical fishery trends, timelines, annual landings, and fish size (De Sylva 1974; Bedford and Hagerman 1983; Kerstetter et al. 2017; Lerner et al. 2017). Consultations with industry representatives were conducted to identify recent gear trends along with bait and tackle sales specific to deep-dropping for swordfish (e.g., electric reels, heavy stick sinkers, illumination sources). Additionally, interviews were conducted with captains and crewmembers of southern California charter vessels that have expanded their operations to include daytime trips directed at targeting swordfish using deep-drop techniques. Collectively, assessments provided information on fishing areas, deep-drop rigging techniques, customized tackle, bait preferences, and expenses.

Catch Estimates

California landing estimates for recreationally caught swordfish onboard both private/rental boats and CPFV were obtained through the 2020 Stock Assessment and Fishery Evaluation (SAFE) Report for U.S. west coast highly migratory species (HMS) from 2017 to 2019. Catch estimates from private/rental boats dating back to 2005 were obtained upon request from CDFW, along with logbook records from the mandatory CPFV and charter vessel logbook program (Hill and Schneider 1999). California private and rental boat catch estimates were based on data extrapolations conducted through the California Recreational Fisheries Survey (CRFS) program through a combination of launch-ramp surveys, phone interviews, and onboard CPFV observers (Horning et al. 2014; Monk et al. 2014). Fishing effort estimates for the private-access fleet have also been generated since 2004 under the CRFS program through phone interviews of randomly-selected fishing license holders. Similarly, the marine recreational fishery statistics survey (MRFSS) generated California recreational catch estimates from 1979 to 2003, based on random-digit dialing telephone surveys of coastal households and angler surveys at select intercept points (Hicks et al. 1999). Additional sources of recreational catch and effort data were examined, however; it was not possible to differentiate between harpoon and hook and line gear prior to 1971 (Bedford and Hagerman 1983).

Swordfish catch records from individual rod-and-reel anglers were obtained from two well-established game fishing clubs that have maintained consistent historical landings and effort data (i.e., Balboa Angling Club [BAC], Avalon Tuna Club [ATC]). Upon club approval, data were compiled and incorporated into a database for analysis based on protocols modified from Gartside et al. (1999). Annual statistics on the number and size of swordfish weighed on certified scales were compiled and plotted by time, with catch data catagorized by surface-based or deep-drop methods. A simple linear regression was calculated from historical ATC recorded weights to predict whether the maximum size of swordfish changed significantly between 1913 and 2020. It was not possible to conduct statistical analysis for mean weight values because all individual weights were not reported and the variation around each mean value was unknown.

Based on data availability and fishery surveying efforts, swordfish landings were seperated into a historic period (1913–1978), a period since California recreational fishery monitoring programs were implemented (1979–2018) and a current period (2019–2020), during which records have incorporated swordfish caught using deep-drop methods. Deep-drop swordfish catches from the current period were compared against angling club records from the previous four decades and throughout the historic period (individuals caught using surface-based techniques). Supplemental information on swordfish catch details and sportfishing vessel specifics were generated from online fishing forums, angling club websites, social media outlets, and sport-fishing video seminars. Data on vessel size were gathered from the U.S. Coast Guard Maritime Information Exchange PSIX Vessel Search for boats with documented swordfish catches[6].

Results

Fishery and Gear Characteristics

Representative recreational vessels that landed swordfish during the 2019–2020 season ranged in size from 5–30 m (mean = 10.4 m, n = 31). Based on weigh-station and angling-club records, vessels targeting swordfish using deep-drop methods primarily originated from private-access marinas located between San Diego and Santa Barbara CA., with most vessels departing from San Diego Bay, Mission Bay, Dana Point Harbor, or Newport Bay. Deep-drop anglers primarily concentrated in areas with prominent oceanographic features (i.e., seamounts, ridges, and submarine canyons) that occur in close proximity to the coast and around the Channel Islands (**Fig. 1**).

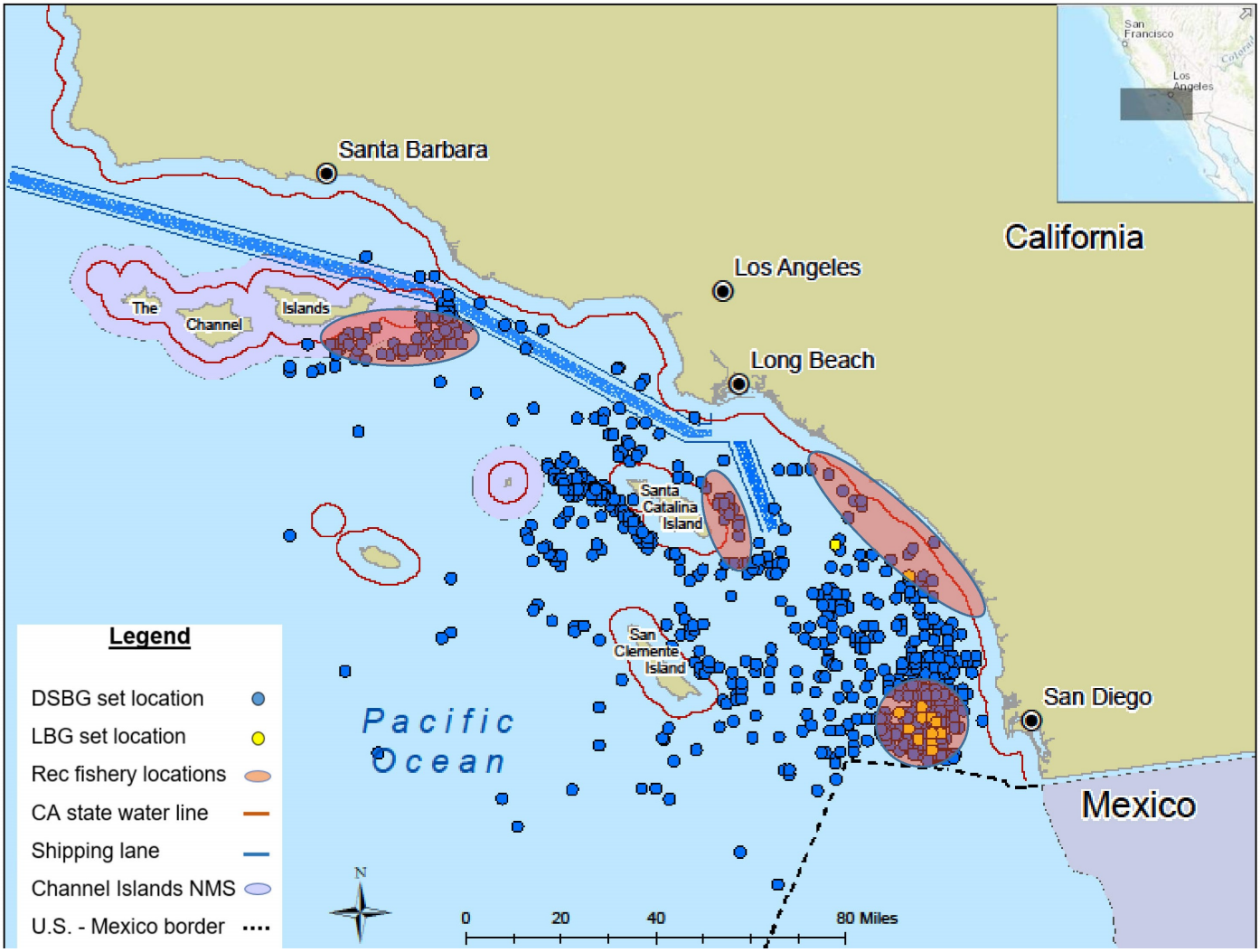

Figure 1. Commercial deep-set buoy gear (DSBG) and linked buoy gear (LBG) effort within the Southern California Bight based on set locations from exempted fishery trials targeting swordfish through December, 2020 overlaid with the California (CA) state water line, Channel Islands National Marine Sanctuary (NMS) and popular recreational (Rec) fishery locations (red shaded areas), as determined from stakeholder interviews and web-based catch records (Modified from NOAA Environmental Impact Statement for the Authorization of Deep-set Buoy Gear under Amendment 6 to the Fishery Management Plan for West Coast Highly Migratory Species Fisheries). Available from: **https://media.fisheries.noaa.gov/2021-08/DraftEIS_Authorization-DeepSetBuoyGear.pdf**

California deep-drop gear configurations commonly used in the developing recreational fishery consisted of stout, bent-butt rods (36 kg) affixed with either manual or electric reels spooled with heavy braided line (>45 kg) and a heavy sinker (2–4 kg) rigged at the terminal end adjacent to a 6-30 m fluorocarbon leader (68–136 kg) crimped to a large circle (12/0–18/0) or J-type hook (8/0–12/0; **Fig. 2a**). Based on stakeholder interviews, electric reels were preferred due to the time and effort involved in retrieval of heavy weights and terminal tackle. Several electric reel models currently used in the Southern California deep-drop fishery include the Daiwa Seaborg 1200MJ, Daiwa MP3000-12V and Lingren-Pitman LP S2-1200. Other anglers used a heavy big-game rod with a large manual-crank reel, that may be retrieved from depth by hand or using a modified electric drill assembly [7]. Anglers preferred the use of multiple rigs set at different depths, with one set-up deployed straight down from the vessel and additional lines set away from the boat with inline floatation affixed at a specified distance from baited hooks to maintain baits at a fixed depth [8] (**Fig. 2b**). In addition to drifting lines away from the boat, inline-floats were utilized as a strike indicator to detect when something was on the line.

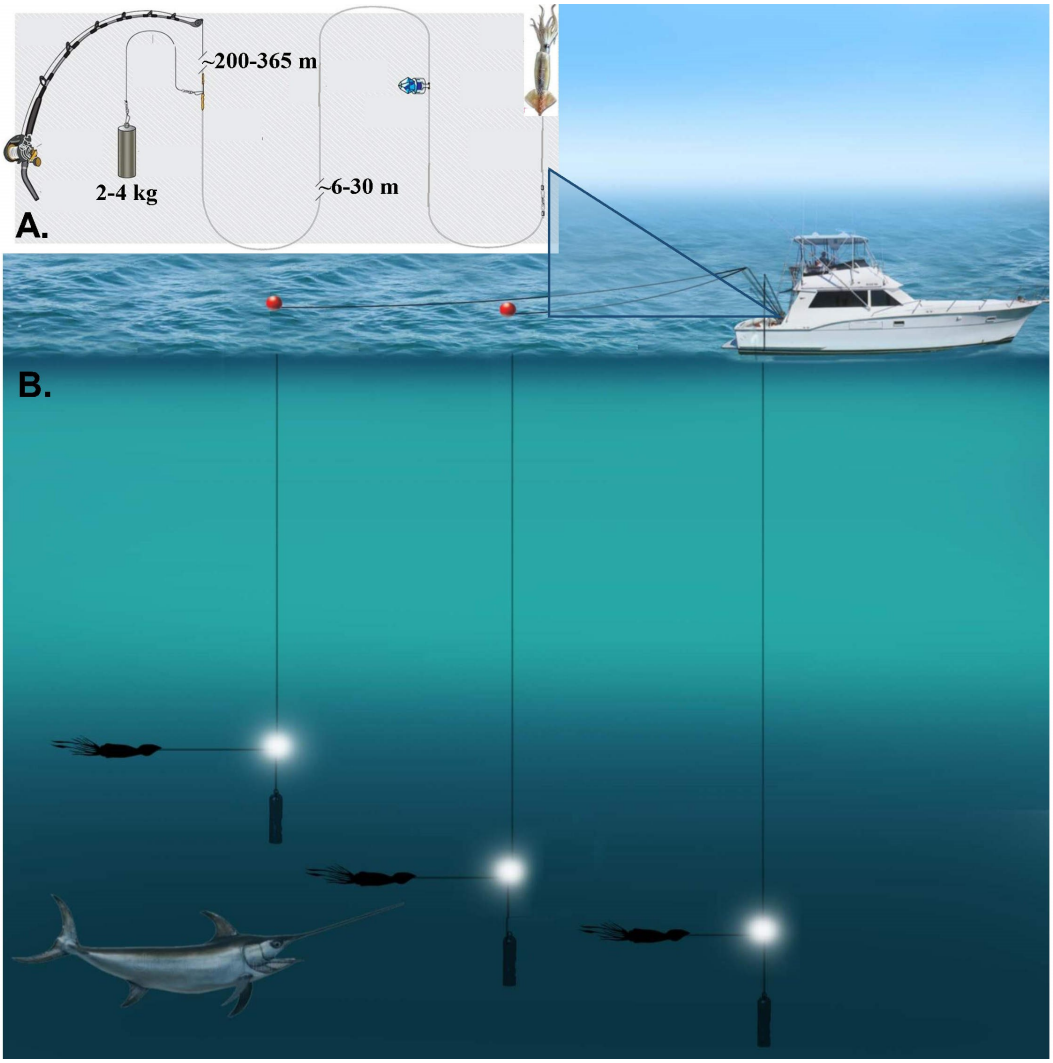

Figure 2. Depiction of a (A) common west-coast recreational swordfish gear setup using a heavily weighted vertical mainline and an illuminated gangion baited with jumbo squid and (B) standard configuration for targeting swordfish at depth during the daytime using multiple lines from a drifting vessel.

Based on consultations with experienced deep-drop anglers and tackle distributers, the preferred bait type was jumbo squid (*Illex* spp.) lashed or bridled to the hook shank to prevent the bait from becoming dislodged during a strike or tangled during descent and retrieval. Battery-powered or chemical light sources were commonly used proximal to the baited hook (i.e., Electalume lights, Duralite Diamonds, or Cyalume lights). Illumination specifics (i.e., manufacturer, model, and color) were found to vary widely based on angler preference. Some of the interviewed deep-drop anglers preferred to use a fixed weight tethered to the terminal end of the mainline, whereas others were more partial to a sacrificial weight system that is broken free from the mainline after descending baited hooks to a desired depth. Preferred depths targeted by deep-drop anglers were found to range from ~200–365 m, with fishing activity occurring throughout the daylight hours.

Catch Estimates

Recreational landing records for private and rental boats obtained from CDFW revealed zero swordfish records between 2005 and 2016, followed by an increase to an estimated 10 swordfish landed in 2016 and an abrupt jump to 94 swordfish in 2019 (Fig. 3). California CPFV/charter vessel catch records

fluctuated between 0 and 3 swordfish from 2005-2018 and increased to 17 swordfish in 2019. California recreational catch data (retained + released) summarized by year and species for private vessels, private vessels fishing in Mexico and U.S. CPFV/charter vessels indicated a sharp increase to a total of 126 swordfish landed in 2019, up from 0 swordfish in 2017, and < 3 swordfish in 2018 (Fig. 3).

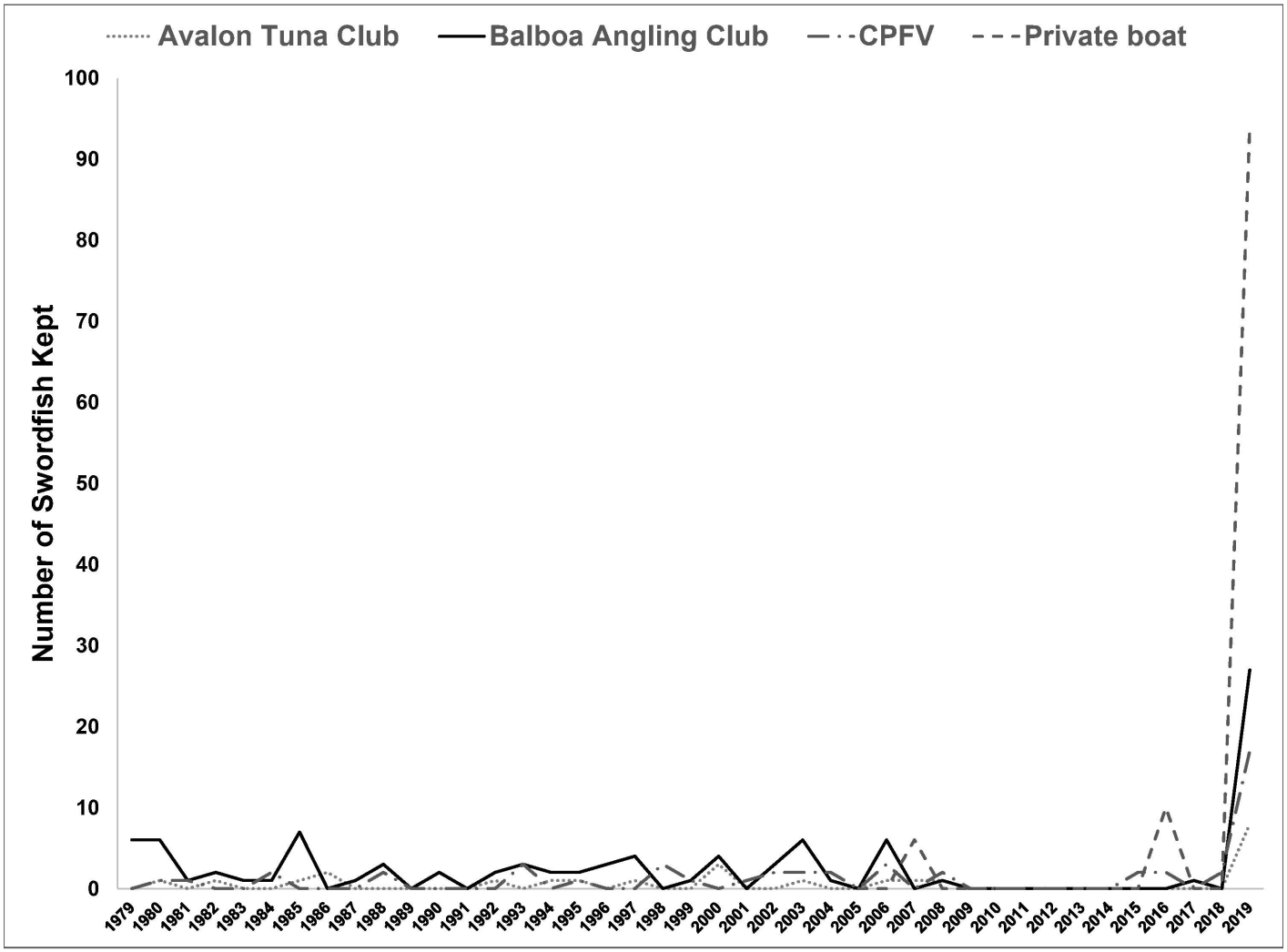

Figure 3. Angling club member catch records of swordfish documented by the Avalon Tuna Club and Balboa Angling Club along with commercial passenger fishing vessel logbook records and private boat catch estimates from the California Department of Fish and Wildlife since 1979, exhibiting a recent spike in swordfish landed by recreational anglers using deep-drop practices.

Recreational catch records since 1940 from the BAC database revealed catches from the months of July through December, with a peak in September (Fig. 4). When compared to an annual average of 4.2 ± 9.3 swordfish caught by BAC club members from when record keeping began in 1940 and just 1.5 ± 1.9 swordfish captured by BAC anglers since 1979, the number of swordfish caught deep dropping by BAC members increased sharply to 27 in 2019 (Fig. 3). Similarly, swordfish catch among Avalon Tuna Club members increased sharply to eight swordfish in 2019 from a previous forty-year average (1979–2018) of 0.4 ± 0.7 swordfish per year. Interviews and club records suggest that all swordfish landed by southern California fishing club members prior to 2018 were caught by casting or slow-trolling baits to swordfish observed basking at the surface.

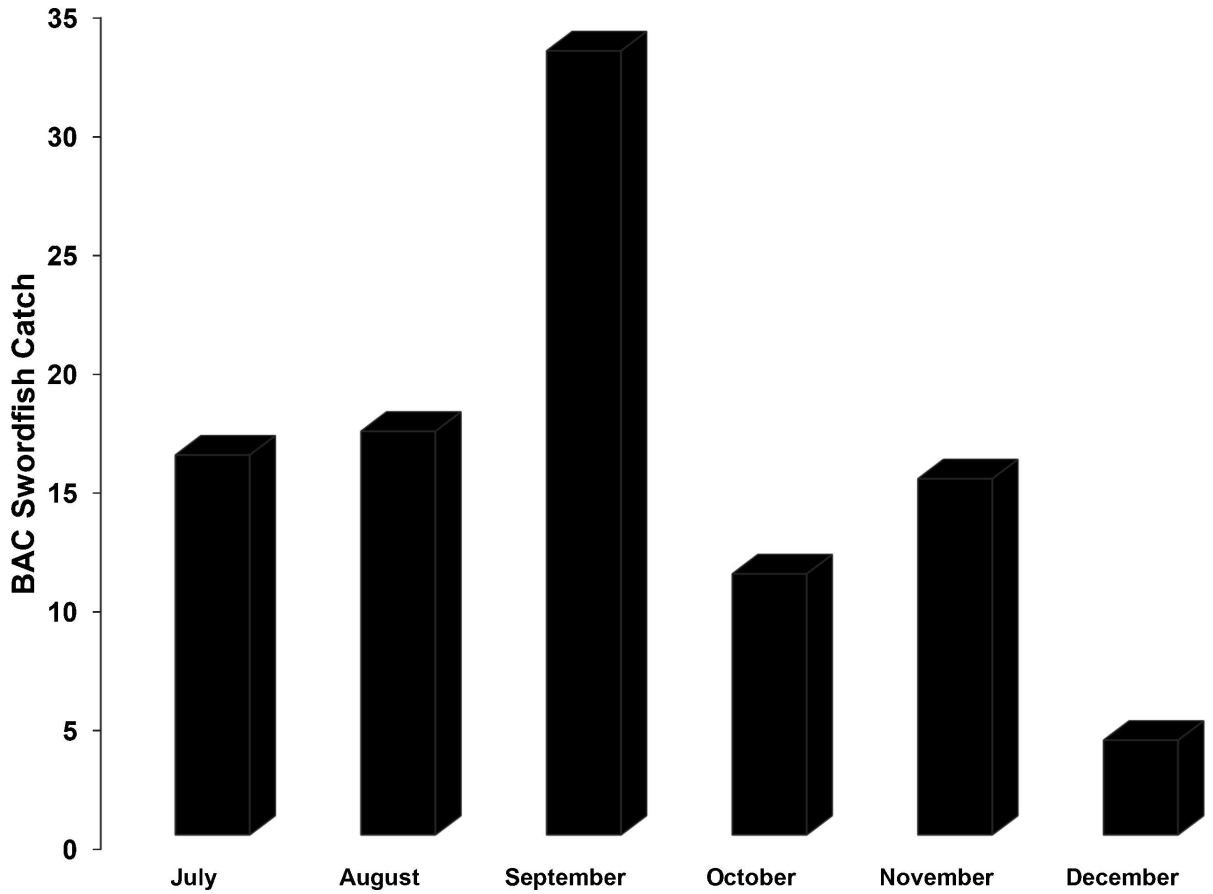

Figure 4. Number of swordfish caught (n = 96) by Balboa Angling Club members aggregated by month for the years of 1941–2019.

Although a select number of swordfish caught using deep-drop practices have been identified since 2017, the bulk of catch and effort began in 2019, following a series of annual billfish tournaments and gear seminars. A rapid surge in deep-drop fishing activity and swordfish catch by the southern California recreational fleet was evident from the increased number of swordfish weighed-in at certified scales and posted on various fishing websites during the 3-month period following a series of southern California billfish tournaments[9]. In September of 2019, two swordfish caught on deep-drop setups were weighed in at the Channel Islands Billfish Tournament, representing the first swordfish recorded in this tournament since 1978. Shortly afterwards, six deep-drop swordfish were caught during the Los Pescadores Tournament and six additional deep-drop swordfish were boated in the Balboa Angling Club Billfish Masters Tournament, four of which were caught by a participating vessel that was deep-dropping for swordfish. The first official billfish tournament to specifically target California swordfish using deep-drop tactics was organized by the International Game Fish Association (IGFA) in November of 2021 and publicly reported catch statistics for the seven swordfish that ranged in size from 45–135 kg (mean = 90.4 ± 31.7 kg)[10]. Swordfish weighed in at the BAC from 7 September 2019 through 11 December 2019 ranged from 34.0–152.2 kg, with a mean size of 82.0 ± 31.7 kg (n = 27). Historic ATC weight records revealed an overall mean weight of 127.3 ± 35.7 kg (n = 278) and a maximum size of 260.5 kg. A significant decrease in the maximum weight of swordfish was observed between 1913 and 2019 (R^2 = 0.289, $F(_{1,54})$ = 21.9, P < 0.001) along with a similarly declining trend in the mean annual weight values of

swordfish caught by ATC members over the past century (Fig. 5).

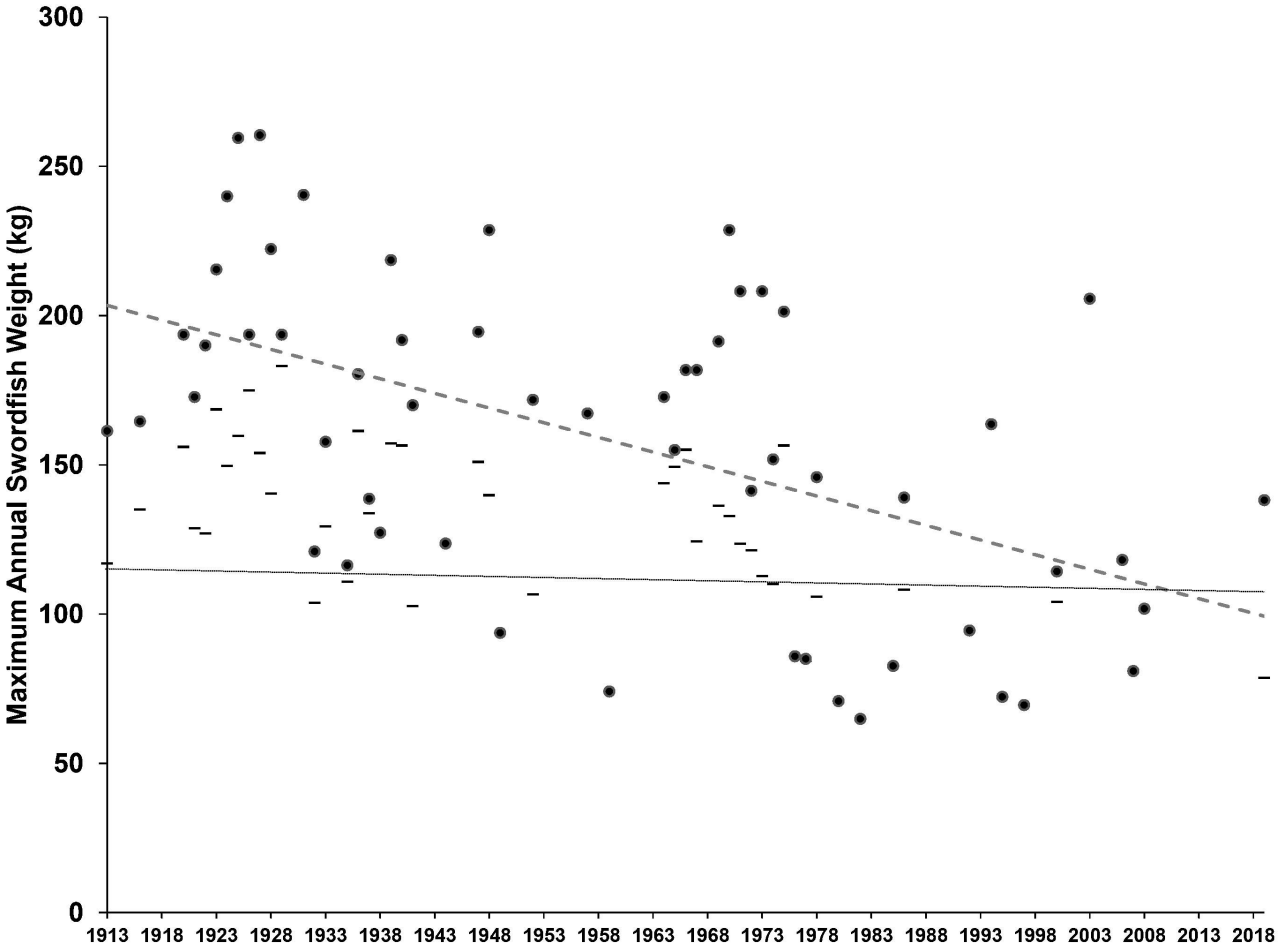

Figure 5. Maximum (•) and mean (–) annual weight (kg) of swordfish recorded by the Avalon Tuna Club from 1913–2019 (n = 278), with declining trend line (—) depicting significant reduction in the max size of swordfish captured over the past century (R2 = 0.289, slope = –2.29, P < 0.001). Horizontal dashed line at 98 kg represents estimated size of 95% female maturity (L95%) from DeMartini et al. (2000).

Economics

Increased spending associated with the surge in deep-drop fishing off California was evident within multiple components of the expanded fishery, including bait and gear sales as well as the advent of new business opportunities capitalizing upon the new charter business industry. Southern California charter operations out of Mission Bay, Dana Point Harbor, and Newport Bay began offering full-day deep-drop trips targeting local swordfish during the fall of 2019, at rates of up to $2,850 for a 12-hour charter trip on an 8-m vessel or up to $6,000 aboard an 18-m sportfisher. Local charter vessels that recently began offering specialized deep-dropping trips advertised catching an average of one swordfish per 12-hour trip from November through December of 2019, with occasional catches of non-target species, including bigeye thresher sharks (*Alopias superciliosus*). In September of 2019, local bait distributers began selling individually frozen “swordfish rigs”, ranging in retail price from $27–$50 each, to capitalize on the rapid increase in demand for baits to target swordfish. Sales of bait and tackle specific to deep-dropping for swordfish jumped exponentially from an insignificant level prior to 2019 to more than $25,000 in 2020 at

Dana Landing Bait and Tackle shop, with the greatest margin of increase coming from the sale of frozen individually packaged squid used for swordfish bait (Pers. Com. John White, Dana Landing Manager; Mission Bay, CA). Tackle sales of swordfish gear, including heavy stick-lead weights, large circle hooks, wind-on leaders, bent-butt rods, and electric reels also increased dramatically in 2019 and continued to grow through 2020. A supply-chain specialist and production manager for a leading tackle manufacturer of electric reels reported a rapid increase in sales across southern California beginning in 2019 for two of their most popular swordfish models, (Pers. Com. Bryan Yamane, Daiwa Corp. Manager; Whittier, CA). Sales of both the Daiwa Seaborg 1200MJ and MP3000-12V electric reels remained elevated as of 21 October 2021 and have been backordered since 2020, as factory production has not been able keep up with heightened demand. Retail cost (MSRP) of the more popular electric reel models ranged from $1,700 for the Daiwa Seaborg 1200MJ to $3,500 for the Daiwa MP3000-12V and $6,500 for the Lingren-Pitman LP SV-1200[11]. In California, record sales and production levels were also reported for Daiwa deep-drop rods, with a higher-end series of big-game rods currently being developed specifically for targeting swordfish at depth.

Discussion

This work characterizes recent changes and rapid growth in the recreational fishery for swordfish off Southern California, a region where approximately 71% of statewide annual recreational fishing effort exists (CDFW 2016). Following the development of a new commercial DSBG fishery off California, the advent of recreational deep-drop practices has led to a sharp increase in the directed targeting of swordfish by California anglers. Increased revenues generated from swordfish gear sales and guided charters directly support the economic importance of the emerging activity. Based on the size and spending capacity of the southern California recreational fishing fleet[12], there remains considerable potential for future economic growth in the rapidly developing fishery. Despite limitations in California catch and effort records, a sharp increase was observed across recreational fishery data sources since the recent introduction of deep-dropping to the west coast. The abrupt increase in recreational deep-drop swordfish catch suggests greater targeting efficacy compared to opportunistically presenting baits to surface-basking swordfish. Improved methods for quantifying catch and recreational effort are needed to better document the growth, economic benefits, and harvest levels of the emerging fishery. Additional monitoring efforts may also help identify and address solutions to social conflicts that are likely to arise over access to the swordfish resource within the Southern California Bight (SCB). It is also important that we continue to assess the potential combined (commercial and recreational) effects on regional swordfish availability and any environmental impacts that result from the new sources of collective deep-set effort within the region.

Fishery Emergence

Although records of recreational swordfish catches off southern California date back to 1913, historical rod and reel landings were limited to the small percentage of successful anglers that opportunistically hooked swordfish found basking at the surface during the day (Hanan et al. 1993; Bedford and Hagerman, 1983). Annual landings of swordfish caught by deep-drop anglers have already greatly exceeded recreational catch rates during the historic surface-based fishery[13], with anglers demonstrating the ability to land multiple swordfish per day using the newly developed techniques[14]. Given the sizeable California recreational fleet and the effectiveness of deep-drop practices, it is likely that catch trends will follow those of the Florida fishery and continue to increase in the future (Lerner et

al 2017).

The growing recreational fishery coincides with the implementation of DSBG which is also projected to expand as it transitions from exempted status to a fully authorized gear-type under the West Coast Fishery Management Plan for Highly Migratory Species[15]. The authorization framework allows NMFS to issue limited entry permits for up to 50 DSBG vessels in the first year, with up to an additional 25 permits/year until a maximum of 300 permits are issued to fish within the SCB[16]. Given the potential social and environmental impacts involved in the authorization of a new fishery within a crowded southern California coastal region, the PFMC and management bodies decided upon an incremental growth strategy that allows managers to halt growth upon reaching an unspecified threshold, based on the cultural and social framework of the fleet. Considering the variable bathymetry, narrow continental shelf, and steep depth contours that occur relatively close to shore within the SCB, recreational anglers frequently converge on productive fishing areas that largely overlap with ongoing commercial DSBG effort (**Fig. 1**; Sepulveda et al. 2014; Sepulveda and Aalbers 2018; PFMC 2020). As the new commercial and recreational fisheries develop, it will be important to monitor activities and social impacts as they evolve. Because commercial DSBG activity is only approved in federal waters (>3 nm) it may be that current spatial limitations can help to mitigate some of the pending social issues between fishery sectors.

Considering the recent recommendation for the federal authorization of DSBG and the potential issuance of up to 300 commercial permits over the next decade, it is important that harvest trends, fishery overlap, and potential conflicts between commercial and recreational fishers are monitored throughout the implementation period. As conflicts arise, accurate landings and effort data can be used to assess socioeconomic impacts of both commercial and recreational activities and help managers structure future regulations that provide the greatest benefit to local fishing communities. Given that harvest and growth potential for both commercial and recreational operations remain unknown, the 12-year structuring of commercial permit issuance offers CDFW and the PFMC the flexibility to make course corrections if and when conflicts arise between sectors or upon development of resource concerns.

Gear Characterization

A review of the recreational fishing techniques and tackle used to deep-drop for swordfish off California has shown that most anglers prefer to use two independent set-ups simultaneously fished at varied depths. Given the novelty of the fishery and the cost associated with the purchase of additional rod-and-reel combos, we anticipate that the number of set-ups will eventually increase up to five rod-and-reel outfits per vessel, similar to what is commonly used in the Florida fishery (Lerner et al. 2017; **Fig. 2b**). Despite differences in swordfish daytime depth distribution and oceanography between the SCB and Florida coast (Sepulveda et al. 2010; Dewar et al. 2011), California techniques are very similar to those pioneered off Venezuela in the 1990s and subsequently introduced to Florida and the Gulf Coast (Davis et al. 2017). However, there are several noticeable differences in the progression of gear used to deep-drop off California, which are likely attributable to more recent advancements in fishing technology. Most notably is the increased use of electric reels and braided line, neither of which were in widespread use during the 1990s. As the Florida deep-drop fishery began to expand in 2008 (Davis et al. 2017), several fishing tackle manufacturers (i.e., Daiwa, Lingren-Pittman, Shimano) launched production lines of mechanized reels tailored specifically for the recreational swordfish market. Similarly, the advent and widespread use of modern braid fishing lines has yielded increased strength at a smaller diameter that allows anglers to reach greater depths with less drag and stretch than monofilament line[17].

Advancements in fishing technology, along with the dramatic increase in real-time information sharing through text messaging, social media, and online fishing forums will continue to increase angler efficacy and contribute to the growth of deep-dropping practices across California. Additional industry growth may also be anticipated over the next few years considering: (1) the low catch rates of other regional HMS stocks (i.e., striped marlin), (2) the relatively close proximity of deep-dropping areas and limited fuel consumption, (3) gear innovations (e.g., electric reels) that allow accurate depth targeting and reduced fight times, and (4) increased participation trends as observed in the Florida recreational fishery.

Economics

In California and Florida, marine recreational fishing industries contribute significantly to state and local economies, particularly for fisheries that target pelagic species (Lovell et al. 2013; Bellquist and Semmens 2016). Nationwide, saltwater anglers accounted for approximately $9 billion in annual revenues to the U.S. economy in 2006, with increased spending trends in more recent years (Lerner 2009). Lerner (2009) suggested that the costs associated with fishing for swordfish are typically greater than the costs associated with other fisheries in Florida, with annual swordfish angler expenditures on fishing equipment totaling approximately $10,473 at the individual level in 2009. In 1969, it was estimated that an angler may spend up to $20,000 on average to catch a single swordfish (De Sylva 1974). Overall, the economic value of the billfish recreational fishery to local communities is extremely high, particularly considering the relatively low number of billfish harvested by recreational fleets and the high prevalence of catch and release techniques used for many billfish species (De Sylva 1974; Lerner 2009). Given the high quality and value of swordfish meat, the percentage of swordfish retained for consumption following capture is typically higher than in other recreational billfish fisheries; however, tournaments and club venues continue to offer recognition for released swordfish[10]. A greater understanding of the economics and potential value of recreational effort is needed to better manage the swordfish resource off California (Ditton and Stoll 2000; Lerner 2009), while also considering any social or economic conflicts that may result from resource competition between commercial and recreational fleets. Given the potential size and economic revenue generated by the emerging recreational activity, there may be some added value towards assessing fishery productivity from a non-traditional perspective,[18] rather than solely evaluating standard metrics of production (i.e., tons of product/year). Given the high degree of spatial and temporal overlap between the recreational and commercial sectors, monitoring fishery growth and harvest will be important to ensure economic viability and long-term sustainability.

Catch Estimates

An initial assessment of the available California recreational fishery data for swordfish suggests that the onset of deep-dropping coincided with a sharp increase in estimated catch relative to previous decades. Heightened recreational catch did not occur during a period of increased west-coast production, but rather when commercial landings were more than 40% reduced from the 2018 harvest level (Pacific Fisheries Management Council 2021). Additionally, increased recreational swordfish catch was observed at established weigh stations, angling clubs, and billfish tournaments. Because not all anglers belong to fishing clubs, or openly share catch information, these estimates only represent a portion of the overall recreational harvest. Similarly, because catch estimates reported in this study were largely based on CPFV logbooks and private boats captured by CRFS surveys conducted at public launch ramps, it was not possible to accurately account for catches onboard vessels berthed at private marinas, a sector of the

fishery that likely makes up the largest component of the catch. Although this work underestimates the total recreational catch of swordfish off California, it does offer insight into regional trends and changing recreational fishery dynamics for swordfish.

The challenges associated with monitoring and quantifying catch and effort in recreational fisheries are not limited to California. Similar attempts to quantify recreational swordfish catch and effort using tournament and fishing club records have also been conducted off Florida and Australia (Gartside et al. 1999; Levesque and Kerstetter 2007; Lerner 2009; Kerstetter et al. 2017; Tracey and Pepperell 2018). Approaches to accurately quantify landings from a large fleet of independent vessels have many inherent limitations (Bellquist et al. 2016); however, directed efforts to subsample discrete groups of reclusive recreational fishers (i.e., Chain-referral sampling) have been effectively implemented (Griffiths et al. 2017). Additional efforts for monitoring specific sectors of the recreational fishing community from web-based forums and social media outlets have also been proposed to be effective at estimating participation and catch data (Shiffman et al. 2017; Monkman and Kaiser 2021). Regardless of the methods used, focused sampling efforts are needed to better collect specific information on HMS (i.e., tuna, billfish, and pelagic sharks) captured by the recreational private-access fleet off Southern California. Given the rapid fishery expansion and evolution of techniques used to target swordfish, it is important to develop sampling protocols that can capture catch statistics indicative of modern-day fishing practices.

Current Sportfishing Regulations and Management

Similar to existing requirements in the Atlantic Ocean, California CPFV and vessels for hire targeting HMS are required to submit daily logbooks, possess valid federal HMS permits, and are prohibited from selling their catch (Kerstetter et al. 2017)[15]. Since 1951, California anglers have been allowed to retain two swordfish per day, with no minimum size or maximum vessel limit[19] (CA Fish and Wildlife Section 28.40; Bedford and Hagerman 1983). The California Fish and Game Commission's Marine Resources Committee discussed potential concerns regarding recreational swordfish take at a 29 April 2020 meeting and agreed that an improved data collection system for HMS (i.e., swordfish) was needed to establish baseline estimates of take and effort. Currently, Florida anglers are restricted daily to one swordfish per person over a minimum size limit of 119 cm lower jaw fork length (Fenton 2012; Kerstetter et al. 2017). Although managed under a separate management scheme, all recreational vessels targeting swordfish and other HMS off of Florida must obtain an HMS angling permit and are required to affix all billfish and bluefin tuna with a landing tag, as well as report catch records to NMFS within 24 h of capture (NMFS 2006; Fenton 2012; Lerner et al. 2017).

While the overall impact of recreational fisheries on regional swordfish stocks were previously considered negligible (Bedford and Hagermen 1983), recent increases in fishing effort and catchability with the advent of deep-drop practices must be considered as the developing fishery moves forward. The concern over SCB harvest is not currently based on regional stock status[20], but rather on local availability and the importance of growing and maintaining healthy and productive fishing operations. This is of particular interest given the seasonal site fidelity displayed by swordfish on foraging grounds and the potential this may have on localized and serial depletion that has already been documented in other parts of the world (Ward et al. 2000; Campbell and Hobday 2003; Wilcox 2014; Tracey and Pepperell 2018; Sepulveda et al. 2019). Although swordfish are a highly migratory species capable of moving thousands of kilometers per year, recent tagging research off Southern California has shown that individuals often return to specific

foraging locations in subsequent years (Sepulveda et al. 2019). This recent finding for SCB swordfish aligns with past concerns over localized depletion within areas of heightened fishing pressure off of Australia (Campbell and Hobday 2003). Given that the California commercial swordfish industry is in a phase of transition and the recreational fishery is a phase of growth, accurate fishery-dependent data (i.e., catch, landings, size, effort, and economic return) are needed for developing an optimal fishery moving forward.

Recommendations and Future Work

This study documents the initial expansion of a southern California recreational fishery targeting swordfish. Findings from this study highlight the importance of improved recreational harvest information and its future role in managing a productive and sustainable swordfish fishery off California. Increased recreational sampling could generate the information needed for making informed management decisions that consider recreational and commercial productivity while building fishery resilience. Given the difficulties associated with monitoring the private access fleet, managers may consider strategies already in place for other states[21], as well as alternative catch reporting platforms (Griffiths et al. 2017). Directed monitoring efforts could also be expanded to incorporate other regionally important HMS that are frequently targeted by private-access fleets (i.e., Pacific bluefin tuna, striped marlin, common thresher sharks) to enhance the overall value and cost effectiveness of additional monitoring programs[5]. Enhanced monitoring would also benefit the recreational sector by documenting the revenues associated with recreational activities, a benefit often overlooked in current management of HMS resources.

Based on the observed decline in the maximum and mean size of swordfish over the past century (**Fig. 5**), more accurate and reliable data on swordfish size structure are needed to identify both temporal and regional trends. Considering that California anglers commonly weigh swordfish and other large pelagic fish at certified scales, detailed landing statistics may be readily obtained by providing official weigh slips for collection at fishing clubs and fuel-dock scales. The collection of catch and size data may be used to better identify the need for modified harvest control rules (i.e., size limits, bag limits, vessel limits) as they develop, while providing a directed outreach platform to discuss relevant options with fishery stakeholders. Although swordfish size limits have been incorporated into Florida recreational fishery regulations, more information on the post-release mortality rates of swordfish captured using deep-drop practices are needed to evaluate the potential effectiveness of implementing a size limit in the California fishery (Pine et al. 2008; Fenton 2012).

Conclusions

This work documents recent changes in the recreational fishery dynamics for swordfish off Southern California and highlights the importance and need for additional monitoring efforts. Accurate harvest and effort data can inform future management decisions towards potential harvest control rules and aid in the development of regional production models that consider both commercial and recreational stakeholder interests. Collectively, these data are needed for achieving optimal growth and development of the future deep-set (commercial and recreational) fishery for swordfish off California (i.e., harvest and generated revenues). A better understanding of recreational fishery dynamics may also help mitigate social impacts between stakeholders and inform management of the overall productivity of the west coast swordfish resource.

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